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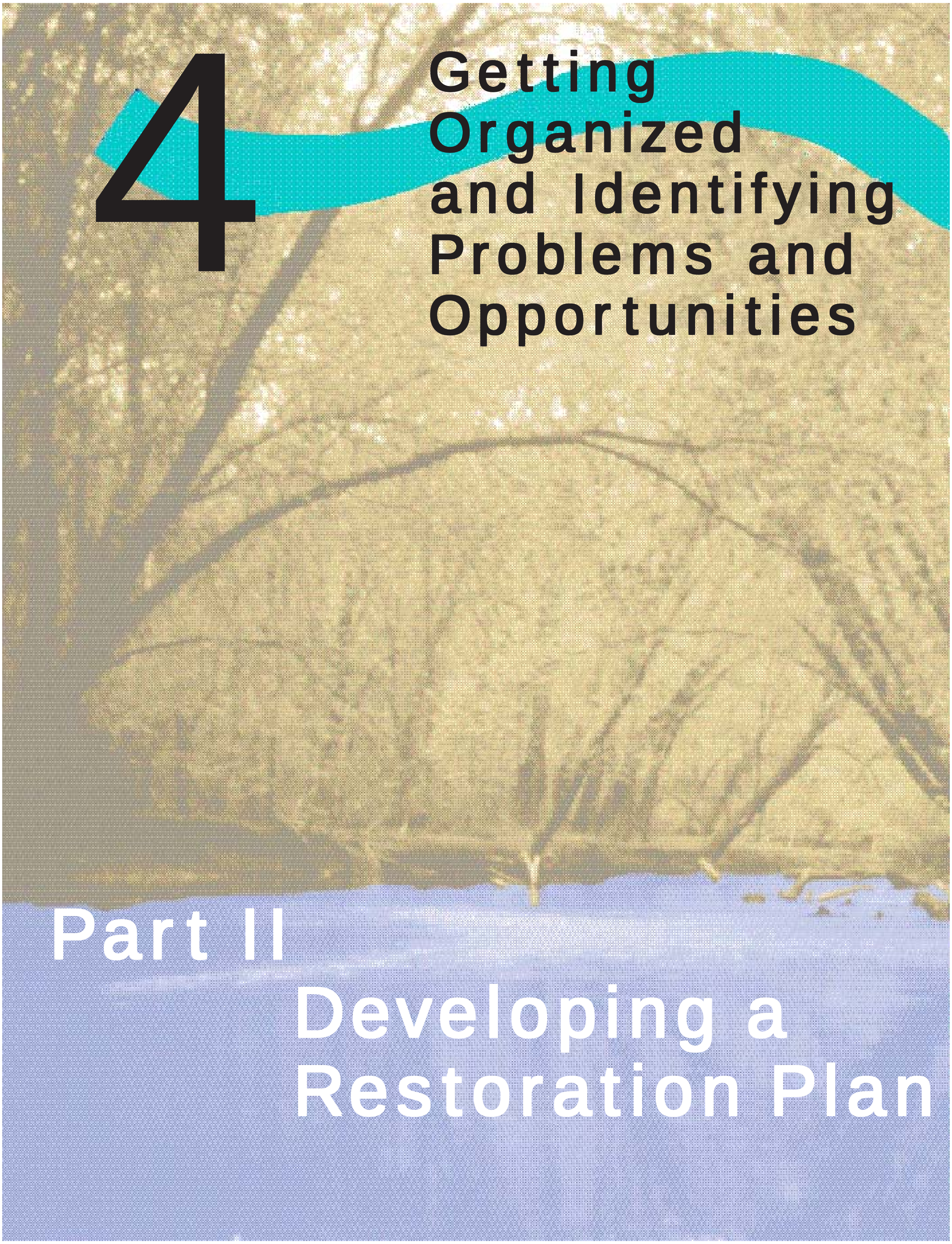


4

Getting Organized and Identifying Problems and Opportunities

Part II

Developing a Restoration Plan

4.A Getting Organized

- Why is planning important?
- Is an Advisory Group needed?
- How is an Advisory Group formed?
- Who should be on an Advisory Group?
- How can funding be identified and acquired?
- How are technical teams established and what are their roles?
- What procedures should an Advisory Group follow?
- How is communication facilitated among affected stakeholders?

4.B Problem and Opportunity Identification

- Why is it important to spend resources on the problem ("When everyone already knows what the problem is")?
- How can the anthropogenic changes that caused the need for the restoration initiative be altered or removed?
- How are data collection and analysis procedures organized?
- How are problems affecting the stream corridor identified?
- How are reference conditions for the stream corridor determined?
- Why are reference conditions needed?
- How are existing management activities influencing the stream corridor?
- How are problems affecting the stream corridor described?.

4

GETTING ORGANIZED AND IDENTIFYING PROBLEMS AND OPPORTUNITIES

The impetus for a restoration initiative may come from several sources. The realization that a problem or opportunity exists in a stream corridor may warrant community action and any number of interested groups, and individuals may be actively involved in recognizing the situation and initiating the restoration effort. Federal or state agencies may be designated to undertake a corridor restoration effort as a result of a legislative mandate or an internal agency directive. Citizen groups or groups with special cultural or economic interests in the corridor (e.g., native tribes, sport fishermen) may also initiate a restoration effort. Still others might undertake stream corridor restora tion as part of a broad-based cooperative initiative that draws from various funding sources and addresses a diversity of interests and objectives.

Accompanying the recognition of the situation and initiation of the restoration effort is the initial proposal of "the solution." This almost instantaneous leap from problem/opportunity recognition to the identification of the initial "solution" occurs during the formative stage of nearly every initiative involving water and multiple landowners. This instantaneous leap might not always address the true causes of the problem or identified opportunity and therefore might not result in a successful restoration initiative. Projects that come through a logical process of plan development tend to be more successful.

Regardless of the origins of the restoration initiative or the introduction of the proposed "solution," it is essential that the focus of the leadership for the restoration planning process be at the local level; i.e., the people who are pushing for action, who own the land, who are affected, who might benefit, who can make decisions, or who can lead. With this local leadership in place, a logical, iterative restoration plan development process can be undertaken. Often, this approach will involve going back to the identification of the problem or opportunity and realizing that the situation is not as simple as initially perceived and needs further definition and refinement.

This chapter concentrates on the two initial steps of stream corridor restoration plan development— getting organized and problem/ opportunity identification. The chapter is divided into two sections and includes a discussion of the core components of each of these initial steps.

Section 4.A: Getting Organized

This section outlines some of the organizational considerations that should be taken into account when conducting stream corridor restoration.

Section 4.B: Problem and Opportunity Identification

Once some of the organizational logistics have been settled, the disturbances affecting the stream corridor ecosystem and the resulting problems/opportunities need to be identified. Section B outlines the core components of the problem/ opportunity identification process.

One of the most common mistakes made in planning restorations is the failure to characterize the nature of the problems to be solved and when, where, and exactly how they affect the stream corridor.

Core Components of Getting Organized

- Setting boundaries
- Forming an advisory group
- Establishing technical teams
- Identifying funding sources
- Establishing points of contact and a decision structure
- Facilitating involvement and information sharing among participants
- Documenting the process.

FAST FORWARD REVERSE

Review Chapter 1. Preview Chapter 5's Identifying Scale Considerations.

4.A Getting Organized

This section presents the key components of organizing and initiating the development of a stream corridor restoration plan and establishing a planning and management framework to facilitate communication among all involved and interested parties. Ensuring the involvement of all partners and beginning to secure their commitment to the project is a central aspect of "getting organized" and undertaking a restoration initiative. (See Chapter 6 for detailed information on securing commitments.) It is often helpful to identify a common motivation for taking action and also to develop a rough outline of restoration goals. In addition, defining the scale of the corridor restoration initiative is important. Often the issues to be addressed require that restoration be considered on a watershed or whole-reach basis, rather than by an individual jurisdiction or one or two landholders.

Setting Boundaries

Geographical boundaries provide a spatial context for technical assessment and a sense of place for organizing community-based involvement. An established set of project boundaries streamlines the process of gathering, organizing, and depicting information for decision making.

When boundaries are selected, the area should reflect relevant ecological processes. The boundaries may also reflect the various scales at which ecological processes influence stream corridors (see Chapter 5, *Identifying Scale Considerations*). For example, matters affecting the conservation of biodiversity tend to play out at broader, more regional scales. On the other hand, the quality of drinking water is usually more of a basin-specific or local-scale issue.

In setting boundaries, two other factors are equally as important. One is the nature of human-induced disturbance, including the magnitude of its impact on stream corridors. The other factor is the social organization of people, including where opportunities for action are distributed across the landscape.

The challenge of establishing useful boundaries is met by conceptually superimposing the three selection factors. One effective way of starting this process is through the identification, by public forum or other free and open means, of a stream reach or aquatic resource area that is particularly valued by the community. The scoping process would continue by having resource managers or landowners define the geographical area that contributes to both the function and condition of the valued site or sites. Those boundaries would then be further adjusted to reflect community interests and goals.

Forming an Advisory Group

Central to the development of a stream corridor restoration plan is the formation of an *advisory group* (**Figure 4.1**). An advisory group is defined as a collection of key participants, including private citizens, public interest groups, economic interests, public officials, and any other groups or individuals who are interested in or might be affected by the restoration initiative. Grassroots citizen groups comprise multiple interests that hopefully share a stated common concern for environmental conservation. Such broad-based participation helps ensure that self-interest or agency agendas do not drive the process from the top down. Local citizens should be enlisted and informed to the extent that their values and preferences drive decision making with technical guidance from agency participants.

The advisory group generally meets for the following purposes:

- Carrying out restoration planning activities.
- Coordinating plan implementation.
- Identifying the public's interest in the restoration effort.
- Making diverse viewpoints and objectives known to decision makers.
- Ensuring that local values are taken into account during the restoration process.

The point to remember is that the true role of the advisory group is to advise the *decision maker* or *sponsor*—the agency(s), organization(s), or individual(s) leading and initiating the restoration effort—on the development of the restoration plan and execution of restoration activities. Although the advisory group will play an active planning and coordinating role, it will not make the final decisions. As a result, it is important that all members of the advisory group understand the issues, develop practical and well thought-out recommendations, and achieve consensus in support of their recommendations.

Typically, it is the responsibility of the decision maker(s) to identify and organize the members of the advisory group. Critical to this process is the identification of the key participants. Participants can be identified by making announcements to the news media, writing to interested organizations, making public appearances, or directly contacting potential partners.

The exact number of groups or individuals that will compose the advisory group is difficult to determine and is usually situation-specific. In general, it is important that the group not be so small that it is not representative of all interests. Exclusion of certain community interests can undermine the legitimacy of or even halt the restoration initiative. Conversely, a large group might include so many interests that organization and consensus building become unmanageable. Include a balance of representative interests such as the following:

- Private citizens
- Public interest groups
- Public officials
- Economic interests

Figure 4.1: Advisory group meeting. *The advisory group, composed of a variety of community interests, plays an active role in advising the decision maker(s) throughout the restoration process.* Source: S. Ratcliffe. Reprinted by permission.

It is important to note that while forming an advisory group is an effective and efficient way to plan and manage the restoration effort, not all restoration decision makers will choose to establish one. There might be cases where a landowner or small group of landowners elect to take on all of the responsibilities of the advisory group in addition to playing a leadership or decision-making role.

Regardless of the number of individuals involved, it is important for all project participants (and funders) to note at this early stage that the usual duration of projects is 2 to 3 years. There are no guarantees that every project will be a success, and in some cases a project may fail simply due to lack of time to allow nature to "heal itself" and restoration methods to take effect. All participants must be reminded up front to set realistic expectations for the project and for themselves.

Establishing Technical Teams

Planning and implementing restoration work requires a high level of knowledge, skill, and ability, as well as professional judgment. Often, the advisory group will find it necessary to establish special technical teams, or subcommittees, to provide more information on a particular issue or subject.

In general, interdisciplinary technical teams should be organized to draw upon the knowledge and skills of different agencies, organizations, and individuals. These teams can provide continuity as well as important information and insight from varied disciplines, experiences, and backgrounds.

The expertise of an experienced multidisciplinary team is essential. No single text, manual, or training course can provide the technical background and judgment needed to plan, design, and implement stream corridor restoration. A team with a broad technical background is needed and should include expertise in both engineering and biological disciplines, particularly in aquatic and terrestrial ecology, hydrology, hydraulics, geomorphology, and sediment transport.

Team members should represent interagency, public, and private interests and include major partners, especially if they are sharing costs or work on the restoration initiative. Team makeup is based on the type of task the team is assembled to undertake. Members of the technical teams can also be members of the advisory committee or even the decision-making body.

Some of the technical teams that could be formed to assist in the restoration initiative will have responsibilities such as these:

- Soliciting financial support for the restoration work.
- Coordinating public outreach.
- Providing scientific support for the

Forming an advisory group is an effective and efficient way to plan and manage the restoration effort, although not all restoration decision makers will choose to establish one.

Lower Missouri River Coordinated Resource Management Efforts in Northeast Montana

The Lower Missouri River Coordinated Resource Management (CRM) Council is an outgrowth of the Lower Fort Peck Missouri River Development Group, which was formed in September 1990 as a result of an irrigation and rural development meeting held in Poplar, Montana. The meeting was held to determine the degree of interest in economic and irrigation development along the Missouri River below Fort Peck Dam.

A major blockade to development seemed to be the erosion problems along the river. The Roosevelt County Conservation District and other local leaders decided that before developing irrigation along the river, streambank erosion needed to be addressed.

The large fluctuation of the water being released from Missouri River dams is causing changes in the downstream river dynamics, channel, and stream-banks. Before the dams, the river carried a sediment load based on the time of the year and flow event. Under natural conditions, a river system matures and tries to be in equilibrium by transporting and depositing sediment. Today, below the dams, the water is much cleaner because the sediment has settled behind the dams ***(Figure 4.2)****. The clean water releases have changed the river system from what it was prior to the dams. The clean water now picks up sediment in the river and attacks the streambanks, while trying to reach equilibrium. These probable causes and a river system out of equilibrium could be part of the cause of the river erosion.*

Leaders in the group are politically active, traveling to Washington, D.C., and meeting with congressional delegates and the US Army Corps of Engineers (USACE) to secure funding to address streambank erosion. As a result of the trips to Washington, $3 million was appropriated and transferred to the USACE for streambank erosion abatement. However, efforts to agree on a mutually beneficial solution continued to delay the progress. The USACE had completed an economic analysis of the area, and the only viable alternative it could offer was sloughing easements. This would do little to save the valuable soils along the Missouri River.

The group seemed to be at a stalemate. In July 1994, then Chief of the Natural Resources Conservation Service (NRCS), Paul Johnson, met with the members of the Lower Fort Peck Missouri River Development Group, local landowners, surrounding Conservation District members, NRCS field office staff, and Bill Miller, Project Manager for the Omaha District of the USACE, at an erosion site along the Missouri River. After sharing of ideas and information, Chief Johnson suggested that a Coordinated Resource Management (CRM) group be formed to resolve the sensitive issues surrounding the erosion and other problems of the river. He instructed local and state NRCS staff to provide technical assistance to the CRM group. The group followed Chief Johnson's idea, and the Lower Missouri River CRM Council was formed. This has helped those involved in solving the problems to overcome many of the stumbling blocks with which they were being confronted. Some of these successes include:

- *Through the CRM Council the $3 million transferred to the USACE was used to try some new innovative erosion solutions on a site in Montana and one in North Dakota. The group helped the USACE to select the site. NRCS assisted in the design and implementation. For the first time in this area, materials such as hay bales, willow cuttings, and log revetments were used.*
- *An interagency meeting and tour of erosion sites was sponsored by the CRM Council in September of 1996. In addition to local producers, CRM Council members, NRCS state and national staff, USACE staff, researchers from the USDA Agricultural Research Service (ARS) National Sedimentation Laboratory of Oxford, Mississippi, attended the session. The group agreed that the erosion problem needed to be studied further. The NRCS, USACE, and ARS have been doing studies on the River System below Fort Peck Dam since the 1996 meeting. A final report on the research is planned for summer of 1998.*
- *The CRM Council has been surveying producers along the river to determine what they perceive to be their major problems. This helps the group to stay in tune with current problems. The CRM Council contracted with a group of Montana State University senior students from the Film and TV Curriculum to develop an informational video about the Missouri River and its resources. This project has been completed, and the video will be used to show legislators and others what the problems and resources along the river are.*

The group has been successful because of the CRM process. The process takes much effort by all involved, but it does work.

Figure 4.2: Lower Missouri River. *Water released from dams is causing downstream erosion.*

restoration work. This support may encompass anything from conducting the baseline condition analysis to designing and implementing restoration measures and monitoring.

- Investigating sensitive legal, economic, or cultural issues that might influence the restoration effort.
- Facilitating the restoration planning, design, and implementation process outlined in this document.

It is important to note that technical expertise often plays an important role in the success of restoration work. For example, a restoration initiative might involve resource management or land use considerations that are controversial or involve complex cultural and social issues. An initiative might address issues like western grazing practices or water rights and require the restriction of certain activities, such as timber or mineral extraction, certain farming and grazing practices, or recreation (**Figure 4.3**). In these cases, involving persons who have the appropriate expertise on regulatory programs, as well as social, political, and legal issues, can prevent derailment of the restoration effort.

Perhaps the most important benefit of establishing technical teams, however, is that the advisory group and decision makers will have the necessary information to develop restoration objectives. The advisory group will be able to integrate the knowledge gained from the analysis of what is affecting stream corridor structure and functions with the information on the social, political, and economic factors operative within the stream corridor. Essentially, the advisory group will be able to help define a thorough set of restoration objectives.

CASE STUDY

Watershed Planning Through a Coordinated Resource Management Planning Process

The American River watershed, located in the Sierra Nevada Mountains of California, comprises 963 square miles. It is an important source of water for the region. The watershed also supports a diversity of habitats from grassland at lower elevations, transitioning to chaparral and to hardwood forest, and eventually to coniferous forest at upper elevations. In addition, the watershed is a recreational and tourist destination for the adjacent foothill communities like the greater Sacramento metropolitan area and the San Francisco Bay area.

Urban development is rapidly expanding in the watershed, particularly at lower elevations. This additional development is challenging environmental managers in the watershed and stressing the natural resources of the area. In 1996, the Placer County Resource Conservation District (PCRCD) spearheaded a multi-interest effort to address watershed concerns within the American River watershed. Due to the range of issues to be addressed, they sought to involve representatives from various municipalities, environmental and recreational groups, fire districts, ranchers, and state and federal agencies. The group established a broad goal "to enhance forest health and the overall condition of the watershed," as well as a set of specific goals that include the following: Actively involve the community and be responsive to its needs.

- *Optimize citizen initiative to manage fuels on private property to enhance forest and watershed.*
- *Restore hydrologic and vegetative characteristics of altered meadows and riparian areas.*
- *Create and sustain diverse habitats supporting diverse species.*
- *Ensure adequate ground cover to prevent siltation of waterways.*
- *Reduce erosion from roads and improvements.*
- *Prevent and correct pollution discharges before they adversely affect water quality.*
- *Reduce excessive growths of fire-dependent brush species.*
- *Increase water retention and water yield of the watershed.*
- *Optimize and sustain native freshwater species.*

Because of past conflicts and competing interests among members of the group, a Memorandum of Understanding (MOU) was prepared to develop a cooperative framework within which the various experts and interest groups could participate in natural resource management of the watershed. The signatories jointly committed to find common ground from which to work. The first step was to establish "future desired conditions" that will meet the needs of all the signatories as well as the local landowners and the public.

By including all of the signatories in the prioritization of implementation actions, PCRCD continues to keep the watershed planning process moving forward. In addition, PCRCD has encouraged the development of a small core group of landowners, agency representatives, and environmental organizations to determine how specific actions will be implemented. Several projects that incorporate holistic ecosystem management and land steward-ship principles to achieve measurable improvements within the watershed are already under way.

Identifying Funding Sources

Identifying funding sources is often an early and vital step toward an effective stream restoration initiative. The funding needed may be minimal or substantial, and it may come from a variety of sources. Funding may come from state or federal sources that have recognized the need for restoration due to the efforts of local citizens' groups. Funding may come from counties or any entity that has taxing authority. Philanthropic organizations, nongovernmental organizations, landowners' associations, and voluntary contributions are other funding sources. Regardless of the source of funds, the funding agent (sponsor) will almost certainly influence restoration decisions or act as the leader and decision maker in the restoration effort.

Interdisciplinary Nature of Stream Corridor Restoration

The complex nature of stream corridor restoration requires that any restoration initiative be approached from an interdisciplinary perspective. Specialists from a variety of disciplines are needed to provide both the advisory group and sponsor with valuable insight on scientific, social, political, and economic issues that might affect the restoration effort. The following is a list of some of the professionals who can provide important input for this interdisciplinary effort:

- *Foresters*
- *Legal consultants*
- *Botanists*
- *Microbiologists*
- *Engineers*
- *Hydrologists*
- *Economists*
- *Geomorphologists*
- *Archaeologists*
- *Sociologists*
- *Soil scientists*
- *Rangeland specialists*
- *Landscape architects*
- *Fish and wildlife biologists*
- *Public involvement specialists*
- *Real estate experts*
- *Ecologists*
- *Native Americans and Tribal Leaders.*

Establishing a Decision Structure and Points of Contact

Once the advisory group and relevant technical teams have been formed, it is important to develop a decision-making structure (**Figure 4.4**) and to establish clear points of contact.

As noted earlier, the advisory group will play an active planning and coordinating role, but it will not make the final decisions. The primary decision-making authority should reside in the hands of the stakeholders. The advisory group, however, will play a strong role by providing recommendations and informing the decision maker(s) of various restoration options and the opinions of the various participants.

It is important to note that the decision maker, as well as the advisory group, may be composed of a collection of interests and organizations. Consequently, both entities should establish some basic protocols to facilitate decision making and communication. Within each group some of the following rules of thumb might be helpful:

- Select officers
- Establish ground rules
- Establish a planning budget
- Appoint technical teams

In conjunction with establishing a decision structure, the sponsor, advisory group, and relevant subcommittees need to establish points of contact. These points of contact should be people who are accessible and possess strong outreach and communication skills. Points of contact play an important role in the restoration process by facilitating communication among the various groups and partners.

Facilitating Involvement and Information Sharing Among Participants

It is important that every effort be made to include all interested parties throughout the duration of the restoration process. Solicit input from participants and keep all interested parties informed of the plan development, including uncertainties associated with a particular solution, approach, or management prescription and what must be involved in modifying and adapting them as the need arises. In other words, it is important to operate under the principles of both information giving and information receiving.

Receiving Input from Restoration Participants

In terms of information receiving, a special effort should be made to directly contact landowners, resource users, and other interested parties to ask them to participate in the planning process. Typically, these groups or individuals will have some personal interest in the condition of the stre-

Figure 4.3: Livestock grazing. *Technical teams can be helpful in addressing controversial and complex issues that have the potential to influence the acceptance and success of a restoration initiative.*

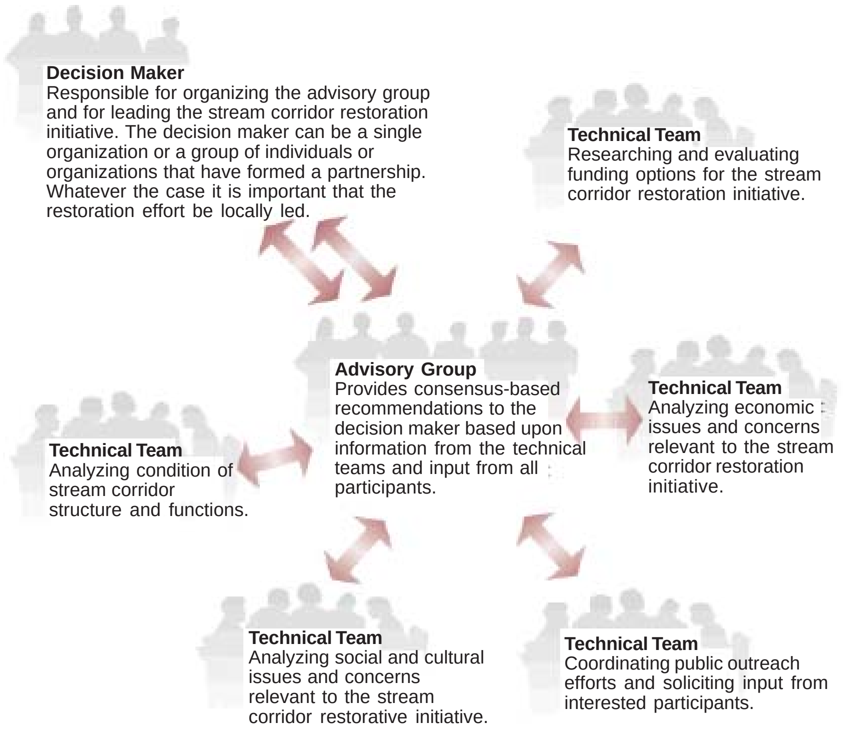


Figure 4.4: Flow of communication. *Restoration plan development requires a decision structure that streamlines communication between the decision maker, the advisory group, and the various technical teams.*

am corridor and associated ecosystems in their region. A failure to provide them the opportunity to review and comment on stream corridor restoration plans will often result in objections later in the process.

Private landowners, in particular, often have the greatest personal stake in the restoration work. As part of the restoration effort it might be necessary for private landowners to place some of their assets at increased risk, make them more available for public use, or reduce the economic return they provide (e.g., restricting grazing in riparian areas or increasing buffer widths between agricultural fields and drainage channels). Thus, it is in the best interest of the restoration initiative to include these persons as decision makers.

A variety of public outreach tools can be useful in soliciting input from participants. Some of the most common mechanisms include public meetings, workshops, and surveys. *Tools for Facilitating Participant Involvement and Information Sharing During the Restoration Process*, provides a more complete list of potential outreach options.

Informing Participants Throughout the Restoration Process

In addition to actively seeking input from participants, it is important that the sponsor(s) and the advisory group regularly inform the public of the status of the restoration effort. The restoration initiative can also be viewed as a strong educational resource for the entire community. Some effective ways to communicate this information and to provide educational opportunities include newsletters, fact sheets, seminars, and brochures. A more complete list of potential outreach tools is provided in the box *Tools for Facilitating Participant Involvement and Information Sharing During the Restoration Process*.

It is important to note that the educational opportunities associated with information giving can help support restoration initiatives. For example, in cases that require the implementation of costly management prescriptions, out-reach tools can be effective in improving landowner awareness of ways in which risks and losses can be offset, such as incentive programs (e.g., Conservation Reserve Program) or cost-sharing projects (e.g., Section 319 of the Clean Water Act). In these cases, the most effective approach might be for the representative landowners serving on the decision-making team to be responsible for conducting this outreach to their constituents.

In addition, educational outreach can also be viewed as an opportunity to demonstrate the anticipated benefits of restoration work, on both regional and local levels. One of the most effective ways to accomplish this is with periodic public field days involving visits to the restoration corridor, as well as pilot demonstration sites, model farms, and similar examples of restoration actions planned.

Finally, wherever possible, information on the effectiveness and lessons learned from restoration work should be made available to persons interested in carrying out restoration work elsewhere. Most large restoration initiatives will require relatively detailed documentation of design and performance, but this information is usually not widely distributed. Summaries of restoration experiences can be published in any of a variety of technical journals, newsletters, bulletins, Internet Web sites, or other media and can be valuable to the success of future restoration initiatives.

Selecting Tools for Facilitating Information Sharing and Participant Involvement

Although a variety of outreach tools can be used to inform participants and solicit input, attention should be paid to selecting the best tool at the most appropriate time. In making this selection, it is helpful to consider the

FAST FORWARD
Preview Chapter 6's
Developing a Monitoring Plan.

CBF NEWS

The Newsletter of the Chesapeake Bay Foundation®

Vol. 18 No. 3 Annapolis, Md. • Richmond, Va. • Harrisburg, Pa. November 1993

Oyster Plan Falls Short on Conservation

Rockfish Rebound Affirms Management Controls

Figure 4.5: Chesapeake Bay Foundation newsletter. *Newsletters can be an effective way to communicate the status of restoration efforts to the community.*

Tools for Facilitating Participant Involvement and Information Sharing During the Restoration Process

Tools for Receiving Input

- *Public Hearings*
- *Task Forces*
- *Training Seminars*
- *Surveys*
- *Focus Groups*
- *Workshops*
- *Interviews*
- *Review Groups*
- *Referendums*
- *Phone-in Radio Programs*
- *Internet Web Sites*

Tools for Informing Participants

- *Public Meetings*
- *Internet Web Sites*
- *Fact Sheets*
- *News Releases*
- *Newsletters*
- *Brochures*
- *Radio or TV Programs or Announcements*
- *Telephone Hotlines*
- *Report Summaries*
- *Federal Register.*

stage of the restoration process as well as the out-reach objectives.

For example, if a restoration initiative is in the early planning stages, providing community members with background information through a newsletter or news release might be effective in bringing interested parties to the table and in generating support for the initiative (**Figures 4.5 and 4.6**). Conversely, once the planning process is well under way and restoration alternatives are being selected, a public hearing may be a useful mechanism for receiving input on the desirability of the various options under consideration (**Figure 4.7**).

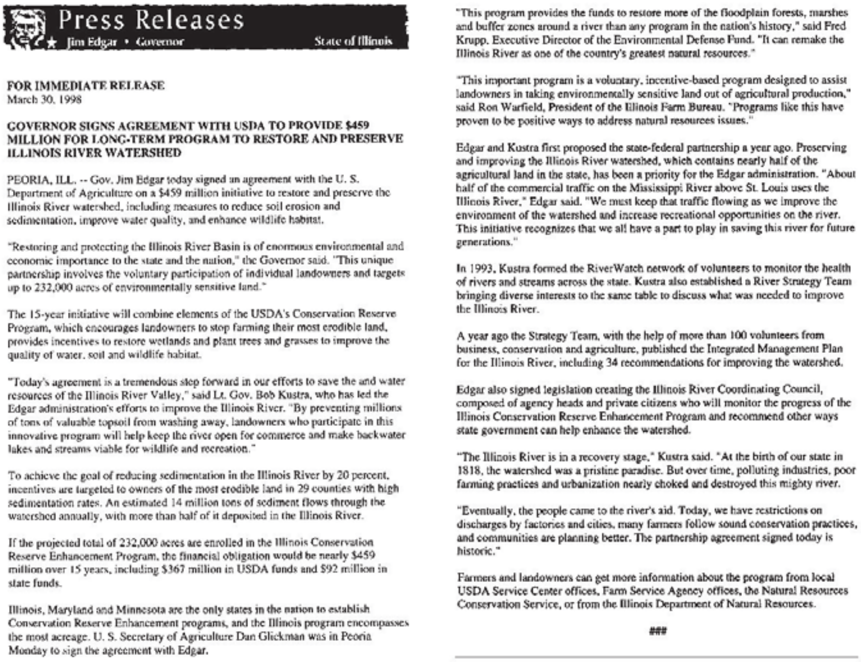
Some additional factors that should be taken into account in selecting outreach tools include the following:

- Strengths and weaknesses of individual techniques.
- Cost, time, and personnel required for implementation.
- Receptivity of the community.

Again, no matter what tools are selected, it is important to make an effort to solicit input from participants as well as to keep all interested parties informed of plan developments. The Interagency Ecosystem Management Task Force (1995) provides the following suggestion for a combination of techniques that can be used to facilitate participant involvement and information sharing:

- Regular newsletters or information sheets apprising people of plans and progress.
- Regularly scheduled meetings of landowner and citizen groups.
- Public hearings.
- Field trips and workdays on project sites for volunteers and interested parties.

In addition, the innovative communication possibilities afforded by the Internet and the World Wide Web cannot be ignored.



Press Releases
Jim Edgar • Governor State of Illinois

FOR IMMEDIATE RELEASE
March 30, 1998

GOVERNOR SIGNS AGREEMENT WITH USDA TO PROVIDE $459 MILLION FOR LONG-TERM PROGRAM TO RESTORE AND PRESERVE ILLINOIS RIVER WATERSHED

PEORIA, ILL. -- Gov. Jim Edgar today signed an agreement with the U. S. Department of Agriculture on a $459 million initiative to restore and preserve the Illinois River watershed, including measures to reduce soil erosion and sedimentation, improve water quality, and enhance wildlife habitat.

"Restoring and protecting the Illinois River Basin is of enormous environmental and economic importance to the state and the nation," the Governor said. "This unique partnership involves the voluntary participation of individual landowners and targets up to 232,000 acres of environmentally sensitive land."

The 15-year initiative will combine elements of the USDA's Conservation Reserve Program, which encourages landowners to stop farming their most erodible land, provides incentives to restore wetlands and plant trees and grasses to improve the quality of water, soil and wildlife habitat.

"Today's agreement is a tremendous step forward in our efforts to save the and water resources of the Illinois River Valley," said Lt. Gov. Bob Kustra, who has led the Edgar administration's efforts to improve the Illinois River. "By preventing millions of tons of valuable topsoil from washing away, landowners who participate in this innovative program will help keep the river open for commerce and make backwater lakes and streams viable for wildlife and recreation."

To achieve the goal of reducing sedimentation in the Illinois River by 20 percent, incentives are targeted to owners of the most erodible land in 29 counties with high sedimentation rates. An estimated 14 million tons of sediment flows through the watershed annually, with more than half of it deposited in the Illinois River.

If the projected total of 232,000 acres are enrolled in the Illinois Conservation Reserve Enhancement Program, the financial obligation would be nearly $459 million over 15 years, including $367 million in USDA funds and $92 million in state funds.

Illinois, Maryland and Minnesota are the only states in the nation to establish Conservation Reserve Enhancement programs, and the Illinois program encompasses the most acreage. U. S. Secretary of Agriculture Dan Glickman was in Peoria Monday to sign the agreement with Edgar.

"This program provides the funds to restore more of the floodplain forests, marshes and buffer zones around a river than any program in the nation's history," said Fred Krupp, Executive Director of the Environmental Defense Fund. "It can remake the Illinois River as one of the country's greatest natural resources."

"This important program is a voluntary, incentive-based program designed to assist landowners in taking environmentally sensitive land out of agricultural production," said Ron Warfield, President of the Illinois Farm Bureau. "Programs like this have proven to be positive ways to address natural resources issues."

Edgar and Kustra first proposed the state-federal partnership a year ago. Preserving and improving the Illinois River watershed, which contains nearly half of the agricultural land in the state, has been a priority for the Edgar administration. "About half of the commercial traffic on the Mississippi River above St. Louis uses the Illinois River," Edgar said. "We must keep that traffic flowing as we improve the environment of the watershed and increase recreational opportunities on the river. This initiative recognizes that we all have a part to play in saving this river for future generations."

In 1993, Kustra formed the RiverWatch network of volunteers to monitor the health of rivers and streams across the state. Kustra also established a River Strategy Team bringing diverse interests to the same table to discuss what was needed to improve the Illinois River.

A year ago the Strategy Team, with the help of more than 100 volunteers from business, conservation and agriculture, published the Integrated Management Plan for the Illinois River, including 34 recommendations for improving the watershed.

Edgar also signed legislation creating the Illinois River Coordinating Council, composed of agency heads and private citizens who will monitor the progress of the Illinois Conservation Reserve Enhancement Program and recommend other ways state government can help enhance the watershed.

"The Illinois River is in a recovery stage," Kustra said. "At the birth of our state in 1818, the watershed was a pristine paradise. But over time, polluting industries, poor farming practices and urbanization nearly choked and destroyed this mighty river.

"Eventually, the people came to the river's aid. Today, we have restrictions on discharges by factories and cities, many farmers follow sound conservation practices, and communities are planning better. The partnership agreement signed today is historic."

Farmers and landowners can get more information about the program from local USDA Service Center offices, Farm Service Agency offices, the Natural Resources Conservation Service, or from the Illinois Department of Natural Resources.

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Figure 4.6: Regional restoration news releases. *A news release is an effective tool for informing the community of the planning of the restoration initiative.* Source: State of Illinois.

Documenting the Process

The final element of getting organized involves the documentation of the various activities being undertaken as part of the stream corridor restoration effort. Although the restoration plan, when completed, will ultimately document the results of the restoration process, it is also important to keep track of activities as they occur.

An effective way to identify important restoration issues and activities as well as keep track of those activities is through the use of a "restoration checklist" (National Research Council, 1992). The checklist can be maintained by the advisory group or sponsor and used to engage project stakeholders and to inform them of the progress of restoration efforts. The checklist can serve as an effective guide through the remaining components of restoration plan development and project implementation. In addition, a draft version of *Developing a Monitoring Plan* (see Chapter 6) should be prepared as part of planning data collection.

Figure 4.7: Local public hearing. *Public hearings are a good way to solicit public input on restoration options.* Source: S. Ratcliffe. Reprinted by permission.

4.B Problem and Opportunity Identification

Development of stream corridor restoration objectives is preceded by an analysis of resource conditions in the corridor. It is also preceded by the formulation of a problem/opportunity statement that identifies conditions to be improved through and benefit from restoration activities. Although problem/ opportunity identification can be very difficult, in terms of measurable stream corridor conditions, it is the single most important step in the development of the restoration plan and in the restoration process. This section focuses on the six steps of the problem/opportunity identification process that are critical to any stream corridor restoration initiative.

FAST FORWARD
Preview Chapter 7's
Data Collection and Analysis
Methods sections.

Data Collection and Analysis

Data collection and analysis are important to all aspects of decision making and are conducted throughout the duration of the restoration process. The same data and analytic techniques are often applied to, and are important components of, problem/opportunity identification; goal formulation; alternative selection; and design, implementation, and monitoring. Data collection and analysis, however, begin with problem/ opportunity identification. They are integral to defining existing stream corridor and reference conditions, identifying causes of impairment, and developing problem/ opportunity statements. Data collection and analysis should be viewed as the first step in this process.

The Six Step of Problem/Opportunity Identification Process

1. Data collection and analysis
2. Definition of existing stream corridor conditions (structure and function) and causes of disturbance
3. Comparison of existing conditions to desired conditions or a reference condition
4. Analysis of the causes (disturbances) of altered or impaired stream corridor conditions
5. Determination of how management practices might be affecting stream corridor structure and functions
6. Development of problem and opportunity statements.

Restoration Checklist (Adapted fron National Research Council 1992)

During Planning...

- Have all potential participants been informed of the restoration initiative?
- Has an advisory committee been established?
- Have funding sources been identified?
- Has a decision structure been developed and points of contact identified?
- Have steps been taken to ensure that participants are included in the restoration processes?
- Has the problem that requires treatment been investigated and defined?
- Has consensus been reached on the mission of the restoration initiative?
- Have restoration goals and objectives been identified by all participants in the restoration effort?
- Has the restoration been planned with adequate scope and expertise?
- Has the restoration plan had an annual or mid-course correction point in line with adaptive management procedures?
- Have the indicators of stream corridor structure and function been directly and appropriately linked to the restoration objectives?
- Have adequate monitoring, surveillance, management, and maintenance programs been specified as an integral part of the restoration plan? Have monitoring costs and operational details been integrated so that results will be available to serve as input in improving techniques used in the restoration work?
- Has an appropriate reference system (or systems) been selected from which to extract target values of performance indicators for comparison in conducting the evaluation of the restoration initiative?
- Have sufficient baseline data been collected over a suitable period of time on the stream corridor and associated ecosystems to facilitate before-and-after treatment comparisons?
- Have critical restoration procedures been tested on a small experimental scale to minimize the risks of failure?
- Has the length of a monitoring program been established that is sufficiently long to determine whether the restoration work is effective?
- Have risk and uncertainty been adequately considered in planning?
- Have alternative designs been formulated?
- Have cost-effectiveness and incremental cost of alternatives been evaluated?

During Project Implementation and Management...

- Based on the monitoring result, are the anticipated intermediate objectives being achieved? If not, are appropriate steps being taken to correct the problem(s)?
- Do the objectives or performance indicators need to be modified? If so, what changes might be required in the monitoring program?
- Is the monitoring program adequate?

During Postrestoration...

- To what extent were restoration plan objectives achieved?
- How similar in structure and function is the restored corridor ecosystem to the reference ecosystem?
- To what extent is the restored corridor self-sustaining (or will be), and what are the maintenance requirements?
- If all stream corridor structure and functions were not restored, have the critical structure and functions been restored?
- How long did the restoration initiative take?
- What lessons have been learned from this effort?
- Have those lessons been shared with interested parties to maximize the potential for technology transfer?
- What was the final cost, in net present value terms, of the restoration work?
- What were the ecological, economic, and social benefits realized by the restoration initiative?
- How cost-effective was the restoration initiative?
- Would another approach to restoration have produced desirable results at lower cost?.

Data Collection

Data collection should begin with a technical team, in consultation with the advisory group and the decision maker, identifying potential data needs based on technical and institutional requirements. The perspective of the public should then be solicited from participants or through public input forums. Data targeted for collection should generally provide information on both the historical and baseline conditions of stream corridor structure and functions, as well as the social, cultural, and economic conditions of the corridor and the larger watershed.

Data are collected with the help of a variety of techniques, including remote sensing, historical maps and photographs, and actual resource inventory using standardized on-site field techniques, evaluation models, and other recognized and widely accepted methodologies. Community mapping (drawing areas of importance to the community or individuals) is becoming a popular method of involving the public and children in restoration initiatives. This technique can solicit information not accessible to traditional survey or data collection techniques and it also makes the data collection process accessible to the public. Additional data collection and analysis methods are discussed in Part III, Chapter 7.

(a)

(b)

Figure 4.8: The Winooski River (a) in the 1930s and (b) at the same location in the 1990s. *Using photographs is one way to identify the historical condition of the corridor.*

Collecting Baseline Data

Restoration work should not be attempted without having knowledge of existing stream corridor conditions. In fact, it is impossible to determine goals and objectives without this basic information. As a result, it is important to collect and analyze information that provides an accurate account of existing conditions. Due to the dynamic nature of hydrologic systems, a range of conditions need to be monitored. Ultimately, these *baseline data* will provide a point from which to compare and measure future changes.

Baseline data consist of the existing structure and functions of the stream corridor and surrounding ecosystems across scales, as well as the associated disturbance factors. These data, when compared to a desired reference condition (derived from either existing conditions elsewhere in the corridor or historical conditions), are important in determining cumulative effects on the stream corridor's structure and functions (i.e., hydrologic, geomorphic, habitat, etc.). Baseline data collection efforts should include information needed to determine associated problems and opportunities to be addressed in later design and implementation stages of the restoration process.

Collecting Historical Data

As described in earlier chapters, stream corridors change over time in response to ongoing natural or human-induced processes and disturbances. It is important to identify historical conditions and activities to understand the present stream corridor condition (**Figure 4.8**).

Part of collecting *historical data* is collecting background information on the requirements of the species and ecosystems of concern. Historical data should also include processes that occurred at the site. The historic description may also be used to establish target conditions, or the reference condition, for restoration. Often the goal of restoration will not be to return a corridor to a pristine, or pre-European settlement, condition. However, by understanding this condition, valuable knowledge is gained for making decisions on restoring and sustaining a state of dynamic equilibrium.

In terms of gathering historical data, emphasis should be placed on understanding changes in land use, channel planform, cover type, and other physical conditions. Historical data, such as maps and photographs, should be reviewed and long-time residents interviewed to determine changes to the stream corridor and associated ecosystems. Major human-induced or natural disturbances, such as land clearing, floods, fires, and channelization, should also be considered. These data will be critical in understanding present conditions, identifying a reference condition, and determining future trends.

Collecting Social, Cultural, and Economic Data

In addition to physical, chemical, and biological data, it is also important to gather data on the social, cultural, and economic conditions in the area. These data more often than not will drive the overall restoration effort, delimit its scale, determine its citizen and land-owner acceptance, determine ability to coordinate and communicate, and generally decide overall stability and capability to maintain and manage. In addition, these data are likely to be of most interest to participants and should be collected with their assistance to avoid derailment or alteration of the restoration effort due to misconceptions and misinformation.

Properly designed surveys of social attitudes, values, and perceptions can also be valuable tools both to assess the changes needed to accomplish the restoration goals and to determine changes in these intangible values over time, throughout the planning process, and after implementation.

Prioritizing Data Collection

Although data on both the historical and baseline conditions related to ecosystem structure and functions and social, cultural, and economic values are important, it is not always practical to collect all of the available information. Budgets and technical limitations often place constraints on the amount and types of data that can be collected. It is therefore important for the technical team, advisory group, and decision maker to prioritize the data needed.

At a minimum, the data necessary to explain the mechanisms or processes that affect stream corridor conditions need to be collected. To illustrate the challenges of data prioritization, consider the example of identifying data for assessing habitat functions. Potential habitat data could include items such as the extent of impacted fish, wildlife, and other biota; ecological aspects; biological characteristics of soils and water; vegetation (both native and nonnative); and relationships among ecological considerations (**Figure 4.9**). Depending on the scope of the restoration plan, however, data for all of these elements might not be necessary to successfully accomplish restoration. This holds especially true for smaller restoration efforts in limited stream reaches.

An effective way to prioritize data collection is through a scoping process designed to determine those data which are critical to decision making. The scoping process identifies significant concerns by institutional recognition (laws, policies, rules, and regulations), public recognition (public concern and local perceptions), or technical recognition (standards, criteria, and procedures).

Figure 4.9: Characterizing stream corridor conditions. *Data collection and analysis are important components of problem identification.*

Data Analysis

Data analysis, like data collection, plays an important role in all elements of problem identification as well as other aspects of the restoration process. Data analysis techniques range from qualitative evaluations using professional judgment to elaborate computer models.

The scope and complexity of the restoration effort, along with the budget, will influence the type of analytical techniques selected. A wealth of techniques are discussed in the literature and various manuals and will not be listed in this document. Part I, however, provides examples of the types of processes and functions that need to be analyzed. In addition, Part III discusses some analytical techniques used for condition analysis and restoration design, offers some analytic methodologies, and provides additional references.

Existing Stream Corridor Structure, Functions, and Disturbances

The second step in problem identification and analysis is determining which stream corridor conditions best characterize the existing situation. Corridor structure, functions, and associated disturbances used to describe the existing condition of the stream corridor will be determined on a case-by-case basis. Just as human health is indexed by such parameters as blood pressure and body temperature, the condition of a stream corridor must be indexed by an appropriate suite of measurable attributes.

There are no hard-and-fast rules about which attributes are most useful in characterizing the condition of stream corridor structure and functions. However, as a starting point, consideration should be given to describing present conditions associated with the following eight components of the corridor:

- Hydrology
- Erosion and sediment yield
- Floodplain/riparian vegetation
- Channel processes
- Connectivity
- Water quality
- Aquatic and riparian species and critical habitats
- Corridor dimension

Since the ultimate goal is to establish restoration objectives in terms of the structure and functions of the stream corridor, it is useful to characterize those attributes which either measure or index the eventual attainment of the desired ecological condition. Some measurable attributes that might be useful for describing the above components of a stream corridor are listed in the box *Measurable Attributes for Describing Conditions in the Stream Corrido*r. Detailed guidance for quantifying many of the following attributes is either described or referenced elsewhere in this document.

Existing vs. Desired Structure and Functions: The Reference Condition

The third step in problem identification and analysis is to define the conditions within which the stream corridor problems and opportunities will be defined and restoration objectives established. It is helpful to describe how the present baseline conditions of the stream corridor compare to a *reference condition* that represents, as closely as possible, the desired outcome of restoration (**Figure 4.10**). The reference condition might be similar to what the stream corridor would have been like had it remained relatively stable. It might represent a condition less ideal than the pristine, but substantially improved from the present condition. Developing a set of reference conditions might not be an easy task, but it is essential to conducting a good problem/opportunity analysis.

Several information sources can be very helpful in defining the reference condition. Published literature might provide information for developing reference conditions. Hydrologic data can often be used to describe natural flow and sediment regimes, and regional hydraulic geometry relations may define reference conditions for channel dimensions, pattern, and profile. Published soil surveys contain soil

Figure 4.10: Example reference condition in the western United States. *A reference condition may be similar to what the corridor would have been like in a state of relative “dynamic equilibrium.*

map-unit descriptions and interpretations reflecting long-term ecological conditions that may be suitable for reference. Species lists of plants and animals (both historical and present) and literature on species habitat needs provide information on distribution of organisms, both by habitat characteristics and by geographic range.

In most cases, however, reference conditions are developed by comparison with *reference reaches* or sites believed to be indicative of the natural potential of the stream corridor. The *reference site* might be the predisturbance condition of the stream to be restored, where such conditions are established by examining relic areas (enclosures, preserves), historical photos, survey notes, and/or other descriptive accounts. Similarly, reference conditions may be developed from nearby stream corridors in similar physiographic settings if those streams are minimally impacted by natural and human-caused disturbances.

Measurable Attributes for Describing Conditions in the Stream Corridor

Hydrology

- total (annual) discharge
- seasonal (monthly) discharge
- peak flows
- minimum flows
- annual flow durations
- rainfall records
- size and shape of the watershed

Erosion and Sediment Yield

- watershed cover and soil health
- dominant erosion processes
- rates of surface erosion and mass wasting
- sediment delivery ratios
- channel erosion processes and rates
- sediment transport functions

Floodplain/Riparian Vegetation

- community type
- type distribution
- surface cover
- canopy
- community dynamics and succession
- recruitment/reproduction
- connectivity

Channel Processes

- flow characteristics
- channel dimensions, shape, profile, and pattern
- substrate composition
- floodplain connectivity
- evidence of entrenchment and/or deposition
- lateral (bank) erosion
- floodplain scour
- channel avulsions/realignments
- meander and braiding processes
- depositional features
- scour-fill processes
- sediment transport class (suspended, bedload)

Water Quality

- color
- temperature, dissolved oxygen (BOD, COD, and TOC)
- suspended sediment
- present chemical condition
- present macroinvertebrate condition

Aquatic and Riparian Species and Critical Habitats

- aquatic species of concern and associated habitats
- riparian species of concern and associated habitats
- native vs. introduced species
- threatened or endangered species
- benthic, macroinvertebrate, or vertebrate indicator species

Corridor Dimension

- plan view maps
- topographic maps
- width
- linearity, etc.

The Condition Continuum

One helpful way to conceptualize the relationship between the current and reference conditions is to think of stream corridor conditions as occurring on a "condition continuum." At one end of this continuum, conditions may be categorized as being natural, pristine, or unimpaired by human activities. A headwater wilderness stream could exist near this end of the continuum ***(Figure 4.11)****. At the other end of the continuum, stream corridor conditions may be considered severely altered or impaired. Streams at this end of the continuum could be totally "trashed" streams or completely channelized water conduits.*

In concept, present conditions in the stream corridor exist somewhere along this condition continuum. The condition objective for stream restoration from an ecological perspective should be as close to the dynamic equilibrium as possible. It should be noted, however, that once other important considerations, such as political, economic, and social values, are introduced during the establishment of restoration goals and objectives, the target may shift to restoring the stream to some condition that lies between the present situation and dynamic equilibrium.

The proper functioning condition (PFC) concept is used as a minimum target in western riparian areas and can be the basis on which to plan additional enhancements (Pritchard et al.1993, rev. 1995).

Figure 4.11: Condition continuum. *The condition continuum runs from (a) untouched by humans to (b) severely impaired.*
Source: L. Goldman.

(a) *(b)*

Causes of Altered or Impaired Conditions

Conditions that provide the impetus for stream corridor restoration activities include degraded stream channel conditions and degraded habitat. A thorough analysis of the cause or causes of these alterations or impairments is fundamental to identifying management opportunities and constraints and to defining realistic and attainable restoration objectives.

As discussed in Chapter 3, for every stream corridor structural attribute and function that is altered or impaired, there may be a causal chain of events responsible for the impairment. As a result, when conducting a problem analysis, it is useful to consider factors that affect stream corridor ecological condition at different levels or scales:

- Landscape
- Stream corridor and reach.

Landscape Factors Affecting Stream Corridor Condition

When analyzing landscape-scale factors that contribute to existing stream corridor conditions, disturbances that result in changes in water and sediment delivery to the stream and in sources of contamination should be considered. In alluvial stream corridors, for example, anything that changes the historical balance between delivery of sediment to the channel and sediment-transport capacity of the stream will elicit a change in channel conditions. When sediment deliveries increase relative to sediment-transport capacities, stream aggradation usually occurs; when sediment-transport capacities increase relative to sediment delivery, stream incision usually occurs. How the channel responds to changes in flow and sediment regime depends on the magnitude of change in runoff and sediment and the type of sediment load being transported by the stream—suspended sediment or bedload.

The analysis of watershed effects on channels is aided by the use of standard hydrologic, hydraulic, and sediment transport tools. Depending on the available data, results may range from highly precise to quantitative. Altered flow regimes, for example, might be readily discernible if the stream has a long-term gauge record. Otherwise, numerical runoff modeling techniques might be needed to place an approximate magnitude on the change in peak flows resulting from a change in land use conditions. Water developments such as storage reservoirs and diversions also must be factored into an analysis of altered watershed hydrology (**Figure 4.13**).

Figure 4.13: Water releases below a dam. *Altering the flow regime of river below Hoover Dam altered the stream condition.*

Common Impaired or Degraded Stream Corridor Conditions

The following list provides some examples of impaired stream corridor conditions. A more complete list of these effects is provided in Chapter 3.

- *Stream aggradation—filling (rise in bed elevation over time)*
- *Stream degradation—incision (drop in bed elevation over time)*
- *Streambank erosion*
- *Impaired aquatic habitat*
- *Impaired riparian habitat*
- *Impaired terrestrial habitat*
- *Loss of gene pool of native species*
- *Increased peak flood elevation*
- *Increased bank failure*
- *Lower water table levels*
- *Increase of fine sediment in the corridor*
- *Decrease of species diversity*
- *Impaired water quality*

The effects of altered land use on sediment delivery to streams may be assessed using various analytical and empirical tools. These are discussed in Chapters 7 and 8. However, these tools should be used with some caution unless they have been verified and calibrated with actual instream sediment sampling data or measured reservoir sedimentation rates.

The stream channel itself might provide some clues as to whether it is experiencing an increase or decrease in sediment delivery from the watershed relative to sediment-transport capacity. Special attention should be paid to channel capacities and depositional features such as sand or gravel bars. If flooding seems to be more frequent, it might be an indication that aggradation is occurring. Conversely, if there is evidence of channel entrenchment, such as exposed bridge pier or abutment footings, degradation is occurring. Similarly, if the number and size of gravel bars are significantly different from what is evident in historical photos, for example, the difference might be an indication that either aggradation or erosion has been enhanced. Care is needed when using the channel to interpret possible changes in watershed conditions since similar channel symptoms can also be caused by changes in conditions within the stream corridor itself or by natural variation of the hydrograph.

Accelerated Bank Erosion: The Importance of Understanding a Causal Chain of Events

*To illustrate the concept of a causal chain of events, consider the problem of accelerated bank erosion **(Figure 4.12)**. Often the cause of accelerated bank erosion might be attributed to increases in peak runoff or sediment delivery to a stream when a surrounding watershed is undergoing land use changes; to the loss of bank vegetation, which also increases the vulnerability of the bank to erosion; or to structures in the stream (e.g., bridge abutments) that redirect the water flow into the bank. In this case, determining that bank erosion has increased relative to some reference rate is central to the identification of an impaired condition. In addition, understanding the cause or causes of the increased erosion is a key step in effective problem analysis. It is critical to the solution of the problem that this understanding be factored into the development of restoration objectives and management alternatives.*

Figure 4.12: Bank erosion. *The cause(s) of bank erosion should be identified.*

Stream Corridor and Reach Factors Affecting Stream Corridor Conditions

In addition to watershed factors affecting stream corridor conditions, it is important to consider disturbances at the stream corridor and reach scales. In general, stream corridor structural attributes and functions are greatly affected by several important categories of activities if they occur within the corridor. Chapter 3 explores these in more detail; the following are some of the activities that commonly impact corridor structure and function.

- Activities that alter or remove stream-bank and riparian vegetation (e.g., grazing, agriculture, logging, and urbanization), resulting in changes in the stability of stre-

ambanks, runoff and transport of contaminants, water quality, or habitat characteristics of riparian zones (**Figure 4.14**).
- Activities that physically alter the morphology of channels, banks, and riparianzones, resulting in effects such as the displacement of aquatic and riparian habitat and the disruption of the flow of energy and materials (e.g., channelization, levee construction, gravel mining, and access trails).
- Instream modifications that alter channel shape and dimensions, flow hydraulics, sediment-transport characteristics, aquatic habitat, and water quality (e.g., dams and grade stabilization measures, bank riprap, logs, bridge piers, and habitat "enhancement" measures) (**Figure 4.15**). In the case of logs, it might be the loss of such structures rather than their addition that alters flow hydraulics and channel structure.

Altered riparian vegetation and physical modification of channels and flood-plains are primary causes of impaired stream corridor structure and functions because their effects are both profound and direct. Addressing the causes of these changes might offer the best, most feasible opportunities for restoring stream corridors. However, the altered vegetation and physical modifications also may create some of the most significant challenges for stream corridor restoration by constraining the number or type of possible solutions.

It is important to remember that there are no simple analytical methods available for analyzing relationships between activities or events potentially disturbing the stream corridor and the structure and functions defining the corridor. However, there are modes by which stream corridor activities and structures can affect ecological conditions that involve both direct and indirect impacts. The box *Examples of How Activities Occurring Within the Corridor Can Affect Structure and Functions* provides some examples of the modes by which activities can affect stream corridor structure and functions.

FAST FORWARD
Preview Chapters 7 and 8, Analytical and Empirical Tools section.

Figure 4.14: Residential development. *Urbanization can severely impair conditions critical for riparian vegetation by increasing impervious surfaces.*

Figure 4.15: Riparian vegetation and structure. *The loss of logs in a stream alters flow hydraulics and channel structure.*

In conducting the problem analysis, it is important to investigate the various modes of ecological interaction at the reach and system scales. The analysis might need to be subjective and deductive, in which case use of an interdisciplinary team is essential. In other cases, the analysis might be enhanced by application of available hydrologic, hydraulic, sedimentation, water quality, or habitat models.

Whatever the situation, it is likely that the analysis will require site-specific application of ecological principles aided by a few quantitative tools. It will rarely be possible to determine causative factors for resource impairment using uninterpreted results from off-the-shelf analytical models. Part III, Chapter 7, contains a detailed discussion of some of the quantitative tools available to assist in the analysis of the resource conditions within the stream corridor ecosystem.

Determination of Management Influence on Stream Corridor Conditions

Once the conditions have been identified and the causes of those conditions described, the key remaining question is whether the causative factors are a function of and responsive to management. Specific management factors that contribute to impairment might or might not have been identified with the causes of impairment previously identified.

To illustrate, consider again the example of increased bank erosion. An initial analysis of impaired conditions might identify causes such as land uses in the watershed that are yielding higher flows and sediment loads, loss of streambank vegetation, or redirection of flow from instream modifications. None of these, however, identify the role of management influences. For

FAST FORWARD
Preview Chapter 7's Quantitative Tools section.

example, if higher water and sediment yields are a function of improper grazing management, the problem might be mitigated simply by altering grazing practices.

The ability to identify management influences becomes critical when identifying alternatives for restoration. Description of past management influences may prevent the repetition of previous mistakes and should facilitate prediction of future system response for evaluating alternatives. Recognition of management influences also is important for predicting the effectiveness of mitigation and the feasibility of specific treatments. Identifying the role of management is a key consideration when evaluating the ability of the stream corridor to heal itself (e.g., without management, with management, with management plus additional treatments). The identification of past management, both in the watershed and in the stream corridor, and its influence on those factors causing impairment will therefore help to sharpen the focus of the restoration effort.

Problem or Opportunity Statements for Stream Corridor Restoration

The final step in the process of problem/ opportunity identification and analysis is development of concise statements to drive the restoration effort. Problem/opportunity statements not only serve as a general focus for the restoration effort but also become the basis for developing specific restoration objectives. Moreover, they form the basis for determining success or failure of the restoration initiative. Problem/opportunity statements are therefore critical for design of a relevant monitoring approach.

For maximum effectiveness, these statements should usually have the following two characteristics:

- They describe impaired stream corridor conditions that are explicitly stated in measurable units and can be related to specific processes within the stream corridor.
- They describe deviation from the desired reference condition (dynamic equilibrium) or proper functioning condition for each impaired condition.

Examples of How Activities Occurring Within the Corridor Can Affects Structure and Function

Direct disturbance or displacement of aquatic and/or riparian species or habitats Indirect disturbance associated with altered stream hydraulics and sediment-transport capacity

Indirect disturbance associated with altered channel and riparian zone sedimentation dynamics

Indirect disturbance associated with altered surface waterground water exchanges

Indirect disturbance associated with chemical discharges and altered water quality.

Localized Impacts Affecting the Stream Corridor

Spatial considerations in stream corridor restoration are usually discussed at the landscape, corridor, and stream scales (e.g., connections to other systems, minimum widths, or maximum edge concerns). However, the critical failures in corridor systems can often occur at the reach scale, where a single break in continuity or other weakness can have a domino effect on the entire corridor. Just as uncontrolled watershed degradation can doom stream corridor restoration effectiveness, so can specific sites where critical problems exist that can prevent the whole corridor from functioning effectively.

Examples of weaknesses or problems at the reach scale that might affect the whole corridor are wide-ranging. Barriers to fish passage, lack of appropriate shade and resultant loss of water temperature moderation, breaks in terrestrial migration lands, or narrow points that make some animals particularly vulnerable to predators can often alter conditions elsewhere in the corridor. In addition, other sites might be direct or indirect source areas for problems, such as headcuts or rapidly eroding banks that contribute excessive sediment to the stream and instability to the system, or locations with populations of noxious exotic plant species that can spread to other parts of the corridor system. Some site-specific land use problems can also have critical impacts on corridor integrity, including chronic damage from grazing livestock, irrigation water returns, and uncontrolled storm water outflows.

CASE STUDY

Bluewater Creek

The watershed analysis and subsequent treatments performed at Bluewater Creek, New Mexico, demonstrate successful watershed and stream corridor restoration. Although most of the work has taken place on federal land, the intermixing of private lands and the values and needs of the varied publics concerned with the watershed make it a valuable case study. The project, begun in 1984, has a record of progress and improved land management. The watershed received the 1997 Chief's Stewardship Award from the Chief of the Forest Service and continues to host numerous studies and research projects.

Located in the Zuni mountains of north-central New Mexico, Bluewater Creek drains a 52,042-acre watershed that enters Bluewater Lake, a 2,350-acre reservoir in the East Rio San Jose watershed. Bluewater Creek and Lake provide the only opportunity to fish for trout and other coldwater species and offer a unique opportunity for water-based recreation in an otherwise arid part of New Mexico.

The watershed has a lengthy history of complex land uses. Between 1890 and 1940, extensive logging using narrow-gauge railroad technology cut over much of the watershed. Extensive grazing of livestock, uncontrolled fires, and some mining activity also occurred. Following logging by private enterprises, large portions of the watershed were sold to the USDA Forest Service in the early 1940s. Grazing, some logging, extensive roading, and increased recreational use continued in the watershed. The Mt. Taylor Ranger District of the Cibola National Forest now manages 86 percent of the watershed, with significant private holdings (12.5 percent) and limited parcels owned by the state of New Mexico and Native Americans.

In the early 1980s, local citizens worked with the Soil Conservation Service (now Natural Resources Conservation Service) to begin a Resource Conservation and Development (RC&D) project to protect water quality in the stream and lake as well as limit lake sedimentation harming irrigation and recreation opportunities. Although the RC&D project did not develop, the Forest Service, as the major land manager in the watershed, conducted a thorough analysis on the lands it managed and implemented a restoration initiative and monitoring that continue to this day.

The effort has been based on five goals: (1) reduce flood peaks and prolong baseflows, (2) reduce soil loss and resultant downstream channel and lake sedimentation, (3) increase fish and wildlife productivity, (4) improve timber and range productivity, and (5) demonstrate proper watershed analysis and treatment methods. Also important is close adherence to a variety of legal requirements to preserve the environmental and cultural values of the watershed, particularly addressing the needs of threatened, endangered, and sensitive plant and animal species; preserving the rich cultural history of the area; and complying with requirements of the Clean Water Act.

*For analysis purposes, the watershed was divided into 13 subwatersheds and further stratified based on vegetation, geology, and slope. Analysis of data gathered measuring ground cover transects and channel analysis from August 1984 through July 1985 resulted in eight major conclusions: (1) areas forested with mixed conifer and ponderosa pine species were generally able to handle rainfall and snowmelt runoff; (2) excessive peak flows, as well as normal flows continually undercut steep channel banks, causing large volumes of bank material to enter the stream and lake system; (3) most perennial and intermittent channels were lacking the riparian vegetation they needed to maintain streambank integrity; (4) most watersheds had an excessive number of roads **(Figure 4.16)**; (5) trails caused by livestock, particularly cattle, concentrate runoff into small streams and erodible areas; (6) several key watersheds suffered from livestock overuse and improper grazing management systems; (7) some instances of timber management practices were exacerbating watershed problems; and (8) excessive runoff in some subwatersheds continued to degrade the main channel.*

*Based on the conclusions of the analysis, a broad range of treatments were prescribed and implemented. Some were active (e.g., construction of particular works or projects); others were more passive (e.g., adjustments to grazing strategies). Channel treatments such as small dams, gully headcut control structures, grade control structures, porous fence revetments **(Figures 4.17, 4.18, and 4.19)**, and channel crossings **(Figure 4.20)** were used to affect flow regimes, channel stability, and water quality. Riparian plantings, riparian pastures, and beaver management programs were also established, and meander*

Figure 4.16: Vehicle traffic through wet meadow in Bluewater Creek, NM. *(May 1984.) Such traffic compacts and damages soil, changes flow patterns, and induces gully erosion.*

Figure 4.17: Recently installed treatment. *(April 1987.) Porous fence revetment designed to reduce bank failure.*

Figure 4.18: Porous fence revetment aided by bank sloping. *(August 1987.) The photo shows initial revegetation during first growing season following treatment installation.*

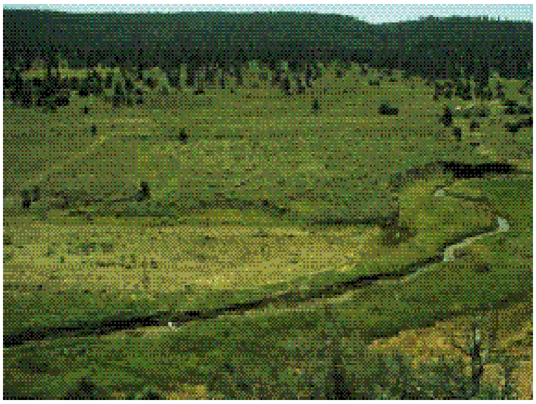


Figure 4.19: Porous fence revetments after two growing seasons. *(September 1988.) Vegetation is noticeably established over first growing season.*

reestablishment and channel relocation were conducted. Land treatments, such as the establishment of best management practices (BMPs) for livestock, timber, roads, and fish and wildlife, were developed to prevent soil loss and maintain site productivity.

In a few cases, land and channel treatments were implemented simultaneously (e.g., livestock drift fences and seasonal area closures). Additional attention was paid to improved road management practices, and unnecessary roads were closed.

Results of the project have largely met its goals, and the watershed is more productive and enjoyable for a broad range of goods, services, and values. Although one weakness of the project was the lack of a carefully designed monitoring and evaluation plan, observers generally agree that the completed treatments continue to perform their designed function, while additional treatments add to the success of the project.

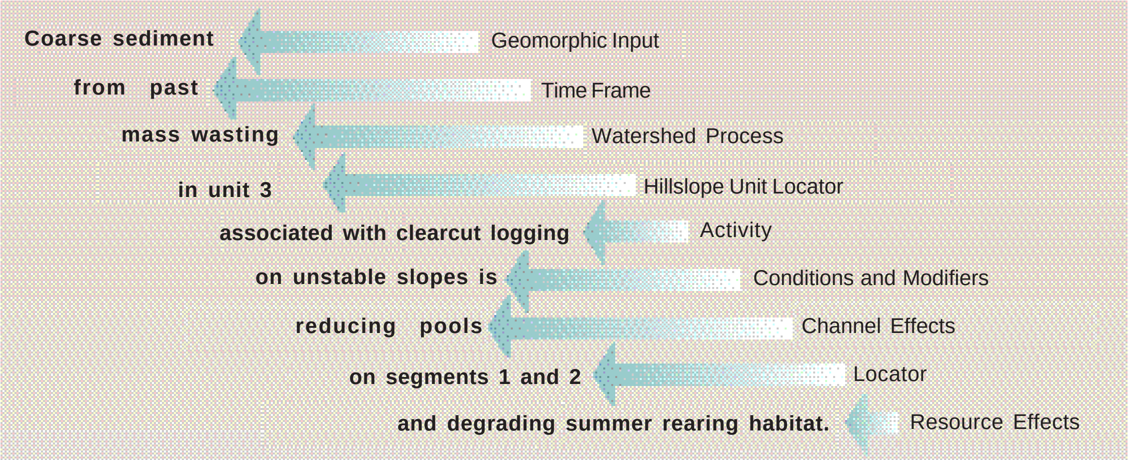
Most of the small in-channel structures are functioning as designed. The meander reestablishment has lengthened the channel and decreased gradient in a critical reach. The channel relocation project has just completed its first year, and initial results are promising. Beaver have established themselves along the main channel of Bluewater Creek, providing significant habitat for fish and wildlife, as their ponds capture sediment and moderate flood peaks. The watershed now provides a more varied and robust population of fish and wildlife species. Changes in road management have yielded significant results. Road closures have removed traffic from sensitive areas, and reconstruction of two key roads has reduced sediment damages to the stream. Special attention to road crossings of wet meadows has begun to rehabilitate scores of acres dewatered by improper crossings. Range management techniques (e.g., combined allotments, improved fencing, and more modern grazing strategies) are improving watershed condition. A limited timber management program on the federal property has had beneficial impacts on the watershed, but significant timber harvest on private lands provided a cause for concern, particularly regarding compliance with Clean Water Act best management practices.

The local citizens who use the watershed have benefited from the improved conditions. Recreation use continues to climb.

Figure 4.20: Multiple elevated culvert array at crossing of wet meadow. *(June 1997.) The culvert spreads flow and decreases erosion energy, captures sediment upstream, reduces flood peaks, and prolongs baseflows.*

Problem/Opportunity Statement

Problem/Opportunity statements should follow directly from the analysis of existing and reference stream corridor conditions. These statements can be viewed as an articulation of some of the potential benefits that can be realized through restoration of the structure and functions of the stream corridor. For example, problem statements might focus on the impaired structural attributes and functions needing attention, while associated opportunities might focus on reintroduction of native species that were previously eliminated from the system. Problem/Opportunity statements can also focus on the economic benefits of a proposed restoration initiative. By identifying such economic benefits to local landowners, it may be possible to increase the number of private citizens participating in the planning process.



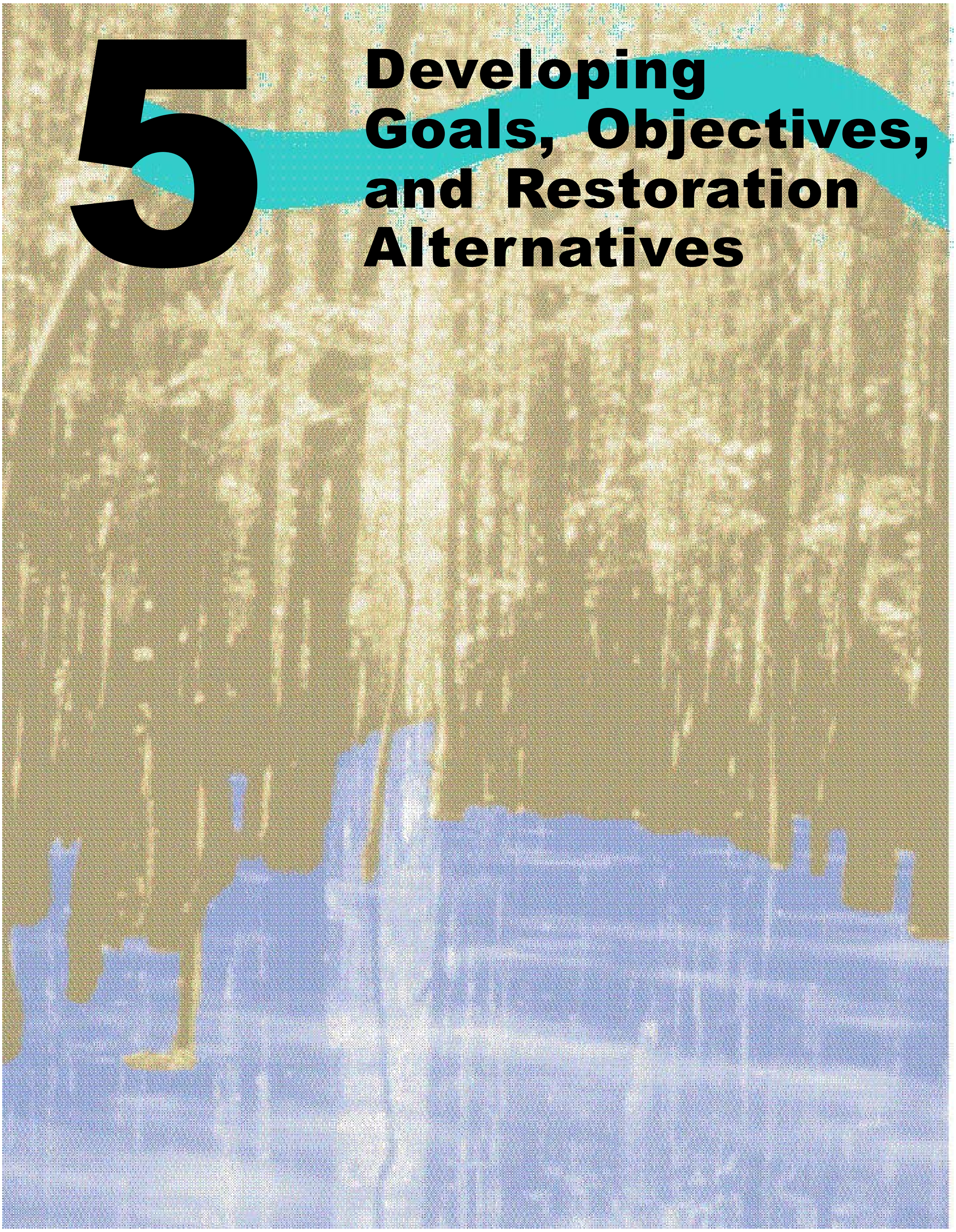
Example opportunity statements:

- *To prevent streambank erosion and sediment damage and provide quality streamside vegetation through bioengineering techniques—Four Mile Run, Virginia.*
- *To protect approximately 750 linear feet of Sligo Creek through the construction of a parallel pipe system for storm water discharge control—Sligo Creek, Maryland.*
- *To enhance the creek through reconstruction of instream habitat (e.g., pools and riffles)—Pipers Creek, Washington.*
- *To reintroduce nongame fish and salamanders in conjunction with implementing several stream restoration techniques and eliminating point source discharges—Berkeley Campus Creek, California.*

Example statements adapted from Center for Watershed Protection 1995.

5

Developing Goals, Objectives, and Restoration Alternatives



5.A Developing Restoration Goals and Objectives

- How are restoration goals and objectives defined?
- How do you describe desired future conditions for the stream corridor and surrounding natural systems?
- What is the appropriate spatial scale for the stream corridor restoration?
- What institutional or legal issues are likely to be encountered during a restoration?
- What are the means to alter or remove the anthropogenic changes that caused the need for the restoration (i.e., passive restoration)?

5.B Alternative Selection and Design

- How does a restoration effort target solutions to treat causes of impairment and not just symptoms?
- What are important factors to consider when selecting among various restoration alternatives?
- What role does spatial scale, economics, and risk play in helping to select the best restoration alternative?
- Who makes the decisions?
- When is active restoration needed?
- When are passive restoration methods appropriate?Chapter 6: Implement, Monitor, Evaluate, and Adapt.

5

DEVELOPING GOALS, OBJECTIVES, AND RESTORATION ALTERNATIVES

Once the basic organizational steps have been completed and the problems/ opportunities associated with the stream corridor have been identified, the next two stages of the restoration plan development process can be initiated.

These two stages, the development of restoration goals and objectives and alternative selection and design, require input from all partners. The advisory group should work in collaboration with the decision maker(s) and technical teams.

During the objective development, alternative selection, and design stages, it is important that continuity be maintained among the fundamental steps of the restoration process. In other words, planners must work to ensure a logical flow and relationship between problem and opportunity statements, restoration goals and objectives, and design.

Remember that the restoration planning process can be as complex as the stream corridor to be restored. A project might involve a large number of landowners and decision makers. It might also be fairly simple, allowing planning through a streamlined process. In either case, proper planning will lead to success.

Proper planning in the beginning of the restoration process will save time and money for the life of the project. This is often accomplished by managing the causes rather than the symptoms.

This chapter is divided into two sections that describe the basic steps of defining goals and objectives, selecting alternatives, and designing restoration measures.

Section 5.A: Developing Restoration Goals and Objectives

Restoration objectives are essential for guiding the development and implementation of restoration efforts and for *establishing a means to measure progress and evaluate success. This section outlines some of the major considerations that need to be taken into account in developing restoration goals and objectives for a restoration plan.*

Although active restorations that include the installation of designed measures are common, the "no action" or passive alternative might be more ecologically desirable, depending on the specific goals and time frame of the plan.

Section 5.B: Alternative Selection and Design

The selection of restoration alternatives is a complex process that is intended to address the identified problems/opportunities and accomplish restoration goals and objectives.

Some of the important factors to consider in designing restoration measures, as well as some of the supporting analysis that facilitates alternative selection, are discussed.

Components of the Goal and Objective Development Process

- Define the desired future condition.
- Identify scale considerations.
- Identify restoration constraints and issues.
- Define goals and objectives.

5.A Developing Restoration Goals and Objectives

Developing goals and objectives for a stream corridor restoration effort follows problem/opportunity identification and analysis. The goals development process should mark the integration of the results of the assessment of existing and desired stream corridor structure and functions with important political, economic, social, and cultural values. This section presents and explains some of the fundamental components of the goal and objective development process.

Defining Desired Future Stream Corridor Conditions

The development of goals and objectives should begin with a rough outline, as discussed in Chapter 4, and with the definition of the *desired future condition* of the stream corridor and surrounding landscape (**Figure 5.1**). The desired future condition should represent the common vision of all participants. This clear, conceptual picture is necessary to serve both as a foundation for more specific goals and objectives and as a target toward which implementation strategies can be directed.

The vision statement should be consistent with the overall ecological goal of restoring stream corridor structure and functions and bringing the system as close to a state of dynamic equilibrium or proper functioning condition as possible.

The development of this vision statement should be seen as an opportunity for participants to articulate an ambitious ecological vision. This vision will ultimately be integrated with important social, political, economic, and cultural values.

Identifying Scale Considerations

In developing stream corridor restoration goals and objectives it is important to consider and address the issue of scale. The scale of stream corridor restoration efforts can vary greatly, from working on a short reach to managing a large river basin corridor. As discussed previously, it is important to recognize, however, that the functions of a specific streambank or reach ecosystem are not performed in isolation and are linked to associated ecosystems in the surrounding landscape. As a result, goals and objectives should recognize the stream corridor and its surrounding landscape.

The Landscape Scale

Technical considerations in stream corridor restoration usually encompass the landscape scale as well as the stream corridor scale. These considerations may include political, economic, historical, and/or cultural values; natural resource management concerns; and biodiversity (Landin 1995). The following are some important issues relevant to the landscape scale.

Regional Economic and Natural Resource Management Considerations

Regional economic priorities and natural resource objectives should be identified and evaluated with respect to their likely influence on the restoration effort. It is important that restoration goals and objectives reflect a clear understanding of the concerns of the people living in the region and the immediate area, as well as the priorities of resource agencies responsible for managing lands within the restoration target area and providing support for the initiative (**Figure 5.3**). In many highly developed areas, restoration may be driven largely by a general re-

Figure 5.1: Example of future conditions. *The desired future condition should represent the common vision of all participants.*

cognition that stream corridors provide the most satisfactory opportunities to repair and preserve natural environments in the midst of increasingly dense human occupation.

In wildland areas, stream corridor restoration might be pursued as part of an overall ecosystem management program or to address the requirements of a particular endangered species.

Land Use Considerations

As discussed in Chapter 2, many of the characteristics and functions of the stream corridor are controlled by hydrologic and geomorphic conditions in the watershed, particularly as they influence streamflow regime, sediment movement, and inputs of nutrients and pollutants (Brinson et al. 1995).

As introduced in Chapter 3, chan-

REVERSE

Review Chapters 2 and 3.

Figure 5.3: Western stream—landscape scale. Developing goals and objectives requires the consideration of important social, economic, ecological, and natural resource factors at the landscape scale.

CASE STUDY

Chesapeake Bay Program

A unique partnership that spanned across all scales of the Chesapeake Bay watershed was formed in 1983. The Chesapeake Bay Agreement was signed that year by the District of Columbia, the state of Maryland, the Commonwealths of Pennsylvania and Virginia, the Chesapeake Bay Commission (a tri-state legislative body), and the federal government represented by the Environmental Protection Agency to coordinate and direct the restoration of the Chesapeake Bay.

Recognizing that local cooperation would be vital in implementing any efforts, the Executive Committee created the Local Government Advisory Committee (LGAC) in 1987. The LGAC acts as a conduit to communicate current efforts in the Program to the local level, as well as a platform for local governments to voice their perceptions, ideas, and concerns. The Land Growth and Stewardship Subcommittee was formed in 1994 to encourage actions that reduce the impacts of growth on the Bay and address other issues related to population growth and expansion in the region.

The Chesapeake Bay was the first estuary targeted for restoration in the 1970s. Based on the scientific data collected during that time, the agreement targeted 40 percent reductions in nutrients, nitrogen, and phosphorus by the year 2000. The committee has been instrumental in moving up the tributaries of the bay and improving agricultural practices, removing nutrients, and educating the millions of residents about their role in improving the quality of the bay. Success has been marked by reduction in nutrients and an increase in populations of striped bass and other species ***(Figure 5.2)****. Recent fish kills in the watershed rivers, however, are reminders that maintaining the health of the Chesapeake Bay is a continuing challenge.*

Success at the local level is key to the success of the overall program. Chesapeake Bay Communities' Making the Connection catalogs some of the local initiatives to restore local environments and improve the condition of the bay. In Lancaster County, Pennsylvania, for example, a Stream Team was formed to preserve and restore the local streams. Its primary role is to coordinate restoration efforts involving local landowners, volunteers, and available programs. In one case, the Stream Team was able to arrange materials for a local fishing group and a farmer to fence a pasture stream and plant trees. With continuous efforts such as this, the Chesapeake Bay will become cleaner one tributary at a time.

Figure 5.2: Chesapeake Bay. *The Chesapeake Bay is a unique estuarine ecosystem protected through interagency cooperation.*
Source: C. Zabawa.

ges in land use and increases in development are a concern, particularly because they can cause rapid changes in the delivery of storm water to the stream system, thereby changing the basic hydrologic patterns that determine stream configuration and plant community distribution (**Figure 5.4**). In addition, future development can influence what the stream corridor will be expected to accomplish in terms of processing or storing floodwaters or nutrients, or with respect to providing wildlife habitat or recreation opportunities.

Landscape concerns pertinent to developing goals and objectives for stream corridor restoration should also include an assessment of land use and projected development trends in the watershed. By making an effort to accommodate predictable future land use and development patterns, degradation of stream corridor conditions can be prevented or reduced.

Biodiversity Considerations

The continuity that corridors provide among different areas and ecosystem types has often been cited as a major tool for maintaining regional biodiversity because it facilitates animal movement (particularly for large mammals) and prevents isolation of plant and animal populations. However, there has been some dispute over the effectiveness of corridors to accomplish these objectives and over the creation of inappropriate corridors having adverse consequences (Knopf 1986, Noss 1987, Simberloff and Cox 1987, Mann and Plummer 1995).

Where corridor restoration is intended to result in establishing connectivity on a landscape scale, management objectives and options should reflect natural patterns of plant community distribution and should be built to provide as much biodiversity as possible. In many instances, however, the driving force behind restoration is the protection of certain threatened, endangered, game, or other specially targeted species. In these cases a balance must be struck. A portion of the overall restoration plan can be directed toward the life requirements of the targeted species, but on the whole the goal should be a diverse community (**Figure 5.5**).

The Stream Corridor Scale

Each stream corridor targeted for restoration is unique. A project goal of restoring multiple ecological functions might encompass the channel systems, the active floodplain, and possibly adjacent hill slopes or other buffer areas that have the potential to directly and indirectly influence the stream or protect it from surrounding land uses (Sedell et al. 1990). A wide corridor is most likely to include a range of biotic community types and to perform many of the stream functions (floodwater and sediment storage, nutrient processing, fish and wildlife habitat, and others) that the restoration effort is intended to restore. In many cases, however, it will not be possible to reestablish the original corridor width, and restoration will be focused on a narrower strip of land directly adjacent to the channel.

Where narrow corridors are established through urban or agricultural landscapes, certain functions might be restored (e.g., stream shading), while others might not (e.g., wildlife movement). In particular, very narrow corridors, such as western riparian areas, may function largely as edge habitat and will favor unique and sometimes opportunistic plant and animal species. In some situations, creating a large amount of edge habitat might be detrimental to species that require large forested habitat or are highly vulnerable to predation or nest parasitism and disturbances.

The corridor configuration and restoration options depend to a large extent on the pattern of land ownership and use at the stream corridor scale. Corridors that traverse agricultural land may involve the interests of many individual landowners with varying levels of commitment to or interest in the restoration initiative.

Often, landowners will not be inclined to remove acreage from production or alter land use practices without incentive. In urban settings, citizen groups may have a strong voice in the objectives and layout of the corridor. On large public land holdings, management agencies might be able to commit to the establishment and management of stream corridors and their watersheds, but the incorpora-

Figure 5.4: Urban stream corridor. *Population growth and land use trends, such as urbanization, should be considered when developing restoration goals and objectives.*

Figure 5.5: Animal population dynamics. *Restoration plans may target species, but biodiversity should be the basic goal of restoration.*

tion of competing interests (timber, grazing, mining, recreation) that are not always consistent with the objectives of the restoration plan can be difficult. In most cases, the final configuration of the corridor should balance multiple and often conflicting objectives, including optimizing ecological structure and function and accommodating the diverse needs of landowners and other participants.

The Reach Scale

A reach is the fundamental unit for design and management of the stream corridor. In establishing goals and objectives, each reach must be evaluated with regard to its landscape and individual characteristics, as well as their influence on stream corridor function and integrity. For example, steep slopes adjacent to a channel reach must be considered where they contribute potentially significant amounts of runoff, subsurface flow, sediment, woody debris, or other inputs. Another reach might be particularly active with respect to channel migration and might warrant expanding the corridor relative to other reaches to accommodate local stream dynamics.

Identifying Restoration Constraints and Issues

Once participants have reached consensus on the desired future condition and examined scale considerations, attention should be given to identifying *restoration constraints and issues*. This process is important in that it helps identify limitations associated with establishing specific restoration goals and objectives.

Moreover, it provides the information that will be needed when integrating ecological, social, political, and economic values.

Due to the innumerable potential challenges involved in identifying all of the constraints and issues, it is often helpful to rely on the services of the interdisciplinary technical teams. Team members support one another and provide critical expertise and the experience necessary to investigate potential constraints. The following are some of the restoration constraints and issues, both technical and nontechnical, that should be considered in defining restoration goals and objectives.

Technical Constraints

Technical constraints include the availability of data and restoration technologies. In terms of data availability, it is important that the technical team begin by compiling and analyzing data available on stream corridor structure and functions. Analyzing these data will enable the identification of information gaps and should allow the restoration effort to proceed, even though all of the information might not be at hand. It should be noted that there is usually a wealth of technical information available either in published sources or in public agency offices as unpublished source material.

In addition to data availability, a second technical constraint might involve the tools or techniques used to analyze or collect stream corridor data. Some restoration techniques and methodologies are not complete and might not be sufficient to conduct the restoration effort. It is also generally known that technology transfer and dissemination associated with available techniques are far behind the existing information base, and field personnel might not readily have access to needed information. It is important that the technical teams are up-to-date with restoration technology and are prepared to modify implemented plans through adaptive management as necessary.

FAST FORWARD
Preview Chapter 6's
Adaptive Management section.

Quality Assurance, Quality Control

The success of a stream corridor restoration plan depends on the following:

- Efficient and accurate use of existing data and information.
- Reliable collection of new data that are needed, recognizing the required level of precision and accuracy(**Figure 5.6**).
- Interpretation of the meaning of the data, including translating the data into information that can be used to make planning decisions.
- A locally led, voluntary approach.

The concept of quality assurance or quality control is not new. When time, materials, or money are to be expended, results should be as reliable and efficiently derived as possible. Provisions for quality control or quality assurance can be built into the restoration plan, especially if a large number of contractors, volunteers, and other people not directly under the control of the planners are involved (Averett and Schroder 1993).

Many standards, conventions, and protocols exist to ensure the quality or reliability of information used for planning a restoration (Knott et al. 1992), including the following:

- Sampling
- Field analytical equipment
- Laboratory testing equipment
- Standard procedures
- Training
- Calibrations
- Documentation
- Reviews

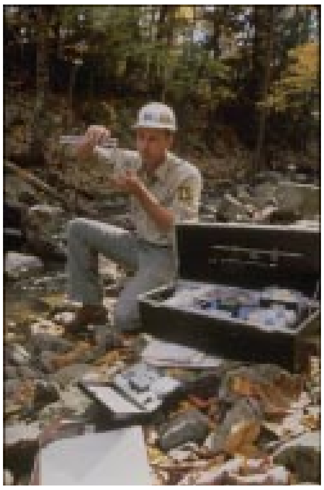


Figure 5.6: Field sampling. *Collecting the right kinds of data with the proper quality control and translating that data into information useful for making decisions is a challenge.*

- Delegations of authority
- Inspections

The quality of work and the restoration actions can be ensured through the following (Shampine et al. 1992, Stanley et al. 1992, Knott et al. 1993):

- Training to ensure that all persons fully understand what is expected of them.
- Products that are produced on time and that meet the plan's goals and objectives.
- Established procedures for remedial actions or adaptive management, which means being able to make adjustments as monitoring results are analyzed.

Nontechnical Constraints

Nontechnical constraints consist of financial, political, institutional, legal and regulatory, social, and cultural constraints, as well as current and future land and water use conflicts. Any one of these has the potential to alter, postpone, or even stop a restoration initiative. As a result, it is important that the advisory group and decision maker consider appointing a technical team to investigate these issues prior to defining restoration goals and objectives.

Contained below is a brief discussion of some of the nontechnical issues that can play a role in restoration initiatives. Although many general examples and case studies offer experience on addressing nontechnical constraints, the nuances of each issue can vary by initiative.

Land and Water Use Conflicts

Land and water use conflicts are frequently a problem, especially in the western United States.

The historical, social, and cultural aspects of grazing, mining, logging, water resources development and use, and unrestricted use of public land are emotional issues that require coordination and education so that local and regional citizens understand what is being proposed in the restoration initiative and what will be accomplished.

Financial Issues

Planning, design, implementation, and other aspects of the restoration initiative must stay within a budget. Since most restoration efforts involve public agencies, the institutional, legal, and regulatory protocols and bureaucracies can delay restoration and increase costs. It is extremely important to recognize these problems early to keep the initiative on schedule and preclude or at least minimize cost overruns.

In some cases, funds might be insufficient to accomplish restoration. The means to undertake the initiative can often be obtained by seeking out and working with a broad variety of cost- and work-sharing partners; seeking out and working with volunteers to perform various levels of field work, as well as to serve as knowledgeable experts for the effort; costing the initiative in phases that are affordable; and other creative approaches (**Figure 5.7**). Logistical support by a local sponsor or community in the form of labor, boats, and other equipment should not be overlooked.

Not all restorations are complex or costly. Some might be as simple as a slight change in the way that resources are managed in and along the stream corridor, involving only minor costs. Other restorations, however, may require substantial funds because of the complexity and extent of measures needed to achieve the planned restoration goals.

Institutional and Legal Issues

Each restoration effort has its own unique set of regulatory requirements, which can range from almost no requirements to a full range of local, county, state, and federal permits. Properly planned restoration efforts should meet or exceed the intent of both federal and non-federal requirements. Restoration planners should contact the appropriate local, state, and federal agencies and involve them early in the process to avoid conflicts with these legal requirements.

Typical institutional and legal requirements cover a wide range of issues. Locally, restoration planners must be concerned with zoning permits and state and county water quality permits.

Most federally sponsored and/or funded initiatives require compliance with the National Environmental Policy Act and the Endangered Species Act. Initiatives that receive federal support must comply with the National Historic Preservation Act and the Wild and Scenic Rivers Act. Permits might also be required from the US Army Corps of Engineers under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899.

Defining Restoration Goals

Restoration goals should be defined by the decision maker(s) with the consensus of the advisory group and input from the interdisciplinary technical team(s) and other participants. As noted earlier, these goals should be an integration of two important groups of factors:

- Desired future condition (ecological reference condition).
- Social, political, and economic values.

Figure 5.7: Field volunteers. *Volunteers assisting in the restoration effort can be an effective way to combat financial constraints.*
Source: C . Zabawa.

Considering Desired Future Condition

As discussed earlier, the desired ecological future condition of the stream corridor is frequently based on predevelopment conditions or some commonly accepted idea of how the natural stream corridors looked and functioned. Consequently, it represents the ideal situation for restoration, whether or not this reference condition is attainable. This ideal situation has been given the term "potential," and it may be described as the highest ecological status an area can attain, given no political, social, or economic constraints (Prichard et al. 1993). When applied to the initiative, however, this statement might require modification to provide realistic and more specific goals for restoration.

Permits

Federal, state, or local permits might be required for some types of stream restoration activities. Some states, such as California, require permits for any activity in a streambed. Placement of dredged or fill material in waters of the United States requires a Clean Water Act (CWA) Section 404 permit from the US Army Corps of Engineers or, when the program has been delegated, from the state. The CWA requires the application of the Section 404(b)(1) guidelines issued by the Environmental Protection Agency in determining whether discharge should be allowed. A permit issued under Section 10 of the Rivers and Harbors Act of 1899 might also be required for activities that change the course, condition, location, or capacity of navigable waters.

Activities that could trigger the need for a CWA Section 404 permit include, but are not limited to, recreation of gravel beds, sand bars, and riffle and pool habitats; wetland restoration; placement of tree root masses; and placement of revetment on channel banks. CWA Section 404 requires that a state or tribe (one or both as appropriate) certify that an activity requiring a Section 404 permit is consistent with the state's or tribe's water quality standards. Given the variety of actions covered by the CWA, as well as jurisdiction issues, it is vital to contact the Corps of Engineers Regulatory Branch and appropriate state officials early in the planning process to determine the conditions triggering the need for permits as well as how to best integrate permit compliance needs into the planning and design of the restoration initiative. Chances are that a well-thought-out planning and design process will address most, if not all, the information needs for evaluation or certification of permit applications. Federal issuance of a permit triggers the need for compliance with the National Environmental Policy Act (see National Environmental Policy Act Considerations).

Example Goals and Objectives

*The following is an excerpt from of a restoration plan used for restoration of Wheaton Branch, a severely degraded urban stream in Maryland. The **goal** of the project was to control storm water flows and improve water quality.*

OBJECTIVES	*ALTERNATIVES*
(1) Remove urban pollutants	*Upstream pond retrofit*
(2) Stabilize channel bundles	*Install a double-wing deflector, imbricated riprap, and brush*
(3) Control hydrologic regime retrofit	*Upstream storm water management pond*
(4) Recolonize stream community	*Fish reintroduction*

Adapted from Center for Watershed Protection 1995.

Factoring in Constraints and Issues

In addition to the desired future ecological condition, definition of restoration goals must also include other considerations. These other factors include the important political, social, and economic values as well as issues of scale.

When these considerations are factored into the analysis, realistic project goals can be identified. The goals provide the overall purpose for the restoration effort and are based on a stream corridor's capability or its ideal ecological condition.

Defining Primary and Secondary Restoration Goals

The identification of realistic goals is a key ingredient for restoration success since it sets the framework for adaptive management within a realistic set of expectations. Unrealistic restoration goals create unrealistic expectations and potential disenchantment among stakeholders when those expectations are unfulfilled.

In defining realistic restoration goals, it might be helpful to divide these goals into two separate, yet connected, categories— primary and secondary.

Primary Restoration Goals

Primary goals should follow from the problem/opportunity identification and analysis, incorporate the participants' vision of the desired future condition, and reflect a recognition of project constraints and issues such as spatial scale, needs found in baseline data collection, practical aspects of budget and human resources requirements, and special requirements for certain target or endangered species. Primary goals are usually the ones that initiated the project, and they may focus on issues such as bank stabilization, sediment management, upland soil and water conservation, flood control, improved aquatic and terrestrial habitat, and aesthetics.

Secondary Restoration Goals

Secondary goals should be developed to either directly or indirectly support the primary goals of the restoration effort.

For example, hiring displaced forestry workers to install conservation practices in a forested watershed or region could serve the secondary goal of revitalizing a locally depressed economy, while also contributing to the primary goal of improving biodiversity in the restoration area.

Defining Restoration Objectives

Objectives give direction to the general approach, design, and implementation of the restoration effort. *Restoration objectives* should support the goals and also flow directly from problem/opportunity identification and analysis.

Restoration objectives should be defined in terms of the same conditions identified in the problem analysis and should specifically state which impaired stream corridor condition(s) will be moved toward which particular reference level or desired condition(s). The reference conditions provide a gauge against which to measure the success of the restoration effort; restoration objectives should therefore identify both impaired stream corridor conditions and a quantitative measure of what constitutes unimpaired (restored) conditions. Restoration objectives expressed in terms of measurable stream corridor conditions provide the basis for monitoring the success of the project in meeting condition objectives for the stream corridor..

As in the case of restoration goals, it is imperative that restoration objectives be realistic for the restoration area and be measurable. Objectives must therefore be based on the site's expected capability and not necessarily on its unaltered natural potential. It is much more useful to have realistic objectives reflecting stream corridor conditions that are both achievable and measurable than to have vague, idealistic objectives reflecting conditions that are neither.

For example, an overall restoration goal might be to improve fish habitat. Several supporting objectives might include the following:

- Improve water temperature by providing shade plants.
- Construct an instream structure to provide a pool as a sediment trap.
- Work with local landowners to encourage nearstream conservation efforts.

If these objectives were to be used as success criteria, however, they would require more specific, measurable wording. For example, the first objective could be written to state that buttonbush planted along streambanks exhibit a 50 percent survival rate after three growing seasons and are not less than 5 feet in height. This vegetative cover results in a net reduction in water temperature within the stream. It should be noted that this issue of success or evaluation criteria is critical to stream corridor restoration. This is explored in more detail in Chapters 6 and 9.

National Environmental Policy Act Considerations

The National Environmental Policy Act (NEPA) of 1969 established the nation's policy to protect and restore the environment and the federal responsibility to use "all practicable means and measures ... to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social and economic and other requirements of present and future generations of Americans." NEPA focuses on major federal actions with the potential to significantly affect the human environment. The Council on Environmental Quality's regulations implementing NEPA require the federal agency taking action to develop alternatives to a proposed action, to analyze and compare the impacts of each alternative and the proposed action, and to keep the public informed and involved throughout the project planning and implementation. Although NEPA does not mandate environmentally sound decisions, it has established a decision-making process that ultimately encourages better, wiser, and fully informed decisions.

When considering restoration of a stream corridor, it is important to determine early on whether a federal action will occur. Federal actions that might be associated with a stream corridor restoration initiative include, but are by no means limited to, a decision to provide federal funds for a restoration initiative, a decision to significantly alter operation and maintenance of federal facilities on a river system, or the need for a federal permit (e.g., a Clean Water Act Section 404 permit for placement of dredged or fill material in waters of the United States).

In addition, many states have environmental impact analysis statutes patterned along the same lines as NEPA. Consultation with state and local agencies should occur early and often throughout the process of developing a stream corridor restoration initiative. Jointly prepared federal and state environmental documentation is routine in some states and is encouraged.

The federal requirement to comply with NEPA should be integrated with the planning approach for developing a restoration plan. When multiple federal actions are required to fully implement a restoration initiative, the identity of the lead federal agency(s) and cooperating agencies should be established. This will facilitate agency adoption of the NEPA document for subsequent decision making.

5.B Alternative Selection and Design

The selection of technically feasible alternatives and subsequent design are intended to solve the identified problems, realize restoration opportunities, and accomplish restoration goals and objectives.

Alternatives range from making minor modifications and letting nature work to total reconstruction of the physical setting. An efficient approach is to conceptualize, evaluate, and select general solutions or overall strategies before developing specific alternatives.

This section focuses on some of the general issues and considerations that should be taken into account in the selection and design of stream corridor *restoration alternatives*. It sets the stage for the more detailed presentation of restoration design in Chapter 8 of this document.

Important Factors to Consider in Designing Restoration Alternatives

The design of restoration alternatives is a challenging process. In developing alternatives, special consideration should be given to managing causes as opposed to treating symptoms, tailoring restoration design to the appropriate scale (landscape/corridor/stream/ reach), and other scale-related issues.

Managing Causes vs. Treating Symptoms

When developing restoration alternatives, three questions regarding the factors that influence conditions in the stream corridor must be addressed.

FAST FORWARD

Preview Chapter 8's restoration design section

These are critical questions in determining whether a passive, nonstructural alternative is appropriate or whether a more active restoration alternative is needed.

1. What have been the implications of past management activities in the stream corridor (a cause-effects analysis)?
2. What are the realistic opportunities for eliminating, modifying, mitigating, or managing these activities?
3. What would be the response of impaired conditions in the corridor if these activities could be eliminated, modified, mitigated, or managed?

Concepts useful in defining restoration goals and objectives

Value*: Social/economic values associated with a change from one set of conditions to another. Often, these values are not economic values, but rather amenity values such as improved water quality, improved habitat for native aquatic or riparian species, or improved recreational experiences. Because stream corridor restoration often requires a monetary investment, the benefits of restoration need to be considered not only in terms of restoration costs, but also in terms of values gained or enhanced.*

Tolerance*: Acceptable levels of change in conditions in the corridor. Two levels of tolerance are suggested:*

(1) Variable “management” tolerance that is responsive to social concerns for selected areas.

(2) Absolute “resource” tolerance or minimal acceptable permanent resource damage.

Stream corridors in need of restoration usually (but not always) exceed these tolerances.

Vulnerability*: How susceptible a stream's present condition is to further deterioration if no new restoration actions are implemented. It can be conceptualized as the ease with which the system might move away from dynamic equilibrium. For example, an alpine stream threatened by a head-cut induced by a poorly placed culvert might be extremely vulnerable to subsequent incision. Conversely, a forested stream that has sluiced to bedrock because large woody debris was lost from the system might be much less vulnerable to further deterioration.*

Responsiveness*: How readily or efficiently restoration actions will achieve improved stream corridor conditions. It can be conceptualized as the ease with which the system can be moved toward dynamic equilibrium. For example, a rangeland stream that has become excessively wide and shallow might respond very rapidly to grazing management by establishing a more natural cross section that is substantially narrower and deeper. On the other hand, an agricultural stream that has deeply incised following channelization might not readily reestablish grade or channel pattern in response to improved watershed or riparian vegetation conditions.*

Self-Sustainability*: The degree to which the restored stream can be expected to continue to maintain its restored (but dynamic) condition. The creation or establishment of dynamic equilibrium should always be a goal. However, it might be that intensive short-term maintenance is necessary to ensure weeds and exotic vegetation do not get a foothold. The short-term and longer-term goals and objectives to ensure sustainability need to be carefully considered relative to funding, proximity of the site to population concentrations, and care-takers.*

CASE STUDY

Restoration of the Elwha River Ecosystem

The construction of numerous hydropower projects fueled the economic growth of the Pacific Northwest during the early 1900s. With the seemingly inexhaustible supply of anadromous salmonids, little care was taken to reduce or mitigate the consequent impacts to these fish (Hoffman and Winter 1996). Two hydropower dams built on the Elwha River, on Washington's Olympic Peninsula, were no exception.

*The 108 ft. high Elwha Dam **(Figure 5.8)** was built from 1910–13 about five miles from the river mouth. Although state law required a fishway, one was not built. As a result, salmon and steelhead populations immediately declined, some to extinction, and remaining populations have been confined to the lower five miles ever since. The 210 ft. high Glines Canyon Dam **(Figure 5.9)** was built from 1925–27 about eight miles upstream of the first dam, also without fish passage facilities. Glines was licensed for a period of 50 years in 1925 while the Elwha Dam has never been licensed.*

In 1968, the project owner filed a license application for Elwha Dam and filed a relicense application for the Glines Canyon Dam in 1973. The Federal Energy Regulatory Commission (FERC) did not actively pursue the licensing of these two projects until the early 1980s when federal and state agencies, the Lower Elwha Klallam Tribe (Tribe), and environmental groups filed petitions with FERC to intervene in the licensing proceeding. The option of dam removal to restore the decimated fish runs was raised in most of these petitions, and FERC addressed dam removal in a draft environmental impact statement (EIS). Nonetheless, it was apparent that disagreements remained over numerous issues, and that litigation could take a decade or more.

Congressional representatives offered to broker a solution. In October 1992, President George Bush signed Public Law 102-495 (the Elwha River Ecosystem and Fisheries Restoration Act; the Elwha Act), which is a negotiated settlement involving all parties to the FERC proceeding. The Elwha Act voids FERC's authority to issue long-term licenses for either dam, and it confers upon the Secretary of the Interior the authority to remove both dams if that action is needed to fully restore the Elwha River ecosystem and native anadromous fisheries. In a report to the Congress (DOI et al. 1994), the Secretary concluded that dam removal was necessary to meet the goal of the Elwha Act. Subsequently, Interior completed the EIS process FERC had begun but using the new standard of full ecosystem restoration rather than "balancing" competing uses as FERC is required to do (NPS 1995).

Interior analyzed various ways to remove the dams and manage the 18 million cubic yards (mcy) of sediments

Figure 5.8: Elwha Dam. *Fish passages were not constructed when the dam was built in 1910–1913.*

(a)

(b)

Figure 5.9: Glines Canyon Dam. *(a) Before removal and (b) simulation after removal.*

that have accumulated in the two reservoirs since dam construction. The preferred alternative for the Glines Canyon Dam is to spill the reservoir water over successive notches constructed in the concrete gravity-arch section, allowing layers of the dam to be removed with a crane under dry conditions (NPS 1996). Standard diamond wire-saw cutting and blasting techniques are planned. Much of the dam, including the left and right side concrete abutments and spillway, will be retained to allow for the interpretation of this historic structure.

The foundation of the Elwha Dam failed during reservoir filling in 1912, flooding downstream areas such as the Tribe's reservation at the mouth of the river. A combination of blasted rock, fir mattresses, and other fill was used to plug the leak (NPS 1996). To avoid a similar failure during removal, the reservoir will be partially drained and the river diverted into a channel constructed through the bedrock footing of the left abutment. This will allow the fill material and original dam structure to be removed under dry conditions. Following removal of this material, the river will be diverted back to its historic location and the bedrock channel refilled. Since the Elwha Dam was built in an area that is religiously and culturally important to the Tribe, all structures will be removed.

The 18 mcy of accumulated sediment consists of about 9.2 mcy of silt and clay (<0.075 mm), 6.2 mcy of sand (0.075-<5 mm), 2.0 mcy of gravel (5-<75 mm), and .25 mcy of cobbles (75-<300 mm). The coarse material (i.e., sand and larger) is considered a resource that is lacking in the river below the dams, the release of which will help restore the size and function of a more natural and dynamic river channel, estuary, and nearshore marine areas. The silt- and clay-sized particles are also reduced in the lower river, but resuspension of this material may cause the loss of aquatic life and adversely affect water users downstream for the approximately two to three years this process is expected to last (NPS 1996). Nevertheless, the preferred alternative incorporates the natural erosive and transport capacity of the river to move this material downstream, although roughly half of the fine and coarse materials will remain in the newly dewatered reservoir areas. Water quality and fisheries mitigation actions are planned to reduce the impacts of sediment releases during and following dam removal. Revegetation actions will be implemented on the previously logged slopes for stabilization purposes and to accelerate the achievement of old-growth characteristics. The old reservoir bottoms will be allowed to revegetate naturally; "greenup" should occur within three to five years.

Following the removal of both dams, the salmon and steelhead runs are expected to total about 390,000 fish, compared to about 12,000 to 20,000 (primarily hatchery) fish. These fish will provide over 800,000 pounds of carcass biomass (NPS 1995). About 13,000 pounds of this biomass is marine-derived nitrogen and phosphorous, the benefits of which will cascade throughout the aquatic and terrestrial ecosystem. The vast majority of wildlife species are expected to benefit from the restoration of this food resource and the recovery of over 700 acres of important lowland habitat. Restoration of the fish runs will also support the federal government's trust responsibility to the Tribe for its treaty-reserved harvest rights. More wetlands will be recovered than will be lost from draining the reservoirs.

Alternative Selection and Design

Supporting Analyses for Selecting Alternatives

- Feasibility study
- Cost-effectiveness analysis
- Risk assessment
- Environmental impact analysis

Factors to Consider in Alternative Design

- Managing causes vs. treating symptoms
- Landscape/Watershed vs. corridor reach
- Other spatial and temporal considerations.

If the causes of impairment can realistically be eliminated, complete ecosystem restoration to a natural or unaltered condition might be a feasible objective and the focus of the restoration activity will be clear. If the causes of impairment cannot realistically be eliminated, it is critical to identify what options exist to manage either the causes or symptoms of altered conditions and what effect, if any, those management options might have on the subject conditions.

If it is not feasible to manage the cause(s) of impaired conditions, then mitigating the impacts of disturbance(s) is an alternative method of implementing sustainable stream corridor restoration. By choosing mitigation, the focus of the restoration effort might then be on addressing only the symptoms of impaired conditions.

When disturbance cannot be fully eliminated, a logical planning process must be used to develop alternative management options. For example, in analyzing bank erosion, one conclusion might be that accelerated watershed sediment delivery has produced lateral instability in the stream system, but modification of land-use patterns causing the problem is not a feasible management option at this time (**Figure 5.10**). It might therefore still be possible to develop a channel erosion condition objective and to identify treatments such as engineered or soil-bioengineered bank erosion control structures, but it will not be possible to return the stream corridor to its predisturbance condition. Other resource implications of increased watershed sediment delivery will persist (e.g., altered substrate conditions, modified

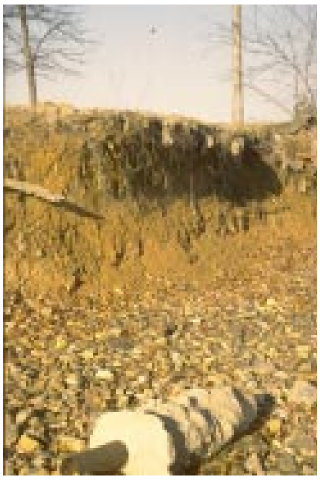


***Figure 5.10: Streambank erosion.** In designing alternatives for bank erosion it is important to assess the feasibility of addressing the cause of the problem (e.g., modify land uses) or treating the symptom (e.g., install bank-erosion control structures).*

riffle-pool structure, and impaired water quality).

It is important to note that in treating causes, a danger always remains that in treating one symptom of impairment, another unwanted change in stream corridor conditions will be triggered. To continue with the erosion example, bank hardening in one location might interfere with sedimentation processes critical to floodplain and riparian habitats, or it might simply transfer lateral instabilities from one location in a stream reach to some other location.

Landscape/Watershed vs. Corridor/Reach

The design and selection of alternatives should address the following relationships:

- Reach to stream
- Stream to corridor
- Corridor to landscape
- Landscape to region

Characterizing those relationships requires a good inventory and analysis of conditions and functions on all levels including stream structure (both vertical and horizontal) and human activities within the watershed.

The restoration design should include innovative solutions to prevent or mitigate, to the extent possible, negative impacts on the stream corridor from upstream land uses. Land use activities within a watershed may vary widely within generalized descriptions of urban, agricultural, recreation, etc. For example, urban residential land use could comprise neighborhoods of manicured lawns, exotic plants, and roof runoff directed to nearby storm sewers.

Or residential use might be composed of neighborhoods with native cover types, overhead canopy, and roof runoff flowing to wetland gardens. Restoration design should address the storm water flows, pollutants, and sediment loadings from these different land uses that could impact the stream corridor.

Since it is usually not possible to remove the human activities that disturb stream corridors, where seemingly detrimental activities like gravel mining, damming, and road crossings are present in the watershed or in the stream corridor itself, restoration design should provide the best possible solutions for maintaining optimum stream corridor functions while meeting economic and social objectives (**Figure 5.11**).

Other Time and Space Considerations

Restoration design flexibility is critical to long-term success and achievement of dynamic equilibrium. Beyond the stream corridor is an entire landscape that functions in much

***Figure 5.11: Stream buffers in agricultural areas.** It is not possible to remove human activity from the corridor. Design alternatives should provide the best possible way of achieving the desired goals without negating the activity.*

Core elements of restoration alternatives

At a minimum, alternatives should contain a management summary of proposed activities, including an overview of the following elements:

- *Detailed site description containing relevant discussion of all variables having a bearing on that alternative.*
- *Identification and quantification of existing stream corridor conditions.*
- *Analysis of the various causes of impairment and the effect of management activities on these impaired conditions and causes in the past.*
- *Statement of specific restoration objectives, expressed in terms of measurable stream corridor conditions and ranked in priority order.*
- *Preliminary design alternatives and feasibility analysis.*
- *Cost-effectiveness analysis for each treatment or alternative.*
- *Assessment of project risks.*
- *Appropriate cultural and environmental clearances.*
- *Monitoring plan linked to stream corridor conditions.*
- *Anticipated maintenance needs and schedule.*
- *Alternative schedule and budget.*
- *Provision to make adjustments per adaptive management.*

REVERSE

Review Chapter 1's Dynamic Equilibrium section.

the same way as the corridor. When designing and choosing alternatives, it is important to consider the effect of the restoration on the entire landscape. A wide, connected, and diverse stream corridor will enhance the functions of the landscape as well as those of the corridor. Connectivity and width also increase the resiliency of the stream corridor to landscape perturbations and stress, whether induced naturally or by humans.

Alternatives should also be relatively elastic, although time and physical boundaries might not be so flexible. As discussed in Chapter 1, dynamic equilibrium requires that the restoration design be allowed an opportunity to mold itself to the changing conditions of the corridor over time and to the disturbances that are a part of the natural environment. Alternatives should be weighed against one another by considering how they might react to increasing land pressures, climate changes, and natural perturbations. Structure should be planned to provide necessary functions at each phase of the corridor's development.

A possible restoration design concept is Forman and Godron's (1986) "string of lights." Over time, the variations among landscape elements mean that some provide more opportunities for desired functions than others. A stream corridor connection provides a pathway through the landscape matrix such that it can be thought of as a string of lights in which some turn on and burn brightly for a time, while others fade away for a short time (**Figure 5.14**). As the string between these lights, the stream corridor is critical to the long-term stability of landscape functions.

Alternatives could therefore fit the metaphor of a string of lights to sustain the corridor through time.

Figure 5.14: "String of lights." *Patches along the stream corridor provide habitat in an agricultural setting.* Source: C. Zabawa.

Supporting Analyses for Selecting Restoration Alternatives

Once the restoration alternatives have been defined, the next step is to evaluate all the feasible alternatives and management options. In conducting this evaluation it is important to apply several different screening criteria that allow the consideration of a diverse number of factors. In general, the application of the following supporting analytical approaches ensures the selection of the best alternative or group of alternatives for the restoration initiative:

- Cost-effectiveness and incremental cost analysis Evaluation of benefits
- Risk assessment
- Environmental impact analysis

Cost-Effectiveness and Incremental Cost Analyses

In its National Strategy for the Restoration of Aquatic Ecosystems, the National Research Council (NRC) states that, in lieu of benefit-cost analysis, the evaluation and ranking of restoration alternatives should be based on a framework of incremental cost analysis: "Continually questioning the value of additional elements of a restoration by asking whether the actions are 'worth' their added cost is the most practical way to decide how much restoration is enough" (NRC 1992). As an example, the Council cites the approach where "a justifiable level [of output] is chosen in recognition of the incremental costs of increasing [output] levels and as part of a negotiation process with affected interests and other federal agencies" (NRC 1992).

As described below, cost-effectiveness analysis is performed to identify the least-cost solution for each possible level of nonmonetary output under consideration. Subsequent incremental cost analysis reveals the increases in cost that accompany increases in the level of output, asking the question "As we increase the scale of this project, is each subsequent level of additional output worth its additional cost?"

Data Requirements: Solutions, Costs, and Outputs

Cost-effectiveness and incremental cost analyses may be used for any scale of planning problem, ranging from local, site-specific problems to problems at the more extensive watershed and ecosystem scales. Regardless of the problem-solving scale, three types of data must be obtained before conducting the analyses: a list of solutions and, for each solution, estimates of its ecosystem or other nonmonetary effects (outputs) and estimates of its economic effects (costs).

The term "solutions" is used here to refer generally to techniques for accomplishing planning objectives. For example, if faced with a planning objective to "Increase waterfowl habitat in the Blue River Watershed," a solution might be to "Construct and install 50 nesting boxes in the Blue River riparian zone." Solutions may be individual management measures (for example, clear a channel, plant vegetation, construct a levee, or install nesting boxes), plans (various combinations of management measures), or programs (various combinations of plans, perhaps at the landscape scale).

Cost estimates for a solution should include both financial implementation costs and economic oppor-

CASE STUDY

Meander Reconstruction on the J. Bar S. Winter Feeding Area

January 1, 1997, was an eventful time for Asotin Creek, Washington, residents. In a period of less than a year, two large flood events occurred, causing extreme damage at numerous sites throughout the watershed.

The ordinary high flow (often referred to as channel forming or bankfull flow) is the natural size channel a river will seek, over time. Asotin Creek's flows exceeded the ordinary high flow 10 times at Asotin and Headgate parks.

One impacted site is on the South Fork of Asotin Creek. This site, referred to as the J. Bar S. winter feeding site ***(Figure 5.12)*** *and owned by Jake and Dan Schlee, received floods more than 10 times the ordinary high flow. Previous to January 1, the stream was located over a hundred feet away from the haysheds and feeding area. When large amounts of rock, cobble, and gravel collapsed into the right side of the stream corridor, the entire channel was directed toward the winter feeding area and hayshed. This redirection of flood flows undermined and eroded away thousands of tons of valuable topsoil and property, threatening the loss of the hayshed and corral. Fences and alternative water sources were destroyed. The challenges for stream restoration at this site were numerous because of the potential bridge constriction at the bottom, excessive downcutting, and limited area within which to work* ***(Figure 5.13)****.*

The Asotin County Conservation District put an interdisciplinary team together in the spring of 1997 to develop a plan and alternative for the J. Bar S. site. An innovative approach referred to as meander reconstruction was proposed by the interdisciplinary team to correct the problem and restore some natural capabilities of the stream. It was accepted by the landowners and Asotin County Conservation District. Some natural capabilities are the dissipation of flood energy over floodplains and maintenance of a stable ordinary high flow channel.

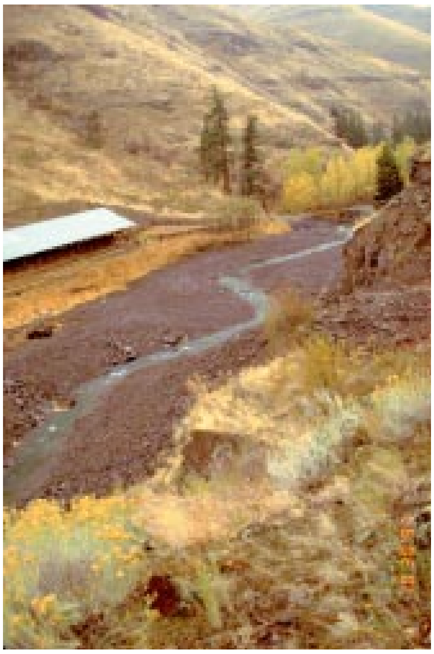


Figure 5.12: The J. Bar S. winter feeding area. *This area received floods more than 10 times the ordinary high flow.*

Additional benefits to the approach would be to reestablish proper alignment with the bridge and restore fish habitat. This alternative was installed within the last 2 weeks of September 1997. Care was used to move young steelhead out of the old channel while the new meandering channel was built. Other practices on site such as alternative water sources and fencing are soon to follow.

The meander reconstruction was designed to address both the landowners' concerns and stream processes. Although on-site stream restoration cannot resolve problems higher up in the watershed, it can address immediate concerns regarding fish habitat and streambank sta-

(a) *(b)*

Figure 5.13: South Fork of Asotin Creek restoration site. *(a) Before reconstruction and (b) after reconstruction.*

bility.

Numerous pools with woody debris were introduced to enhance salmon rearing and resting habitat. The pools were designed and set to a scour pattern unique to this stream type. This meander reconstruction is the first of its kind in the state of Washington.

The principal funding for this project was provided by the Bonneville Power Administration (BPA) ***(Table 5.1)****. The BPA funds are used to help implement the Asotin Creek Model Watershed Plan, which is part of the Northwest Power Planning Council's "Strategy for Salmon." The moneys for funding by BPA are generated from power rate payers in the Northwest. The purpose for funding is to improve the fish habitat component of the "Strategy for Salmon," which is one of the four elements referred to as the four H's— harvest management, hatcheries and their practices, survival at hydroelectric dams, and fish habitat improvement.*

Table 5.1: Project costs for J. Bar S. winter feeding area meander reconstruction and upstream revetments.

Projects	Costs
Reconstruction meanders	$10,200
Upstream revetments	$2,800
Fencing	$400
Riparian/streambank plantings and potential operation and maintenance (to be completed)	$3,500

Note: Original estimate in April 1997 was $26,600

The Instream Flow Incremental Methodology

The Instream Flow Incremental Methodology (IFIM) is designed for river system management. IFIM is composed of models linked to describe the spatial and temporal habitat features of a given river ***(Figure 5.15)****. It uses hydrologic analyses to describe, evaluate, and compare water use throughout a river system to understand the limits of water supply. Its organizational framework is useful for evaluating and formulating alternative water management options. Ultimately, the goal of any IFIM application is to ensure the preservation or enhancement of fish and wildlife resources. Emphasis is placed on displaying data from several years to understand variability in both water supply and habitat. IFIM is meant to be implemented in five sequential phases—problem identification, study planning, study implementation, alternatives analysis, and problem resolution. Each phase must precede the remaining phases, though iteration is necessary for complex projects.*

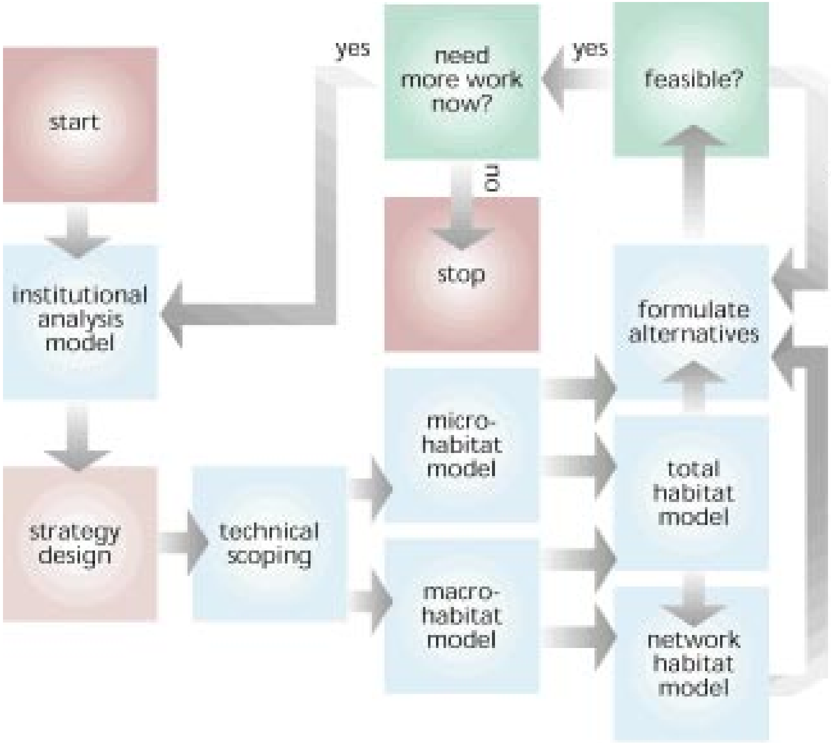


Figure 5.15: Overview of the instream flow incremental methodology. *IFIM describes the spatial and temporal habitat features of a given river.*

Problem identification

The first phase has two parts—a legal-institutional analysis and a physical analysis. The legal-institutional analysis identifies all affected or interested parties, their concerns, information needs, relative influence or power, and the potential decision process (e.g., brokered or arbitrated). The physical analysis determines the physical location and geographic extent of probable physical and chemical changes to the system and the aquatic resources of greatest concern, along with their respective management objectives.

Study planning

The study planning phase identifies information needed to address project concerns, information already available, information that must be obtained, and data and information collection methods. Study planning should result in a concise, written plan that documents all aspects of project execution and costs. It should also identify pertinent temporal and spatial scales of evaluation.

Hydrologic information chosen to represent the baseline or reference condition should be reexamined in detail during this phase to ensure that biological reference conditions are adequate to evaluate critical life history phases of fish populations.

Study implementation

The third phase consists of several sequential activities—data collection, model calibration, predictive simulation, and synthesis of results. Data are collected for physical and chemical water quality, habitat suitability, population analysis, and hydrologic analysis. IFIM relies heavily on models because they can be used to evaluate new projects or new operations of existing projects. Model calibration and quality assurance are key during this phase to obtain reliable estimates of the total habitat available for each life stage of each species over time.

Alternatives analysis

The alternatives analysis phase compares all alternatives, including a preferred alternative and other alternatives, with the baseline condition and can lead to new alternatives that meet the multiple objectives of the involved parties. Alternatives are examined for:

- *Effectiveness: Are objectives sustainable?*
- *Physical feasibility: Are water supply limits exceeded?*
- *Risk: How often does the biological system collapse?*
- *Economics: What are the costs and benefits?*

Problem Resolution

This final phase includes selection of the preferred alternative, appropriate mitigation measures, and a monitoring plan. Because biological and economic values differ, data and models are incomplete or imperfect, opinions differ, and the future is uncertain, IFIM relies heavily on professional judgment by interdisciplinary teams to reach a negotiated solution with some balance among conflicting social values.

A monitoring plan is necessary to ensure compliance with the agreed-upon flow management rules and mitigation measures. Post-project monitoring and evaluation should be considered when appropriate and should be mandatory when channel form will respond strongly to the selected new flow and sediment transport conditions.

For more information on IFIM

The earliest and best documented application of IFIM involved a large hydroelectric project on the Terror River in Alaska (Lamb 1984, Olive and Lamb 1984). Another application involved a Section 404 permit on the James River, Missouri (Cavendish and Duncan 1986). Nehring and Anderson (1993) discuss the habitat bottleneck hypothesis. Stalnaker et al. (1996) discuss the temporal aspects of instream habitats and the identification of potential physical habitat bottlenecks. Relations between habitat variability and population dynamics are described by Bovee et al. (1994). Thomas and Bovee (1993) discuss habitat suitability criteria.

IFIM has been used widely by state and federal agencies (Reiser et al. 1989, Armour and Taylor 1991). Additional references and information on available training can currently be obtained from the Internet at http://www.mesc.nbs.gov/rsm/ IFIM.html.

tunity costs. Implementation costs are direct financial outlays, such as costs for design, real estate acquisition, construction, operation and maintenance, and monitoring. The opportunity costs of a solution are any current benefits available with the existing state of the watershed that would be foregone if the solution were implemented. For example, restoration of a river ecosystem might require that some navigation benefits derived from an existing river channel be given up to achieve the desired restoration. It is important that the opportunity costs of foregone benefits be accounted for and brought to the table to inform the decision-making process.

The level to which a solution accomplishes a planning objective is measured by the solution's output estimate. Historically, environmental outputs have been expressed as changes in populations (waterfowl and fish counts, for example) and in physical dimensions (acres of wetlands, for example). In recent years, output estimates have been derived through a variety of environmental models such as the U.S. Fish and Wildlife Service's Habitat Evaluation Procedures (HEP), which summarize habitat quality and quantity for specific species in units called "habitat units." Models for ecological communities and ecosystems are in the early stages of development and application and might be more useful at the watershed scale.

Cost-Effectiveness Analysis

In *cost-effectiveness analysis*, solutions that are not rational (from a production perspective) are identified and can be screened out from inclusion in subsequent incremental cost analysis.

Cost-effectiveness screening is fairly straightforward when monetary values are easily assigned. The "output" or nonmonetary benefits of restoration actions are more difficult to evaluate. These benefits may include changes in intangible values of habitat, aesthetics, nongame species populations, and others. The ultimate goal, however, is to be able to weigh objectively all of the benefits of the restoration against its costs.

There are two rules for cost-effectiveness screening. These rules state that solutions should be identified as inefficient in production, and thus not cost-effective, if (1) the same level of output could be produced by another solution at less cost or (2) a greater level of output could be produced by another solution at the same or less cost.

For example, look at the range of solutions in **Figure 5.16**. Applying Rule 1, Solution C is identified as inefficient in production: why spend $3,600 for 100 units of output when 100 units can be obtained for $2,600 with Solution B, a savings of $1,000? In this example, Solution C could also be screened out by the application of Rule 2: why settle for 100 units of output with Solution C when 20 additional units can be provided by Solution E at the same cost?

Also by applying Rule 2, Solution D is screened out: why spend $4,500 for 110 units when 10 more units could be produced by E for $900 less cost?

Figure 5.16 shows the "cost-effectiveness frontier" for the solutions listed in the table. This graph, which plots the solutions' total cost (vertical axis) against their output levels (horizontal axis), graphically depicts the two screening rules. The cost-effective solutions delineate the cost-effectiveness frontier. Any solutions lying inside the frontier (above and to the left), such as C and D, are not cost-effective and should not be included in subsequent incremental cost analysis.

Solution	Units of Output	Total Cost ($)
No action	0	0
A	80	2,000
B	100	2,600
C	100	3,600
D	110	4,500
E	120	3,600
F	140	7,000

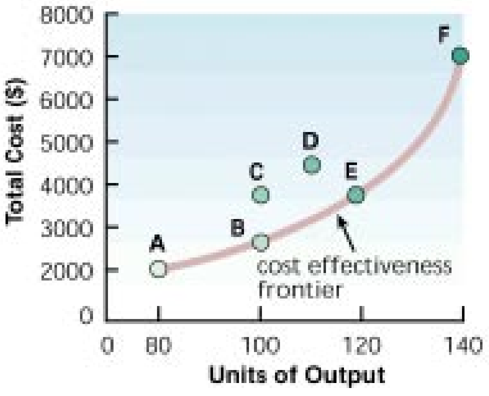


Figure 5.16: Cost effectiveness frontier. *This graph plots the solutions' total cost (vertical axis) against their output levels (horizontal axis).*

Incremental Cost Analysis

Incremental cost analysis is intended to provide additional information to support a decision about the desired level of investment. The analysis is an investigation of how the costs of extra units of output increase as the output level increases. Whereas total cost and total output information for each solution is needed for cost-effectiveness analysis, incremental cost analysis requires data showing the difference in cost (incremental cost) and the difference in output (incremental output) between each solution and the next-larger solution.

Continuing with the previous example, the incremental cost and incremental output associated with each solution are shown in **Figure 5.17**. Solution A would provide 80 units of output at a cost of $2,000, or $25 per unit. Solution B would provide an additional 20 units of output (100 – 80) at an additional cost of $600 ($2,600 – $2,000).

The incremental cost per unit (incremental cost divided by incremental output) for the additional 20 units B provides over A is, therefore, $30. Similar computations can be made for solutions E and F. Solutions C and D have been deleted from the analysis because they were previously identified as inefficient in production.

As shown in **Figure 5.17,** the incremental cost per unit is measured on the vertical axis; both total output and incremental output can be measured on the horizontal axis. The distance from the origin to the end of each bar indicates total output provided by the corresponding solution. The width of the bar associated with each solution identifies the incremental amount of output that would be provided over the previous, smaller-scaled solution; for example, Solution E provides 20 more units of output than Solution B . The height of the bar illustrates the cost per unit of that additional output; for example, those 20 additional units obtainable through Solution E cost $50 each.

Decision Making — "Is It Worth It?"

The table in Figure 5.17 presents cost and output information for the

Solution	Level of Output		Cost ($)		
	Total Output	Incremental Output	Total Cost	Incremental Cost	Incremental Cost Incremental Output
No action	0	0	0	0	0
A	80	80	2,000	2,000	25
B	100	20	2,600	600	30
E	120	20	3,600	1,000	50
F	140	20	7,000	3,400	170

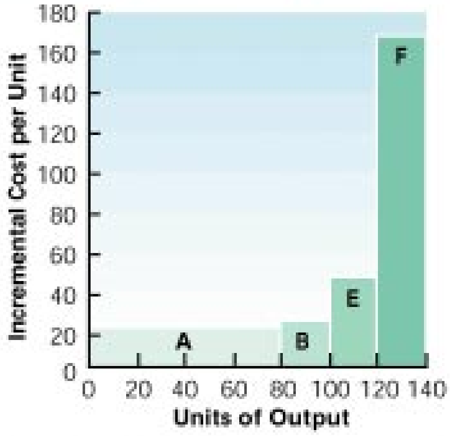


Figure 5.17: Incremental cost and output display. *This graph plots the cost per unit (vertical axis) against the total output and incremental output (horizontal axis).*

range of cost-effective solutions under consideration in a format that facilitates the investment decision of which (if any) solution should be implemented. This decision process begins with the decision of whether it is "worth it" to implement Solution A.

Figure 5.17 shows Solution A provides 80 units of output at a cost of $25 each. If it is decided that these units of output are worth $25 each, the question becomes "Should the level of output be increased?" To answer this question, look at Solution B, which provides 20 more units than Solution A. These 20 additional units cost $30 each. "Are they worth it?" If "yes," look to the next larger solution, E, which provides 20 more units than B at $50 each, again asking "Are they worth it?" If it is decided that E's additional output is worth its additional cost, look to F, which provides 20 more units than E at a cost of $170 each.

Cost-effectiveness and incremental cost analyses will not result in the identification of an "optimal" solution as is the case with cost-benefit analysis. However, they do provide information that decision makers can use to facilitate and support the selection of a single solution. Selection may also be guided by decision guidelines such as output "targets" (legislative requirements or regulatory standards, for example), minimum and maximum output thresholds, maximum cost thresholds, sharp breakpoints in the cost-effectiveness or incremental cost curves, and levels of uncertainty associated with the data.

In addition, the analyses are not intended to eliminate potential solutions from consideration, but rather to present the available information on costs and outputs in a format to facilitate plan selection and communicate the decision process. A solution identified as "inefficient in production" in cost-effectiveness analysis might still be desirable; the analysis is intended to make the other options and the associated trade-offs explicit. Reasons for selecting "off the cost-effectiveness curve" might include considerations that were not captured in the output model being used, or uncertainty present in cost and output estimates. Where such issues exist, it is important that they be explicitly introduced to the decision process. After all, the purpose of conducting cost-effectiveness and incremental cost analyses is to provide more, and hopefully better, information to support decisions about investments in environmental (or other non-monetary) resources.

Evaluation of Benefits

Cost-effectiveness and incremental cost analyses are but one approach for evaluating restoration projects. More broadly defined approaches, sometimes referred to as benefit maximization, fall into three categories (USEPA 1995a):

1. Prioritized benefits are ranked by preference or priority, such as best, next best, and worst. Available information might be limited to qualitative descriptions of benefits, but might be sufficient.
2. Quantifiable benefits can be counted but not priced. If benefits are quantifiable on some common scale (e.g., percent removal of fine sediment as an index of spawning substrate improvement), a cost per unit of benefits that identifies the most efficient producer of benefits can be devised (similar to the previously described cost effectiveness and incremental cost analyses).

3. Nonmonetary benefits can be described in monetary terms. For example, when restoration provides better fish habitat than point source controls would provide, the monetary value of improved fish habitat (e.g., economic benefits of better fishing) needs to be described. Assigning a monetary value to game or commercial species might be relatively easy; other benefits of improved habitat quality (e.g., improved aesthetics) are not as easily determined, and some (e.g., improved biodiversity) cannot be quantified monetarily. Each benefit must, therefore, be analyzed differently.

Key considerations in evaluating benefits include timing, scale, and value. The short-term and long-term benefits of each project must be measured. In addition, potential benefits and costs must be considered with respect to results on a local level versus a watershed level. Finally, there are several ways to value the environment based on human use and appreciation. Commercial fish values can be calculated, recreational or sport-fishing values can be estimated by evaluating the costs of travel and expenditures, some aesthetic and improved flood control values can be estimated through changes in real estate value, and social values (such as wildlife, aesthetics, and biodiversity) can be estimated by surveying people to determine their willingness to pay.

Risk Assessment

Stream-corridor restoration involves a certain amount of risk that, regardless of the treatment chosen, restoration efforts will fail. To the extent possible, an identification of these risks for each alternative under consideration is a useful tool for analysis by the decision maker. A thorough risk assessment is particularly important for those large-scale restoration efforts which involve significant outlays of labor and money or where a significant risk to human life or property would occur downstream should the restoration fail.

A primary source of risk is the uncertainty associated with the quality of data used in problem analysis or restoration design. Data uncertainty results from errors in data collection and analysis, external influences on resource variables, and random error associated with certain statistical procedures (e.g., regression analysis). Data uncertainty is usually handled by application of statistical procedures to select confidence intervals that estimate the quality of the data used for analysis and design.

The first source of risk is the possibility that design conditions will be exceeded by natural variability before the project is established. For example, if a channel is designed to pass a 50-year flood on the active floodplain, but it takes 5 years to establish riparian vegetation on that floodplain, there is a certain risk that the 50-year flood will be exceeded during the 5 years it takes to establish natural riparian conditions on the floodplain. A similar situation would exist where a revegetation treatment requires a certain amount of moisture for vegetation establishment and assumes the worst drought of record does not occur during the establishment period. This kind of risk is readily amenable to statistical analysis using the binomial distribution and is presented in several existing reports on hydrologic risk (e.g., Van Haveren 1986).

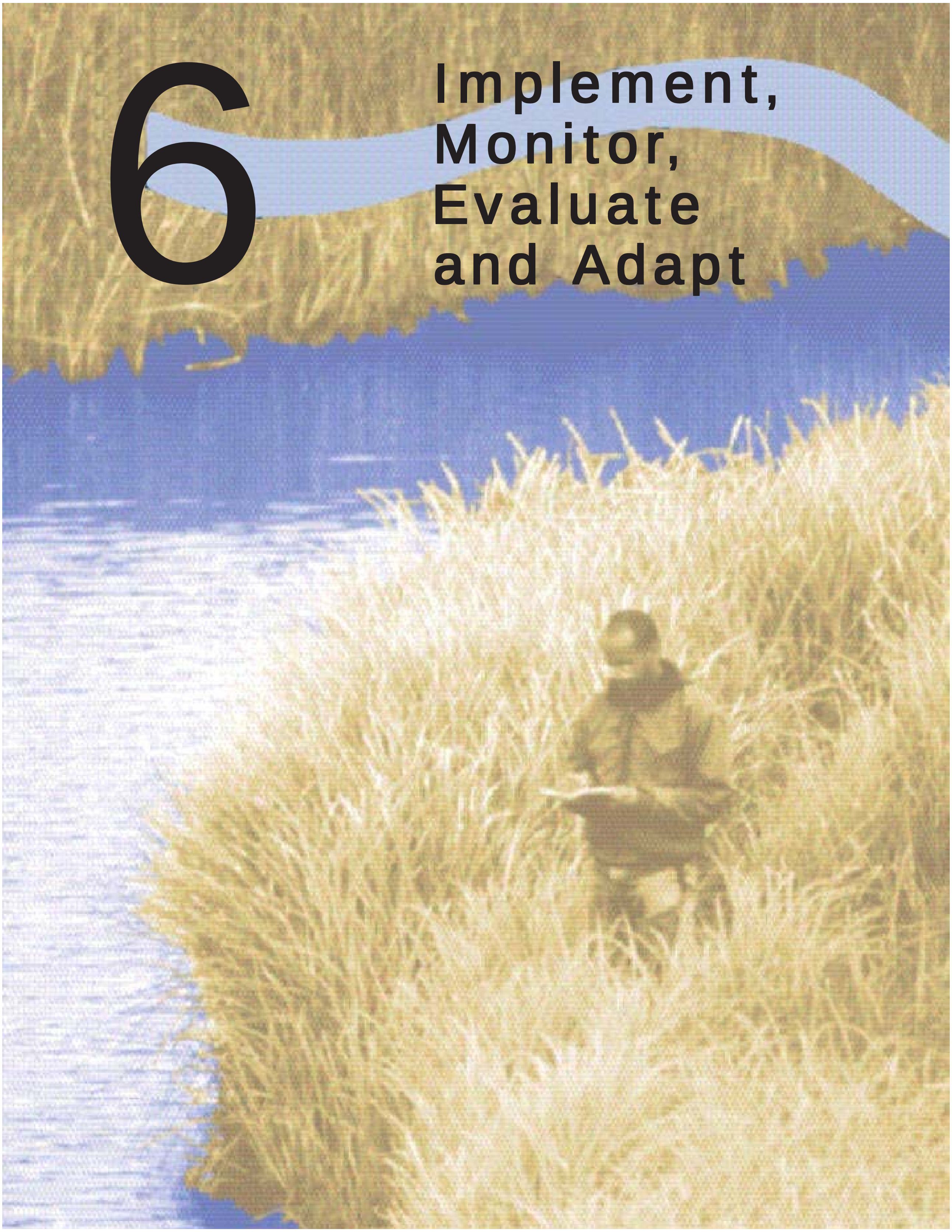
Environmental Impact Analysis

The fact that the impetus behind any stream corridor restoration initiative is recovery or rehabilitation does not necessarily mean that the proposal is without adverse effects or public controversy. Short-term and long-term adverse impacts might result. For example, implementation activity such as earth-work involving heavy equipment might temporarily increase sedimentation or soil compaction. Furthermore, restoration of one habitat type is probably at the expense of another habitat type; for example, recreating habitat to benefit fish might come at the expense of habitat used by birds.

Some alternatives, such as total exclusion to an area, might be well defined scientifically but have little social acceptability. Notwithstanding the environmental impacts and tradeoffs, both fish and birds have active constituencies that must be involved and whose concerns must be acknowledged. Therefore, careful environmental impact analysis considers the potential short- and long-term direct, indirect, and cumulative impacts, together with full public involvement and disclosure of both the impacts and possible mitigating measures. This is no less important for an initiative to restore a stream corridor than for any other type of related activity.

6

Implement, Monitor, Evaluate and Adapt



6.A Restoration Implementation

- What are the steps that should be followed for successful implementation?
- How are boundaries for the restoration defined?
- How is adequate funding secured for the duration of the project?
- What tools are useful for facilitating implementation?
- Why and how are changes made in the restoration plan once implementation has begun?
- How are implementation activities organized?
- How are roles and responsibilities distributed among restoration participants?
- How is a schedule developed for installation of the restoration measures?
- What permits and regulations will be necessary before moving forward with restoration measures?

6.B Restoration Monitoring, Evaluation, and Adaptive Management

- What is the role of monitoring in stream corridor restoration?
- When should monitoring begin?
- How is a monitoring plan tailored to the specific objectives of a restoration initiative?
- Why and how is the success or failure of a restoration effort evaluated?
- What are some important considerations in developing a monitoring plan to evaluate the restoration effort?

6

IMPLEMENTING, MONITORING, EVALUATING, AND ADAPTING

The development of restoration goals and objectives and the formulation and selection of restoration alternatives does not mark the end of the restoration plan development process. Successful stream corridor restoration requires careful consideration of how the restoration design will be implemented, monitored, and evaluated. In addition, it requires a commitment to long-term planning and management that facilitates adaptation and adjustment in light of changing ecological, social, and economic factors.

This chapter focuses on the final stages of restoration plan development. It presents the basics of restoration implementation, monitoring, evaluation, and management within a planning context. Specifically, the administrative and planning elements associated with these activities are discussed in detail. This chapter is intended to set the stage for the technical or "how to" discussion of restoration implementation, monitoring, maintenance, and management presented in Chapter 9. The present chapter is divided into two main sections.

Section 6.A: Restoration Implementation

The first section examines the basics of restoration implementation. It includes a discussion of all aspects relevant to carrying out the design, including fun-

ding, incentives, division of responsibilities, and the actual implementation process.

Section 6.B: Restoration Monitoring, Evaluation, and Adaptive Management

Once the basic design is executed, the monitoring, evaluation, and adaptation process begins. This section explores some of the basic considerations that need to be addressed in examining and evaluating the success of the restoration initiative. In addition, it emphasizes the importance of making adjustments to the restoration design based on information received during the monitoring and evaluation process. Note especially that the plan development process can be reiterated if conditions in or affecting the stream corridor change or if perceptions or goals change due to social, economic, or legal developments.

6.A Restoration Implementation

Implementation is a critical component of the stream corridor restoration process. It includes all the activities necessary to execute the restoration design and achieve restoration goals and objectives. Although implementation is typically considered the "doing," not the "planning," successful restoration implementation demands a high level of advance scheduling and foresight that constitutes planning by any measure.

Securing Funding for Restoration Implementation

An essential component of any stream corridor restoration initiative is the availability of funds to implement the restoration design. As discussed in Chapter 4, identifying potential funding sources should be one of the first priorities of the advisory group and decision maker. By the time the restoration initiative reaches the implementation stage, however, the initial identification of sources should be translated into tangible resource allocations. In other words, all needed funding should be secured so that restoration implementation can be initiated. It is important to remember that financing might ultimately come from several sources. All benefactors, both public and private, should be identified and appropriate cost-sharing arrangements should be developed.

An important element of securing funding for restoration is linking the available resources to the specific activities that will be part of implementation. Specifically, it should be the responsibility of the restoration

Securing Funding for Anacostia Restoration Initiatives

The Anacostia Watershed Restoration Committee annually seeks funding for many restoration initiatives. In FY91, more than 50 projects were funded by over a dozen local, state, and federal agencies. Funding sources are matched with appropriate watershed projects. In about half a dozen cases, special funding came from federal agencies like the Corps of Engineers, USDA, and EPA. The overwhelming majority of projects, however, involved a skillful coordination of existing sources of support from state and local governmental programs combined with additional help from nongovernmental organizations such as Trout Unlimited and from other citizen volunteers. The signatory agencies (e.g., the District of Columbia, Prince George's and Montgomery Counties, and the state of Maryland) fund most of the storm water retrofit, monitoring, and demonstration projects, as well as public participation activities.

A key element in maximizing resources from existing programs is the organization of special technical assistance teams for priority subwatersheds ***(Figure 6.1)****. Subwatershed Action Plan (SWAP) coordinators carry out public education and outreach efforts, and they also assist in comparing the management needs of their subwatersheds with activities of local government. Because many of the problems in the Anacostia relate to urban storm water runoff, many infrastructure projects can have a bearing on restoration needs. When such infrastructure projects are identified, SWAP coordinators try to coordinate with the project sponsor and involve the sponsor in the Anacostia program. If possible, the SWAP coordinator attempts to integrate the retrofit and management objectives of the program and the project.*

Figure 6.1: Anacostia Basin. *Nine priority subwatersheds compose the Anacostia Basin.*
Source: MWCOG 1997. Reprinted by permission.

planners to categorize the various activities that will be part of the restoration, determine how much each activity will cost to implement, and determine how much funding is available for each activity. In performing this analysis it should be noted that funding need not be thought of exclusively in terms of available "cash." Often many of the activities that are part of the restoration effort can be completed with the work of the staff of a participating agency or other organization.

It is important to note that there might be insufficient funding to carry out all of the activities outlined in the stream corridor restoration design. In this situation, planners should recognize that this is, in fact, a common occurrence and that restoration should proceed. An effort should be made, however, to prioritize restoration activities, execute them as effectively and efficiently as possible, and document success. Typically, if the restoration initiative is demonstrated as producing positive results and benefits, additional funding can be acquired.

Identifying Tools to Facilitate Restoration Implementation

In addition to securing funding, it is important to identify the various tools and mechanisms available to facilitate the implementation of the restoration design. Tools available to the stream corridor restoration practitioner include a mix of both nonregulatory or incentive-based mechanisms and regulatory mechanisms. The *Tools for Facilitating the Implementation of Stream Corridor Restoration Measures* box contains a list and description of some of these tools.

As discussed in Chapter 4, the use of incentives can be effective in obtaining participation from private landowners in the corridor and in gaining their support for the restoration initiative (**Figure 6.2**). Incentive programs involving cost shares, tax advantages, or technical assistance can encourage private landowners to implement restoration measures on their property, even if the results of these practices are not directly beneficial to the owner.

Figure 6.2: Landowner participation. *Restoration on private lands can be facilitated by landowners.*

In addition to incentives, regulatory approaches are an important option for stream corridor restoration. Regulatory programs can be simple, direct, and easy to enforce. They can be effectively used to control land use and various land use activities.

Deciding which tool, or combination of tools, is most appropriate for the restoration initiative is not an easy endeavor.

The following is a list of some important tips that should be kept in mind when selecting among these tools (USEPA 1995a).

- Without targeted and effective education programs, technical assistance and cost sharing alone will not ensure implementation.
- Enforcement programs can also be costly because of the necessary inspections and personnel needed to make them effective.
- The most successful efforts appear to use a mix of both regulatory and incentive-based approaches. An effective combination might include variable cost-share rates, market-based incentives, and regulatory backup coupled with support services (governmental and private) to keep controls maintained and properly functioning.

REVERSE

Review Chapter 4's conservation easement section.

Important Components of Restoration Implementation

- Securing Funding for Restoration Implementation
- Identifying Tools to Facilitate Implementation
- Dividing Implementation Responsibilities
- Installing Restoration Measures.

Dividing Implementation Responsibilities

With funding in place and restoration tools and activities identified, the focus should shift to dividing the responsibilities of restoration implementation among the participants. This process involves identifying all the relevant players, assigning responsibilities, and securing commitments.

Identifying the Players

The identification of the individuals and organizations that will be responsible for implementing the design is essential to successful stream corridor restoration. Since the restoration partners are identified early in the planning process, at this point the focus should be on "reviewing" the list of participants and identifying the ones who are most interested in the implementation phase. Although some new players might emerge, most of the participants interested in the implementation phase will already have been involved in some aspect of the restoration effort (**Figure 6.4**). Typically, partners will change their participation as the process shifts from "evaluating" to "doing."

Tools for facilitating the implementation of stream corridor restoration measures

Education	*Programs that target the key audience involved with or affected by the restoration initiative to elicit awareness and support. Programs can include technical information as well as information on the benefits and costs of selected measures.*
Technical Assistance	*One-to-one interaction between professionals and the interested citizen or landowner. Includes provision of recommendations and technical assistance about restoration measures specific to a stream corridor or reach.*
Tax Advantages	*Benefits that can be provided through state and local taxing authorities or by a change in the federal taxing system that rewards those who implement certain restoration measures.*
Cost-share to Individuals	*Direct payment to individuals for installation of specific restoration measures. Most effective where the cost-share rate is high enough to elicit widespread participation.*
Cross-compliance Among Existing Programs	*A type of quasi-regulatory incentive/disincentive that conditions benefits received on meeting certain requirements or performing in a certain way. Currently in effect through the 1985, 1990, and 1996 Farm Bills.*
Direct Purchase of Stream Corridors or of Lands Causing the Greatest Problems	*Direct purchase of special areas for preservation or community-owned greenbelts in urban areas. Costs of direct purchase are usually high, but the results can be very effective. Sometimes used to obtain access to critical areas whose owners are unwilling to implement restoration measures.*
Nonregulatory Site Inspections	*Periodic site visits by staff of local, state, or federal agencies can be a powerful incentive for voluntary implementation of restoration measures.*
Peers	*Simple social acceptance by one’s peers or members of the surrounding community, which can provide the impetus for an individual landowner to implement restoration measures. For example, if a community values the use of certain agricultural best management practices (BMPs), producers in those communities are more likely to install them.*
Direct Regulation of Land Use and Production Activities	*Regulatory programs that are simple, direct, and easy to enforce. Such programs can regulate land uses in the corridor (through zoning ordinances) or the kind and extent of activities permitted, or they can set performance standards for a land activity (such as retention of the first inch of runoff from urban property in the corridor).*
Easements	*Conservation easements on private property are excellent tools for implementing parts of a stream corridor restoration plan (see more detailed discussion in following box). Flowage easements may be a critical component in order to design, construct, and maintain structures and flow conditions.*
Donations	*In some instances, private landowners may be willing, or may be provided economic or tax incentives, to donate land to help implement a restoration initiative.*
Financing	*Normally, a restoration initiative will require multiple sources of funds, and no single funding source may be sufficient. Non-monetary resources may also be instrumental in successfully implementing a restoration initiative.*

The decision maker(s), with assistance from the advisory group, should identify the key partners that will be actively involved in the implementation process.

Assigning Responsibilities

To ensure the effective allocation of responsibilities among the various participants, the decision maker(s) and advisory group should rely on a special interdisciplinary technical team. Specifically, the technical team should oversee and manage the implementation process as well as coordinate the work of other participants, such as contractors and volunteers, involved with restoration implementation. The following are some of the responsibilities of the major participants involved in the implementation process.

Interdisciplinary Technical Team

As noted above, the interdisciplinary technical team is responsible for over-seeing and coordinating restoration implementation and will assign implementation responsibilities. Before identifying roles, however, the technical team should establish some organizational ground rules. The box *Some Important Organizational Considerations for Successful Teamwork* reviews

Conservation easements

Conservation easements are an effective tool for protecting valuable areas of the stream corridor.

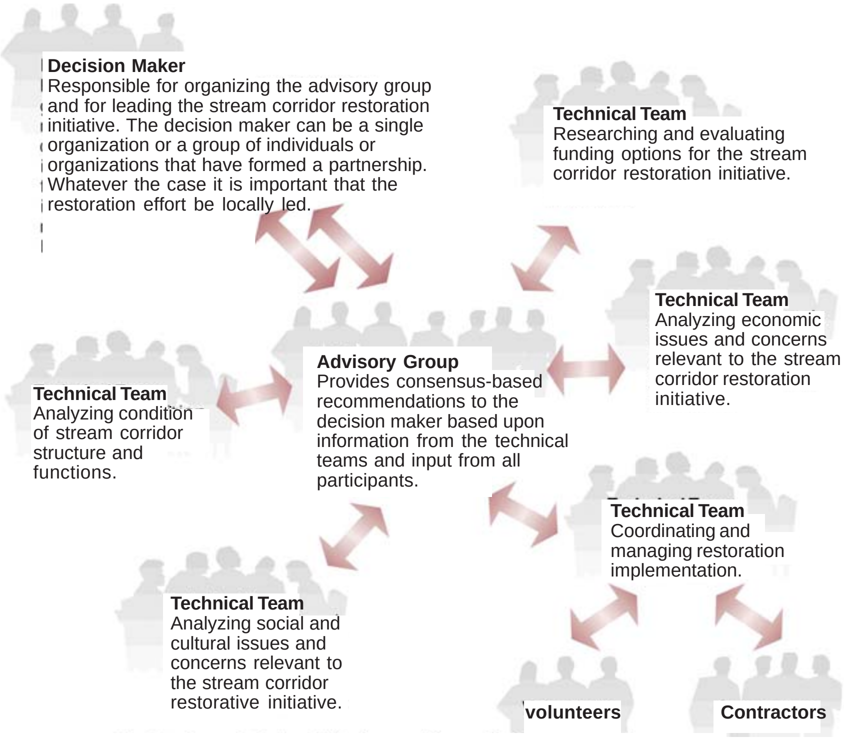
Conservation easements are an effective stream corridor management tool on private property regardless of whether the stream reach supports high biodiversity or the stream corridor would benefit from active restoration in conjunction with a modification of adjacent land use activities **(Figure 6.3)**. Through a conservation easement, landowners receive financial compensation for giving up or modifying some of their development rights while the easement holder acquires the right to enforce restrictions on the use of the property.

Specific details of a conservation easement are developed on a case-by-case basis. Only those activities which may be considered incompatible with stream corridor management objectives may be restricted. The value of a conservation easement is typically estimated as the difference between the values of the underlying land with and without the restrictions imposed by the conservation easement. Government agencies or non-profit organizations must compensate landowners for the rights they are giving up, but not to exceed more than the results are worth to society. The fair market values of the land before and after an easement is established are based on the “highest and best” uses of the land with and without the restrictions imposed by the easement. Once a conservation easement is established, it becomes part of the title on the property, and any stipulations of the conservation easement are retained when the property is sold. Conservation easements may be established indefinitely or for 25 to 30 years.

Conservation easements may be established with federal agencies, such as the U.S. Fish and Wildlife Service or the Natural Resources Conservation Service, with state agencies, or through nonprofit organizations like The Nature Conservancy or Public Land Trusts. It is often beneficial for federal, state, or local governments to establish conservation easements in partnership with nonprofit organizations. These organizations can assist public agencies in acquiring and conveying easements more efficiently since they are able to act quickly, take advantage of tax incentives, and mobilize local knowledge and support.

Conservation easements are beneficial to all parties involved. The landowners benefit by receiving financial compensation for giving up the rights to certain land use activities, enhancing the quality of the natural resources present on their property, and, when applicable, eliminating problems associated with human use in difficult areas. The quality of the land will also increase as a result of providing increased fish and wildlife habitat, improving water quality by filtering and attenuating sediments and chemicals, reducing flooding, recharging ground water, and protecting or restoring biological diversity. Conservation easements are also beneficial to public resource agencies because, in addition to the public benefit of improved quality of the stream corridor’s natural resources, they provide an opportunity for public agencies to influence resource use without incurring the political costs of regulation or the full financial costs of outright land acquisition.

Figure 6.3: Conservation easement. *Conservation easements are an effective tool for protecting valuable areas of the stream corridor.*



Decision Maker
Responsible for organizing the advisory group and for leading the stream corridor restoration initiative. The decision maker can be a single organization or a group of individuals or organizations that have formed a partnership. Whatever the case it is important that the restoration effort be locally led.

Technical Team
Researching and evaluating funding options for the stream corridor restoration initiative.

Technical Team
Analyzing economic issues and concerns relevant to the stream corridor restoration initiative.

Technical Team
Analyzing condition of stream corridor structure and functions.

Advisory Group
Provides consensus-based recommendations to the decision maker based upon information from the technical teams and input from all participants.

Technical Team
Coordinating and managing restoration implementation.

Technical Team
Analyzing social and cultural issues and concerns relevant to the stream corridor restorative initiative.

volunteers

Contractors

In Stream Corridor Restoration: Principles, Processes, and Practices (10/98).
By the Federal Interagency Stream Restoration Working Group (FISRWG) (15 Federal agencies of the U.S.).

Figure 6.4: Communication flow. *This depicts a possible scenario in which volunteers and contractors may become actively involved.*

REVERSE

Review Chapter4's Organizational consideration section.

some of the important logistical issues that need to be addressed by the team. Organizational considerations are also addressed in Chapter 4.

In addition to establishing ground rules, the technical team should appoint a single project manager. This person must be knowledgeable about the structure, function, and condition of the stream corridor; the various elements of the restoration design; and the policies and missions of the various cooperating agencies, citizen groups, and local governments. When consensus-based decisions are not possible due to time limitations, the project manager must be able to make quick and informed decisions relevant to restoration implementation.

Once the organizational issues have been taken care of, the technical team can begin to address its coordination and management responsibilities. In general, the technical team must grapple with several major management issues during the implementation process. The following are some of the major questions that are essential to successful management:

- How much time is required to implement the restoration?
- Which tasks are critical to meeting the schedule?
- What resources are necessary to complete the restoration?
- Who will perform the various restoration activities?
- Is the implementation team adequately staffed?
- Are adequate lines of communication and responsibility established?
- Are all competing and potentially damaging interests and concerns adequately represented, understood, and addressed?

Volunteers

Volunteers can be very effective in assisting with stream corridor restoration (**Figure 6.5**). Numerous activities that are part of the restoration implementation process are suitable for volunteer labor. For example, soil bioengineering and other uses of plants to stabilize slopes are labor-intensive. Two crews of at least two people each are needed for all but the largest installations—one crew at the harvest location and the other at the implementation site. However, a high level of skill or experience is often not required except for the crew leader, and training can commonly occur on the job. Restoration installations involving plant materials are therefore particularly suitable for youth, Job Corps, or volunteer forces.

It should be noted that the use of volunteers is not without some cost. Equipment, transportation, meals, insurance, and training might all be required, and each carries a real dollar need that must be met by the project budget or by a separate agency sponsoring the volunteer effort. However, those costs are still but a fraction of what would otherwise be needed for nonvolunteer forces.

Contractors

Contractors typically have responsibilities in the implementation of the restoration design. In fact, many restoration efforts require contracting due to the staff limitations of participating agencies, organizations, and landowners.

Contractors can assist in performing some of the tasks involved in implementing restoration design. Specifically, they can be hired to perform various tasks such as channel modification, installation of instream structures, and bank revegetation (**Figure 6.6**). All tasks performed by the contractor should be specified in the scope of the contract and should be subject to frequent and periodic inspection to ensure that they are completed within the proper specifications.

Although the contract will outline the role the contractor is to perform, it might be helpful for the technical team (or a member of the technical team) to meet with the contractor to establish a clear understanding of the

Some important organizational considerations for successfull framework

Meeting Mechanics	• How often will the team meet? • Where? • What will the agenda include? • How do members get items on the agenda? • Who will take minutes? • How will minutes be distribuited? • Who will facilitate the meeting?
Team Decision Making	• How will the team make decisions (vote, consensus, advise only)? • What decision must be deferred to higher authorities?
Problem Solving	• How will problems be addressed? • How will disagreements be resolved? • What step will be taken in the event of an impass?
Communication and Information	• What additional information does the team need to function? • How will necessary information be shared among team membrers, and by whom?
Leadership Support	• What is needed fron supervisors and/or managers to ensure project success?

respective roles and responsibilities. This preinstallation meeting might also be used to formally determine the frequency and mechanisms for reporting the progress of any installation activities. On the next page is a checklist of issues that are helpful in determining some of the roles and responsibilities associated with using contractors to perform restoration-related activities.

Securing Commitments

The final element of the division of responsibilities is securing commitments from the organizations and individuals that have agreed to assist in the implementation process. Two types of commitments are particularly important to ensuring the success of stream corridor restoration implementation (USEPA 1995):

- Commitments from public agencies, private organizations, individuals, and others who will fund and implement programs that involve restoration activities.
- Commitments from public agencies, private organizations, individuals, and others who will actually install the restoration measures.

One tool that can be used to help secure a commitment is a Memorandum of Understanding (MOU). An MOU is an agreement between two or more parties that is placed in writing. Essentially, by documenting what each party specifically agrees to, defining ambiguous concepts or terms, and outlining a conflict resolution process in the event of misunderstandings, an MOU serves to formalize commitments, avoid disappointment, and minimize potential conflict.

FAST FORWARD
Preview Chapter 9's Restoration measures section.

A second tool that can be effective is public accountability. As emphasized earlier, the restoration process should be an "open process" that is accessible to the interested public. Once written commitments have been made and announced, a series of periodic public meetings can be scheduled for the purpose of providing updates on the attainment of the various restoration activities being performed. In this way, participants in the restoration effort can be held accountable.

Installing Restoration Measures

A final element of stream corridor restoration implementation is the initiation of management and/or installation of restoration measures in accordance with the restoration design (**Figure 6.7**). If the plan involves construction, implementation responsibilities are often given to a private contractor. As a result, the contractor is required to perform a variety of restoration implementation activities, which can include large-scale actions like channel reconfiguration as well as small-scale actions like bank revegetation.

Figure 6.5: Volunteer team. *Volunteers can perform important functions during the restoration implementation process.*

Figure 6.6: Contractor team. *Contractors can assist in performing tasks that might be involved in restoration such as installing bank stabilization measures.*
Source: Robin Sotir and Associates.

REVERSE
Review Chapter 5's
Permit section.

Some issue that should be considered in addressing contractor roles and responsibilities

- What constitutes successful completion of the contract obligations by the contractor?
- What is the planned order of work and necessary scheduling?
- Who is responsible for permitting?
- Where are utilities located and what are the related concerns?
- What is the relationship between the prime contractor and subcontractors? (In general, the chain of communication should always pass through the prime contractor, and the prime contractor's representative is always present on site. Normally, clients reserve the right to approve or reject individual subcontractors.)
- What records and reports will be needed to provide necessary documentation (forms, required job site postings, etc.)?
- What arrangements are needed for traffic control?
- What specific environmental concerns are present on the site? Who has permit responsibility, both for obtaining and for compliance?

Whatever the scale of the restoration action, the process itself typically involves several stages. These stages generally include site preparation, site clearing, site construction, and site inspection. Each stage must be carefully executed to ensure successful installation of restoration measures. (See Chapter 9 for a more detailed explanation of this process.)

In addition to careful execution of the installation process, it is important that all actions be preceded by careful planning. Such preinstallation planning is essential to achieve the desired restoration objectives and to avoid adverse environmental, social, and economic impacts that could result. The following is a discussion of some of the major steps that should be taken to ensure successful implementation of restoration-related installation actions.

Determining the Schedule

Scheduling is a very important and highly developed component of implementation planning and management. For large-scale installation actions, scheduling is now almost always executed with the assistance of a computer-based software program. Even for small actions, however, the principles of scheduling are worth following.

For tasks that are part of the actual installation work, scheduling is most efficiently done by the contractor actually charged with doing the work. All supporting activities, both before and during installation, must be carefully scheduled as well and should be the responsibility of the project manager.

Obtaining the Necessary Permits

Restoration installation actions conducted in or in contact with streams, wetlands, and other water bodies are subject to various federal, state, and local regulatory programs and requirements. At the federal level, a number of these are aimed at protecting natural resources values and the integrity of the nation's water resources. As discussed in Chapter 5, most of these require the issuance of permits by local, state, and federal agencies.

If the action will be conducted or assistance provided by a federal agency, the agency is required to comply with federal legislation, including the National Environmental Policy Act; sections 401, 402, and 404 of the Clean Water Act; the Endangered Species Act; Section 10 of the Rivers and Harbors Act of 1899; executive orders for floodplain management and wetland protection; and possibly other federal mandates depending on the areas that would be affected (see **Table 6.1**).

For example, under the Endangered Species Act, federal agencies must ensure that actions they take will not jeopardize the continued existence of listed threatened or endangered species or destroy or adversely modify their critical habitats (**Figure 6.8**). Where an action would jeopardize a species, reasonable and prudent alternatives must be implemented to avoid jeopardy. In addition, for federal agencies, an incidental take statement is required in those instances where there will be a "taking" of species associated with the federal action. For nonfederal activities that might result in "taking" of a listed species, an incidental take permit is required.

Any work in floodplains delineated for the National Flood Insurance Program might also require participating communities to adhere to local ordinances and obtain special permits.

If the activity will affect lands such as historic sites, archaeological sites and remains, parklands, National Wildlife Refuges, floodplains, or

Figure 6.7: Installation of erosion control fabric. *Installing measures can be considered a "mid-point" in restoration and not the completion. Preceding installation is the necessary planning, with monitoring and adaptive management subsequent to the installation.*

Table 6.1: Examples of permit requirements for restoration activities.

Permits Required			**Activities Covered**	**Administered By**
Local/State				
Varies thresholds and definitions vary by state			e.g., clearing/grading, sensitive/critical areas, water quality, aquatic access	Local grading, planning, or building departments; various state departments
Federal				
Section 10, Rivers and Harbors Act of 1849			Building of any structure in the channel or along the banks of navigable waters of the U.S. that changes the course, condition, location, or capacity	U.S. Army Corps of Engineers
Section 404, Federal Clean Water Act	Letters of permission		Minor or routine work with minimum impacts	U.S. Army Corps of Engineers
	Nationwide permits	3	Repair, rehabilitation, or replacement of structures destroyed by storms, fire, or floods in past 2 years	
		13	Bank stabilization less than 500 feet in length solely for erosion protection	
		26	Filling of up to 1 acre of a non-tidal wetland or less than 500 linear feet of non-tidal stream that is either isolated from other surface waters or upstream of the point in a drainage network where the average annual flow is less than 5cfs	
		27	Restoration of natural wetland hydrology, vegetation, and function to altered and degraded non-tidal wetlands, and restoration of natural functions of riparian areas on private lands, provided a wetland restoration or creation agreement has been developed	
	Regional permits		Small projects with insignificant environmental impacts	
	Individual permits		Proposed filling or excavation that causes severe impacts, but for which no practical alternative exists; may require an environmental assessment	
Section 401, Federal Clean Water Act			Water quality certification	State agencies
Section 402, Federal Clean Water Act National Pollutant Discharge Elimination System (NPDES)			Point source discharges, as well as nonpoint pollution discharges	State agencies
Endangered Species Act Incidental Take Permit			Otherwise lawful activities that may take listed species	U.S. Fish and Wildlife Service

other federal lands, meeting requirements under a number of federal, state, or local laws might be necessary. Familiarity with the likely requirements associated with the activities to be conducted and early contact with permitting authorities will help to minimize delays. Local grading, planning, or building departments are usually the best place to begin the permit application process. They should be approached as soon as a conceptual outline of the project has been developed. At such a preapplication meeting, the project manager should bring such basic design information as the following:

- A site map or plan.
- A simple description of the restoration measures to be installed.
- Property ownership of the site and potential access route(s).
- Preferred month and year of implementation.

Whether or not that local agency claims jurisdiction over the particular activity, its staff will normally be aware of state and federal requirements that might be applicable. Local permit requirements vary from place to place and change periodically, so it is best to contact the appropriate agency for the most current information. In addition, different jurisdictions handle the designation of sensitive or critical areas differently. Work that occurs in the vicinity of a stream or wetland might or might not be subject to state or local permit requirements unique to aquatic environments. In addition, state and local agencies might regulate other aspects of a project as well.

The sheer number of permits required for an aquatic restoration effort might appear daunting, but much of the required information and many of the remedial measures are the same

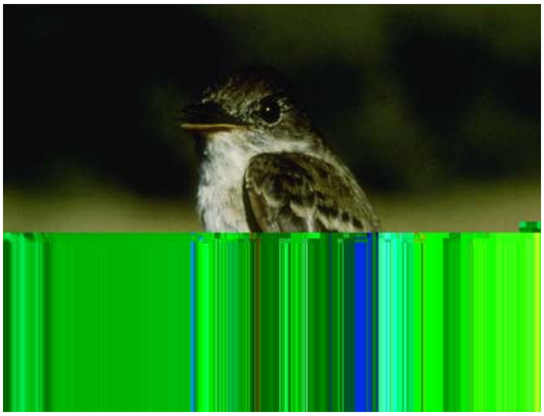
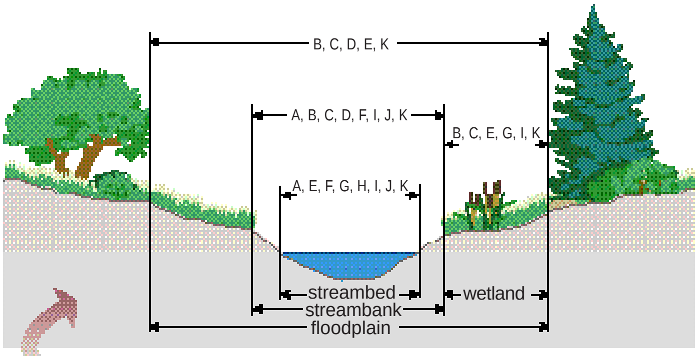


Figure 6.8: Southwestern willow flycatcher. *Prior to initiating implementation activities, permits may be needed to ensure the protection of certain species such as the Southwestern willow flycatcher.*

for all. **Figure 6.9** shows an example of how Montana's permitting requirements mesh with those at the federal level.



Using this diagram, determine where your activity will occurr. The letters refer to the permits listed below.

	Permit	**Government Agency**
A	Montana Stream Protection Act (124)	Montana Fish, Wildlife & Parks
B	Storm Water Discharge General Permits	Department of Environmental Quality
C	Streamside Management Zone Law	Department of Natural Resources & Conservation
D	Montana Floodplain and Floodway Management Act	Department of Natural Resources & Conservation
E	Short-term exemption from Montana's Surface Water Quality Standards (3A)	Department of Environmental Quality
F	Montana Natural Streambed and Land Preservation Act (310)	Montana Association of Conservation Districts and Department of Natural Resources & Conservation
G	Montana Land-use License or Easement on Navigable Waters	Department of Natural Resources & Conservation/ Special Uses
H	Montana Water Use Act	Department of Natural Resources & Conservation
I	Federal Clean Water Act (Section 404)	U.S. Army Corps of Engineers
J	Federal Rivers and Harbors Act (Section 10)	U.S. Army Corps of Engineers
K	Other laws that may apply depending upon your location & activity	various agencies

Figure 6.9: Example of permits necessary for working in and around streams in Montana. *The number of permits required for an aquatic restoration effort may appear daunting but they are all necessary.* Source: MDEQ 1996. Reprinted by permission.

Holding Preinstallation Conferences

Preinstallation conferences should be conducted on site between the project manager and supervisor, crew foreman, and contractor(s) as appropriate. The purpose is to establish a clear understanding of the respective roles and responsibilities, and to formally determine the frequency and mechanisms for reporting the progress of the work. In a typical situation, the agency reviews consultant work, provides guidance in the interpretation of internal agency documents or guidelines, and takes a lead or at least supporting role in acquiring permits and satisfying the requirements imposed by regulatory agencies. An additional conference with any inspectors should be held with all affected contractors and field supervisors to avoid potential misunderstandings. Volunteers and noncontractor personnel should also be involved if they are critical to implementation.

At particularly sensitive sites, the need to avoid installation-related damage should be valued at least as highly as the need to complete the planned implementation actions as designed. An on-site meeting, if appropriate to the timing of installation and the seasonality of storms, can avoid many of the emergency problems that might otherwise be encountered in the future. At a minimum, the project manager or on-site superintendent and the local inspector(s) for the permitting jurisdiction(s) should attend. Other people with relevant knowledge and responsibility could also include the grading contractor's superintendent, the civil engineer or landscape architect responsible for the erosion and sediment control plans, a soil scientist or geologist, a biologist, and the plan checker(s) from the permitting jurisdiction(s) (**Figure 6.10**).

The meeting should ensure that all aspects of the plans are understood by the field supervisors, that the key actions and most sensitive areas of the site are recognized, that the sequence and schedule of implementing control measures are agreed upon, and that the mechanism for emergency response is clear. Any changes to the erosion and sediment control plan should be noted on the plan documents for future reference. Final copies of plans and permits should be obtained, and particular attention should be paid to changes that might have been recorded on submitted and approved plan copies, but not transferred to archived or contractor copies.

Involving Property Owners

If possible, the project manager should contact and meet with neighbors affected by the work, including those with site ownership, those granting access and other easements, and others nearby who might endure potential noise or dust impacts.

Securing Site Access

Obtaining right of entry onto private property can be a problematic and time-consuming part of restoration (**Figure 6.11**). Several types of access agreements with differing rights and obligations are available:

- *Right of entry* is the right to pass over the property for a specific purpose for a limited period of time. In many cases, if landowners are involved from the beginning, they will be aware of the need to enter private property. Various types of easements can accomplish this goal.
- *Implementation easement* defines the location, time period, and purpose for which the property can be used during implementation.
- *Access easement* provides for permanent access across and on private property for maintenance and monitoring of a project. The geographic limits and allowable activities are specified.
- *Drainage easement* allows for the im-

Figure 6.10: On-site meeting. *Many problems that might otherwise be encountered can be avoided by appropriately timed on-site meetings.*

Figure 6.11: Site access. *In certain areas, access agreements, such as a right of entry or implementation easement, might have to be obtained to install restoration measures.*

plementation and permanent maintenance of a drainage facility at a particular site. Usually, the property owner has free use of the property for any nonconflicting activities.

- *Fee acquisition* is the outright purchase of the property. It is the most secure, but most expensive, alternative. Normally, it is unnecessary unless the project is so extensive that all other potential activities on the property will be precluded.

In many cases little or no money may be exchanged in return for the easement because the landowner receives substantial property improvements, such as stabilized streambanks, improved appearance, better fisheries, and permanent stream access and stream crossings. In some instances, however, the proposed implementation is in direct conflict with existing or planned uses, and the purchase of an easement must be anticipated.

Locating Existing Utilities

Since most restoration efforts have a lower possibility of encountering utilities than other earthwork activities, special measures might not be necessary. If utilities are present, however, certain principles should be remembered (King 1987).

First, field location and highly visible markings are mandatory; utility atlases are notoriously incomplete or inaccurate. Utilities have a particular size and shape, not just a location, which might affect the nature or extent of adjacent implementation. They also require continuous support by the adjacent soil or temporary restraining structures. Rights-of-way might also create constraints during and after implementation. Even though all potential conflicts between utilities and the proposed implementation should be resolved during implementation planning, field discovery of unanticipated problems occurs frequently. Resolution comes only with the active involvement of the utility companies themselves, and the project manager should not hesitate to bring them on site as soon as a conflict is recognized.

Confirming Sources and Ensuring Material Standards

First, the project manager must determine the final sources of any required fill dirt and then arrange a pickup and/or delivery schedule. The project manager should also confirm the sources of nursery and donor sites for plant materials. Note, however, that delaying the initial identification of these sources until the time of site preparation almost guarantees that the project will suffer unexpected delays. In addition, it is important to double check with suppliers that all materials scheduled for delivery or pickup will meet the specified requirements. Early attention to this detail will avoid delays imposed by the rejection of substandard materials.

Characteristics of Successful Implementation

As was discussed earlier, successful restoration requires the efficient and effective execution of several core implementation activities, such as installing restoration measures, assigning responsibilities, identifying incentives, and securing funding. The Winooski River Case Study is a good example. Cutting across these core activities, however, are a few key concepts that can be considered characteristics of successful restoration implementation efforts.

Central Responsibility in One Person

Most restoration efforts are a product of teamwork, involving specialists from such disparate disciplines as biology, geology, engineering, landscape architecture, and others. Yet the value of a single identifiable person with final responsibility cannot be overemphasized.

This project manager ignores the recommendations and concerns of the project team only at his or her peril.

Rapid decisions, particularly during implementation, must nonetheless often be made. Rarely are financial resources available to keep all members of the design team on site during implementation, and even if some members are present, the time needed to achieve a consensus is simply not available.

The success of restoration efforts depends more on having a competent project manager than on any other factor. The ideal project manager should be skilled in leadership, scheduling, budgeting, technical issues, human relationships, communicating, negotiating, and customer relations. Most will find this a daunting list of attributes, but an honest evaluation of a manager's shortcomings before restoration is under way might permit a complementary support team to assist the one who most commonly guides restoration to completion.

Thorough Understanding of Planning and Design Materials

Orchestrating the implementation of all but the simplest restoration efforts requires the integration of labor, equipment, and supplies, all within a context determined by requirements of both the natural system and the legal system. Designs must be adequate and based on a foundation of sound physical and biological principles, tempered with the experience of past efforts, both successful and unsuccessful. Schedules must anticipate the duration of specific implementa-

Characteristics of Successfull Implementation

- Central responsibility in one person
- Thorough understanding of planning and design documents
- Familiarity with the site and its biological and physical framework
- Knowledge of laws and regulations
- Understanding of environmental control plans
- Communication among all parties involved in the project action.

CASE STUDY

Successful Implementation: The Winooski River Watershed Project, Vermont

In the late 1930s, an extensive watershed restoration effort known as "Project Vermont" was implemented in the Lower Winooski River Watershed, Chittenden County, Vermont. The project encompassed the lower 111 square miles (including 340 farms) of the 1,076-square-mile Winooski River Watershed.

The Winooski River Watershed sustained severe damage from major floods during the 1920s and 1930s. In addition, overgrazing, poor soil conservation practices on cropland areas, encroachment to the streambanks, and forest clear-cutting also led to excessive erosion ***(Figure 6.12****). Annual ice-flows and jams during snowmelt runoff further exacerbated riverbank erosion. Throughout the watershed, both water and wind erosion were prevalent. In addition to problems in the lowlying areas, there were many environmental problems to address on the uplands. The soil organic matter was depleted in some areas, cropland had low productivity, pastures were frequently overgrazed, cover for wildlife was sparse, and forest areas had been clear-cut in many areas. In some cases, this newly cleared land was subject to grazing, which created additional problems.*

The Soil Conservation Service (SCS) joined with the University of Vermont (UVM) and local landowners to formulate a comprehensive, low-input approach to restoring and protecting the watershed. One hundred eighty-nine farmers participated in developing conservation plans for their farms, which covered approximatey 57 square miles. Other cooperators applied practices to another 38-square-mile area. Their approach relied heavily on plantings or a combination of plantings and mechanical techniques to overcome losses of both land and vegetated buffer along the river corridor, and in the uplands to make agricultural land sustainable and to restore deteriorating forestland.

The measures, many of which were experimental at the time, were installed from 1938 to 1941 primarily by landowners. Landowners provided extensive labor and, occasionally, heavy equipment for earthmoving and transportation and placement of materials too heavy for laborers. SCS provided interdisciplinary (e.g., agronomy, biology, forestry, soil conservation, soil science, and engineering) technical assistance in the planning, design, and installation. UVM provided extensive educational services for marketing and operation and maintenance.

In the stream corridor, a variety of measures were implemented along 17 percent of the 33 river miles to control bank losses, restore buffers, and heal overbank floodflow channels. They included the following:

- *Livestock Exclusion: Heavy-use areas were fenced back 15 feet from the top of the bank on straight reaches, 200 feet or wider on the out-sides of curves, and 200 feet wide in flood over-flow entrance and exit sections.*
- *Plantings and Soil Bioengineering Bank Stabilization: Where the main current was not directed toward the treatment, streambanks were sloped back and planted with more than 600,000 cuttings and 70,000 plants, primarily willow. Brushmattresses, which involved applying a layer of brush fastened down with live stakes and wire, were used to protect the bank until plantings could be made and established. Where streamflow was directed*

Figure 6.12: Brushmattress and plantings after spring runoff in March 1938. *Note pole jetties. Brushmatting involves applying a layer of brush fastened down with live stakes and wire.*

toward the bank, rock riprap was embedded at the toe up to 2 or more feet above the normal water line. Other toe protection techniques, such as pile jetties, were used.

- *Structures: In reaches where nearshore water was deep (up to 14 feet) and bank voiding was occurring, whole tree deflectors were used to trap sediment and rebuild the voided section. Trees with butt diameters of 2 to 3 feet were placed longitudinally along the riverbank with branches intact and with butts and tops slightly overlapped. The butts were cabled to wooden piles driven 8 to 10 feet into the bank. The slope above the normal waterline was brush-matted and planted.*
- *Log pile check dams were constructed at the entrances of flood overflow channels and filled with one-person-size rocks for ballast. These served as barriers to overbank flow along channels sculpted by previous floods. They were installed in conjunction with extensive buffer plantings, and in some cases, whole tree barricades, that were laced down parallel to the river along the top of the denuded bank.*
- *At overbank locations where flow threatened buffer plantings, log cribs were inset parallel to the bank and filled with rock. Various tree species were planted as a 200-foot or wider buffer behind the cribs. The cribs provided protection needed until the trees became well established.*

In the watershed, the conservation plans provided for comprehensive management for sustainable farming, grazing, forestry, and wildlife. The cropland practices included contour strips, contour tillage, cover crops, crop and pasture rotation, grass and legume plantings, diversions, grassed waterways, log culvert crossings, contour furrows in pastures, livestock fencing, planting of hedgerows, field border plantings, reforestation, and sustainable forest practices.

Wildlife habitat improvement practices provided connectivity among the cropland, pasture, and forest areas; hedgerow plantings as travelways, food sources, and cover; livestock exclusion areas to encourage understory herbaceous growth for cover and food sources; snags for small mammals and birds; and slash pile shelters as cover for rabbits and grouse.

One reason for this historic project's usefulness to modern environmental managers is the extensive documentation, including photos, maps, and detailed observations and records, available for many of the sites. Complete aerial photography is available from before, during, and after implementation. More than 600 photos provide a chronology of the measures, and three successive studies (Edminster and Atkinson 1949, Kasvinsky 1968, Ryan and Short 1995) document the performance of the project.

The restoration measures implemented are continuing to function well today, more than 55 years after installation. Tree plantings along the corridor have matured to diameters as great as 45 inches and heights exceeding 100 feet ***(Figure 6.13****). The wooded river corridor averages 50 feet wider than it did in the 1930s. Some of the measures have failed, however, including all plantings without toe protection. Lack of maintenance and long-term follow-up also resulted in the failure of restoration efforts at several sites.*

Although the Winooski project was experimental in the 1930s, many of its elements were highly successful:

- *Recognition of the importance of landscape relationships and an emphasis on comprehensive treatment of the entire watershed rather than isolated, individual problem areas.*
- *Using an interdisciplinary technical team for planning and implementation.*
- *Strong landowner participation.*
- *Empowerment of landowners to carry out the restoration measures using low-cost approaches (often using materials from the farm).*
- *Fostering the use of experimental methods that are now recognized as viable biotechnical approaches.*

Figure 6.13: Same site (Figure 6.12) in April 1995. Note remnants of old jetties and heavy bank cover. *Restoration measures are continuing to function well, more than 55 years after installation.*

tion tasks, the lead time necessary to prepare for those tasks, and the consequences of inevitable delays. A manager who has little familiarity with the planning and design effort can neither execute the implementation plans efficiently nor adjust those plans in the face of unanticipated conditions. A certain amount of flexibility is key. Often specific techniques are tied to specific building material, for example. Adjustments are often made according to what is available.

Familiarity With the Reach

Existing site conditions are seldom as they appear on a set of engineering plans. Variability in landform and vegetation, surface water and ground water flow, and changing site conditions during the interval between initial design and final implementation are all inevitable. There is no substitute for familiarity with the site that extends beyond what is shown on the plans, so that implementation-period "surprises" are kept to a minimum (**Figure 6.14**). Similarly, when such surprises do occur, a sound response must be based on the project manager's understanding of both the restoration goals and the likely behavior of the natural system.

Knowledge of Laws and Regulations

Site work in and around aquatic features is one of the most heavily regulated types of implementation in the United States (**Figure 6.15**). Restrictions on equipment use, season of the year, distance from the water's edge, and types of material are common in regulations from the local to the federal level. Not appreciating those regulations can easily delay implementation by a year or more, particularly if narrow seasonal windows are missed. The cost of a project can also multiply if required measures or mitigation are discovered late in the design or implementation process.

Understanding of Environmental Control Plans

A project in which a designed restoration measure is installed but the ecological structure and function of an area are destroyed is no success. The designer must create a workable plan for minimizing environmental degradation, but the best of plans can fail in the field through careless implementation.

Communication Among All Parties Involved in the Action

Despite the emphasis here on a single responsible project manager, the success of a project depends on regular, frequent, and open communication among all parties involved in implementation— manager, technical support people, contractor, crews, inspectors, and decision maker(s). No restoration effort proceeds exactly according to plans, and not every contingency can be predicted ahead of time. But well-established lines of communication can overcome most complications that arise.

6.B Restoration Monitoring, Evaluation, and Adaptive Management

The restoration effort is not considered complete once the design has been implemented. Monitoring, evaluation, and adaptive management are essential components that must be undertaken to ensure the success of stream corridor restoration. Each is carried out at a different level depending on the size and scope of the design.

Monitoring includes both pre- and post-restoration monitoring, as well as monitoring during actual implementation. All are essential to determining the success of the restoration design and require a complete picture or understanding of the structure and functions of the stream corridor. Monitoring provides needed information, documents chronological and other aspects of restoration succession, and provides lessons learned to be used in similar future efforts (Landin 1995).

Directly linked to monitoring are restoration evaluation and adaptive management. Using the information obtained from the monitoring process, the restoration effort should be evaluated to ensure it is functioning as planned and achieving the restoration goals and objectives. Even with the best plans, designs, and implementation, the evaluation will often result in the identification of some unforeseen problems and require midcourse correction either during or shortly following implementation. Most restoration efforts will require some level of oversight and on-site adaptive management.

This section examines some of the basics of restoration monitoring, evaluation, and adaptive management. A more detailed discussion on the technical aspects of restoration monitoring management is provided in Chapter 9 of this document.

Monitoring as Part of Stream Corridor Restoration Initiative

Restoration monitoring should be guided by predetermined criteria and checklists and allow for the recording of results in regular monitoring reports. The technical analyses in a monitoring report should reflect resto-

Figure 6.14: Workers installing a silt fence. *Familiarity with on-site conditions is critical to successful implementation of restoration measures.*

Figure 6.15: Instream construction activity. *Site work in and around aquatic features is one of the most heavily regulated types of activity in the United States and should not be attempted without a sound knowledge of the relevant laws and regulations.*

ration objectives and should identify and discuss options to address deficiencies. For example, the report might include data summaries that indicate that forest understory conditions are not as structurally complex as expected in a particular management unit, that this finding has negative consequences for certain wildlife species, and that a program of canopy tree thinning is recommended to rectify the problem. The recommendation should be accompanied by an estimate of costs associated with the proposed action, a proposed schedule, and identification of possible conflicts with other restoration objectives.

Monitoring plans should be conceived during the planning phase when the goals and performance criteria are developed for the restoration effort. Baseline studies required to provide more information on the site, to develop restoration goals, and to refine the monitoring plan often are conducted during the planning phase and can be considered the initial phase of the monitoring plan. Baseline information can form a very useful data set on pre-restoration conditions against which performance of the system can be evaluated.

Monitoring during the implementation phase is done primarily to ensure that the restoration plans are correctly carried out and that the natural habitats surrounding the site are not unduly damaged.

Actual performance monitoring of the completed plan is done later in the assessment phase (**Figure 6.16**). Management of the system includes both management of the monitoring plan and application of the results to make midcourse corrections.

Finally, results are disseminated to inform interested parties of the progress of the system toward the intended goals.

FAST FORWARD

Preview Chapter 9's

Restoration monitoring management section.

Restoration Monitoring, Evaluation, and Adaptive Management

Restoration Monitoring
- *Progress Toward Objectives*
- *Regional Resource Priorities and Trends*
- *Watershed Activities*

Restoration Evaluation
- *Reasons to Evaluate Restoration Efforts*
- *A Conceptual Framework for Evaluation.*

Components of a Monitoring Plan

Based on a thorough review of freshwater monitoring plans, some of which had been in place for over 30 years, the National Research Council (NRC) recommended the following factors to ensure a sound monitoring plan (NRC 1990):

- Clear, meaningful monitoring plan goals and objectives that provide the basis for scientific investigation.
- Appropriate allocation of resources for data collection, management, synthesis, interpretation, and analysis.
- Quality assurance procedures and peer review.
- Supportive research beyond the primary objectives of the plan.
- Flexible plans that allow modifications where changes in conditions or new information suggests the need.
- Useful and accessible monitoring information available to all interested parties.

The box, *Developing a Monitoring Plan*, shows the monitoring steps throughout the planning and implementation of a restoration. Each step is discussed in this chapter.

When to Develop the Monitoring Plan

The monitoring plan should be developed in conjunction with planning for the restoration. Once the goals and objectives have been established in the planning phase, the condition of the system must be considered.

Baseline monitoring enables planners to identify goals and objectives and provides a basis for assessing the performance of the completed restoration. Monitoring therefore begins with the determination of baseline conditions and continues through the planning and implementation of the restoration plan.

Developing a Monitoring Plan

Step 1: Define the Restoration Vision, Goals, and Objectives

The goals set for the restoration drive the monitoring plan design. Above all, it is important to do the fol-

Figure 6.16: Monitoring of revegetation efforts. *Monitoring the results of revegetation efforts is a critical part of restoring riparian zones along highly eroded channels.*

Goals of a Restoration Monitoring Plan

- Assess the performance of the restoration initiative relative to the project goals.
- Provide information that can be used to improve the performance of the restoration actions.
- Provide information about the restoration initiative in general.

Developing a Monitoring Plan

A. Planning

Step 1: Define the restoration, vision, goals, and objectives

Step 2: Develop the conceptual model

Step 3: Choose performance criteria

- *Link performance to goals*
- *Develop the criteria*
- *Identify reference sites*

Step 4: Choose monitoring parameters and methods

- *Choose efficient monitoring parameters*
- *Review watershed activities*
- *Choose methods for sampling design, sampling, and sample handling/ processing*
- *Conduct sociological surveys*
- *Rely on instream organisms for evidence of project success*
- *Minimize the necessary measurements of performance*
- *Incorporate supplemental parameters*

Step 5: Estimate cost

- *Cost for developing the monitoring plan itself*
- *Quality assurance*
- *Data management*
- *Field sampling program*
- *Laboratory sample analysis*
- *Data analysis and interpretation*
- *Report preparation*
- *Presentation of results*

Step 6: Categorize the types of data

Step 7: Determine the level of effort and duration of monitoring

- *Incorporate landscape ecology*
- *Determine timing, frequency, and duration of sampling*
- *Develop statistical framework*
- *Choose the sampling level*

B. Implementing and Managing

- *Manager must have a vision for the life of the monitoring plan*
- *Roles and responsibilities must be clearly defined*
- *Enact quality assurance procedures Interpret the results*
- *Manage the data*
- *Provide for contracts*

C. Responding to the Monitoring Results

- *No action*
- *Maintenance*
- *Adding, abandoning, or decommissioning plan elements*
- *Modification of project goals*
- *Adaptive management*
- *Documentation and reporting*
- *Dissemination of results.*

lowing:

- Make goals as simple and unambiguous as possible.
- Relate goals directly to the vision for the restoration.
- Set goals that can be measured or assessed in the plan.

Step 2: Develop the Conceptual Model

A conceptual model is a useful tool for developing linkages between planned goals and parameters that can be used to assess performance. In fact, a conceptual model is a useful tool throughout the planning process. The model forces persons planning the restoration to identify direct and indirect connections among the physical, chemical, and biological components of the ecosystem, as well as the principal components on which to focus restoration and monitoring efforts.

Baseline studies might be necessary to meet the following needs:

- To define existing conditions without any actions.
- To identify actions required to restore the system to desired functions and values.
- To help design the restoration actions.
- To help design the monitoring plan.

Step 3: Choose Performance Criteria

Link Performance to Goals

A link between the performance of the system and the planned goals is critical. If the goals are stated in a clear manner and can be reworded as a

Developing Performance Criteria Involves:

- Linking criteria to restoration goals.
- Linking criteria to the actual measurement parameters.
- Specifying the bounds or limit • values for the criteria.

set of testable hypotheses, performance criteria can be developed. *Performance criteria* are standards by which to evaluate measurable or otherwise observable aspects of the restored system and thereby indicate the progress of the system toward meeting the planned goals. The closer the tie between goals and performance criteria, the better the ability to judge the success of the restoration efforts.

Develop the Criteria

The primary reason for implementing the monitoring plan must be kept in mind: to assess progress and to indicate the steps required to fix a system or a component of the system that is not successful.

Criteria are usually developed through an iterative process that involves listing measures of performance relative to goals and refining them to arrive at the most efficient and relevant set of criteria.

Identify Reference Sites

A reference site or sites should be monitored along with the restored site. Although pre- and post-implementation comparisons of the system are useful in documenting effects, the level of success can be judged only relative to reference systems.

Step 4: Choose Monitoring Parameters and Methods

Monitoring should include an overall assessment of the condition and development of the stream corridor relative to projected trends or "target" conditions. In some cases, this assessment may involve technical analyses of stream flow data, channel and bank condition, bedload measurements, and comparisons of periodic aerial photography to determine whether stream migration and debris storage and transport are within the range of equilibrium conditions. Monitoring may also include forest inventories, range condition assessments, evaluations of fish and wildlife habitat or populations, and measurements of fire fuel loading. In small rural or urban "greenbelt" projects, more general qualitative characterization of corridor integrity and quality might be sufficient.

Numerous monitoring programs and techniques have been developed for particular types of resources, different regions, and specific management questions. For example, general stream survey techniques are described by Harrelson et al. (1994), while a regional programmatic approach for monitoring streams in the context of forest management practices in the Northwest is described in Schuett-Hames et al. (1993). Similarly, monitoring of fish and wildlife habitat quality and availability can be approached from various avenues, ranging from direct sampling of animal populations to application of the habitat evaluation procedures developed and used by the U.S. Fish and Wildlife Service (1980a). Techniques specific to riparian zone monitoring are given by Platts et al. (1987).

Choose Efficient Monitoring Parameters

There are two critical steps in choosing efficient monitoring parameters. The first is to identify parameters to monitor. A scientifically based, relatively easily measured set of parameters that provide direct feedback on success or failure of restoration actions are identified. The NRC (1992) has recommended that at least three parameters should be selected and that they include physical, hydrological, and ecological measures. The second step is to select regional and system-specific parameters. Criteria development must be based on a thorough knowledge of the system under consideration.

Primary Functions of Reference Site

- Can be used as models for developing restoration actions for a site.
- Provide a target to judge success or failure.
- Provide a control system by which environmental effects, unrelated to the restoration action, can be assessed.

Basic Question to Ask when Selecting Methods for Monitoring

- Does the method efficiently provide accurate data?
- Does the method provide reasonable and replicable data?
- Is the method feasible within time and cost constraints?

Those responsible for resources in the stream corridor must be aware of changing watershed and regional resource priorities. The appropriate place to consider the implications of regional needs is in the context of periodic reevaluation of restoration objectives, which is a function of the monitoring process. Therefore, an annual monitoring report should include recognition of ongoing or proposed initiatives (e.g., changes in regulations, emphasis on restoration of specific fish populations, endangered species listings) that might influence priorities in the restored corridor. Awareness of larger regional programs may produce opportunities to secure funding to support management of the corridor.

Review Watershed Activities

The condition of the watershed controls the potential to restore and maintain ecological functions in the stream corridor. As discussed in Chapter 3, changes in land use and/or hydrology can profoundly alter basic stream interactions with the floodplain, inputs of sediment and nutrients to the system, and fish and wildlife habitat quality. Therefore, it is important that stream corridor monitoring include periodic review of watershed cover and land use, including proposed changes (**Figure 6.17**).

Patterns of water movement through and within the stream corridor are basic considerations in developing objectives, design features, and management programs. Proposals to increase impervious surfaces, develop storm water management systems, or construct flood protection projects that reduce floodplain storage potential and increase surface and ground water consumption are all of legitimate concern to the integrity of the stream corridor. Stream corridor managers should be aware of such proposals and provide relevant input to the planning process. As changes are implemented, their probable influence on the corridor should be considered in periodic reevaluation of objectives and maintenance and management plans.

In rural settings, the corridor managers should be alert to land use changes in agricultural areas (**Figure 6.18**). Conversions between crop and pasture lands might require verification that fencing and drainage practices are consistent with agreed-upon BMPs or renegotiation of those agreements. Similarly, in wildland areas, major watershed management actions (timber harvests, prescribed burn programs) should be evaluated to ensure that stream corridors are adequately considered.

Increasing development and urbanization may reduce the ability of the stream corridor to support a wide variety of fish and wildlife species and, at the same time, generate additional pressure for recreational uses. Awareness of development and population growth trends will allow a rational, rather than reactive, adjustment of corridor management and restoration objectives. Proposals for specific implementation activities, such as roads, bridges, or storm water detention facilities, within or near the stream corridor should be scrutinized so that concerns can be considered before authorization of the implementation.

Choose Methods for Sampling Design, Sampling, and Sample Handling and Processing

Parameters that might be included in a restoration monitoring plan are well established in the scientific literature. Any methods used for sampling a particular parameter should have a documented protocol (e.g., Loeb and Spacie 1994).

Conduct Sociological Surveys

Scientifically designed surveys can be used to determine changes in social attitudes, values, and perceptions from prerestoration planning through implementation phases. Such surveys may complement physical, chemical, and biological parameters that are normally considered in a monitoring plan. Sociological surveys can reveal important shifts in the ways a community perceives the success of a restoration effort.

Rely on Instream Organisms for Evidence of Project Success

The restoration evaluation should usually focus on aquatic organisms and instream conditions as the "judge and jury" for evaluating restoration success. Instream physical, chemical, and biological conditions integrate the other factors within the stream corridor. Instream biota, however, have shown sensitivity to complex problems not as well detected by chemical or physical indicators alone in state water quality monitoring programs. For instance, in comparing chemical and biological criteria, the state of Ohio found that biological criteria detected an impairment in 49.8 percent of the situations where no impairment was evident with chemical criteria alone. Agreement between chemical and biological criteria was evident in 47.3 percent of the cases, while chemical criteria detected an impairment in only 2.8 percent of the cases where biological criteria indicated attainment (Ohio EPA 1990). As a result, Ohio's Surface Water Monitoring and Assessment Program has recognized that biological criteria must play a key role in defining water quality standards and in evaluating and monitoring standards attainment if the goal to restore and maintain the physical, chemical, and biological integrity of Ohio's waters is to be met.

REVERSE
Review Chapter 3's
Land use and hydrology Sections.

Figure 6.17: Urban sprawl. *Understanding changes in watershed land uses, such as increased urbanization, is an important aspect of restoration monitoring.*
Source: C. Zabawa.

Figure 6.18: Confinement farm. *Practitioners monitoring stream corridor restoration in rural areas should be aware of changes in agricultural land use.*

Minimize the Necessary Measurements of Performance

A holistic perspective is needed when monitoring restoration performance. Still, monitoring should focus narrowly on the fewest possible measurements or indicators that most efficiently demonstrate the overall condition of the stream corridor system and the success of the restoration effort. Costs and the ability to develop statistically sound data may quickly get out of hand unless the evaluation measures chosen are narrowly focused, are limited in number, and incorporate existing data and work wherever appropriate.

Existing data from state and federal agencies, community monitoring programs, educational institutions, research projects, and sportsmen's and other groups should be considered when planning for restoration evaluation. For example, turbidity data are generally more common than sediment data. If one of the objectives of a restoration effort is to reduce sediment concentrations, turbidity may provide a suitable surrogate measurement of sediment at little or no expense to restoration planners. **Table 6.2** provides some other examples of restoration objectives linked to specific performance evaluation tools and measures.

Incorporate Supplemental Parameters

Although the focus of the monitoring plan is on parameters that relate directly to assessment of performance, data on other parameters are often useful and may add considerably to interpretation of the results. For example, stream flow should be monitored if water temperature is a concern.

Step 5: Estimate Cost

Various project components must be considered when developing a cost estimate. These cost components include:

- *Monitoring plan.* Development of a monitoring plan is an important and often ignored component of a monitoring cost assessment. The plan should determine monitoring goals, acceptable and unacceptable results, and potential contingencies for addressing unacceptable results (**Figure 6.19**). The plan should specify responsibilities of participants.
- *Quality assurance (QA).* The monitoring plan should include an independent review to ensure that the plan meets the restoration goals, the data quality objectives, and the expectations of the restoration manager. The major cost component of quality assurance is labor.
- *Data management.* Monitoring plans should have data management specifications that start with sample tracking (i.e., that define the protocols and procedures) and conclude with the final archiving of the information. Major costs include staff labor time for data management, data entry, database maintenance, computer time, and data audits.
- *Field sampling plan.* Sampling may range from the very simple, such as photo monitoring, wildlife observation, and behavioral observation (e.g., feeding, resting, movement), to the more complex, such as nutrient and contaminant measurement, water quality parameter measurement, plankton group measurement, productivity measurement in water column and substrate surface, macrophyte or vegetation sampling, and hydrological monitoring. The cost components for a complex plan may include the following:
  - Restoration management and field staff labor.
  - Subcontracts for specific field sampling or measurement activities (including costs of managing and overseeing the subcontracted activities).
  - Mobilization and demobilization costs.
  - Purchase, rental, or lease of

*Figure 6.19: **Monitoring.** It is important to develop a framework for the monitoring protocol and a plan for monitoring evaluation.*

Table 6.2: Environmental management. Source: Kondolf and Micheli 1995.

General Objectives	Potential Evaluation Tools and Criteria
Channel capacity and stability	Channel cross sections
	Flood stage surveys
	Width-to-depth ratio
	Rates of bank or bed erosion
	Longitudinal profile
	Aerial photography interpretation
Improve aquatic habitat	Water depths
	Water velocities
	Percent overhang, cover, shading
	Pool/riffle composition
	Stream temperature
	Bed material composition
	Population assessments for fish, invertebrates, macrophytes
Improve riparian habitat	Percent vegetative cover
	Species density
	Size distribution
	Age class distribution
	Plantings survival
	Reproductive vigor
	Bird and wildlife use
	Aerial photography
Improve water quality	Temperature
	pH
	Dissolved oxygen
	Conductivity
	Nitrogen
	Phosphorus
	Herbicides/pesticides
	Turbidity/opacity
	Suspended/floating matter
	Trash loading
	Odor
Recreation and community involvement	Visual resource improvement based on landscape control point surveys
	Recreational use surveys
	Community participation in management

  equipment.
  - Supplies.
  - Travel.
  - Shipping.
- *Laboratory sample analysis.* Laboratory analyses can range from simple tests of water chemistry parameters such as turbidity, to highly complex and expensive tests, such as organic contaminant analyses and toxicity assays. The cost components of laboratory sample analysis are usually estimated in terms of dollars per sample.
- *Data analysis and interpretation.* Analysis and interpretation require the expertise of trained personnel and may include database management, which can be conducted by a data management specialist if the data are complex or by a technician or restoration manager if they are relatively straightforward.
- *Report preparation.* One of the final steps in the monitoring plan is to prepare a report outlining the restoration action, monitoring goals, methods, and findings. These documents are meant to serve as interpretative reports, synthesizing the field and lab data analysis results. These reports are typically prepared by a research scientist with the aid of a research assistant. Report production costs depend on the type and quality of reports requested.
- *Presentation of results.* Though not often considered a critical component of a monitoring plan, presentation of plan results should be considered, including costs for labor and travel.

Step 6: Categorize the Types of Data

Several types of data gathered as part of the monitoring plan may be useful in developing the plan or may provide additional information on the performance of the system. The restoration manager should also be aware of available information that is not part of the monitoring plan but could be useful.

Consultation with agency personnel, local universities and consultants, citizen environmental groups (e.g., Audubon chapters), and landowners in the area can reveal important information.

Step 7: Determine the Level of Effort and Duration

How much monitoring is required? The answer to this question is dependent on the goals and performance criteria for the restoration as well as on the type of ecological system being restored. A monitoring plan does not need to be complex and expensive to be effective.

Incorporate Landscape Ecology

The restoration size or scale affects the complexity of the monitoring required. As heterogeneity increases, the problem of effectively sampling the entire system becomes more complex. Consideration must be given to the potential effect on the restoration success of such things as road noise, dogs, dune buggies, air pollution, waterborne contamination, stream flow diversions, human trampling, grazing animals, and myriad other elements (**Figure 6.20**).

Determine Timing, Frequency, and Duration of Sampling

The monitoring plan should be carried out according to a systematic schedule. The plan should include a start date, the time of the year during which field studies should take place, the frequency of field studies, and the end date for the plan. Timing, frequency, and duration are dependent on the aspects of system type and complexity, controversy, and uncertainty.

- *Timing.* The monitoring plan should be designed prior to conducting any baseline studies. A problem often encountered with this initial sampling is seasonality. Implementation may be completed in midwinter, when vegetation and other conditions are not as relevant to the performance criteria and goals of the restoration, which might focus on midsummer conditions.

  The field studies should be carried out during an appropriate time of the year. The driving consideration is the performance criteria. Because weather varies from year to year, it is wise to "bracket" the season with the sampling. For example, sampling temperature four times during the midsummer may be better than a single sampling in the middle of the season. Sampling can be performed either by concentrating all tasks during a single site visit or by carrying out one task or a similar set of tasks at several sites in a single day.
- *Frequency.* Frequency of sampling refers to the period of time between samplings. In general, "new" systems change rapidly and should be monitored more often than older systems. As a system becomes established, it is generally less vulnerable to disturbances. Hence, monitoring can be less frequent. An example of this is annual monitoring of a marsh for the first 3 years, followed by monitoring at intervals of 2 to 5 years for the duration of the planned restoration or until the system stabilizes.
- *Duration.* The monitoring plan should extend long enough to provide reasonable assurances either that the system has met its performance criteria or that it will or will not likely meet the criteria. A restored system should be reasonably self-maintaining after a certain

Types of data important to various phases of Restoration

- Restoration Planning
  - Develop baseline data at the site.
- Implementation of Restoration Plan
  - Monitor implementation activities.
  - Collect as-built or as-implemented information.
- Postimplementation
  - Collect performance data.
  - Conduct other studies as needed.

Figure 6.20: Streams n the (a) western and (b) eastern United States. *The wide variability of stream structure and function among different regions of the country makes standardized restoration evaluation difficult.*

period of time. Fluctuations on an annual basis in some parameters of the system will occur even in the most stable mature systems. It is important for the plan to extend to a point somewhere after the period of most rapid change and into the period of stabilization of the system.

Develop a Statistical Framework

The monitoring study design needs to include consideration of statistical issues, including the location of sample collection, the number of replicate samples to collect, the sample size, and others. Decisions should be made based on an understanding of the accuracy and precision required for the data (**Figure 6.21**). The ultimate use of the data must be kept in mind when developing the sampling plan. It is useful to frequently ask, “Will this sampling method give us the answers we need for planning?” and “Will we be able to determine the success or performance of the restoration?”

Monitoring can consist of many different methods and can occur at varying locations, times, and intensities, depending on the conditions to be monitored. The costs or expenditures of time and resources also vary accordingly. The challenge is to design the monitoring plan to provide, in a cost-efficient and timely manner, accurate information to provide the rationale for decisions made throughout the planning process, and during and after implementation to assess success.

The accuracy of the data to define environmental conditions is of paramount concern, but the acceptable precision of the data can vary, depending on the target of concern. For example, if the amount of pesticides in surface water is a concern, it is much cheaper to assay for the presence of groups of pesticides than to test for specific ones. Also, if overall water quality conditions are needed, seasonal sampling of biological indicators may act as a surrogate for long-term sampling of specific chemical parameters.

Choose the Sampling Level

The appropriate level of sampling or the number of replicates under any particular field or laboratory sampling effort depends on the information required and the level of accuracy needed.

Quantity and quality of information desired is in turn dependent in part on the expenditures necessary to carry out the identified components of the sampling plan.

Implementing and Managing the Monitoring Plan

Management of the monitoring plan is perhaps the least appreciated but one of the most important components of restoration. Because monitoring continues well after implementation activities, there is a natural tendency for the plan to lose momentum, for the data to accumulate with little analysis, and for little documentation and dissemination of the information to occur. This section presents methods for preventing or minimizing these problems.

Envisioning the Plan

The restoration manager must have a vision of the life (i.e., duration) of the monitoring plan and must see how the plan fits into the broader topic of restoration as a viable tool for meeting the goals of participating agencies, organizations, and sponsors.

Determining Roles

Carrying out the monitoring plan is usually the responsibility of the restoration sponsor. However, responsibility should be established clearly in writing during the development of the restoration because this responsibility can last for a decade or more.

Ensuring Quality

The restoration manager should consider data quality as a high priority in the monitoring plan. Scientifically defensible data require that at least

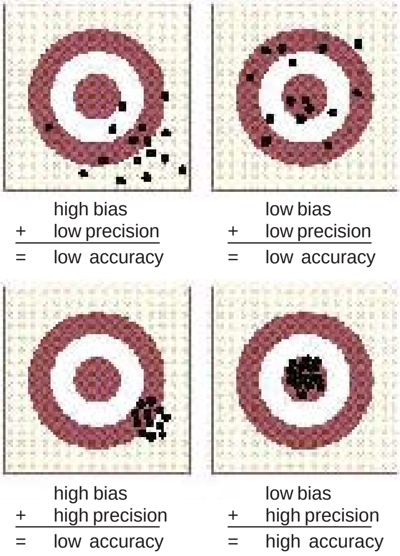


Figure 6.21: Patterns of shots at a target. *Monitoring design decisions should be made based on an understanding of the accuracy and precision required of the data.*
Source: Gilbert 1987 after Jessen 1978.

minimal quality assurance procedures be in place.

Interpreting Results

Results of the monitoring plan should be interpreted with objectivity, completeness, and relevance to the restoration objectives. The restoration manager and the local sponsor may share responsibility in interpreting the results generated by the monitoring plan. The roles of the restoration manager and local sponsor need to be determined before any data-gathering effort begins. Both parties should seek appropriate technical expertise as needed.

Managing Data

Data should be stored in a systematic and logical manner that facilitates analysis and presentation. Development of the monitoring plan should address the types of graphs and tables that will be used to summarize the results of the monitoring plan. Most monitoring data sets can be organized to allow direct graphing of the data using database or spreadsheet software.

Managing Contracts

One of the most difficult aspects of managing a monitoring plan can be management of the contracts required to conduct the plan. Most restoration requires that at least some of the work be contracted to a consultant or another agency. Because monitoring plans are frequently carried out on a seasonal basis, timing is important.

Restoration Evaluation

Directly linked to monitoring is the evaluation of the success of the restoration effort. Restoration evaluation is intended to determine whether restoration is achieving the specific goals identified during planning, namely, whether the stream corridor has reestablished and will continue to maintain the conditions desired.

Approaches to evaluation most often emphasize biological features, physical attributes, or both. The primary tool of evaluation is monitoring indicators of stream corridor structure, function, and condition that were chosen because they best estimate the degree to which restoration goals were met. Evaluation may target certain aquatic species or communities as biological indicators of whether specific water quality or habitat conditions have been restored. Or, for example, evaluation may focus on the physical traits of the channel or riparian zone that were intentionally modified by project implementation (**Figure 6.22**). In any case, the job is not finished unless the condition and function of the modified stream corridor are assessed and adjustments, if necessary, are made. The time frame for evaluating restoration success can vary from months to years, depending on the speed of the stream system's response to the treatment applied. Therefore, performance evaluation often means a commitment to evaluate restoration long after it was implemented.

Reasons to Evaluate Restoration Efforts

The evaluation of stream corridor restoration is a key step that is often omitted. Kondolf and Micheli (1995) indicate that despite increased commitment to stream restoration, postrestoration evaluations have generally been neglected. In one study in Great Britain, only 5 of almost 100 river conservation enhancement projects had postimplementation appraisal reports (Holmes 1991).

Why do practitioners of restoration sometimes leave out the final evaluation process? One probable reason is that evaluation takes time and money and is often seen as expendable excess in a proposed restoration effort when it is misunderstood. It appears that the final restoration evaluation is sometimes abandoned so the remaining time and money can be spent on the restoration itself. Although an understandable temptation, this is not an acceptable course of action for most restoration efforts, and collectively the lack of evaluation slows the development and improvement of successful restoration techniques.

Protecting the Restoration Investment

Stream corridor restoration can be extremely costly and represent substantial financial losses if it fails to work properly. Monitoring during and after the restoration is one way to detect problems before they become prohibitively complex or expensive to correct.

Restoration may involve a commitment of resources from multiple agencies, groups, and individuals to achieve a variety of objectives within a stream corridor. All participants have made an investment in reaching their own goals. Reaching consensus on restoration goals is a process that keeps these participants aware of each others' aims. Evaluating restoration success should maintain the existing group awareness and keep participants involved in helping to protect their own investment.

Helping to Advance Restoration Knowledge for Future Applications

Restoration actions are relatively new and evolving and have the risk of

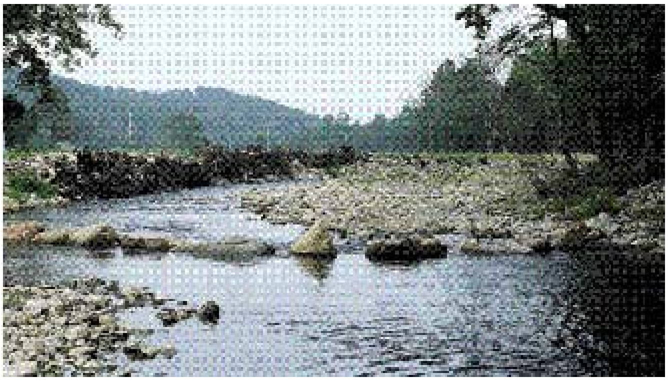


Figure 6.22: Instream modifications. *Restoration evaluation may focus on the physical traits of the channel that were intentionally modified during project implementation such as the riffles pictured*

failure that is inherent in efforts with limited experience or history. Restoration practitioners should share their experiences and increase the overall knowledge of restoration practices—those that work and those that do not. Shared experience is essential to our limited knowledge base for future restoration.

Maintaining Accountability to Restoration Supporters

The coalition of forces that make a restoration effort possible can include a wide variety of interest groups, active participants, funding sources, and political backers, and all deserve to know the outcome of what they have supported.

Sometimes, restoration monitoring may be strongly recommended or required by regulation or as a condition of restoration funding. For example, the USEPA has listed an evaluation and reporting plan in guidance for grants involving restoration practices to reduce nonpoint source pollution. Requirements notwithstanding, it is worthwhile to provide the restoration effort's key financial supporters and participants with a final evaluation. Other benefits such as enhancing public relations or gaining good examples of restoration successes and publishable case histories, can also stem from well-designed, well-executed evaluations.

Acting on the Results

Identified goals and objectives, as discussed in Chapter 5, should be very clear and specific concerning the resulting on-site conditions desired. However, large or complex restoration efforts are sometimes likely to involve a wide range of goals. Restoration evaluations are needed to determine whether the restoration effort is meeting and will continue to meet specific goals identified during planning, to allow for mid-course adjustments, and to report on any unanticipated benefits or problems as a result of the program.

The results from a monitoring plan are an important tool for assessing the progress of a restoration and informing restoration decision makers about the potential need for action.

REVERSE
Review Chapter 5's
Goals and objectives section.

Alternative Actions

Because restoration involves natural systems, unexpected consequences of restoration activities can occur. The four basic options available are as follows:

- *No action.* If the restoration is generally progressing as expected or if progress is slower than expected but will probably meet restoration goals within a reasonable amount of time, no action is appropriate.
- *Maintenance.* Physical actions might be required to keep restoration development on course toward its goals.
- *Adding, abandoning, or decommissioning plan elements.* Significant changes in parts of the implemented restoration plan might be needed. These entail revisiting the overall plan, as well as considering changes in the design of individual elements.
- *Modification of restoration goals.* Monitoring might indicate that the restoration is not progressing toward the original goals, but is progressing toward a system that has other highly desirable functions. In this case, the participants might decide that the most cost-effective action would be to modify the restoration goals rather than to make extensive physical changes to meet the original goals for the restoration.

Adaptive Management

The expectations created during the decision to proceed with restoration might not always influence the outcome, but they are certainly capable of influencing the opinions of participants and clients concerning the outcome.

The first fundamental rule, then, is to set proper expectations for the restoration effort. If the techniques to be used are experimental, have some risk of failure, or are likely to need midcourse corrections, these facts need to be made clear. One effective way to set reasonable expectations from the beginning is to acknowledge uncertainty, evaluation of performance, and adjustments as part of the game plan.

Adaptive management involves adjusting management direction as new information becomes available (**Figure 6.23**). It requires willingness to experiment scientifically and prudently, and to accept occasional failures (Interagency Ecosystem Management Task Force 1995). Since restoration is a new science with substantial uncertainty, adaptive management to incorporate new midcourse information should be expected. Moreover, through adaptive management specific problems can be focused on and corrected.

It is recognized that restoration is uncertain. Therefore, it is prudent to allow for contingencies to address problems during or after restoration implementation. The progress of the

Reasons to prepare written documentation for monitoring plan

- Demonstrates that the monitoring plan is "happening."
- Demonstrates that the restoration meets the design specifications and performance criteria.
- Assists in discussions with others about the restoration.
- Documents details that may otherwise be forgotten.
- Provides valuable information to new participants.
- Informs decision makers

system should be assessed annually. At that time, decisions can be made regarding any mid-course corrections or other alternative actions, including modification of goals. The annual assessments would use monitoring data and might require additional data or expertise from out-side the restoration team. Because the overall idea is to make the restoration "work," while not expending large amounts of funds to adhere to inflexible and unrealistic goals, decisions would be made regarding the physical actions that might be needed versus alterations in restoration goals.

Restoration participants must remain willing to acknowledge failures and to learn from them. Kondolf (1995) emphasizes that even if restoration fails, it provides valuable experimental results that can help in the design of future efforts. Repeatedly, a cultural reluctance to admit failure perpetuates the same mistakes instead of educating others about pitfalls that might affect their efforts, too. Accepting failure reiterates the importance of setting appropriate expectations. Participants should all acknowledge that failure is one of the possible outcomes of restoration. Should failure occur, they should resist the natural temptation to bury their disappointment and instead help others to learn from their experience.

- Modify plans using monitoring, technical, and social feedback
- Track restoration policy, programs, and individual projects as feedback for further restoration policy and program redesign
- Restoration initiatives: recommend annual assessments use monitoring data and other data/expertise midcourse corrections or alternative actions link reporting/monitoring schedules for midcourse corrections
- Manager may contract some/all monitoring, but periodically must visit sites, review reports, discuss with contractors.

Figure 6.23: Adaptive management. *Adjusting management direction as new information becomes available requires a willingness to experiment and accept occassional failures.*

Adaptive management is not "adjustment management" but a way of establishing hypotheses early in the planning, then treating the restoration process as an experiment to test the hypotheses.

Documenting and Reporting

The monitoring report should also include a systematic review of changes in resource management priorities and watershed conditions along with a discussion of the possible implications for restoration measures and objectives. The review should be wide-ranging, including observations and concerns that might not require immediate attention but should be documented to ensure continuity in case of turnover in personnel. The monitoring report should alert project managers to proposed developments or regulation changes that could affect the restoration effort, so that feedback can be provided and stream corridor concerns can be considered during planning for the proposed developments.

Documentation and reporting of the progress and development of the restoration provide written evidence that the restoration manager can use for a variety of purposes. Three simple concepts are common among the best-documented restorations:

- A single file that was the repository of all restoration information was developed.
- The events and tasks of the restoration were recorded chronologically in a systematic manner.
- Well-written documents (i.e., planning and monitoring documents) were produced and distributed widely enough to become part of the general regional or national awareness of the restoration.

Main sections in a general format for a monitoring report should include title page, summary or abstract, introduction, site description, methods, results, discussion, conclusions, recommendations, acknowledgments, and literature cited.

Dissemination of the Results

Recipients of the report and other monitoring information should include all interested parties (e.g., all state and federal agencies involved in a permit action). In addition, complete files should be maintained. The audience can include beach-goers, birders, fishers, developers, industry representatives, engineers, government environmental managers, politicians, and scientists. The recipient list and schedule for delivery of the reports should be developed by the restoration manager. If appropriate, a meeting with interested parties should be held to present the results of the monitoring effort and to discuss the future of the restoration. Large, complex, and expensive restorations might have wide appeal and interest, and meetings on these restorations will require more planning. Presentations should be tailored to the audience to provide the information in the clearest and most relevant form.

Planning for Feedback During Restoration Implementation

A sound quality control/quality assurance component of the restoration plan incorporates the means to measure and control the quality of an activity so that it meets expectations

(USEPA 1995a). Especially in restoration efforts that involve substantial earthmoving and other major structural modifications, risk of unintentional damage to water quality or aquatic biota exists. Mid-course monitoring should be part of the plan, both to guard against unexpected additional damage and to detect positive improvements (**Figure 6.24**).

Making a Commitment to the Time Frame Needed to Judge Success

The time required for system recovery should be considered in determining the frequency of monitoring.

- Data on fractions of an hour might be needed to characterize streamflow.
- Hourly data might be needed for water temperature and water quality.
- Weekly data might be appropriate to show changes in the growth rate of aquatic organisms.
- Monthly or quarterly data might be necessary to investigate annual cycles.
- Annual measures might be adequate to show the stability of streambanks.
- Organisms with long life spans, such as paddlefish or trees, might need to be assessed only on the order of decades (**Figure 6.25**).

The time of day for measurement should also be considered. It might be most appropriate to measure dissolved oxygen at dawn, whereas temperature might be measured most appropriately in the mid- to late afternoon. Migrations or climatic patterns might require that studies be conducted during specific months or seasons. For example, restoration efforts expected to result in increased baseflow might require studies only in late summer and early fall.

The expected time for recovery of the stream corridor could involve years or decades, which should be addressed in the duration of the study and its evaluation. Moreover, if the purpose of restoration is to maintain natural floodplain functions during a 10-year flood event, it might take years for such an event to occur and allow a meaningful evaluation of performance.

Some efforts have been made to integrate short- and long-term performance monitoring requirements into overall design. Bryant (1995) recently presented the techniques of a pulsed monitoring strategy involving a series of short-term, high-intensity studies separated by longer periods of low-intensity data collection. MacDonald et al. (1991) have described several different types of monitoring by frequency, duration, and intensity.

Evaluating Changes in the Sources of Stress as Well as in the System Itself

Restoration might be necessary because of stress currently affecting the stream corridor or because of damage in the past. It is critical to know whether the sources of stress are still present or are absent, and to incorporate treatment of the sources of stress as part of the restoration approach. In fact, some practitioners will not enter into a restoration effort that does not include reducing or eliminating the source of negative impacts because simply improving the stream itself will likely result in only temporary enhancements.

The beginning steps of ecological risk assessment are largely designed around characterization of an ecosystem's valued features, characterization of the stressors degrading the ecosystem, identification of the routes of exposure of the ecosystem to the stressors, and description of ecological effects that might result. If these factors are documented for restoration during its design and execution, it should be clear how evaluating performance should address each factor after completion. Has the source of stress, or its route of exposure, been diminished or eliminated? Are the negative ecological effects reversed or no longer present?

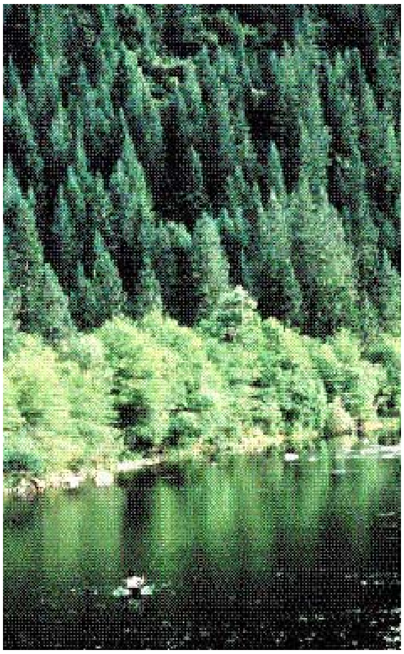
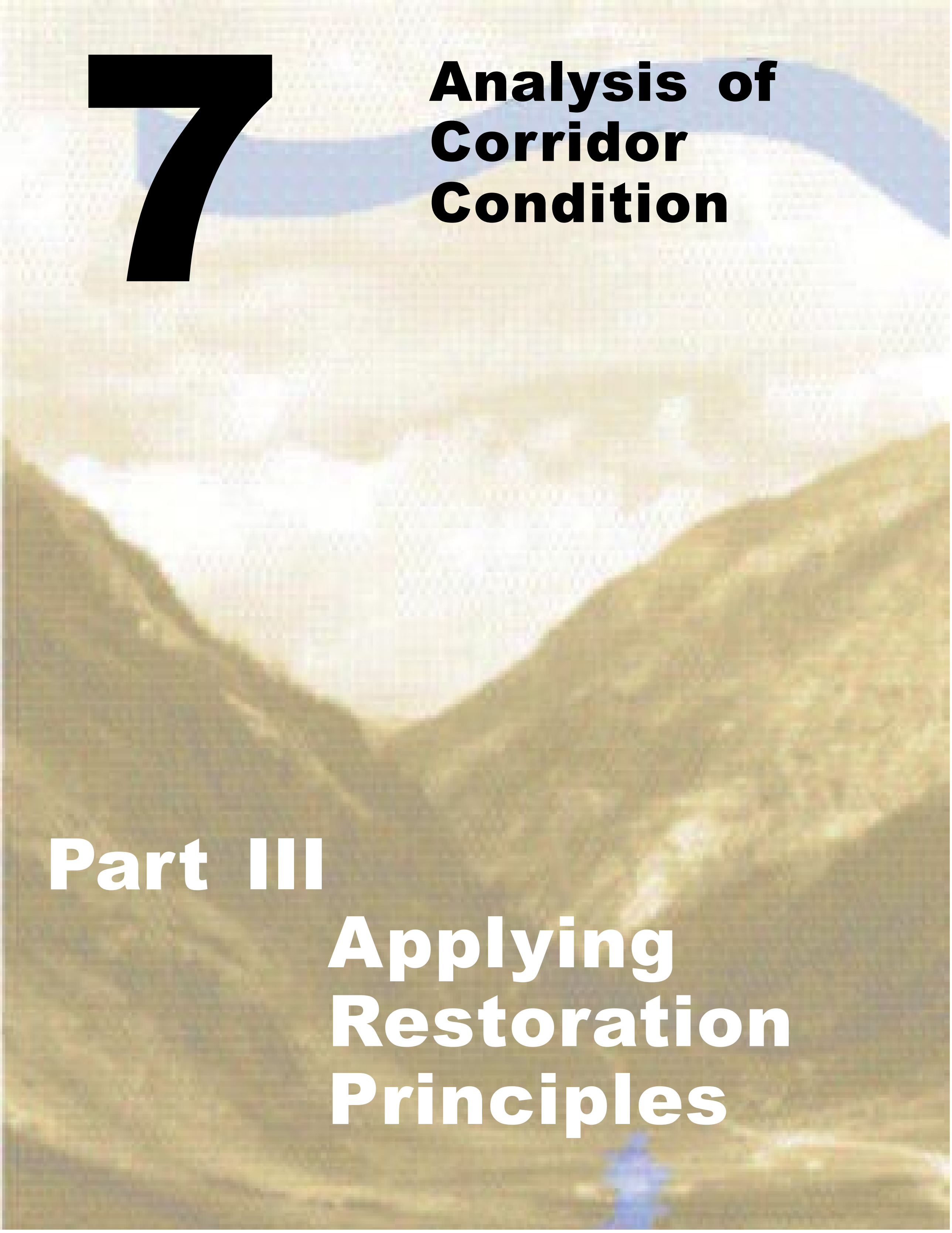


Figure 6.25: Revegetated streambank. *Monitoring and evaluation must take into account the differences in life spans among organisms. Tree growth along the streambank will be evaluated on a much longer time scale than other restoration results.*

Figure 6.24: Streambank failure. *Midcourse monitoring will guard against unexpected damages.*



7

Analysis of Corridor Condition

Part III

Applying Restoration Principles

7.A Hydrologic and Hydraulic Processes

- How does the stream flow and why is this understanding important?
- Is streamflow perennial, ephemeral or intermittent?
- What is the discharge, frequency and duration of extreme high and low flows?
- How often does the stream flood?
- How does roughness affect flow levels?
- What is the discharge most effective in maintaining the stream channel under equilibrium conditions?
- How does one determine if equilibrium conditions exist?
- What field measurements are necessary?

7.B Geomorphic Processes

- How do I inventory geomorphic information on streams and use it to understand and develop physically appropriate restoration plans?
- How do I interpret the dominant channel adjustment processes active at the site?
- How deep and wide should a stream be?
- Is the stream stable?
- Are basin-wide adjustments occurring, or is this a local problem?
- Are channel banks stable, at-risk, or unstable?
- What measurements are necessary?

7.C Chemical Characteristics

- How do you measure the condition of the physical and chemical conditions within a stream corridor?
- Why is quality assurance an important component of stream corridor analysis activities?
- What are some of the water quality models that can be used to evaluate water chemistry data?

7.D Biological Characteristics

- What are some important considerations in using biological indicators for analyzing stream corridor conditions?
- Which indicators have been used successfully?
- What role do habitat surveys play in analyzing the biological condition of the stream corridor?
- How do you measure biological diversity in a stream corridor?
- What is the role of stream classification systems in analyzing stream corridor conditions?
- How can models be used to evaluate the biological condition of a stream corridor?
- What are the characteristics of models that have been used to evaluate stream corridor conditions?.

7

Analysis of Corridor Conditions

Section 7.A: Hydrologic Processes

Understanding how water flows into and through stream corridors is critical to developing restoration initiatives. How fast, how much, how deep, how often, and when water flows are important basic questions that must be answered in order to make appropriate decisions about the implementation of a stream corridor's restoration.

Section 7.B: Geomorphic Processes

This section combines the basic hydrologic processes with the physical or geomorphic functions and characteristics. Water flows through streams but is affected by the kinds of soils and alluvial features within the channel, in the floodplain, and in the uplands. The amount and kind of sediments carried by a stream is largely a determinant of its equilibrium characteristics, including size, shape, and profile. Successful implementation of the stream corridor restoration, whether active (requiring direct intervention) or passive, (removing only disturbance factors), depends on an understanding of how water and sediment are related to channel form and function, and on what processes are involved with channel evolution.

Section 7.C: Chemical Characteristics

The quality of water in the stream corridor is normally a primary objective of restoration, either to improve it to a desired condition, or to sustain it. Restoration initiatives should consider the physical and chemical characteristics that may not be readily apparent but that are nonetheless critical to the functions and processes of stream corridors. Chemical manipulation of specific characteristics usually involves the management or alteration of elements in the landscape or corridor.

Section 7.D: Biological Characteristics

The fish, wildlife, plants, and human beings that use, live in, or just visit the stream corridor are key elements to consider, not only in terms of increasing populations or species diversity, but also in terms of usually being one of the primary goals of the restoration effort. A thorough understanding of how water flows, how sediment is transported, and how geomorphic features and processes evolve is important. However, a prerequisite to successful restoration is an understanding of the living parts of the system and how the physical and chemical processes affect the stream corridor.

7.A Hydrologic Processes

Flow Analysis

Restoring stream structure and function requires knowledge of flow characteristics. At a minimum, it is helpful to know whether the stream is perennial, intermittent, or ephemeral, and the relative contributions of baseflow and stormflow in the annual runoff. It might also be helpful to know whether streamflow is derived primarily from rainfall, snowmelt, or a combination of the two.

Other desirable information includes the relative frequency and duration of extreme high and low flows for the site and the duration of certain stream flow levels. High and low flow extremes usually are described with a statistical procedure called a frequency analysis, and the amount of time that various flow levels are present is usually described with a flow duration curve.

Finally, it is often desirable to estimate the channel-forming or dominant discharge for a stream (i.e., the discharge that is most effective in shaping and maintaining the natural stream channel). *Channel-forming* or *dominant discharge* is used for design when the restoration includes channel reconstruction.

Estimates of streamflow characteristics needed for restoration can be obtained from stream gauge data. Procedures for determining flow duration characteristics and the magnitude and frequency of floods and low flows at gauged sites are described in this section. The procedures are illustrated using daily mean flows and annual peak flows (the maximum discharge for each year) for the Scott River near Fort Jones, a 653-square-mile watershed in northern California.

Most stream corridor restoration initiatives are on streams or reaches that lack systematic stream gauge data. Therefore, estimates of flow duration and the frequency of extreme high and low flows must be based on indirect methods from regional hydrologic analysis. Several methods are available for indirect estimation of mean annual flow and flood characteristics; however, few methods have been developed for estimating low flows and general flow duration characteristics.

Users are cautioned that statistical analyses using historical streamflow data need to account for watershed changes that might have occurred during the period of record. Many basins in the United States have experienced substantial urbanization and development; construction of upstream reservoirs, dams, and storm water management structures; and construction of levees or channel modifications.

These features have a direct impact on the statistical analyses of the data for peak flows, and for low flows and flow duration curves in some instances. Depending on basin modifications and the analyses to be performed, this could require substantial time and effort.

Flow Duration

The amount of time certain flow levels exist in the stream is represented by a *flow duration curve* which depicts the percentage of time a given streamflow was equaled or exceeded over a given period. Flow duration curves are usually based on daily streamflow (a record containing the average flow for each day) and describe the flow characteristics of a stream throughout a range of discharges without regard to the sequence of occurrence. A flow duration curve is the cumulative histogram of the set of all daily flows. The construction of flow duration curves is described by Searcy (1959), who recommends defining the cumulative histogram of stream-flow by using 25 to 35 well-distributed class intervals of streamflow data.

Figure 7.1 is a flow duration curve that was defined using 34 class intervals and software documented by Lumb et al. (1990). The numerical output is provided in the accompanying table.

The curve shows that a daily mean flow of 1,100 cubic feet per second (cfs) is exceeded about 20 percent of the time or by about 20 percent of the observed daily flows. The long-term mean daily flow (the average flow for the period of record) for this watershed was determined to be 623 cfs. The duration curve shows that this flow is exceeded about 38 percent of the time.

For over half the states, the USGS has published reports for estimating flow duration percentiles and low flows at ungauged locations. Estimating flow duration characteristics at ungauged sites usually is attempted by adjusting data from a nearby stream gauge in a hydrologically similar basin. Flow duration characteristics from the stream gauge record are expressed per unit area of drainage basin at the gauge (i.e., in cfs/mi^2) and are multiplied by the drainage area of the ungauged site to estimate flow duration characteristics there. The accuracy of such a procedure is directly related to the similarity of the two sites. Generally, the drainage area at the stream gauge and ungauged sites should be fairly similar, and streamflow characteristics should be similar for both sites. Additionally, mean basin elevation and physiography should be similar for both sites. Such a procedure does not work well and should not be attempted in stream systems dominated by local convective storm runoff or where land uses vary significantly between the gauged and ungauged basins.

Flow Frequency Analysis

The frequency of floods and low flows for gauged sites is determined by analyzing an annual time series of maximum or minimum flow values (a chronological list of the largest or smallest flow that occurred each year). Although previously described in Chapter 1, *flow frequency* is redefined here because of its relevance to the sections that follow. Flow frequency is defined as the probability or percent chance of a given flow's being exceeded or not exceeded in any given year. Flow frequency is often expressed in terms of *recurrence interval* or the average number of years between exceeding or not exceeding the given flows. For example, a given flood flow that has a 100-year recurrence interval is expected to be exceeded, on average, only once in any 100-year period; that is, in any given year, the annual flood flow has a 1 percent chance or 0.01 probability of exceeding the 100-year flood. The exceedance probability, p, and the recurrence interval, T, are related in that one is the reciprocal of the other (i.e., $T = 1/p$). Statistical procedures for determining the frequency of floods and low flows at gauged sites follow.

As mentioned earlier, most stream corridor restoration initiatives are on streams or reaches lacking systematic stream gauge data; therefore, estimates of flow duration characteristics and the frequency of extreme high and extreme low flows must be based on indirect methods from regional hydrologic analysis.

Flood Frequency Analysis

Guidelines for determining the frequency of floods at a particular location using streamflow records are documented by the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data (IACWD 1982, Bulletin 17B). The guidelines described in Bulletin 17B are used by all federal agencies in planning activities involving water and related land resources. Bulletin 17B recommends fitting the Pearson Type III frequency distribution to the logarithms of the annual peak flows using sample statistics (mean, standard deviation, and skew) to estimate the distribution parameters. Procedures for outlier detection and adjustment, adjustment for historical data, development of generalized skew, and weighting of station and generalized skews are provided. The station skew is computed from the observed peak flows, and the generalized skew is a regional estimate determined from estimates at several long-term stations in the region. The US Army Corps of Engineers also has produced a user's manual for *flood frequency analysis* (Report CPD-13, 1994) that can aid in determining flood frequency distribution parameters. NRCS has also produced a manual *(National Engineering Handbook*, Section 4, Chapter 18) that can also be used in determining flood frequency distribution (USDA-SCS 1983).

Discharges (cfs)	% of Time Flow Equaled or Exceeded
0	100
1	100
1.4	100
2	100
2.8	100
4	100
5.7	99.96
8.1	99.76
11	99.68
16	99.43
23	98.7
33	96.89
46	94.2
66	95.02
93	74.54
130	65.98
190	60.15
270	55.03
380	49.03
530	42.05
760	31.47
1,100	20.75
1,500	11.95
2,200	5.1
3,100	2.25
4,300	1.2
6,100	0.68
8,700	0.35
12,000	0.16
17,000	0.06
25,000	0.04
35,000	0.01
50,000	0
71,000	0

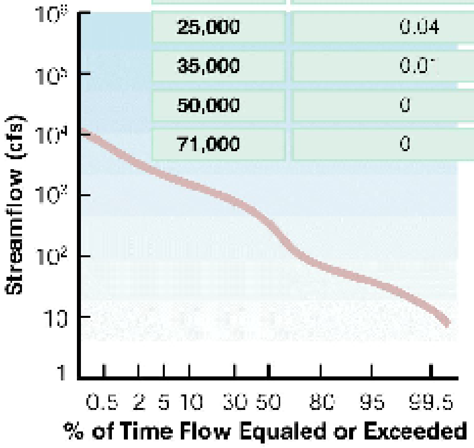


Figure 7.1: Flow duration curve and associated data tables. *Data for the Scott River, near Fort Jones, CA, 1951-1980, show that a flow of 1,100 cubic feet per second (cfs) is exceeded about 20 percent of the time.* Source: Lumb et al. (1990).

Throughout the United States, flood frequency estimates for USGS gauging stations have been correlated with certain climatic and basin characteristics. The result is a set of regression equations that can be used to estimate flood magnitude for various return periods in ungauged basins (Jennings et al. 1994). Reports outlining these equations often are prepared for state highway departments to help them size culverts and rural road bridge openings.

Estimates of the frequency of peak flows at ungauged sites may be made by using these regional regression equations, provided that the gauged and ungauged sites have similar climatic and physiographic characteristics.

Frequently the user needs only such limited information as mean annual precipitation, drainage area, storage in lakes and wetlands, land use, major soil types, stream gradients, and a topographic map to calculate flood magnitudes at a site. Again, the accuracy of the procedure is directly related to the hydrologic similarity of the two sites. Similarly, in many locations, flood frequency estimates from USGS gauging stations have been correlated with certain channel geometry characteristics. These correlations produce a set of regression equations relating some channel feature, usually active channel width, to flood magnitudes for various return periods. A review of these equations is provided by Wharton (1995). Again, the standard errors of the estimate might be large.

Regardless of the procedure or source of information chosen for obtaining flood frequency information, estimates for the 1.5, 2, 5, 10, 25, and (record permitting) 50 and 100-year flood events may be plotted on standard log-probability paper, and a smooth curve may be drawn between the points. (Note that these are flood events with probabilities of 67, 50, 20, 10, 4, 2, and 1 percent, respectively.) This plot becomes the flood frequency relationship for the restoration site under consideration. It provides the background information for determining the frequency of inundation of surfaces and vegetation communities along the channel.

Low-Flow Frequency Analysis

Guidelines for *low-flow frequency analysis* are not as standardized as those for flood frequency analysis. No single frequency distribution or curve-fitting method has been generally accepted. Vogel and Kroll (1989) provide a summary of the limited number of studies that have evaluated frequency distributions and fitting methods for low flows. The methodology used by USGS and USEPA is described below.

Sources of Daily Mean Discharge and other Data from USGS Stream Gauges

Daily mean streamflow

Daily mean streamflow data needed for defining flow duration curves are published on a water-year (October 1 to September 30) basis for each state by the U.S. Geological Survey (USGS) in the report series Water Resources Data. The data collected and published by the USGS are archived in the National Water Information System (NWIS).

The USGS currently provides access to streamflow data by means of the Internet. The USGS URL address for access to streamflow data is http://water.usgs.gov. Approximately 400,000 station years of historical daily mean flows for about 18,500 stations are available through this source. The USGS data for the entire United States are also available from commercial vendors on two CD-ROMs, one for the eastern and one for the western half of the country (e.g., CD-ROMs for DOS can be obtained from Earth Info, and CD-ROMs for Windows can be obtained from Hydrosphere Data Products. Both companies are located in Boulder, Colorado.)

In addition to the daily mean flows, summary statistics are also published for active streamflow stations in the USGS annual Water Resources Data reports. Among the summary statistics are the daily mean flows that are exceeded 10, 50, and 90 percent of the time of record. These durations are computed by ranking the observed daily mean flows from $q_{(1)}$ *to* $q_{(n \cdot 365)}$ *where n is the number of years of record,* $q_{(1)}$ *is the largest observation, and* $q_{(365 \cdot n)}$ *is the smallest observation. The ranked list is called a set of ordered observations. The* $q_{(1)}$ *that are exceeded 10, 50, and 90 percent of the time are then determined. Flow duration percentiles (quantiles) for gauged sites are also published by USGS in reports on low flow frequency and other streamflow statistics (e.g., Atkins and Pearman 1994, Zalants 1991, Telis 1991, and Ries 1994).*

Peak flow

Annual peak flow data needed for flood frequency analysis are also published by the USGS, archived in NWIS, and available through the internet at the URL address provided above. Flood frequency estimates at gauged sites are routinely published by USGS as part of cooperative studies with state agencies to develop regional regression equations for ungauged watersheds. Jennings et al. (1994) provide a nationwide summary of the current USGS reports that summarize flood frequency estimates at gauged sites as well as regression equations for estimating flood peak flows for ungauged watersheds. Annual and partial-duration (peaks-above-threshold) peak flow data for all USGS gauges can be obtained on one CD-ROM from commercial vendors.

The hypothetical daily hydrograph shown in **Figure 7.2** is typical of many areas of the United States where the annual minimum flows occur in late summer and early fall. The climatic year (April 1 to March 31) rather than the water year is used in low-flow analyses so that the entire low-flow period is contained within one year.

Data used in low-flow frequency analyses are typically the annual minimum average flow for a specified number of consecutive days. The annual minimum 7- and 14-day low flows are illustrated in Figure 7.2. For example, the annual minimum 7-day flow is the annual minimum value of running 7-day means.

USGS and USEPA recommend using the Pearson Type III distribution to the logarithms of annual minimum d-day low flows to obtain the flow with a nonexceedance probability p (or recurrence interval T = 1/p). The Pearson Type III low-flow estimates are computed from the following equation:

$$X_{d,T} = M_d - K_T S_d$$

where:

$X_{d,T}$ = the logarithm of the annual minimum d-day low flow for which the flow is not exceeded in 1 of T years or which has a probability of p = 1/T of not being exceeded in any given year

M_d = the mean of the logarithms of annual minimum d-day low flows

S_d = the standard deviation of the logarithms of the annual minimum d-day low flows

K_T = the Pearson Type III frequency factor

The desired quantile, $Q_{d,T}$, can be obtained by taking the antilogarithm of the equation.

The 7-day, 10-year low flow ($Q_{7,10}$) is used by about half of the regulatory agencies in the United States for managing water quality in receiving waters (USEPA 1986, Riggs et al. 1980). Low flows for other durations and frequencies are used in some states.

Computer software for performing low-flow analyses using a record of daily mean flows is documented by Hutchison (1975) and Lumb et al. (1990). An example of a low-flow frequency curve for the annual minimum 7-day low flow is given in **Figure 7.3** for Scott River near Fort Jones, California, for the same period (1951 to 1980) used in the flood frequency analyses above.

From Figure 7.3, one can determine that the $Q_{7,10}$ is about 20 cfs, which is comparable to the 99th percentile (daily mean flow exceeded 99 percent of the time) of the flow duration curve (Figure 7.1). This comparison is consistent with findings of Fennessey and Vogel (1990), who concluded that the $Q_{7,10}$ from 23 rivers in Massachusetts was approximately equal to the 99th flow duration percentile. The USGS routinely publishes low flow estimates at gauged sites (Zalants 1991, Telis 1991, Atkins and Pearman 1994).

Flood frequency estimates

Flood frequency estimates also may be generated using precipitation data and applicable watershed runoff models such as HEC-1, TR-20, and TR-55. The precipitation record for various return-period storm events is used by the watershed model to generate a runoff hydrograph and peak flow for that event. The modeled rainfall may be from historical data or from an assumed time distribution of precipitation (e.g., a 2-year, 24-hour rainfall event). This method of generating flood frequency estimates assumes the return period of the runoff event equals the return period of the precipitation event (e.g., a 2-year rainfall event will generate a 2-year peak flow). The validity of this assumption depends on antecedent moisture conditions, basin size, and a number of other factors.

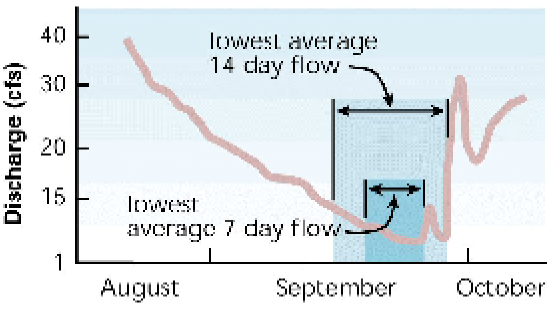


Figure 7.2: Annual hydrograph displaying low flows. *The daily mean flows on the lowest part of the annual hydrograph are averaged to give the 7-day and 14-day low flows for that year.*

Following are discussions of different ways to look at the flows that tend to form and maintain streams. Restorations that include alterations of flows or changes in the dimensions of the stream must include engineering analyses as described in Chapter 8.

Channel-forming Flow

The *channel-forming* or *dominant discharge* is a theoretical discharge that if constantly maintained in an alluvial stream over a long period of time would produce the same channel geometry that is produced by the long-term natural hydrograph. Channel-forming discharge is the most commonly used single independent variable that is found to govern channel shape and form. Using a channel-forming discharge to design channel geometry is not a universally accepted technique, although most river engineers and scientists agree that the concept has merit, at least for perennial (humid and temperate) and perhaps ephemeral (semiarid) rivers. For arid channels, where runoff is generated by localized high-intensity storms and the absence of vegetation ensures that the channel will adjust to each major flood event, the channel-forming discharge concept is generally not applicable.

Natural alluvial rivers experience a wide range of discharges and may adjust their geometry to flow events of different magnitudes by mobilizing either bed or bank sediments. Although Wolman and Miller (1960) noted that "it is logical to assume that the

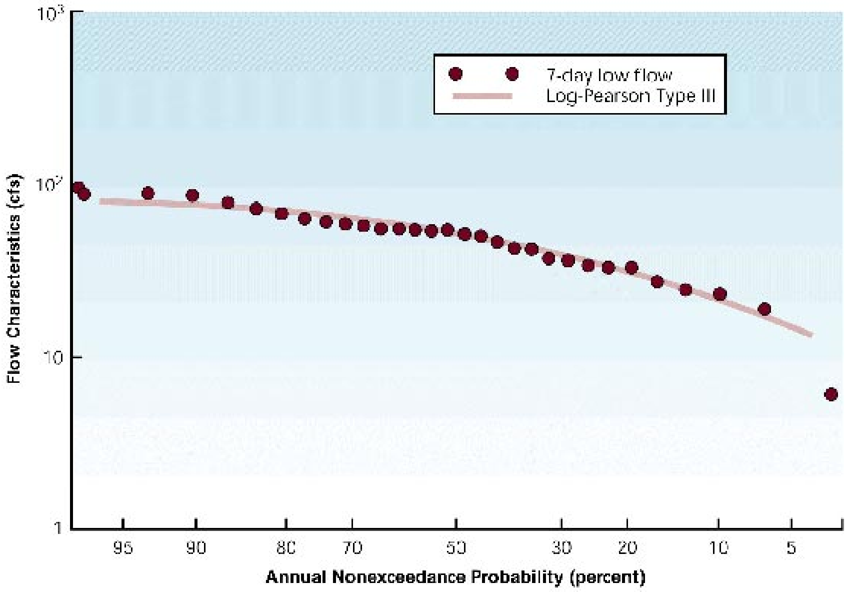


Figure 7.3: Annual minimum 7-day low flow frequency curve. *The Q7,10 on this graph is about 20 cfs. The annual minimum value of 7-day running means for this gauge is about 10 percent.*

channel shape is affected by a range of flows rather than a single discharge," they concurred with the view put forward earlier by civil engineers working on "regime theory" that the channel-forming or dominant discharge is the steady flow that produces the same gross channel shapes and dimensions as the natural sequence of events (Inglis 1949). Wolman and Miller (1960) defined "moderate frequency" as events occurring "at least once each year or two and in many cases several or more times per year." They also considered the sediment load transported by a given flow as a percentage of the total amount of sediment carried by the river during the period of record. Their results, for a variety of American rivers located in different climatic and physiographic regions, showed that the greater part (that is, 50 percent or more) of the total sediment load was carried by moderate flows rather than catastrophic floods. Ninety percent of the load was carried by events with a return period of less than 5 years. The precise form of the cumulative curve actually depends on factors such as the predominant mode of transport (bed load, suspended load, or mixed load) and the flow variability, which is influenced by the size and hydrologic characteristics of the watershed. Small watersheds generally experience a wider range of flows than large watersheds, and this tends to increase the proportion of sediment load carried by infrequent events. Thorough reviews of arguments about the conceptual basis of channel-forming discharge theory can be found in textbooks by Richards (1982), Knighton (1984), and Summerfield (1991).

Researchers have used various discharge levels to represent the channel-forming discharge. The most common are (1) bankfull discharge, (2) a specific discharge recurrence interval from the annual peak or partial duration frequency curves, and (3) effective discharge. These approaches are frequently used and can produce a good approximation of the channel-forming discharge in many situations; however, as discussed in the following paragraphs, considerable uncertainties are involved in all three of these approaches. Many practitioners are using specific approaches to determine channel-forming discharge and the response of stream corridors. Bibliographic information on these methods is available later in the document.

Because of the spatial variability within a given geographical region, the response of any particular stream corridor within the region can differ from that expected for the region as a whole. This is especially critical for streams draining small, ungauged drainage areas. Therefore, the expected channel-forming discharge of ungauged areas should be estimated by more than one alternative method, hopefully leading to consistent estimates.

Bankfull Discharge

The *bankfull discharge* is the discharge that fills a stable alluvial channel up to the elevation of the active floodplain. In many natural channels, this is the discharge that just fills the cross section without overtopping the banks, hence the term "bankfull." This discharge is considered to have morphological significance because it represents the breakpoint between the

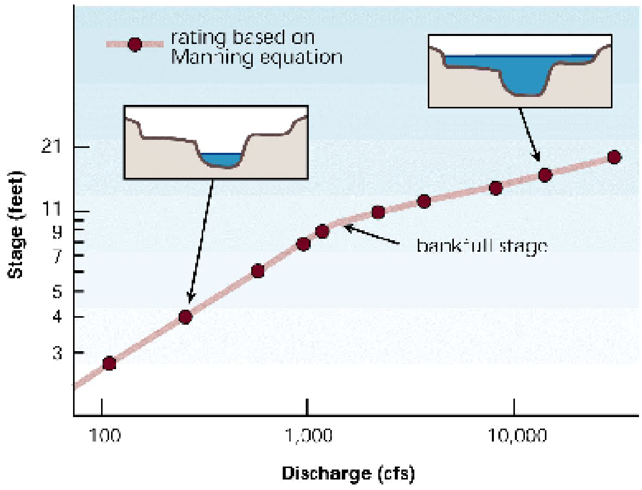


Figure 7.4: Determination of bankfull stage from a rating curve. *The discharge that corresponds to the elevation of the first flat depositional surface is the bankfull discharge.*

processes of channel formation and floodplain formation. In stable alluvial channels, bankfull discharge corresponds closely with effective discharge and channel-forming discharge.

The stage vs. discharge or rating curve presented in **Figure 7.4** was developed for a hypothetical stream by computing the discharge for different water surface elevations or stages. Since discharges greater than bankfull spread across the active floodplain, stage increases more gradually with increasing discharge above bankfull than below bankfull, when flows are confined to the channel. Another method for determining the bankfull stage and discharge is to determine the minimum value on a plot relating water surface elevation to the ratio of surface width to area. The frequency of the bankfull discharge can be determined from a frequency distribution plot like Figure 7.1.

Bankfull stage can also be identified from field indicators of the elevation of the active floodplain. The corresponding bankfull discharge is then determined from a stage vs. discharge relationship.

Field Indicators of Bankfull Discharge

Various field indicators can be used for estimating the elevation of the stage associated with bankfull flow. Although the first flat depositional surface is often used, the identification of depositional surfaces in the field can be difficult and misleading and, at the very least, requires trained, experienced field personnel. After an elevation is selected as the bankfull, the stage vs. discharge curve can be computed to determine the magnitude of the discharge corresponding to that elevation.

The above relationships seldom work in incised streams. In an incised stream, the top of the bank might be a terrace (an abandoned floodplain), and indicators of the active floodplain might be found well below the existing top of bank. In this situation, the elevation of the channel-forming discharge will be well below the top of the bank. In addition, the difference between the ordinary use of the term "bankfull" and the geomorphic use of the term can cause major communication problems.

Field identification of bankfull elevation can be difficult (Williams 1978), but is usually based on a minimum width/depth ratio (Wolman 1955), together with the recognition of some discontinuity in the nature of the channel banks such as a change in its sedimentary or vegetative characteristics. Others have defined bankfull discharge as follows:

- Nixon (1959) defined the bankfull stage as the highest elevation of a river that can be contained within the channel without spilling water on the river floodplain or washlands.
- Wolman and Leopold (1957) defined bankfull stage as the elevation of the active floodplain.
- Woodyer (1968) suggested bankfull stage as the elevation of the middle bench of rivers having several over-flow surfaces.
- Pickup and Warner (1976) defined bankfull stage as the elevation at which the width/depth ratio becomes a minimum.

Bankfull stage has also been defined using morphologic factors, as follows:

- Schumm (1960) defined bankfull stage as the height of the lower limit of perennial vegetation, primarily trees.
- Similarly, Leopold (1994) states that bankfull stage is indicated by a change in vegetation, such as herbs, grasses, and shrubs.
- Finally, the bankfull stage is also defined as the average elevation of the highest surface of the channel bars (Wolman and Leopold 1957).

The field identification of bankfull stage indicators is often difficult and subjective and should be performed in stream reaches that are stable and alluvial (Knighton 1984). Additional guidelines are reviewed by Wharton (1995). In unstable streams, bankfull indicators are often missing, embryonic, or difficult to determine.

Direct determination of the discharge at bankfull stage is possible if a stream gauge is located near the reach of interest. Otherwise, discharge must be calculated using applicable hydraulic resistance equations and, preferably, standard hydraulic backwater techniques. This approach typically requires that an estimation of channel roughness be made, which adds to the uncertainty associated with calculated bankfull discharge.

Because of its convenience, bankfull discharge is widely used to represent channel-forming discharge. There is no universally accepted definition of bankfull stage or discharge that can be consistently applied, has general application, and integrates the processes that create the bankfull dimensions of the river. The reader is cautioned that the indicators used to define the bankfull condition must be spelled out each time a bankfull discharge is used in a project plan or design.

Determining Channel-Forming Discharge from Recurrence Interval

To avoid some of the problems related to field determination of bankfull stage, the *channel-forming discharge* is often assumed to be represented by a specific *recurrence interval* discharge. Some researchers consider this representative discharge to be equivalent to the bankfull discharge. Note that "bankfull discharge" is used synonymously with "channel-forming discharge" in this document. The earliest estimate for channel-forming discharge was the mean annual flow (Leopold and Maddock 1953). Wolman and Leopold (1957) suggested that the channel-forming discharge has a recurrence interval of 1 to 2 years. Dury (1973) concluded that the channel-forming discharge is approximately 97 percent of the 1.58-year discharge or the most probable annual flood. Hey (1975) showed that for three British gravel-bed rivers, the 1.5-year flow in an annual maximum series passed through

The reader is cautioned that the indicators used to define the bankfull condition must be spelled out each time a bankfull discharge is used in a project plan or design.

the scatter of bankfull discharges measured along the course of the rivers. Richards (1982) suggested that in a partial duration series bankfull discharge equals the most probable annual flood, which has a 1 year return period. Leopold (1994) stated that most investigations have concluded that the bankfull discharge recurrence intervals ranged from 1.0 to 2.5 years. Pickup and Warner (1976) determined bankfull recurrence intervals ranged from 4 to 10 years on the annual series.

However, there are many instances where the bankfull discharge does not fall within this range. For example, Williams (1978) determined that approximately 75 percent of 51 streams that he analyzed appeared to have recurrence intervals for the bankfull discharge of between 1.03 and 5.0 years. Williams used the elevation of the active floodplain or the valley flat, if no active floodplain was defined at a station, as the elevation of the bankfull surface in his analyses. He did not establish whether these streams were in equilibrium, so the validity of using the top of the streambank as the bankfull elevation is in question, especially for those stations with valley flats. This might explain the wide range (1.02 to 200 years) he reported for bankfull discharge return intervals for streams with valley flats as opposed to active floodplains. The range in return intervals for 19 of the 28 streams with active floodplains was from 1.01 to 32 years. Nine of the 28 streams had bankfull discharge recurrence intervals of less than 1.0 year. It should be noted that only 3 of those 28 streams had bankfull discharge recurrence intervals greater than 4.8 years. About one-third of the active floodplain stations had bankfull discharges near the 1.5-year recurrence interval.

Although the assumption that the channel- forming flow has a recurrence interval of 1 to 3 years is sufficient for reconnaissance-level studies, it should not be used for design until verified through inspection of reference reaches, data collection, and analysis. This is especially true in highly modified streams such as in urban or mined areas, as well as ephemeral streams in arid and semi-arid areas.

Effective Discharge

The *effective discharge* is defined as the increment of discharge that transports the largest fraction of the sediment load over a period of years (Andrews 1980). The effective discharge incorporates the principle prescribed by Wolman and Miller (1960) that the channel-forming discharge is a function of both the magnitude of the event and its frequency of occurrence. An advantage of using the effective discharge is that it is a calculated rather than field-determined value. The effective discharge is calculated by numerically integrating the flow duration curve (A) and the sediment transport rating curve (B). A graphical representation of the relationship between sediment transport, frequency of the transport, and the effective discharge is shown in **Figure 7.5**. The peak of curve C marks the discharge that is most effective in transporting sediment and, therefore, does the most work in forming the channel.

For stable alluvial streams, effective discharge has been shown to be highly correlated with bankfull discharge. Of the various discharges related to channel morphology (i.e., dominant, bankfull, and effective discharges), effective discharge is the only one that can be computed directly. The effective discharge has morphological significance since it is the discharge that transports the bulk of the sediment.

The effective discharge represents the single flow increment that is responsible for transporting the most sediment over some time period. However, there is a range of flows on either side of the effective discharge that also carry a significant portion of the total annual sediment load.

Biedenharn and Thorne (1994) used a graphical relationship between the cumulative percentage of sediment transported and the water discharge to define a range of effective discharges responsible for the majority of the sediment transport on the Lower Mississippi River. They found that approximately 70 percent of the total sediment was moved in a range of flows between 500,000 cfs and 1,200,000 cfs, which corresponds to the flow that is equaled or exceeded 40 percent of the time and 3 percent of the time, respectively. Thorne et al. (1996) used a similar approach to define the range of effective discharges on the Brahmaputra River.

A standard procedure should be used for the determination of the effective discharge to ensure that the results for different sites can be compared. To be practical, it must either be based on readily available gauging station data or require only limited additional information and computational procedures.

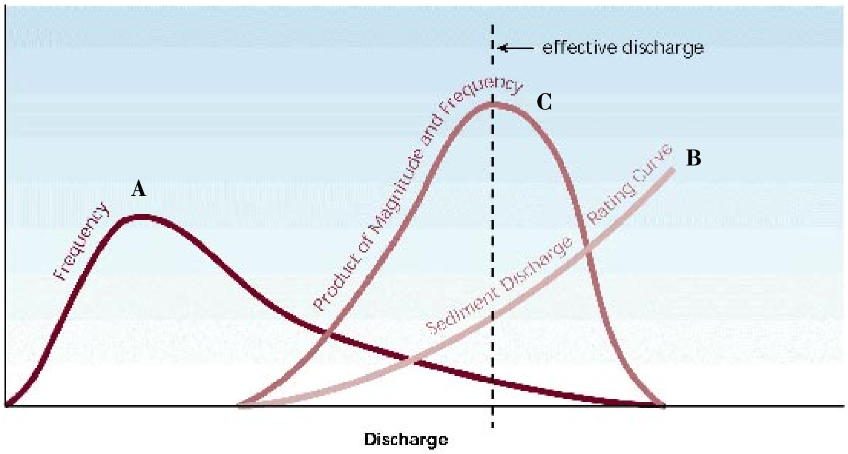


*Figure 7.5: **Effective discharge determination from sediment rating and flow duration curves.** The peak of curve C marks the discharge that is most effective in transporting sediment. Source: Wolman and Miller (1960)*

The basic components required for calculation of effective discharge are (1) flow duration data and (2) sediment load as a function of water discharge.

The method most commonly adopted for determining the effective discharge is to calculate the total bed material sediment load (tons) transported by each flow increment over a period of time by multiplying the frequency of occurrence for the flow increment (number of days) by the sediment load (tons/day) transported by that flow level. The flow increment with the largest product is the effective discharge. Although this approach has the merit of simplicity, the accuracy of the estimate of the effective discharge is clearly dependent on the calculation procedure adopted.

Values of mean daily discharges are usually used to compute the flow duration curve, as discussed above and presented in Figure 7.1. However, on flashy streams, mean daily values can underestimate the influence of the high flows, and, therefore, it might be necessary to reduce the discharge averaging period from 24 hours (mean daily) to 1 hour, or perhaps 15 minutes.

A *sediment rating curve* must be developed to determine the effective discharge. (See the *Sediment Yield and Delivery* section in Chapter 8 for more details.) The bed material load should be used in the calculation of the effective discharge. This sediment load can be determined from measured data or computed using an appropriate sediment transport equation. If measured suspended sediment data are used, the wash load should be subtracted and only the suspended bed material portion of the suspended load used. If the bed load is a significant portion of the load, it should be calculated using an appropriate sediment transport function and added to the suspended bed material load to provide an estimate of the total bed material load. If bed load measurements are available, these data can be used.

Design Discharge and Ecological Function

Although a channel-forming or dominant discharge is important for design, it is often not sufficient for channel restoration initiatives. An assessment of a wider range of discharges might be necessary to ensure that the functional objectives of the project are met. For example, a restoration initiative targeting low-flow habitat conditions must consider the physical conditions in the channel during low flows.

Determination of effective discharge using flow and sediment data is further discussed by Wolman and Miller (1960) and Carling (1988).

Determining Channel-Forming Discharge from Other Watershed Variables

When neither time nor resources permit field determination of bankfull discharge or data are unavailable to calculate the effective discharge, indirect methods based on *regional hydrologic analysis* may be used (Ponce 1989). In its simplest form, regional analysis entails regression techniques to develop empirical relationships applicable to homogeneous hydrologic regions. For example, some workers have used watershed areas as surrogates for discharge (Brookes 1987, Madej 1982, Newbury and Gaboury 1993). Regional relationships of drainage area with bankfull discharge can provide good starting points for selecting the channel-forming discharge.

Within hydrologically homogeneous regions where runoff varies with contributing area, runoff is proportional to watershed drainage area. Dunne and Leopold (1978) and Leopold (1994) developed average curves relating bankfull discharge to drainage area for widely separated regions of the United States. For example, relationships between bankfull discharge and drainage area for Brandywine Creek in Pennsylvania and the upper Green River basin in Wyoming are shown in the **Figure 7.6**.

Two important points are immediately apparent from Figure 7.6. First, humid regions that have sustained, widely distributed storms yield higher bankfull discharges per unit of drainage area than semiarid regions where storms of high intensity are usually localized. Second, bankfull discharge is correlated with drainage area, and the general relationship can be repre-

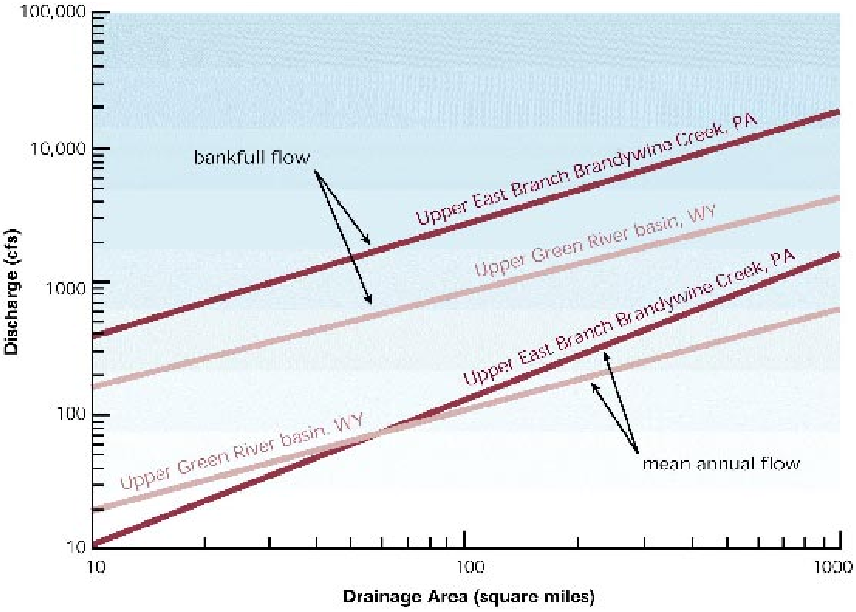


Figure 7.6: Regional relationships for bankfull and mean annual discharge as a function of drainage area. *The mean annual flow is normally less than the bankfull flow.*
Source: Dunne and Leopold 1978.

sented by functions of the form:

$$Q_{bf} = a\,A^{b}$$

where Q_{bf} is the bankfull discharge in cfs, A is the drainage area in square miles, and a and b are regression coefficients and exponents given in **Table 7.1**.

Establishing similar parametric relationships for other rivers of interest is useful because the upstream area draining into a stream corridor can be easily determined from either maps or digital terrain analysis tools. Once the area is determined, an estimate of the expected bankfull discharge for the corridor can be made from the above equation.

Mean Annual Flow

Another frequently used surrogate for channel-forming discharge in empirical regression equations is the *mean annual flow*. The mean annual flow, Q_m , is equivalent to the constant discharge that would yield the same volume of water in a water year as the sum of all continuously measured discharges. Just as in the case of bankfull discharge, Q_m varies proportionally with drainage area within hydrologically homogeneous basins. Given that both Q_{bf} and Q_m exhibit a similar functional dependence on A, a consistent proportionality is to be expected between these discharge measures within the same region. In fact, Leopold (1994) gives the following average values of the ratio Q_{bf}/Q_m for three widely separated regions of the United States: 29.4 for 21 stations in the Coast Range of California, 7.1 for 20 stations in the Front Range of Colorado, and 8.3 for 13 stations in the Eastern United States.

Table 7.1: Functional parameters used in regional estimates of bankfull discharge. *In column a are regression coefficients and in column b are exponents that can be used in the bankfull discharge equation.*
Source: Dunne and Leopold 1978.

River Basin	a	b
Southeastern PA	61	0.82
Upper Salmon River, ID	36	0.68
Upper Green River, WY	28	0.69
San Francisco Bay Region, CA	53	0.93

$Q_{bf} = a\,A^{b}$

Regional Relationship Between Bankfull and Mean Annual Discharge

Because the mean annual flow for each stream gauge operated by the USGS is readily available, it is useful to establish regional relationships between bankfull and mean annual discharges so that one can be estimated whenever the other is available. This information can be compared to the bankfull discharge estimated for any given ungauged site within a U.S. region.

The user is cautioned, however, that regional curve values have a high degree of error and can vary significantly for specific sites or reaches to be restored.

Stage vs. Discharge Relationships

Surveys of stream channel cross sections are useful for analyzing channel form, function, and processes. Use of survey data to construct relationships among streamflow, channel geometry, and various hydraulic characteristics provides information that serves a variety of applications. Although stage-discharge curves often can be computed from such cross section data, users should be cautioned to verify their computations with direct discharge measurements whenever possible.

Information on stream channel geometry and hydraulic characteristics is useful for channel design, riparian area restoration, and instream structure placement. Ideally, once a channel-forming discharge is defined, the channel is designed to contain that flow and higher flows are allowed to spread over the floodplain. Such periodic flooding is extremely important for the formation of channel macrofeatures, such as point bars and meander bends, and for establishing certain kinds of riparian vegetation. A cross section analysis also may help in optimal design and placement of items such as culverts and fish habitat structures.

Additionally, knowledge of the relationships between discharge and channel geometry and hydraulics is useful for reconstructing the conditions associated with a particular flow rate. For example, in many channel stability analyses, it is customary to relate movement of bed materials to some measure of stream power or average bed shear stress. If the relationships between discharge and certain hydraulic variables (e.g., mean depth and water surface slope) are known, it is possible to estimate stream power and average bed shear as a function of discharge. A cross section analysis therefore makes it possible to estimate conditions of substrate movement at various levels of streamflow.

Continuity Equation

Discharge at a cross section is computed using the simplified form of the *continuity equation*:

$$Q = AV$$

where:
Q = discharge
A = cross sectional area of the flow
V = average velocity in the downstream direction

Computing the cross-sectional area is a geometry problem. The area of interest is bounded by the channel cross section and the water surface elevation (stage) (**Figure 7.7**). In addition to cross-sectional area, the top width, wetted perimeter, mean depth, and hydraulic radius are computed for selected stages (Figure 7.7).

Uniform flow equations may be used for estimating mean velocity as a function of cross section hydraulic parameters.

Manning's Equation

Manning's equation was developed for conditions of uniform flow in which the water surface profile and energy grade line are parallel to the streambed, and the area, hydraulic radius, and average depth remain constant throughout the reach. The energy grade line is a theoretical line whose elevation above the streambed is

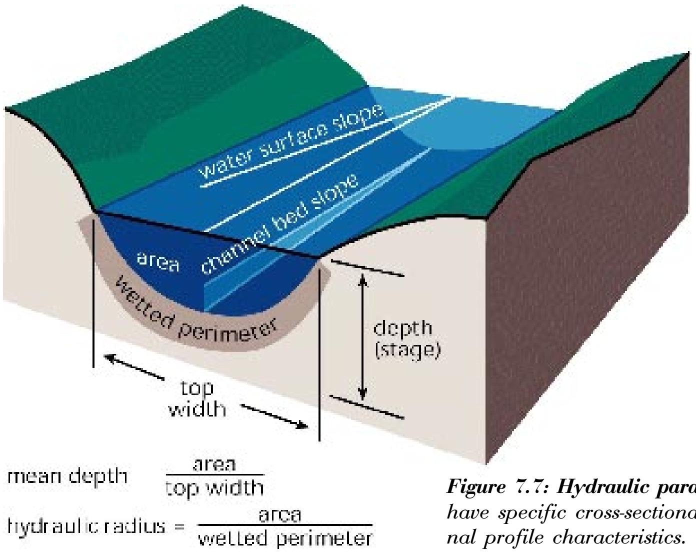


Figure 7.7: Hydraulic parameters. *Streams have specific cross-sectional and longitudinal profile characteristics.*

the sum of the water surface elevation and a term that represents the kinetic energy of the flow (Chow 1959). The slope of the energy grade line represents the rate at which energy is dissipated through turbulence and boundary friction. When the water surface slope and the energy grade line parallel the streambed, the slope of the energy grade line is assumed to equal the water surface slope. When the slope of the energy grade line is known, various resistance formulas allow computing mean cross-sectional velocity.

The importance of Manning's equation in stream restoration is that it provides the basis for computing differences in flow velocities and elevations due to differences in hydraulic roughness. Note that the flow characteristics can be altered to meet the goals of the restoration either by direct intervention or by changing the vegetation and roughness of the stream. Manning's equation is also useful in determining bankfull discharge for bankfull stage.

Manning's equation is also used to calculate energy losses in natural channels with gradually varied flow. In this case, calculations proceed from one cross section to the next, and unique hydraulic parameters are calculated at each cross section. Computer models, such as HEC-2, perform these calculations and are widely used analytical tools.

Manning's equation for mean velocity, V (in feet per second or meters per second), is given as:

$$V = \frac{k\ R^{2/3}\ S^{1/2}}{n}$$

where:

k = 1.486 for English units (1 for metric units)
n = Manning's roughness coefficient
R = hydraulic radius (feet or meters)
S = energy slope (water surface slope).

Manning's roughness coefficient may be thought of as an index of the features of channel roughness that contribute to the dissipation of stream energy. **Table 7.2** shows a range of n values for various boundary materials and conditions.

Two methods are presented for estimating Manning's roughness coefficient for natural channels:

- Direct solution of Manning's equation for n.
- Comparison with computed n values for other channels.

Each method has its own limitations and advantages.

Direct Solution for Determining Manning's n

Even slightly nonuniform flow

Table 7.2: Manning roughness coefficients for various boundaries.
Source: Ven te Chow 1964.

Boundary	Manning Roughness, *n* Coefficient
Smooth concrete	0.012
Ordinary concrete lining	0.013
Vitrified clay	0.015
Shot concrete, untroweled, and earth channels in best condition	0.017
Straight unlined earth canals in good condition	0.020
Rivers and earth canals in fair condition—some growth	0.025
Winding natural streams and canals in poor condition—considerable moss growth	0.035
Mountain streams with rocky beds and rivers with variable sections and some vegetation along banks	0.040-0.050
Alluvial channels, sand bed, no vegetation	
1. Lower regime	
Ripples	0.017-0.028
Dunes	0.018-0.035
2. Washed-out dunes or transition	**0.014-0.024**
3. Upper regime	
Plane bed	0.011-0.015
Standing waves	0.012-0.016
Antidunes	0.012-0.020

can be difficult to find in natural channels. The method of direct solution for Manning's n does not require perfectly uniform flow. Manning n values are computed for a reach in which multiple cross sections, water surface elevations, and at least one discharge have been measured. A series of water surface profiles are then computed with different n values, and the computed profile that matches the measured profile is deemed to have an n value that most nearly represents the roughness of that stream reach at the specific discharge.

Using Manning's n Measured at Other Channels

The second method for estimating n values involves comparing the reach to a similar reach for which Manning's n has already been computed. This procedure is probably the quickest and most commonly used for estimating Manning's n. It usually involves using values from a table or comparing the study reach with photographs of natural channels. Tables of Manning's n values for a variety of natural and artificial channels are common in the literature on hydrology (Chow 1959, Van Haveren 1986) (Table 7.2). Photographs of stream reaches with computed n values have been compiled by Chow (1959) and Barnes (1967). Estimates should be made for several stages, and the relationship between n and stage should be defined for the range of flows of interest.

When the roughness coefficient is estimated from table values, the chosen n value (n_b) is considered a base value that may need to be adjusted for additional resistance features. Several publications provide procedures for adjusting base values of n to account for channel irregularities, vegetation, obstructions, and sinuosity (Chow 1959, Benson and Dalrymple 1967, Arcement and Schneider 1984, Parsons and Hudson 1985).

The most common procedure uses the following formula, proposed by Cowan (1959) to estimate the value of n:

$$n = (n_b + n_1 + n_2 + n_3 + n_4)\, m$$

where

n_b= base value of n for a straight, uniform, smooth channel in natural materials
n_1= correction for the effect of surface irregularities
n_2= correction for variations in cross section size and shape
n_3= correction for obstructions
n_4= correction for vegetation and flow conditions
m= correction for degree of channel meandering

Table 7.3 is taken from Aldridge and Garrett (1973) and may be used to estimate each of the above correction factors to produce a final estimated n.

Energy Equation

The *energy equation* is used to calculate changes in water-surface elevation between two relatively similar cross sections. A simplified version of this equation is:

$$z_1 + d_1 + V_1^2/2g = z_2 + d_2 + V_2^2/2g + h_e$$

where:

z = minimum elevation of streambed
d = maximum depth of flow
V = average velocity
g = acceleration of gravity
h_e = energy loss between the two sections

Subscript 1 indicates that the variable is at the upstream cross section, and subscript 2 indicates that the variable is at the downstream cross section.

This simplified equation is applicable when hydraulic conditions between the two cross sections are relatively similar (gradually varied flow) and the channel slope is small (less than 0.18).

Energy losses between the two cross sections occur due to channel boundary roughness and other factors described above. These roughnesses may be represented by a Manning's roughness coefficient, n, and then energy losses can be computed using the Manning equation.

$$h_e = L\,[Q\,n\,/\,k\,A\,R^{2/3}]^2$$

where:

L = distance between cross sections
Q = discharge
n = Manning's roughness coefficient
A = channel cross-sectional area
R = hydraulic radius (Area/wetted perimeter)
k = 1 (SI units)
k = 1.486 (ft-lb-sec units)

Computer models (such as HEC-2 and others) are available to perform these calculations for more complex cross-sectional shapes, including floodplains, and for cases where roughness varies laterally across the cross section (USACE 1991).

Analyzing Composite and Compound Cross Sections

Natural channel cross sections are rarely perfectly uniform, and it may be necessary to analyze hydraulics for very irregular cross sections (compound

Manning's n in Relation to Channel Bedform

Just as Manning's n may vary significantly with changes in stage (water level), channel irregularities, obstructions, vegetation, sinuosity, and bed-material size distribution, n may also vary with bedforms in the channel. The hydraulics of sand and mobile-bed channels produce changes in bedforms as the velocity, stream power, and Froude number increase with discharge. The Froude number is a dimensionless number that represents the ratio of inertial forces to gravitational force. As velocity and stream power increase, bedforms evolve from ripples to dunes, to washed-out dunes, to plane bed, to antidunes, to chutes and pools. A stationary plane bed, ripples, and dunes occur when the Froude number (long wave equation) is less than 1 (subcritical flow); washed- out dunes occur at a Froude number equal to 1 (critical flow); and a plane bed in motion, antidunes, and chutes and pools occur at a Froude number greater than 1 (supercritical flow). Manning's n attains maximum values when dune bedforms are present, and minimum values when ripples and plane bedforms are present (Parsons and Hudson 1985).

Uniform Flow

Under conditions of constant width, depth, area, and velocity, the water surface slope and energy grade line approach the slope of the streambed, producing a condition known as “uniform flow.”

One feature of uniform flow is that the streamlines are parallel and straight (Roberson and Crowe 1996). Perfectly uniform flow is rarely realized in natural channels, but the condition is approached in some reaches where the geometry of the channel cross section is relatively constant throughout the reach.

Conditions that tend to disrupt uniform flow include bends in the stream course; changes in cross-sectional geometry; obstructions to flow caused by large roughness elements, such as channel bars, large boulders, and woody debris; or other features that cause convergence, divergence, acceleration, or deceleration of flow **(Figure 7.8)**.

Resistance equations may also be used to evaluate these nonuniform flow conditions (gradually varied flow); however, energy-transition considerations (backwater calculations) must then be factored into the analysis. This requires the use of multiple-transect models (e.g., HEC-2 and WSP2; HEC-2 is a water surface profile computer program developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Center, in Davis, California; WSP2 is a similar program developed by the USDA Natural Resources Conservation Service.).

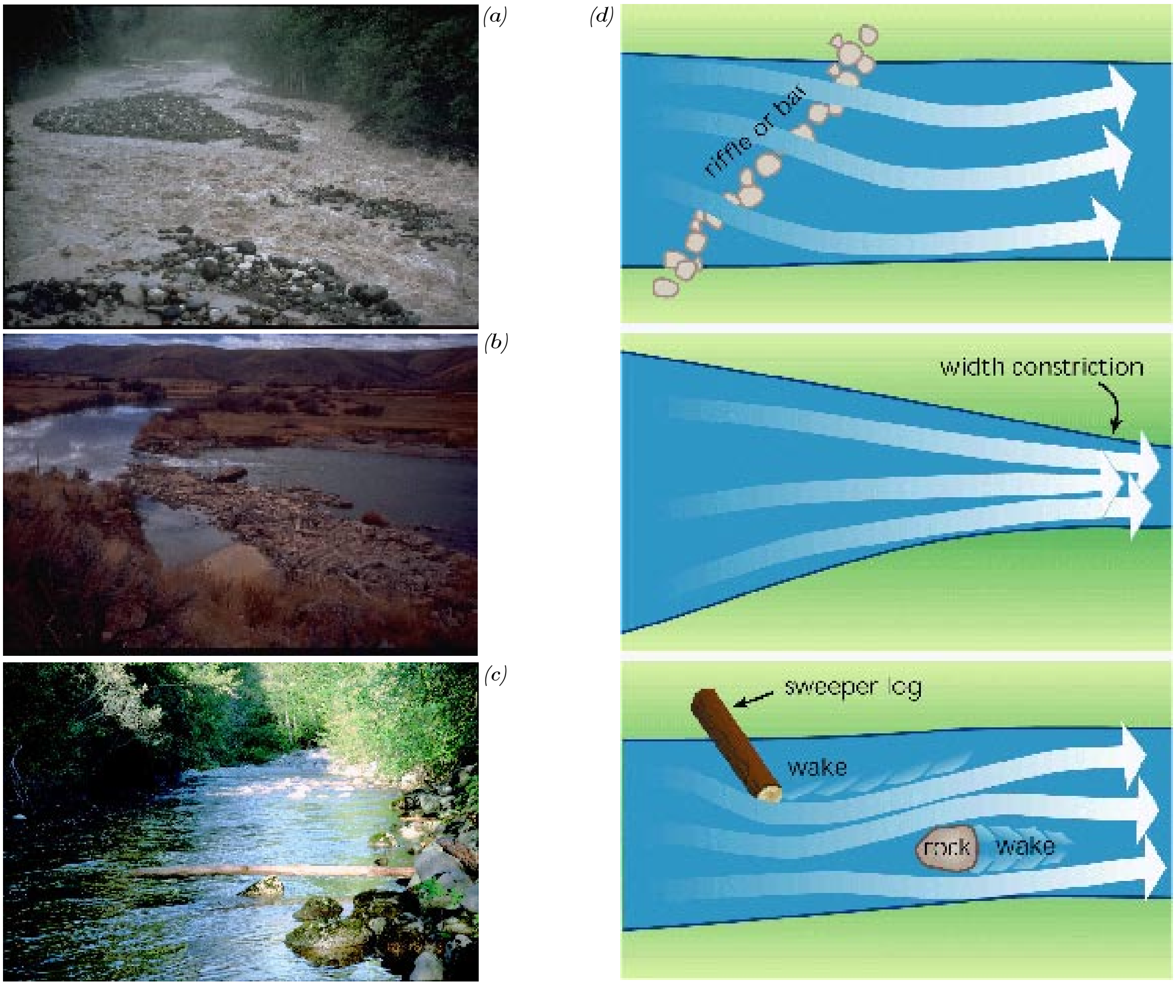


Figure 7.8: Streamflow paths for channels with constrictions or obstructions.
(a) Riffle or bar, Nisqually, Washington.
(b) Stream width restriction.
(c) Sweeper log.
(d) Stream lines through a reach.

Table 7.3: "n" value adjustments. Source: Aldridge and Garrett (1973).

	Channel Conditions	n Value Adjustment[1]	Example
Degree of irregularity (n_1)	Smooth	0.000	Compares to the smoothest channel attainable in a given bed material.
	Minor	0.001-0.005	Compares to carefully dredged channels in good condition but having slightly eroded or scoured side slopes.
	Moderate	0.006-0.010	Compares to dredged channels having moderate to considerable bed roughness and moderately sloughed or eroded side slopes.
	Severe	0.011-0.020	Badly sloughed or scalloped banks of natural streams; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged, and irregular surfaces of channels in rock.
Variation in channel cross section (n_2)	Gradual	0.000	Size and shape of channel cross sections change gradually.
	Alternating occasionally	0.001-0.005	Large and small cross sections alternate occasionally, or the main flow occasionally shifts from side to side owing to changes in cross-sectional shape.
	Alternating frequently	0.010-0.015	Large and small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape.
Effect of obstruction (n_3)	Negligible	0.000-0.004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
	Minor	0.005-0.015	Obstructions occupy less than 15 percent of the cross-sectional area and the spacing between obstructions is such that the sphere of influence around one obstruction does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth-surfaced objects than are used for sharp-edged angular objects.
	Appreciable	0.020-0.030	Obstructions occupy from 15 to 20 percent of the cross-sectional area or the space between obstructions is small enough to cause the effects of several obstructions to be additive, thereby blocking an equivalent part of a cross section.
	Severe	0.040-0.050	Obstructions occupy more than 50 percent of the cross-sectional area or the space between obstructions is small enough to cause turbulence across most of the cross section.
Amount of vegetation (n_4)	Small	0.002-0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrowweed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
	Medium	0.010-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemmy grass, weeds, or tree seedlings growing where the average depth of the flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1- to 2-year-old willow trees in the dormant season, growing along the banks and no significant vegetation along the channel bottoms where the hydraulic radius exceeds 2 feet.
	Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of vegetation; 8- to 10-year-old willow or cottonwood trees intergrown with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 2 feet; bushy willows about 1 year old intergrown with some weeds along side slopes (all vegetation in full foliage) and no significant vegetation along channel bottoms where the hydraulic radius is greater than 2 feet.
	Very Large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; bushy willow trees about 1 year old intergrown with weeds along side slopes (all vegetation in full foliage) or dense cattails growing along channel bottom; trees intergrown with weeds and brush (all vegetation in full foliage).
Degree of meandering[1] (adjustment values apply to flow confined in the channel and do not apply where downvalley flow crosses meanders) (m)	Minor	1.00	Ratio of the channel length to valley length is 1.0 to 1.2.
	Appreciable	1.15	Ratio of the channel length to valley length is 1.2 to 1.5.
	Severe	1.30	Ratio of the channel length to valley length is greater than 1.5.

[1] Adjustments for degree of irregularity, variations in cross section, effect of obstructions, and vegetation are added to the base n value before multiplying by the adjustment for meander.

channel). Streams frequently have overflow channels on one or both sides that carry water only during unusually high flows. Overflow channels and overbank areas, which may also carry out-of-bank flows at various flood stages, usually have hydraulic properties significantly different from those of the main channel. These areas are usually treated as separate subchannels, and the discharge computed for each of these subsections is added to the main channel to compute total discharge. This procedure ignores lateral momentum losses, which could cause n values to be underestimated.

A composite cross section has roughness that varies laterally across the section, but the mean velocity can still be computed by a uniform flow equation without subdividing the section. For example, a stream may have heavily vegetated banks, a coarse cobble bed at its lowest elevations, and a sand bar vegetated with small annual willow sprouts.

A standard hydraulics text or reference (such as Chow 1959, Henderson 1986, USACE 1991, etc.) should be consulted for methods of computing a composite n value for varying conditions across a section and for varying depths of flow.

Reach Selection

The intended use of the cross section analysis plays a large role in locating the reach and cross sections. Cross sections can be located in either a short critical reach where hydraulic characteristics change or in a reach that is considered representative of some larger area. The reach most sensitive to change or most likely to meet (or fail to meet) some important condition may be considered a critical reach. A representative reach typifies a definable extent of the channel system and is used to describe that portion of the system (Parsons and Hudson 1985).

Once a reach has been selected, the channel cross sections should be measured at locations considered most suitable for meeting the uniform flow requirements of Manning's equation. The uniform flow requirement is approached by siting cross sections where channel width, depth, and cross-sectional flow area remain relatively constant within the reach, and the water surface slope and energy grade line approach the slope of the stream-bed. For this reason, marked changes in channel geometry and discontinuities in the flow (steps, falls, and hydraulic jumps) should be avoided. Generally, sections should be located where it appears the streamlines are parallel to the bank and each other within the selected reach. If uniform flow conditions cannot be met and backwater computations are required, defining cross sections located at changes in channel geometry is essential.

Backwater Effects

Straight channel reaches with perfectly uniform flow are rare in nature and, in most cases, may only be approached to varying degrees. If a reach with constant cross-sectional area and shape is not available, a slightly contracting reach is acceptable, provided there is no significant backwater effect from the constriction. Backwater occurs where the stage vs. discharge relationship is controlled by the geometry downstream of the area of interest (e.g., a high riffle controls conditions in the upstream pool at low flow). Manning's equation assumes uniform flow conditions. Manning's equation used with a single cross section, therefore, will not produce an accurate stage vs. discharge relationship in backwater areas. In addition, expanding reaches also should be avoided since there are additional energy losses associated with channel expansions. When no channel reaches are available that meet or approach the condition of uniform flow, it might be necessary to use multitransect models (e.g., HEC-2) to analyze cross section hydraulics. If there are elevation restrictions corresponding to given flows (e.g., flood control requirements), the water surface profile for the entire reach is needed and use of a multitransect (backwater) model is required.

Field Procedures

The basic information to be collected in the reach selected for analysis is a survey of the channel cross sections and water surface slope, a measurement of bed-material particle size distribution, and a discharge measurement. The U.S. Forest Service has produced an illustrated guide to field techniques for stream channel reference sites (Harrelson et al. 1994) that is a good reference for conducting field surveys.

Survey of Cross Section and Water Surface Slope

The cross section is established perpendicular to the flow line, and the points across the section are surveyed relative to a known or arbitrarily established benchmark elevation. The distance/elevation paired data associated with each point on the section may be obtained by sag tape, rod-and-level survey, hydrographic surveys, or other methods.

Water surface slope is also required for a cross section analysis. The survey of water surface slope is somewhat more complicated than the cross section survey in that the slope of

Standard Step Backwater Computation

Many computer programs (e.g., HEC-2) are available to compute water surface profiles. The standard step method of Chow (1959, p. 265) can be used to determine the water surface elevation (depth) at the upstream end of the reach by iterative approximations. This method uses trial water surface elevations to determine the elevation that satisfies the energy and Manning equations written for the end sections of the reach. In using this method, cross sections should be selected so that velocities increase or decrease continuously throughout the reach (USACE 1991).

the water surface at the location of the section (e.g., pool, run, or riffle) must be distinguished from the more constant slope of the entire reach. (See Grant et al. 1990 for a detailed discussion on recognition and characteristics of channel units.) Water surface slope in individual channel reaches may vary significantly with changes in stage and discharge.

For this reason, when water surface slopes are surveyed in the field, the low-water slope may be approximated by the change in elevation over the individual channel unit where the cross section is located, approximately 1 to 5 channel widths in length, while the high-water slope is obtained by measuring the change in elevation over a much longer reach of channel, usually at least 15 to 20 channel widths in length.

Bed Material Particle Size Distribution

Computing mean velocity with resistance equations based on relative roughness, such as the ones suggested by Thorne and Zevenbergen (1985), requires an evaluation of the particle size distribution of the bed material of the stream. For streams with no significant channel armor and bed material finer than medium gravel, bed material samplers developed by the Federal Interagency Sedimentation Project (FISP 1986) may be used to obtain a representative sample of the streambed, which is then passed through a set of standard sieves to determine percent by weight of particles of various sizes. The cumulative percent of material finer than a given size may then be determined.

Particle size data are usually reported in terms of d_i, where i represents some nominal percentile of the distribution and d_i represents the particle size, usually expressed in millimeters, at which i percent of the total sample by weight is finer. For example, 84 percent of the total sample would be finer than the d_{84} particle size. For additional guidance on bed material sampling in sand-bed streams, refer to Ashmore et al. (1988).

For estimating velocity in steep mountain rivers with substrate much coarser than the medium-gravel limitation of FISP samplers, a *pebble count*, in which at least 100 bed material particles are manually collected from the streambed and measured, is used to measure surface particle size (Wolman 1954).

At each sample point along a cross section, a particle is retrieved from the bed, and the intermediate axis (not the longest or shortest axis) is measured. The measurements are tabulated as to number of particles occurring within predetermined size intervals, and the percentage of the total number in each interval is then determined. Again, the percentage in each interval is accumulated to give a particle size distribution, and the particle size data are reported as described above. Additional guidance for bed material sampling in coarse-bed streams is provided in Yuzyk (1986). If an armor layer or pavement is present, standard techniques may be employed to characterize bed sediments, as described by Hey and Thorne (1986).

Discharge Measurement

If several discharge measurements can be made over a wide range of flows, relationships among stage, discharge, and other hydraulic parameters may be developed directly. If only one discharge measurement is obtained, it likely will occur during low water and will be useful for defining the lower end of the rating table. If two measurements can be made, it is desirable to have a low-water measurement and a high-water measurement to define both ends of the rating table and to establish the relationship between Manning's n and stage. If high water cannot be measured directly, it may be necessary to estimate the high-water n (see the discussion earlier in the chapter).

The Bureau of Reclamation *Water Measurement Manual* (USDI-BOR 1997) is an excellent source of information for measuring channel and stream discharge (**Figure 7.9**). Buchanan and Somers (1969) and Rantz et al. (1982) also provide in-depth discussions of discharge measurement techniques. When equipment is functioning properly and standard procedures are followed correctly, it is possible to measure streamflow to within 5 percent of the true value. The USGS considers a "good" measurement of discharge to account for plus or minus 5 percent and an "excellent" discharge measurement to be within plus or minus 3 percent of the true value.

Figure 7.9: Station measuring discharge. *Permanent stations provide measurements for a wide range of flow, but the necessary measurements can be made in other ways.*
Source: C. Zabawa.

7.B Geomorphic Processes

In planning a project along a river or stream, awareness of the fundamentals of fluvial geomorphology and channel processes allows the investigator to see the relationship between form and process in the landscape. The detailed study of the fluvial geomorphic processes in a channel system is often referred to as a *geomorphic assessment*. The geomorphic assessment provides the process-based framework to define past and present watershed dynamics, develop integrated solutions, and assess the consequences of restoration activities. A geomorphic assessment generally includes data collection, field investigations, and channel stability assessments. It forms the foundation for analysis and design and is therefore an essential first step in the design process, whether planning the treatment of a single reach or attempting to develop a comprehensive plan for an entire watershed.

Stream Classification

The use of any *stream classification* system is an attempt to simplify what are complex relationships between streams and their watersheds.

Although classification can be used as a communications tool and as part of the overall restoration planning process, the use of a classification system is not required to assess, analyze, and design stream restoration initiatives. The design of a restoration does, however, require site-specific engineering analyses and biological criteria, which are covered in more detail in Chapter 8.

Restoration designs range from simple to complex, depending on whether "no action," only management techniques, direct manipulation, or combinations of these approaches are used. Complete stream corridor restoration designs require an interdisciplinary approach as discussed in Chapter 4. A poorly designed restoration might be difficult to repair and can lead to more extensive problems.

More recent attempts to develop a comprehensive stream classification system have focused on morphological forms and processes of channels and valley bottoms, and drainage networks. Classification systems might be categorized as systems based on sediment transport processes and systems based on channel response to perturbation.

Stream classification methods are related to fundamental variables and processes that form streams. Streams are classified as either alluvial or non-alluvial. An *alluvial stream* is free to adjust its dimensions, such as width, depth, and slope, in response to changes in watershed sediment discharge. The bed and banks of an alluvial stream are composed of material transported by the river under present flow conditions. Conversely, a *non-alluvial* river, like a bedrock-controlled channel, is not free to adjust. Other conditions, such as a high mountain stream flowing in very coarse glacially deposited materials or streams which are significantly controlled by fallen timber, would suggest a non-alluvial system.

Streams may also be classified as either perennial, intermittent, or ephemeral, as discussed in Chapter 1. A perennial stream is one that has flow at all times. An intermittent stream has the potential for continued flow, but at times the entire flow is absorbed by the bed material. This may be seasonal in nature. An ephemeral stream has flow only following a rainfall event. When carrying flow, intermittent and ephemeral streams both have characteristics very similar to those of perennial streams.

Advantages of Stream Classification Systems

The following are some advantages of stream classification systems:

- Classification systems promote communication among persons trained in different resource disciplines.
- They also enable extrapolation of inventory data collected on a few channels of each stream class to a much larger number of channels over a broader geographical area.
- Classification helps the restoration practitioner consider the landscape context and determine the expected range of variability for parameters related to channel size, shape, and pattern and composition of bed and bank materials.
- Stream classification also enables the practitioner to interpret the channel-forming or dominant processes active at the site, providing a base on which to begin the process of designing restoration.
- Classified reference reaches can be used as the stable or desired form of the restoration.
- A classification system is also very useful in providing an important cross-check to verify if the selected design values for width/depth ratio, sinuosity, etc., are within a rea-

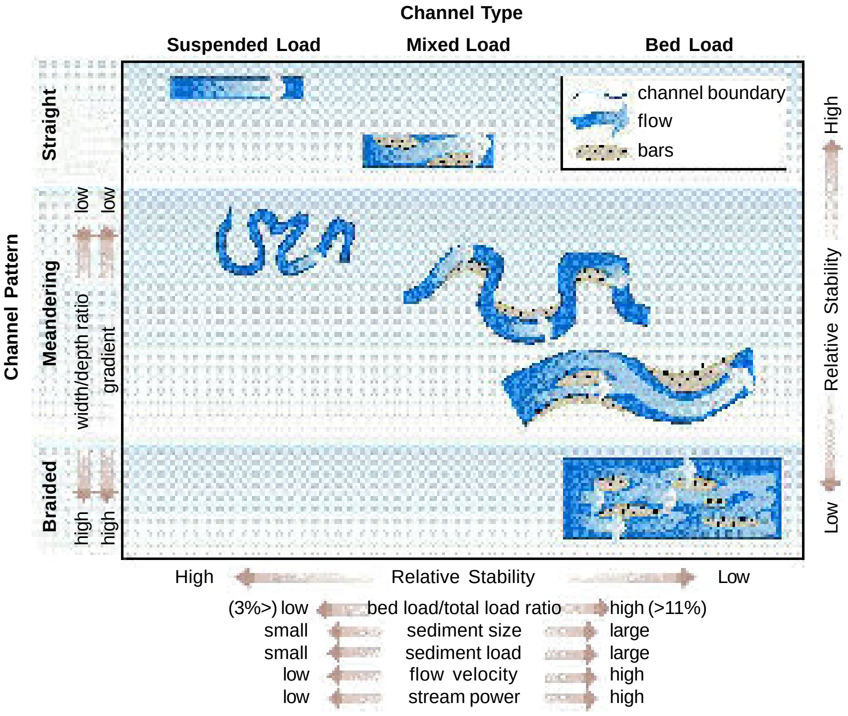


Figure 7.10: Classification of alluvial channels. *Schumm's classification system relates channel stability to kind of sediment load and channel type.*

Source: Schumm, The Fluvial System. © 1977.
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sonable range for the stream type being restored.

Limitations of Stream Classification Systems

All stream classification systems have limitations that are inherent to their approaches, data requirements, and range of applicabilities. They should be used cautiously and only for establishing some of the baseline conditions on which to base initial restoration planning. Standard design techniques should never be replaced by stream classification alone.

Some limitations of classification systems are as follows:

- Determination of bankfull or channel-forming flow depth may be difficult or inaccurate. Field indicators are often subtle or missing and are not valid if the stream is not stable and alluvial.
- The dynamic condition of the stream is not indicated in most classification systems. The knowledge of whether the stream is stable, aggrading, or degrading or is approaching a critical geomorphic threshold is important for a successful restoration initiative.
- River response to a perturbation or restoration action is normally not determined from the classification system alone.
- Biological health of a stream is usually not directly determined through a stream classification system.
- A classification system alone should not be used for determining the type, location, and purpose of restoration activities. These are determined through the planning steps in Part II and the design process in Chapter 8.

When the results of stream classification will be used for planning or design, the field data collection should be performed or directed by persons with experience and training in hydrology, hydraulics, terrestrial and aquatic ecology, sediment transport, and river mechanics. Field data collected by personnel with only limited formal training may not be reliable, particularly in the field determination of bankfull indicators and the assessment of channel instability trends.

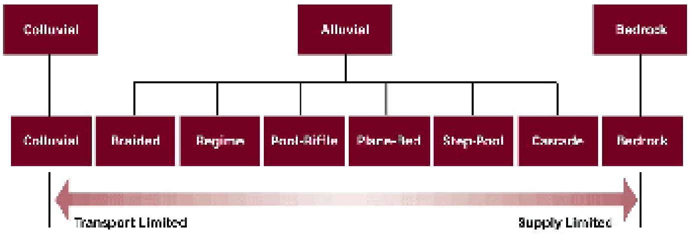
Stream Classification Systems

Stream Order

Designation of *stream order*, using the Strahler (1957) method, described in Chapter 1, is dependent on the scale of maps used to identify first-order streams. It is difficult to make direct comparisons of the morphological characteristics of two river basins obtained from topographic maps of different scales. However, the basic morphological relationships defined by Horton (1945) and Yang (1971) are valid for a given river basin regardless of maps used, as shown in the case study of the Rogue River Basin (Yang and Stall 1971, 1973).

Horton (1945) developed some basic empirical stream morphology relations, i.e., Horton's law of stream order, stream slope, and stream length. These show that the relationships between stream order, average stream length, and slope are straight lines on semilog paper.

Yang (1971) derived his theory of average stream fall based on an analogy with thermodynamic principles. The theory states that the ratio of ave-



	Braided	Regime	Pool-Riffle	Plane-Bed	Step-Pool	Cascade	Bedrock	Colluvial
Typical Bed Material	Variable	Sand	Gravel	Gravel, cobble	Cobble, boulder	Boulder	N/A	Variable
Bedform Pattern	Laterally oscillary	Multi layered	Laterally oscillary	None	Vertically oscillary	None	-	Variable
Reach Type	Response	Response	Response	Response	Transport	Transport	Transport	Source
Dominant Roughness Elements	Bedforms (bars, pools)	Sinuosity, bedforms (dunes, ripples, bars) banks	Bedforms (bars, pools), grains, LWD, sinuosity, banks	Grains, banks	Bedforms (steps, pools), grains, LWD, banks	Grains, banks	Boundaries (bed & banks)	Grains, LWD
Dominant Sediment Sources	Fluvial, bank failure, debris flow	Fluvial, bank failure, inactive channel	Fluvial, bank failure, inactive channel, debris flows	Fluvial, bank failure, debris flow	Fluvial, hillslope, debris flow	Fluvial, hillslope, debris flow	Fluvial, hillslope, debris flow	Hillslope, debris flow
Sediment Storage Elements	Overbank, bedforms	Overbank, bedforms, inactive channel	Overbank, bedforms, inactive channel	Overbank, inactive channel	Bedforms	Lee & stoss sides of flow obstructions	-	Bed
Typical Slope (m/m)	S < 0.03	S < 0.001	0.001 < S and S < 0.02	0.01 < S and S < 0.03	0.03 < S and S < 0.08	0.08 < S and S < 0.30	Variable	S > 0.20
Typical Confinement	Unconfined	Unconfined	Unconfined	Variable	Confined	Confined	Confined	Confined
Pool Spacing (Channel Widths)	Variable	5 to 7	5 to 7	none	1 to 4	< 1	Variable	Variable

Figure 7.11: Suggested stream classification system for Pacific Northwest. *Included are classifications for nonalluvial streams.*
Source: Montgomery and Buffington 1993.

rage fall (change in bed elevation) between any two stream orders in a given river basin is unity. These theoretical results were supported by data from 14 river basins in the United States with an average fall ratio of 0.995. The Rogue River basin data were used by Yang and Stall (1973) to demonstrate the relationships between average stream length, slope, fall, and number of streams.

Stream order is used in the *River Continuum Concept* (Vannote et al. 1980), described in Chapter 1, to distinguish different levels of biological activity. However, stream order is of little help to planners and designers looking for clues to restore hydrologic and geomorphic functions to stream corridors.

Schumm

Other classification schemes combine morphological criteria with dominant modes of sediment transport. Schumm (1977) identified straight, meandering, and braided channels and related both channel pattern and stability to modes of sediment transport (**Figure 7.10**).

Schumm recognized relatively stable straight and meandering channels, with predominantly suspended sediment load and cohesive bank materials. On the other end of the spectrum are relatively unstable braided streams characterized by predominantly bedload sediment transport and wide, sandy channels with noncohesive bank materials. The intermediate condition is generally represented by meandering mixed-load channels.

Montgomery and Buffington

Schumm's classification system primarily applies to alluvial channels; Montgomery and Buffington (1993) have proposed a similar classification system for alluvial, colluvial, and bedrock streams in the Pacific Northwest that addresses channel response to sediment inputs throughout the drainage network. Montgomery and Buffington recognize six classes of alluvial channels—cascade, step-pool, plane-bed, riffle-pool, regime, and braided (**Figure 7.11**).

The stream types are differentiated on the basis of channel response to sediment inputs, with steeper channels (cascade and step-pool) maintaining their morphology while transmitting increased sediment loads, and low-gradient channels (regime and pool-riffle) responding to increased sediment through morphological adjustments. In general, steep channels act as sediment-delivery conduits connecting zones of sediment production with low-gradient response channels.

Rosgen Stream Classification System

One comprehensive stream classification system in common use is based on morphological characteristics described by Rosgen (1996) (**Figure 7.12**). The Rosgen system uses six morphological measurements for classifying a stream reach—entrenchment, width/depth ratio, sinuosity, number of channels, slope, and bedmaterial particle size. These criteria are used to

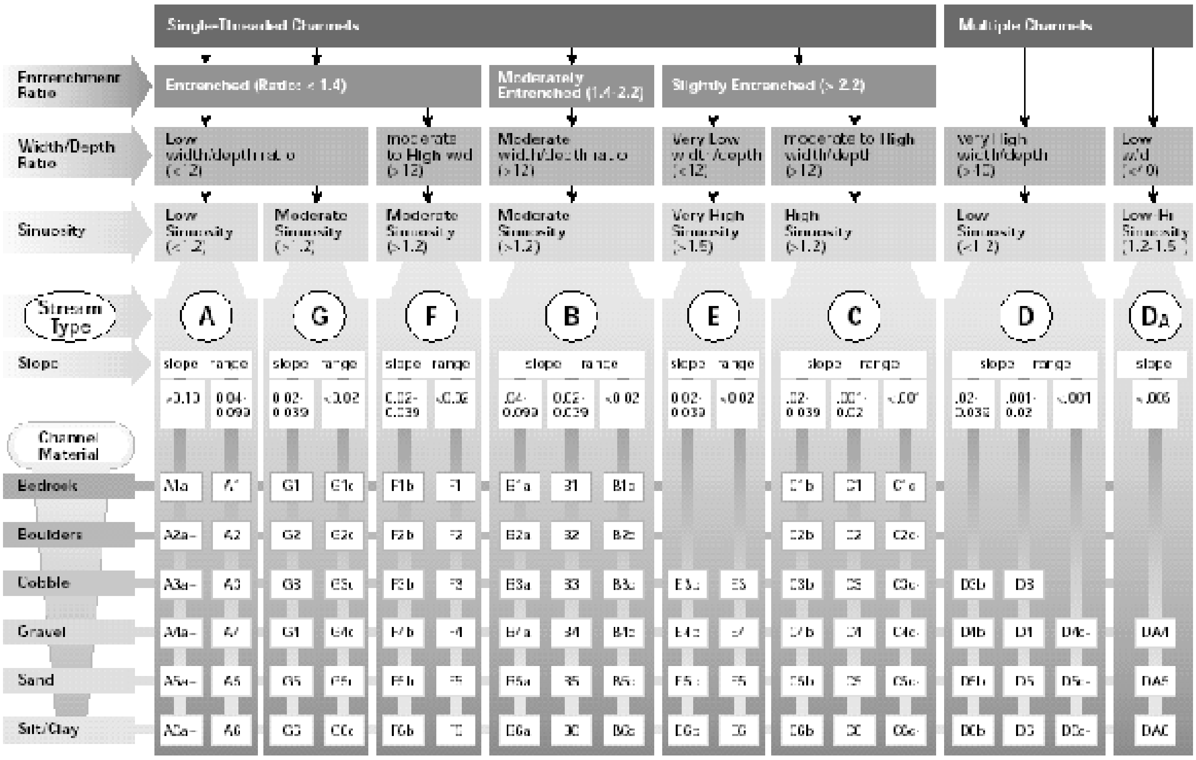


***Figure 7.12: Rosgen's stream channel classification system (Level II).** This classification system includes a recognition of specific characteristics of channel morphology and the relationship between the stream and its floodplain.*
Source: Rosgen D., 1996. Applied River Morphology. Copyright by Wildland Hydrology. Published by permission of Wildland Hydrology.

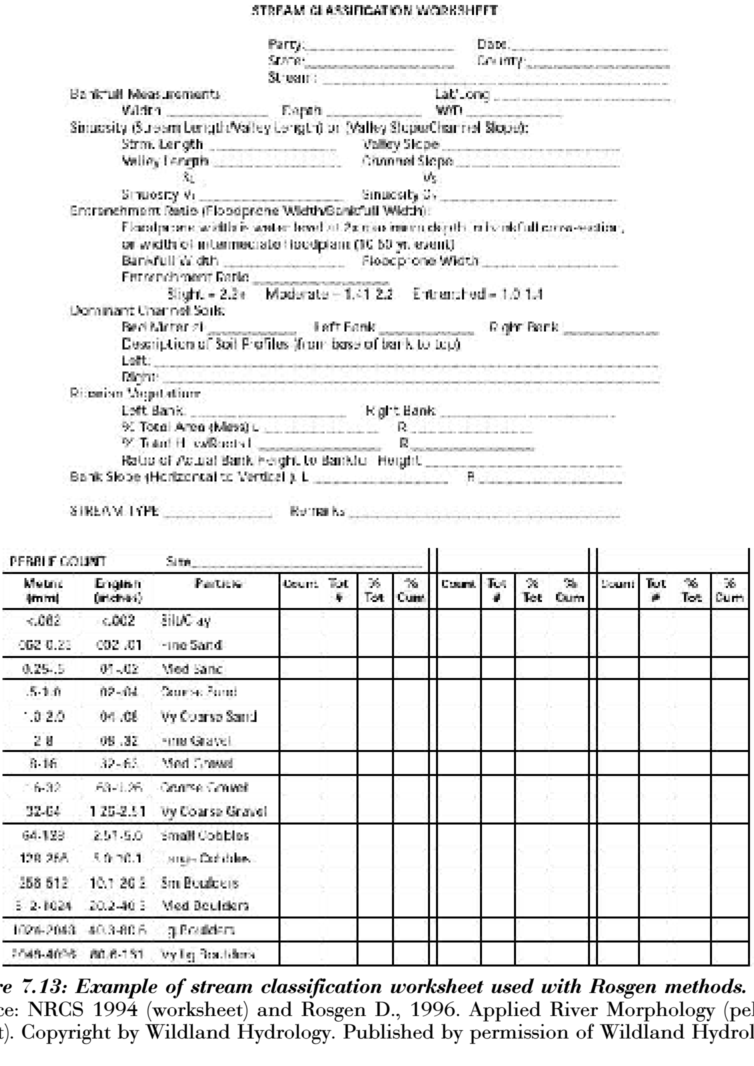
define eight major stream classes with about 100 individual stream types.

Rosgen uses the bankfull discharge to represent the stream-forming discharge or channel-forming flow. Bankfull discharge is needed to use this classification system because all of the morphological relationships are related to this flow condition: width and depth of flow are measured at the bankfull elevation, for example.

Except for entrenchment and width/depth ratio (both of which depend on a determination of bankfull depth), the parameters used are relatively straightforward measurements. The problems in determining bankfull depth were discussed earlier in Chapter 1. The width/depth ratio is taken at bankfull stage and is the ratio of top width to mean depth for the bankfull channel. Sinuosity is the ratio of stream length to valley length or, alternatively, valley slope to stream slope. The bed material particle size used in the classification is the dominant bed surface particle size, determined in the field by a pebble-count procedure (Wolman 1954) or as modified for sand and smaller sizes. Stream slope is measured over a channel reach of at least 20 widths in length.

Entrenchment describes the relationship between a stream and its valley and is defined as the vertical containment of the stream and the degree to which it is incised in the valley floor. It is, therefore, a measure of how accessible a floodplain is to the stream. The entrenchment ratio used in the Rosgen classification system is the flood-prone width of the valley divided by the bankfull width of the channel. Flood-prone width is determined by doubling the maximum depth in the bankfull channel and measuring the width of the valley at that elevation. If the flood-prone width is greater than 2.2 times the bankfull width, the stream is considered to be slightly entrenched or confined and the stream has ready access to its floodplain. A stream is classified as entrenched if its flood-prone width is less than 1.4 times the bankfull width.

A sample worksheet for collecting data and classifying a stream using the Rosgen system is shown in **Figure 7.13**. A field book for collecting reference reach information is available (Leopold et al. 1997).



STREAM CLASSIFICATION WORKSHEET

Party: ____________ Date: ____________
State: ____________ County: ____________
Stream: ____________
Bankfull Measurements Lat/Long ____________
Width ________ Depth ________ W/D ________
Sinuosity (Stream Length/Valley Length) or (Valley Slope/Channel Slope):
Strm. Length ________ Valley Slope ________
Valley Length ________ Channel Slope ________
SL VS
Sinuosity VL ________ Sinuosity CS ________
Entrenchment Ratio (Floodprone Width/Bankfull Width):
Floodprone width is water level at 2x maximum depth in bankfull cross-section,
or width of intermediate floodplain (10-50 yr. event)
Bankfull Width ________ Floodprone Width ________
Entrenchment Ratio ________
Slight = 2.2+ Moderate = 1.41-2.2 Entrenched = 1.0-1.4
Dominant Channel Soils
Bed Material ________ Left Bank ________ Right Bank ________
Description of Soil Profiles (from base of bank to top)
Left: ____________
Right: ____________
Riparian Vegetation
Left Bank ________ Right Bank ________
% Total Area (Mass) L ________ R ________
% Total Flow/Roots L ________ R ________
Ratio of Actual Bank Height to Bankful Height ________
Bank Slope (Horizontal to Vertical): L ________ R ________

STREAM TYPE ________ Remarks ________

PEBBLE COUNT Site ____________

Metric (mm)	English (inches)	Particle	Count	Tot #	% Tot	% Cum	Count	Tot #	% Tot	% Cum	Count	Tot #	% Tot	% Cum
<.062	<.002	Silt/Clay												
.062-0.25	.002-.01	Fine Sand												
0.25-.5	.01-.02	Med Sand												
.5-1.0	.02-.04	Coarse Sand												
1.0-2.0	.04-.08	Vy Coarse Sand												
2-8	.08-.32	Fine Gravel												
8-16	.32-.63	Med Gravel												
16-32	.63-1.26	Coarse Gravel												
32-64	1.26-2.51	Vy Coarse Gravel												
64-128	2.51-5.0	Small Cobbles												
128-256	5.0-10.1	Large Cobbles												
256-512	10.1-20.2	Sm Boulders												
512-1024	20.2-40.3	Med Boulders												
1024-2048	40.3-80.6	Lg Boulders												
2048-4096	80.6-161	Vy Lg Boulders												

Figure 7.13: Example of stream classification worksheet used with Rosgen methods. Source: NRCS 1994 (worksheet) and Rosgen D., 1996. Applied River Morphology (pebble count). Copyright by Wildland Hydrology. Published by permission of Wildland Hydrology.

Channel Evolution Models

Conceptual *models of channel evolution* describe the sequence of changes a stream undergoes after certain kinds of disturbances. The changes can include increases or decreases in the width/depth ratio of the channel and also involve alterations in the floodplain. The sequence of changes is somewhat predictable, so it is important that the current stage of evolution be identified so appropriate actions can be planned.

Schumm et al. (1984), Harvey and Watson (1986), and Simon (1989) have proposed similar channel evolution models due to bank collapse based on a "space-for-time" substitution, whereby downstream conditions are interpreted as preceding (in time) the immediate location of interest and upstream conditions are interpreted as following (in time) the immediate location of interest. Thus, a reach in the middle of the watershed that previously looked like the channel upstream will evolve to look like the channel downstream.

Downs (1995) reviews a number of classification schemes for interpreting channel processes of lateral and vertical adjustment (i.e., aggradation, degradation, bend migration, and bar formation). When these adjustment processes are placed in a specific order of occurrence, a channel evolution model (CEM) is developed. Although a number of CEMs have been suggested, two models (Schumm et al. 1984 and Simon 1989, 1995) have gained wide acceptance as being generally applicable for channels with cohesive banks.

Both models begin with a predisturbance condition, in which the channel is well vegetated and has frequent interaction with its floodplain. Following a perturbation in the system (e.g., channelization or change in land use), degradation occurs, usually as a result of excess stream power in the disturbed reach. Channel degradation eventually leads to oversteepening of the banks, and when critical bank heights are exceeded, bank failures and mass wasting (the episodic downslope movement of soil and rock) lead to channel widening. As channel widening and mass wasting proceed upstream, an aggradation phase follows in which a new low-flow channel begins to form in the sediment deposits. Upper banks may continue to be unstable at this time. The final stage of evolution is the development of a channel within the deposited alluvium with dimensions and capacity similar to those of the predisturbance channel (Downs 1995). The new channel is usually lower than the predisturbance channel, and the old floodplain now functions primarily as a terrace.

Once streambanks become high, either by downcutting or by sediment deposition on the floodplain, they begin to fail due to a combination of erosion at the base of the banks and mass wasting. The channel continues to widen until flow depths do not reach the depths required to move the sloughed bank materials. Sloughed materials at the base of the banks may begin to be colonized by vegetation. This added roughness helps increase deposition at the base of the banks, and a new small-capacity channel begins to form between the stabilized sediment deposits. The final stage of channel evolution results in a new bankfull channel and active floodplain at a new lower elevation. The original floodplain has been abandoned due to channel incision or excessive sediment deposition and is now termed a terrace.

Schumm et al. (1984) applied the basic concepts of channel evolution to the problem of unstable channelized streams in Mississippi. Simon (1989) built on Schumm's work in a study of channelized streams in Tennessee. Simon's CEM consisted of six stages (**Figure 7.14**). Both models use the cross section, longitudinal profile, and geomorphic processes to distinguish stages of evolution. Both models were developed for landscapes dominated by streams with cohesive banks. However, the same physical processes of evolution can occur in streams with noncohesive banks but not necessarily in the same well-defined stages.

Table 7.4 and **Figure 7.15** show the processes at work in each of Simon's stages.

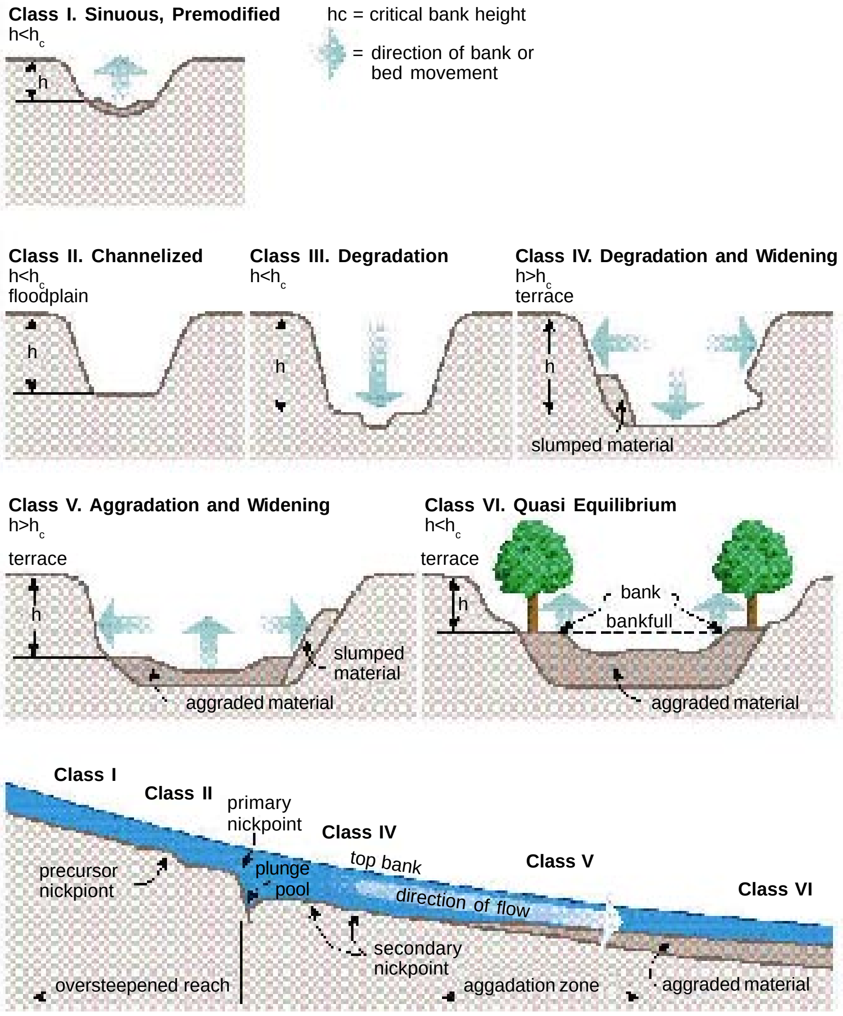


Figure 7.14: Channel evolution model. A disturbed or unstable stream is in varying stages of disequilibrium along its length or profile. A channel evolution model theoretically may help predict future upstream or downstream changes in habitat and stream morphology. Source: Simon 1989, USACE 1990. Reprinted by permission of John Wiley and Sons, Inc.

Advantages of Channel Evolution Models

CEMs are useful in stream corridor restoration in the following ways (Note: Stages are from Simon's 1989 six-stage CEM):

- CEMs help to establish the direction of current trends in disturbed or constructed channels. For example, if a reach of stream is classified as being in Stage IV of evolution (Figure 7.14), more stable reaches should occur downstream and unstable reaches should occur upstream. Once downcutting or incision occurs in a stream (Stage III), the headcut will advance upstream until it reaches a resistant soil lay-

Table 7.4: Dominant hillslope and instream processes, characteristic cross section shape and bedforms, and condition of vegetation in the various stages of channel evolution.
Source: Simon 1989.

Class		Dominant Processes		Characteristic Forms	Geobotanical Evidence
No.	**Name**	**Fluvial**	**Hillslope**		
I	**Premodified**	Sediment transport – mild aggradation; basal erosion on outside bends; deposition on inside bends.		Stable, alternate channel bars; convex top-bank shape; flow line high relative to top bank; channel straight or meandering.	Vegetated banks to flow line.
II	**Constructed**			Trapezoidal cross section; linear bank surfaces; flow line lower relative to top bank.	Removal of vegetation.
III	**Degradation**	Degradation; basal erosion on banks.	Pop-out failures.	Heightening and steepening of banks; alternate bars eroded; flow line lower relative to top bank.	Riparian vegetation high relative to flow line and may lean toward channel.
IV	**Threshold**	Degradation; basal erosion on banks.	Slab, rotational and pop-out failures.	Large scallops and bank retreat; vertical face and upper-bank surfaces; failure blocks on upper bank; some reduction in bank angles; flow line very low relative to top bank.	Riparian vegetation high relative to flow line and may lean toward channel.
V	**Aggradation**	Aggradation; development of meandering thalweg; initial deposition of alternate bars; reworking of failed material on lower banks.	Slab, rotational and pop-out failures; low-angle slides of previously failed material.	Large scallops and bank retreat; vertical face, upper bank, and slough line; flattening of bank angles; flow line low relative to top bank; development of new floodplain.	Tilted and fallen riparian vegetation; reestablishing vegetation on slough line; deposition of material above root collars of slough line vegetation.
VI	**Restabilization**	Aggradation; further development of meandering thalweg; further deposition of alternate bars; reworking of failed material; some basal erosion on outside bends deposition of floodplain and bank surfaces.	Low-angle slides; some pop-out failures near flow line.	Stable, alternate channel bars; convex-short vertical face on top bank; flattening of bank angles; development of new floodplain; flow line high relative to top bank.	Reestablishing vegetation extends up slough line and upper bank; deposition of material above root collars of slough-line and upper-bank vegetation; some vegetation establishing on bars.

er, the drainage area becomes too small to generate erosive runoff, or the slope flattens to the point that the stream cannot generate enough energy to downcut. Stages IV to VI will follow the headcut upstream.

- CEMs can help to prioritize restoration activities if modification is planned. By stabilizing a reach of stream in early Stage III with grade control measures, the potential degradation of that reach and upstream reaches can be prevented. It also takes less intensive efforts to successfully restore stream reaches in Stages V and VI than to restore those in Stages III and IV.
- CEMs can help match solutions to the problems. Downcutting in Stage III occurs due to the greater capacity of the stream created by construction, or earlier incision, in Stage II. The downcutting in Stage III requires treatments such as grade control aimed at modifying the factors causing the bottom instability. Bank stability problems are dominant in Stages IV and V, so the approaches to stabilization required are different from those for Stage III. Stages I and VI typically require only maintenance activities.
- CEMs can help provide goals or models for restoration. Reaches of streams in Stages I and VI are graded streams, and their profile, form, and pattern can be used as models for restoring unstable reaches.

Limitations of Channel Evolution Models

The chief limitations in using CEMs for stream restoration are as follows:

- Future changes in base level elevations and watershed water and sediment yield are not considered when predicting channel response.
- Multiple adjustments by the stream simultaneously are difficult to predict.

Applications of Geomorphic Analysis

Stream classification systems and channel evolution models may be used together in resource inventories and analysis to characterize and group streams. Although many classification systems are based on morphological parameters, and channel evolution models are based on adjustment processes, the two approaches to stream characterization complement each other. Both indicate the present condition of a stream reach under investigation, but characterization of additional reaches upstream and downstream

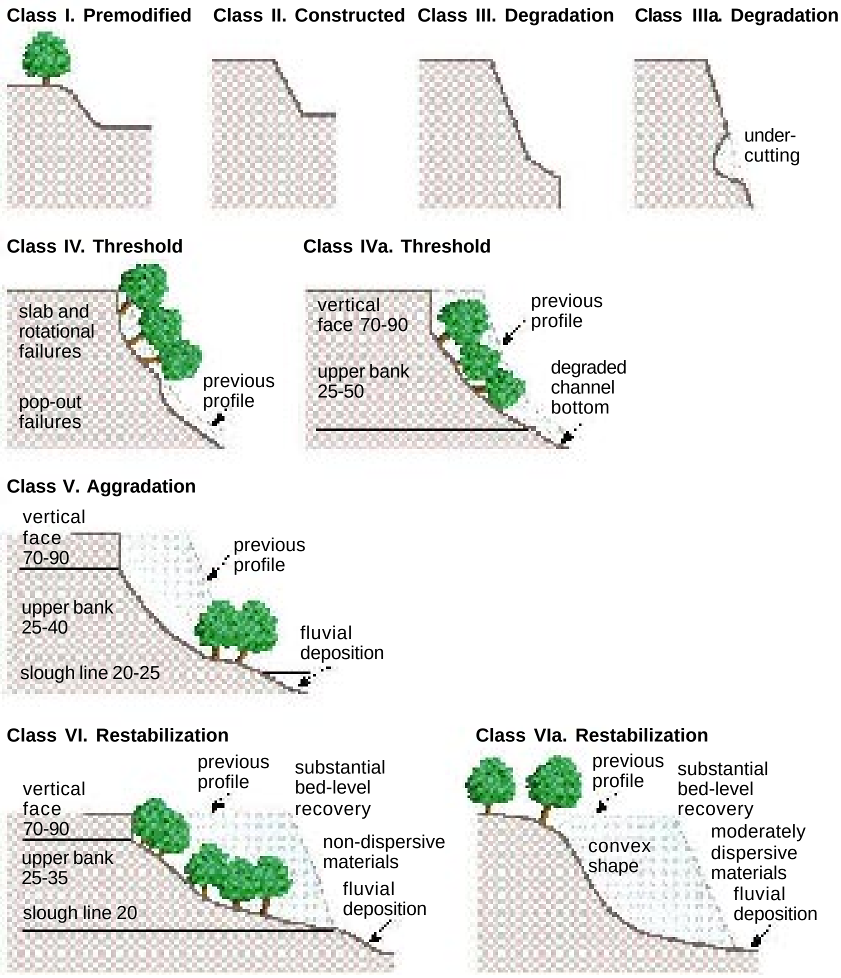


Figure 7.15: Simon's channel evolution stages related to streambank shape. *The cross-sectional shape of the streambank may be a good indicator of its evolutionary stage.*
Source: Simon 1989. Published by permission of the American Water Resources Association.

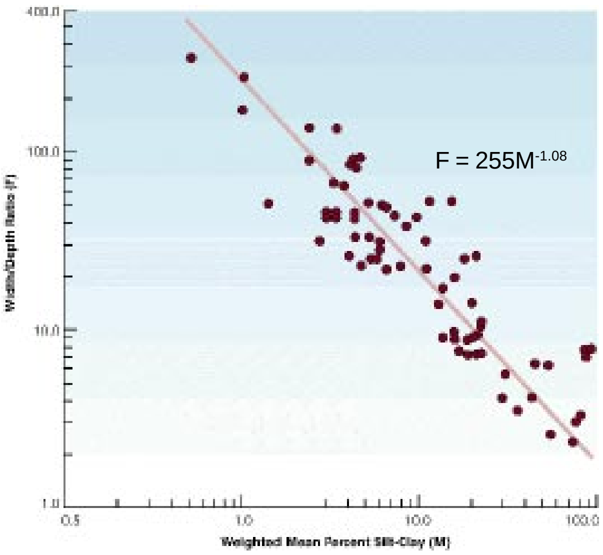


Figure 7.16: Schumm's F versus M relationship. *Data for aggrading streams generally plot above or to the right of the line. Degrading or incising streams plot below the line.*
Source: Schumm 1960.

of the investigation area can provide an understanding of the overall trend of the stream.

Stream classification systems and channel evolution models also provide insights as to the type of stability problems occurring within the stream corridor and potential opportunities for restoration. Gullied stream channels are downcutting, so grade stabilization is required before time and money are spent on bank stabilization or floodplain restoration. Similarly, incised channels with lateral instabilities are in the initial stages of widening, a process that often must be accommodated before equilibrium conditions can be attained. Although most argue that channel widening must be accommodated to restore incised channels, in some cases not allowing the stream to widen might be preferred, depending on the value and priority placed on adjacent land use and structures within the corridor.

On the other hand, incised streams that have widened enough for a new inner channel and floodplain to begin forming are excellent candidates for vegetation management since these streams are already tending toward renewed stability and establishing riparian vegetation can accelerate the process.

Both the stream classification and the stage of channel evolution inventories can serve as the foundation for assessing systemwide stability. Channel width/depth ratio (F) at mean annual discharge and the percent of silt and clay in the channel boundary (M) are useful diagnostics for determining systemwide adjustments. These variables can be plotted on Schumm's (1960) curve of width/depth ratio versus percent silt-clay ($F = 255M\ -1.08$) to assess stability (**Figure 7.16**). Schumm's width/depth ratio is the top width of the bankfull channel and the deepest depth in the bankfull channel cross section. The term "M" is defined by the relationship:

$$M = [(S_c W) + (S_b 2D)] / (W + 2D)$$

where

S_c = percentage of silt and clay in the bed material

S_b = percentage of silt and clay in the bank material

W = channel width
D = channel depth

Data from aggrading streams generally plot above the line of best fit, whereas data for degrading streams plot below the line. Schumm's graph could also be used as a guide in selecting an appropriate width/depth ratio for an incised or recently disturbed channel. Finally, classification systems and evolution models can help guide the selection of restoration treatments. As mentioned above, there is little opportunity for successfully establishing streambank vegetation in streams with vertical and horizontal instability. The banks of such streams are subject to deep-seated slope failures that are not usually prevented even by mature woody vegetation. Conversely, establishing and managing perennial grasses and woody vegetation is critical to protecting streams that are already functioning properly.

Proper Functioning Condition (PFC)

The Bureau of Land Management (BLM) has developed guidelines and procedures to rapidly assess whether a stream riparian area is functioning properly in terms of its hydrology, landform/soils, channel characteristics, and vegetation (Prichard et al. 1993, rev. 1995). This assessment, commonly called PFC, is useful as a baseline analysis of stream condition and physical function, and it can also be useful in watershed analysis.

It is essential to do a thorough analysis of the stream corridor and watershed conditions prior to development of restoration plans and selection of restoration approaches to be used. There are many cases where selection of the wrong approach has led to complete failure of stream restoration efforts and the waste of costs of restoration. In many cases, particularly in wildland situations, restoration through natural processes and control of land uses is the preferred and most cost-effective method. If hydrologic conditions are rapidly changing in a drainage, no restoration might be the wisest course until equilibrium is restored.

Identifying streams and drainages where riparian areas along streams are not in proper functioning condition, and those at risk of losing function, is an important first step in restoration analysis. Physical conditions in riparian zones are excellent indicators of what is happening in a stream or the drainage above.

With the results of PFC analysis, it is possible to begin to determine stream corridor and watershed restoration needs and priorities. PFC results may also be used to identify where gathering more detailed information is needed and where additional data are not needed.

PFC is a methodology for assessing the physical functioning of a riparian-wetland area. It provides information critical to determining the "health" of a riparian ecosystem. PFC considers both abiotic and biotic components as they relate to the physical functioning of riparian areas, but it does not consider the biotic component as it relates to habitat requirements. For habitat analysis, other techniques must be employed.

The PFC procedure is currently a standard baseline assessment for stream/riparian surveys for the BLM, and PFC is beginning to be used by the U.S. Forest Service in the West. This technique is not a substitute for inventory or monitoring protocols designed to yield detailed information on the habitat or populations of plants or animals dependent on the riparian-stream ecosystem.

PFC is a useful tool for watershed analysis. Although the assessment is conducted on a stream reach basis, the ratings can be aggregated and analyzed at the watershed scale. PFC, along with other watershed and habitat condition information, provides a good picture of watershed "health" and causal factors affecting watershed "health." Use of PFC will help to identify watershed-scale problems and suggest management remedies.

The following are definitions of proper function as set forth in TR 1737-9:

- *Proper Functioning Condition*— Riparian-wetland areas are functioning properly when adequate vegetation, landform, or large woody debris is present to:
  1. Dissipate stream energy associated with high waterflows, thereby reducing erosion and improving water quality.
  2. Filter sediment, capture bedload, and aid floodplain development.
  3. Improve floodwater retention and ground water storage.
  4. Develop root masses that stabilize streambanks against cutting action.
  5. Develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses.
  6. Support greater biodiversity.
- *Functional-at Risk*— Riparian-wetland areas that are in functional condition, but an existing soil, water, or vegetation attribute makes them susceptible to degradation.
- *Nonfunctional*— Riparian-wetland areas that clearly are not providing adequate vegetation, landform, or large debris to dissipate stream energy associated with high flow and thus are not reducing erosion, improving water quality, or performing other functions as listed above under the definition of proper function. The absence of certain physical attributes, such as absence of a floodplain where one should be, is an indicator of nonfunctioning conditions.

Assessing functionality with the PFC technique involves procedures for determining a riparian-wetland area's capability and potential, and comparing that potential with current conditions. Although the PFC procedure defines streams without floodplains (when a floodplain would normally be present) as nonfunctional, many streams that lose their floodplains through incision or encroachment still retain ecological functions. The importance of a floodplain needs to be assessed in view of the site-specific aquatic and riparian community.

When using the PFC technique, it is important not to equate "proper function" with "desired condition." Proper function is intended to describe the state in which the stream channel and associated riparian areas are in a relatively stable and self-sustaining condition. Properly functioning streams can be expected to withstand intermediate flood events (e.g., 25- to 30-year flood events) without substantial damage to existing values. However, proper functioning condition will often develop well before riparian succession provides shrub habitat for nesting birds. Put another way, proper functioning condition is a prerequisite to a variety of desired conditions.

Although based on sound science, the PFC field technique is not quantitative. An advantage of this approach is that it is less time-consuming than other techniques because measurements are not required. The procedure is performed by an interdisciplinary team and involves completing a checklist evaluating 17 factors dealing with hydrology, vegetation, and erosional/depositional characteristics. Training in the technique is required, but the technique is not difficult to learn. With training, the functional determinations resulting from surveys are reproducible to a high degree.

Other advantages of the PFC technique are that it provides an easy-to-understand "language" for discussing stream conditions with a variety of agencies and publics, PFC training is readily available, and there is growing interagency acceptance of the technique.

Hydraulic Geometry: Streams in Cross Section

Stream corridor restoration initiatives frequently involve partial or total reconstruction of channels that have been severely degraded. Channel reconstruction design requires criteria for channel size and alignment. The following material presents an overview of *hydraulic geometry theory* and provides some sample hydraulic geometry relationships for relating bankfull dimensions to bankfull discharge. Correlations between certain planform dimensions (e.g., meander characteristics) of stable alluvial stream channels to bankfull discharge and channel width also are discussed.

Hydraulic geometry theory is based on the concept that a river system tends to develop in a way that produces an approximate equilibrium between the channel and the inflowing water and sediment (Leopold and Maddock 1953). The theory typically relates an independent or driving varia-

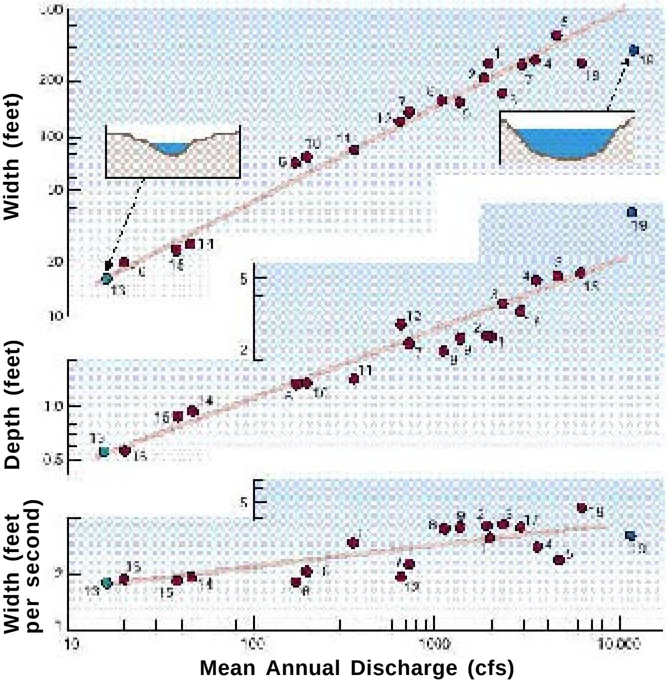


Figure 7.17: Channel morphology related to average annual discharge. *Width, depth, and velocity in relation to mean annual discharge as discharge increases downstream on 19 rivers in Wyoming and Montana.* Source: Leopold and Maddock 1953.

Regime Theory and Hydraulic Geometry

Regime theory was developed about a century ago by British engineers working on irrigation canals in what is now India and Pakistan. Canals that required little maintenance were said to be "in regime," meaning that they conveyed the imposed water and sediment loads in a state of dynamic equilibrium, with width, depth, and slope varying about some long-term average. These engineers developed empirical formulas linking low-maintenance canal geometry and design discharge by fitting data from relatively straight canals carrying near-constant discharges (Blench 1957, 1969; Simons and Albertson 1963). Since few streams will be restored to look and act as canals, the regime relationships are not presented here.

About 50 years later, hydraulic geometry formulas similar to regime relationships were developed by geomorphologists studying stable, natural rivers. These rivers, of course, were not straight and had varying discharges. A sample of these hydraulic geometry relationship is presented in the table on the following page. In general, these formulas take the form:

$$w = k_1\, Q^{k2}\, D_{50}{}^{k3}$$

$$D = k_4\, Q^{k5}\, D_{50}{}^{k6}$$

$$S = k_7\, Q^{k8}\, D_{50}{}^{k9}$$

where w and D are reach average width and depth in feet, S is the reach average slope, D_{50} is the median bed sediment size in millimeters, and Q is the bankfull discharge in cubic feet per second. These formulas are most reliable for width, less reliable for depth, and least reliable for slope.

ble, such as drainage area or discharge, to dependent variables such as width, depth, slope, and velocity. Hydraulic geometry relations are sometimes stratified according to bed material size or other factors. These relationships are empirically derived, and their development requires a relatively large amount of data.

Figure 7.17 presents hydraulic geometry relations based on the mean annual discharge rather than the bankfull discharge. Similar hydraulic geometry relationships can be determined for a watershed of interest by measuring channel parameters at numerous cross sections and plotting them against a discharge. Such plots can be used with care for planning and preliminary design. The use of hydraulic geometry relationships alone for final design is not recommended.

Careful attention to defining stable channel conditions, channel-forming discharge, and streambed and bank characteristics are required in the data collection effort. The primary role of discharge in determining channel cross sections has been clearly demonstrated, but there is a lack of consensus about which secondary factors such as sediment loads, bank materials, and vegetation are significant, particularly with respect to width. Hydraulic geometry relationships that do not explicitly consider sediment transport are applicable mainly to channels with relatively low bed-material loads (USACE 1994).

Hydraulic geometry relations can be developed for a specific river, watershed, or for streams with similar physiographic characteristics. Data scatter is expected about the developed curves even in the same river reach. The more dissimilar the stream and watershed characteristics are, the greater the expected data scatter is. It is important to recognize that this scatter represents a valid range of stable channel configurations due to variables such as geology, vegetation, land use, sediment load and gradation, and runoff characteristics.

Figures 7.18 and 7.19 show hydraulic geometry curves developed for the upper Salmon River watershed in Idaho (Emmett 1975). The scatter of

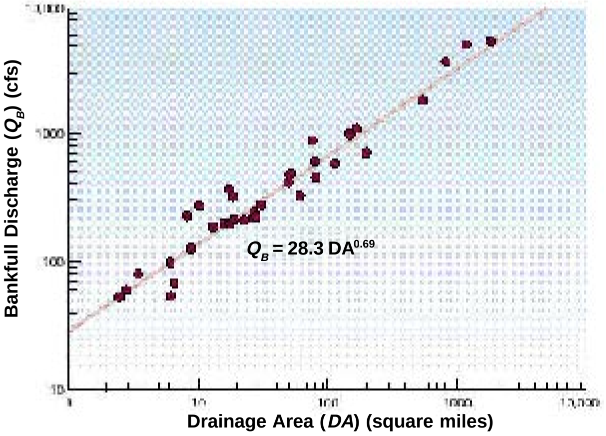


Figure 7.18: Bankfull discharge versus drainage area—Upper Salmon River area. *Curves based on measured data such as this can be valuable tools for designing restorations (Emmett 1975).*

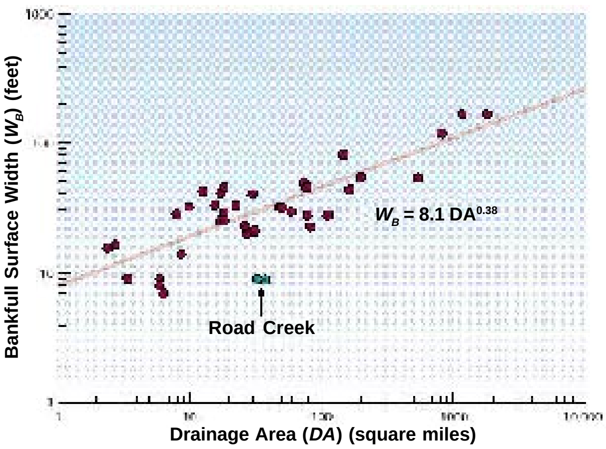


Figure 7.19: Bankfull surface width versus drainage area—Upper Salmon River area. *Local variations in bankfull width may be significant. Road Creek widths are narrower because of lower precipitation.*

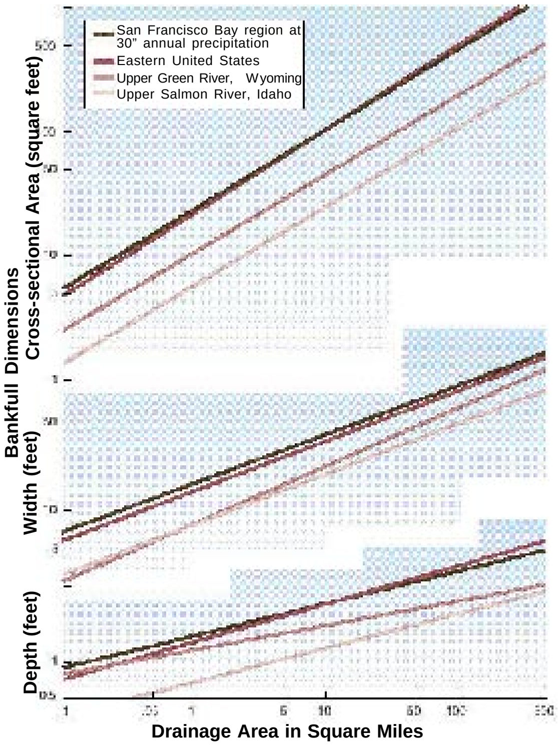


Figure 7.20: Regional curves for bankfull channel dimensions versus drainage area. *Curves showing channel dimensions relating to drainage area for a region of the country can be useful in determining departure from "normal" conditions. The use of such curves must be tempered with an understanding of the limitations of the specific data that produced the curves.*

Source: Dunne and Leopold 1978.

Table 7.5: Limits of data sets used to derive regime formulas. Source: Hey 1988, 1990.

Reference	Data Source	Median Bed Material Size (mm)	Banks	Discharge (ft^3/s)	Sediment Concentration (ppm)	Slope	Bedforms
Lacey 1958	Indian canals	0.1 to 0.4	Cohesive to slightly cohesive	100 to 10,000	< 500		
Blench 1969	Indian canals	0.1 to 0.6	Cohesive	1 to 100,000	< 30[1]	Not specified	Ripples to dunes
Simons and Albertson 1963	U.S. and Indian canals	0.318 to 0.465	Sand	100 to 400	< 500	.000135 to .000388	Ripples to dunes
		0.06 to 0.46	Cohesive	5 to 88,300	< 500	.000059 to .00034	Ripples to dunes
		Cohesive, 0.029 to 0.36	Cohesive	137 to 510	< 500	.000063 to .000114	Plane
Nixon 1959	U.K. rivers	gravel		700 to 18,050	Not measured		
Kellerhals 1967	U.S., Canadian, and Swiss rivers of low sinuousity, and lab	7 to 265	Noncohesive	1.1 to 70,600	Negligible	.00017 to .0131	Plane
Bray 1982	Sinuous Canadian rivers	1.9 to 145		194 to 138,400	"Mobile" bed	.00022 to .015	
Parker 1982	Single channel Canadian rivers		Little cohesion	353 to 211,900			
Hey and Thorne 1986	Meandering U.K. rivers	14 to 176		138 to 14,970	Q s computed to range up to 114	.0011 to .021	

[1] Blench (1969) provides adjustment factors for sediment concentrations between 30 and 100 ppm.

data for stable reaches in the watershed indicates that for a drainage area of 10 square miles, the bankfull discharge could reasonably range from 100 to 250 cfs and the bankfull width could reasonably range from 10 to 35 feet. These relations were developed for a relatively homogeneous watershed, yet there is still quite a bit of natural variation in the data. This illustrates the importance of viewing the data used to develop any curve (not just the curve itself), along with statistical parameters such as R^2 values and confidence limits. (Refer to a text on statistics for additional information.)

Given the natural variation related to stream and watershed characteristics, the preferred source of data for a hydraulic geometry relationship would be the restoration initiative reach. This choice may be untenable due to channel instability. The second preferred choice is the project watershed, although care must be taken to ensure that data are acquired for portions of the watershed with physiographic conditions similar to those of the project reach.

Statistically, channel-forming discharge is a more reliable independent variable for hydraulic geometry relations than drainage area. This is because the magnitude of the channel forming discharge is the driving force that creates the observed channel geometry, and drainage area is merely a surrogate for discharge.Typically, channel-forming discharge correlates best with channel width. Correlations with depth are somewhat less reliable. Correlations with slope and velocity are the least reliable.

Hydraulic Geometry and Stability Assessment

The use of hydraulic geometry relations to assess the stability of a given channel reach requires two things. First, the watershed and stream channel characteristics of the reach in question must be the same as (or similar to) the data set used to develop the hydraulic geometry relations. Second, the reasonable scatter of the data in the hydraulic geometry relations must be known. If the data for a specific reach fall outside the reasonable scatter of data for stable reaches in a similar watershed, there is reason to believe that the reach in question may be unstable. This is only an indicator, since variability in other factors (geology, land use, vegetation, etc.) may cause a given reach to plot high or low on a curve. For instance, in Figure 7.17, the data points from the Road Creek subbasin plot well below the line (narrower bankfull surface width) because the precipitation in this subbasin is lower. These reaches are not unstable; they have developed smaller channel widths in response to lower discharges (as one would expect).

In summary, the use of hydraulic geometry relations requires that the actual data be plotted and the statistical coefficients known. Hydraulic geometry relations can be used as a preliminary guide to indicate stability or instability in stream reaches, but these indications should be checked using other techniques due to the wide natural variability of the data (see Chapter 8 for more information on assessment of channel stability).

Table 7.6: Coefficients for selected hydraulic geometry formulas.

Author	Year	Data	Domain	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9
Nixon	1959	U.K. rivers	Gravel-bed rivers		0.5		0.545	0.33		$1.258n^{2b}$	-0.11	
Leopold et al.	1964	Midwestern U.S.		1.65	0.5			0.4			-0.49	
		Ephemeral streams in semiarid U.S.			0.5			0.3			-0.95	
Kellerhals	1967	Field (U.S., Canada, and Switzerland) and laboratory	Gravel-bed rivers with paved beds and small bed material concentration	1.8	0.5		0.33	0.4	-0.12^a	0.00062	-0.4	0.92^a
Schumm	1977	U.S. (Great Plains) and Australia (Riverine Plains of New South Wales)	Sand-bed rivers with properties shown in Table 6	$37k_1^*$	0.38		$0.6k_4^*$	0.29	-0.12^a	$0.01136k_7^*$	-0.32	
Bray	1982	Canadian rivers	Gravel-bed rivers	3.1	0.53	-0.07	0.304	0.33	-0.03	0.00033	-0.33	0.59
Parker	1982	Single-channel Alberta rivers	Gravel-bed rivers, banks with little cohesion	6.06	0.444	-0.11	0.161	0.401	-0.0025	0.00127	-0.394	0.985
Hay and Thorne	1986	U.K. rivers	Gravel-bed rivers with:									
			Grassy banks with no trees or shrubs	2.39	0.5		0.41	0.37	-0.11	$0.00296k_7^{**}$	-0.43	-0.09
			1-5% tree/shrub cover	1.84	0.5		0.41	0.37	-0.11	$0.00296k_7^{**}$	-0.43	-0.09
			Greater than 5-50% tree/shrub cover	1.51	0.5		0.41	0.37	-0.11	$0.00296k_7^{**}$	-0.43	-0.09
			Greater than 50% shrub cover or incised flood plain	1.29	0.5		0.41	0.37	-0.11	$0.00296k_7^{**}$	-0.43	-0.09

[a] Bed material size in Kellerhals' equation is D_{90}.

b_n = Manning n.

$k_1^* = M^{-0.39}$, where M is the percent of bank materials finer than 0.074 mm. The discharge used in this equation is mean annual rather than bankfull.

$k_4^* = M^{0.432}$, where M is the percent of bank materials finer than 0.074 mm. The discharge used in this equation is mean annual rather than bankfull.

$k_7^* = M^{-0.36}$, where M is the percent of bank materials finer than 0.074 mm. The discharge used in this equation is mean annual rather than bankfull.

$k_7^{**} = D_{54}^{0.84} Q_x^{0.10}$, where Q_x = bed material transport rate in kg s^{-1} at water discharge *Q,* and D_{54} refers to bed material and is in mm.

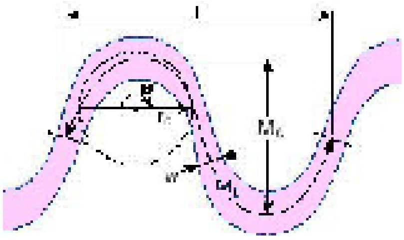
Regional Curves

Dunne and Leopold (1978) looked at similar relationships from numerous watersheds and published *regional curves* relating bankfull channel dimensions to drainage area (**Figure 7.20**).

Using these curves, the width and depth of the bankfull channel can be approximated once the drainage area of a watershed within one of these regions is known. Obviously, more curves such as these are needed for regions that experience different topographic, geologic, and hydrologic regimes; therefore, additional regional relationships should be developed for specific areas of interest. Several hydraulic geometry formulas are presented in **Table 7.6**.

Regional curves should be used only as indicators to help identify the channel geometry at a restoration initiative site because of the large degree of natural variation in most data sets. Published hydraulic geometry relationships usually are based on stable, single-thread alluvial channels. Channel geometry-discharge relationships are more complex for multithread channels.

Exponents and coefficients for hydraulic geometry formulas are usually determined from data sets for a specific stream or watershed. The relatively small range of variation of the exponents k2 , k5 , and k8 is impressive, considering the wide range of situations represented. Extremes for the data sets used to generate the hydraulic geometry formulas are given in **Tables 7.6 and 7.7**. Because formula coefficients vary, applying a given set of hydraulic geometry relationships should be limited to channels similar to the calibration sites. This principle severely limits applying the Lacey, Blench, and Simons and Albertson formulas in channel restoration work since these curves were developed using canal data. Additionally, hydraulic geometry relationships developed for pristine or largely undeveloped watersheds should not be applied to urban watersheds.



L	meander wavelength
M_L	*meander arc length*
w	*average width at bankfull discharge*
M_A	*meander amplitude*
r_c	*radius of curvature*
Θ	*arc angle*

Figure 7.21: Meander geometry variables. Adapted from Williams 1986.

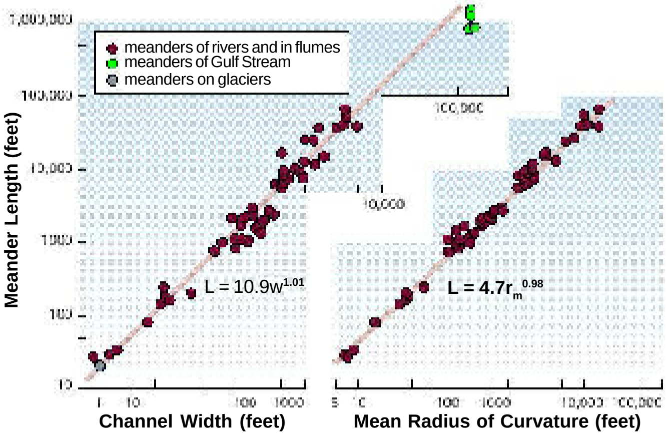


Figure 7.22: Planform geometry relationships. *Meander geometries that do not plot close to the predicted relationship may indicate stream instability.* Source: Leopold 1994.

Table 7.7: Meander geometry equations. Source: Williams 1986.

Equation Number	Equation	Applicable Range
Interrelations between meander features		
2	$L_m= 1.25Lb$	$18.0 \leq L_b \leq 43{,}600$ ft
3	$L_m= 1.63B$	$12.1 \leq B \leq 44{,}900$ ft
4	$L_m= 4.53R_c$	$8.5 \leq R_c \leq 11{,}800$ ft
5	$L_b= 0.8Lm$	$26 \leq L_m \leq 54{,}100$ ft
6	$L_b= 1.29B$	$12.1 \leq B \leq 32{,}800$ ft
7	$L_b= 3.77R_c$	$8.5 \leq R_c \leq 11{,}800$ ft
8	$B = 0.61Lm$	$26 \leq L_m \leq 76{,}100$ ft
9	$B = 0.78Lb$	$18.0 \leq L_b \leq 43{,}600$ ft
10	$B = 2.88R_c$	$8.5 \leq R_c \leq 11{,}800$ ft
11	$R_c= 0.22Lm$	$33 \leq L_m \leq 54{,}100$ ft
12	$R_c= 0.26Lb$	$22.3 \leq L_b \leq 43{,}600$ ft
13	$R_c= 0.35B$	$16 \leq B \leq 32{,}800$ ft
Relations of channel size to meander features		
14	$A = 0.0094L_m^{1.53}$	$33 \leq L_m \leq 76{,}100$ ft
15	$A = 0.0149L_b^{1.53}$	$20 \leq L_b \leq 43{,}600$ ft
16	$A = 0.021B^{1.53}$	$16 \leq B \leq 38{,}100$ ft
17	$A = 0.117R_c^{1.53}$	$7 \leq R_c \leq 11{,}800$ ft
18	$W = 0.019L_m^{0.89}$	$26 \leq L_m \leq 76{,}100$ ft
19	$W = 0.026L_b^{0.89}$	$16 \leq L_b \leq 43{,}600$ ft
20	$W = 0.031B^{0.89}$	$10 \leq B \leq 44{,}900$ ft
21	$W = 0.81R_c^{0.89}$	$8.5 \leq R_c \leq 11{,}800$ ft
22	$D = 0.040L_m^{0.66}$	$33 \leq L_m \leq 76{,}100$ ft
23	$D = 0.054L_b^{0.66}$	$23 \leq L_b \leq 43{,}600$ ft
24	$D = 0.055B^{0.66}$	$16 \leq B \leq 38{,}100$ ft
25	$D = 0.127R_c^{0.66}$	$8.5 \leq R_c \leq 11{,}800$ ft
Relations of meander features to channel size		
26	$L_m= 21A^{0.65}$	$0.43 \leq A \leq 225{,}000$ ft
27	$L_b= 15A^{0.65}$	$0.43 \leq A \leq 225{,}000$ ft
28	$B = 13A^{0.65}$	$0.43 \leq A \leq 225{,}000$ ft
29	$R_c= 4.1A^{0.65}$	$0.43 \leq A \leq 225{,}000$ ft
30	$L_m= 6.5W^{1.12}$	$4.9 \leq W \leq 13{,}000$ ft
31	$L_b= 4.4W^{1.12}$	$4.9 \leq W \leq 7{,}000$ ft
32	$B = 3.7W^{1.12}$	$4.9 \leq W \leq 13{,}000$ ft
33	$R_c= 1.3W^{1.12}$	$4.9 \leq W \leq 7{,}000$ ft
34	$L_m= 129D^{1.52}$	$0.10 \leq D \leq 59$ ft
35	$L_b= 86D^{1.52}$	$0.10 \leq D \leq 57.7$ ft
36	$B = 80D^{1.52}$	$0.10 \leq D \leq 59$ ft
37	$R_c= 23D^{1.52}$	$0.10 \leq D \leq 57.7$ ft
Relations between channel width, channel depth, and channel sinuosity		
38	$W = 12.5D^{1.45}$	$0.10 \leq D \leq 59$ ft
39	$D = 0.17W^{0.89}$	$4.92 \leq W \leq 13{,}000$ ft
40	$W =73D^{1.23}K^{-2.35}$	$0.10 \leq D \leq 59$ ft and $1.20 \leq K \leq 2.60$
41	$D= 0.15w^{0.5}K^{1.48}$	$4.9 \leq W \leq 13{,}000$ ft and $1.20 \leq K \leq 2.60$

Derived empirical equations for river-meander and channel-size features.

A = bankfull cross-sectional area.
W = bankfull width.
D = bankfull mean depth.
L_m= meander wavelength.
L_b= along-channel bend length.
B = meander belt width.
R_c= loop radius of curvature.
K = channel sinuosity

As shown in Table 7.6, hydraulic geometry relationships for gravel-bed rivers are far more numerous than those for sand-bed rivers. Gravel-bed relationships have been adjusted for bank soil characteristics and vegetation, whereas sand-bed formulas have been modified to include bank silt-clay content (Schumm 1977). Parker (1982) argues in favor of regime-type relationships based on dimensionless variables. Accordingly, the original form of the Parker formula was based on dimensionless variables.

Planform and Meander Geometry: Stream Channel Patterns

Meander geometry variables are shown in **Figure 7.21**. Channel planform parameters may be measured in the field or from aerial photographs and may be compared with published relationships, such as those identified in the box.

Developing regional relationships or coefficients specific to the site of interest is, however, preferable to using published relationships that may span wide ranges in value. **Figure 7.22** shows some planform geometry relations by Leopold (1994). Meander geometries that do not fall within the range of predicted relationships may indicate stream instability and deserve attention in restoration design.

Meander Geometry Formulas

Reviews of meander geometry formulas are provided by Nunnally and Shields (1985, Table 3) and Chitale (1973). Ackers and Charlton (1970) developed a typical formula that relates meander wavelength and bankfull discharge, Q (cfs), using laboratory data and checking against field data from a wide range of stream sizes:

$$L = 38\ Q^{0.467}$$

There is considerable scatter about this regression line; examination of the plotted data is recommended. Other formulas, such as this one by Schumm (1977), also incorporate bed sediment size or the fraction of silt-clay in the channel perimeter:

$$L = 1890 Q_m^{0.34} / M^{0.74}$$

where Q_m is average discharge (cfs) and M is the percentage of silt-clay in the perimeter of the channel. These types of relationships are most powerful when developed from regional data sets with conditions that are typical of the area being restored. Radius of curvature, r_c, is generally between 1.5 and 4.5 times the channel width, w, and more commonly between 2w and 3w, while meander amplitude is 0.5 to 1.5 times the meander wavelength, L (USACE 1994). Empirical (Apmann 1972, Nanson and Hickin 1983) and analytical (Begin 1981) results indicate that lateral migration rates are greatest for bends with radii of curvature between 2w and 4w.

Stream System Dynamics

Stream management and restoration require knowledge of the complex interactions between watershed and stream processes, boundary sediments, and bank and floodplain vegetation. Identifying the causes of channel instability or potential instability and having knowledge of the magnitude and distribution of channel adjustment processes are important for the following:

- Estimating future channel changes.
- Developing appropriate mitigation measures.
- Protecting the stream corridor.

Adjustment processes that affect entire fluvial systems often include channel incision (lowering of the channel bed with time), aggradation (raising of the channel bed with time), planform geometry changes, channel widening or narrowing, and changes in the magnitude and type of sediment loads. These processes differ from localized processes, such as scour and fill, which can be limited in magnitude and extent.

In contrast, the processes of channel incision and aggradation can affect long reaches of a stream or whole stream systems. Long-term adjustment processes, such as incision, aggradation, and channel widening, can exacerbate local scour problems. Whether streambed erosion occurs due to local scour or channel incision, sufficient bed level lowering can lead to bank instability and to changes in channel planform.

It is often difficult to differentiate between local and systemwide processes without extending the investigation upstream and downstream of the site in question. This is because channels migrate over time and space and so may affect previously undisturbed reaches. For example, erosion at a logjam initially may be attributed to the deflection of flows caused by the woody debris blocking the channel. However, the appearance of large amounts of woody debris may indicate upstream channel degradation related to instability of larger scope.

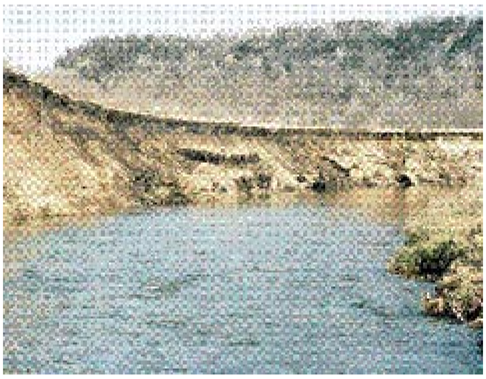


*Figure 7.23: **Bank instability.** Determining if instability is localized or systemwide is imperative to establish a correct path of action.*

Determining Stream Instability: Is It Local or Systemwide?

Stage of channel evolution is the primary diagnostic variable for differentiating between local and systemwide channel stability problems in a disturbed stream or constructed channel. During basinwide adjustments, stage of channel evolution usually varies systematically with distance upstream. Downstream sites might be characterized by aggradation and the waning stages of widening, whereas upstream sites might be characterized (in progressive upstream order) by widening and mild degradation, then degradation, and if the investigation is extended far enough upstream, the stable, predisturbed condition (**Figure 7.23**). This sequence of stages can be used to reveal systemwide instabilities. Stream classification can be applied in a similar manner to natural streams. The sequence of stream types can reveal systemwide instabilities.

Restoration measures often fail, not as the result of inadequate structural design, but rather because of the failure of the designers to incorporate the existing and future channel morphology into the design. For this reason, it is important for the designer to have some general understanding of stream processes to ensure that the selected restoration measures will work in harmony with the existing and future river conditions. This will allow the designer to assess whether the conditions at a particular site are due to local instability processes or are the result of some systemwide instability that may be affecting the entire watershed.

Systemwide Instability

The equilibrium of a stream system can be disrupted by various factors. Once this occurs, the stream will attempt to regain equilibrium by making adjustments in the dependent variables. These adjustments in the context of physical processes are generally reflected in aggradation, degradation, or changes in planform characteristics (meander wavelength, sinuosity, etc.). Depending on the magnitude of the change and the basin characteristics (bed and bank materials, hydrology, geologic or man-made controls, sediment sources, etc.), these adjustments can propagate throughout the entire watershed and even into neighboring systems. For this reason, this type of disruption of the equilibrium condition is referred to as system instability. If system instability is occurring or expected to occur, it is imperative that the restoration initiative address these problems before any bank stabilization or instream habitat development is considered.

Local Instability

Local instability refers to erosion and deposition processes that are not symptomatic of a disequilibrium condition in the watershed (i.e., system instability). Perhaps the most common form of local instability is bank erosion along the concave bank in a meander bend that is occurring as part of the natural meander process. Local instability can also occur in isolated locations as the result of channel constriction, flow obstructions (ice, debris, structures, etc.), or geotechnical instability. Local instability problems are amenable to local bank protection. Local instability can also exist in channels where severe system instability exists. In these situations, the local instability problems will probably be accelerated due to the system instability, and a more comprehensive treatment plan will be necessary.

Caution must be exercised if only local treatments on one site are implemented. If the upstream reach is stable and the downstream reach is unstable, a systemwide problem may again be indicated. The instability may continue moving upstream unless the root cause of the instability at the watershed level is removed or channel stabilization at and downstream of the site is implemented.

Local channel instabilities often can be attributed to redirection of flow caused by debris, structures, or the approach angle from upstream. During moderate and high flows, obstructions often result in vortices and secondary-flow cells that accelerate impacts on channel boundaries, causing local bed scour, erosion of bank toes, and ultimately bank failures. A general constriction of the channel cross section from debris accumulation or a bridge causes a backwater condition upstream, with acceleration of the flow and scour through the constriction.

Bed Stability

In unstable channels, the relationship between bed elevation and time (years) can be described by nonlinear functions, where change in response to a disturbance occurs rapidly at first and then slows and becomes asymptotic with time(**Figure 7.24**). Plotting bed elevations against time permits evaluating bed-level adjustment and indicates whether a major phase of channel incision has passed or is ongoing. Various mathematical forms of this function have been used to characterize bed-level adjustment at a site and to predict future bed elevations. This method also can provide valuable information on trends of channel stability at gauged locations where abundant data from discharge measurements are available.

Specific Gauge Analysis

Perhaps one of the most useful tools available to the river engineer or geomorphologist for assessing the historical stability of a river system is the specific gauge record. A specific gauge record is a graph of stage for a specific discharge at a particular stream gauging location plotted against time (Blench 1969). A channel is considered to be in equilibrium if the specific gauge record shows no consistent increasing or decreasing trends over time, while an increasing or decreasing trend is indicative of an aggrada-

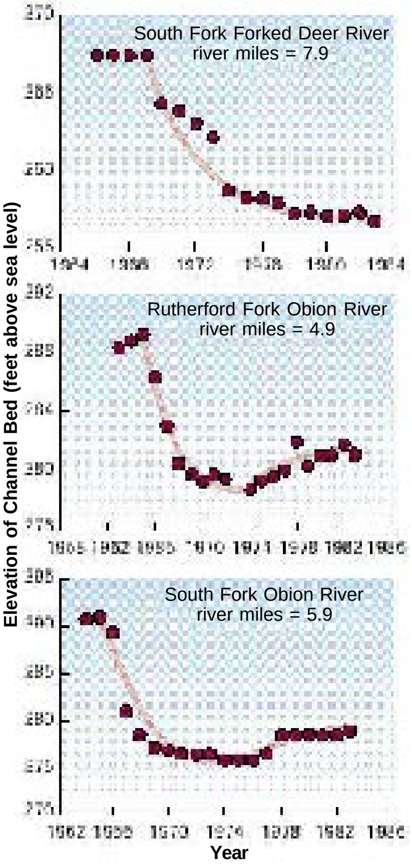


Figure 7.24: Changes in bed elevations over time. *Plotting river bed elevations at a point along the river over time can indicate whether a major phase of channel incision is ongoing or has passed.*

tional or degradational condition, respectively. An example of a specific gauge record is shown in **Figure 7.25.**

The first step in a specific gauge analysis is to establish the stage vs. discharge relationship at the gauge for the period of record being analyzed. A rating curve is developed for each year in the period of record. A regression curve is then fitted to the data and plotted on the scatter plot. Once the rating curves have been developed, the discharges to be used in the specific gauge record must be selected.

This selection depends largely on the objectives of the study. It is usually advisable to select discharges that encompass the entire range of observed flows. A plot is then developed showing the stage for the given flow plotted against time.

Specific gauge records are an excellent tool for assessing the historical stability at a specific location. However, specific gauge records indicate only the conditions in the vicinity of the particular gauging station and do not necessarily reflect river response farther upstream or downstream of the gauge. Therefore, even though the specific gauge record is one of the most valuable tools used by river engineers, it should be coupled with other assessment techniques to assess reach conditions or to make predictions about the ultimate response on a river.

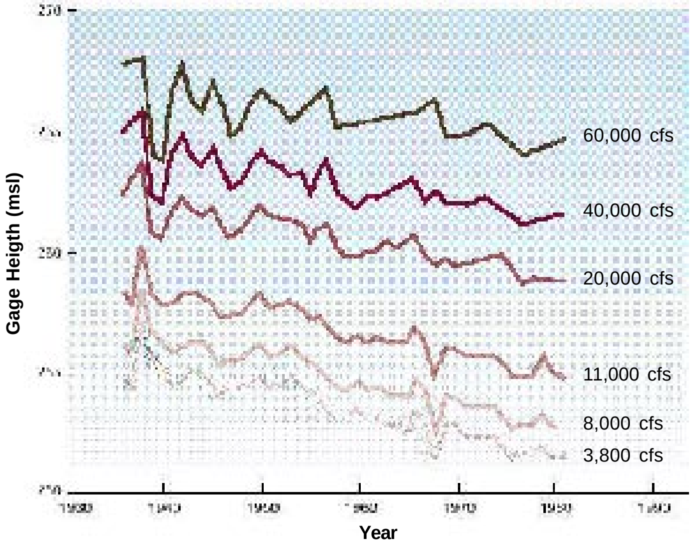


Figure 7.25: Specific gauge plot for Red River at Index, Arkansas. *Select discharges from the gauge data that represent the range of flows.* Source: Biedenharn et al. 1997.

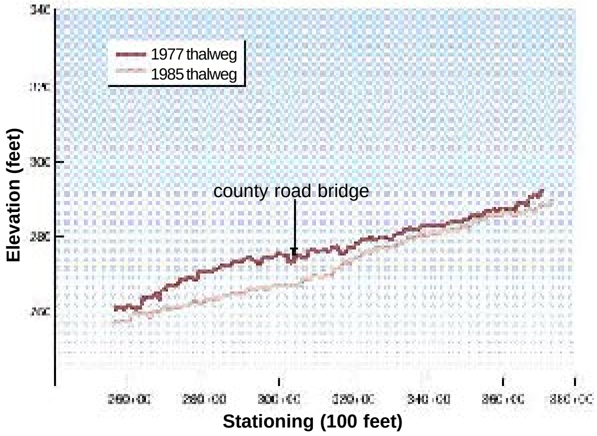


Figure 7.26: Comparative thalweg profiles. *Changes in bed elevation over the length of a stream can indicate areas of transition and reaches where more information is needed.* Source: Biedenharn et al., USACE 1997.

Comparative Surveys and Mapping

One of the best methods for directly assessing channel changes is to compare channel surveys (thalweg and cross section).

Thalweg surveys are taken along the channel at the lowest point in the cross section. Comparison of several thalweg surveys taken at different points in time allows the engineer or geomorphologist to chart the change in the bed elevation through time (**Figure 7.26**).

Certain limitations should be considered when comparing surveys on a river system. When comparing thalweg profiles, it is often difficult, especially on larger streams, to determine any distinct trends of aggradation or degradation if there are large scour holes, particularly in bendways. The existence of very deep local scour holes may completely obscure temporal variations in the thalweg. This problem can sometimes be overcome by eliminating the pool sections and focusing only on the crossing locations, thereby allowing aggradational or degradational trends to be more easily observed.

Although thalweg profiles are a useful tool, it must be recognized that they reflect only the behavior of the channel bed and do not provide information about the channel as a whole. For this reason it is usually advisable to study changes in the cross-sectional geometry. Cross-sectional geometry refers to width, depth, area, wetted perimeter, hydraulic radius, and channel conveyance at a specific cross section.

If channel cross sections are surveyed at permanent monumented range locations, the crosssectional geometry at different times can be compared directly. The cross section plots for each range at the various times can be overlaid and compared. It is seldom the case, however, that the cross sections are located in the exact same place year after year. Because of these problems, it is often advisable to compare reach-average values of the cross-sectional geometry parameters. This requires the study area to be divided into distinct reaches based on geomorphic characteristics. Next, the cross-sectional parameters are calculated at each cross section and then averaged for the entire reach. Then the reach-average values can be compared for each survey. Cross-sectional variability between bends (pools) and crossings (riffles) can obscure temporal trends, so it is often preferable to use only cross sections from crossing reaches when analyzing long-term trends of channel change.

Comparison of time-sequential maps can provide insight into the planform instability of the channel. Rates and magnitude of channel migration (bank caving), locations of natural and man-made cutoffs, and spatial and temporal changes in channel width and planform geometry can be determined from maps. With these types of data, channel response to imposed conditions can be documented and used to substantiate predictions of future channel response to a proposed alteration. Planform data can be obtained from aerial photos, maps, or field investigations.

Regression Functions for Degradation

Two mathematical functions have been used to describe bed level adjustments with time. Both may be used to predict channel response to a disturbance, subject to the caution statements below. The first is a power function (Simon 1989a):

$$E = a\,t^{b}$$

where E = elevation of the channel bed, in feet; a = coefficient, determined by regression, representing the premodified elevation of the channel bed, in feet; t = time since beginning of adjustment process, in years, where t_0 = 1.0 (year prior to onset of the adjustment process); and b = dimensionless exponent, determined by regression and indicative of the nonlinear rate of channel bed change (negative for degradation and positive for aggradation).

The second function is a dimensionless form of an exponential equation (Simon 1992):

$$z / z_0 = a + b\,e^{(-kt)}$$

where

z = the elevation of the channel bed (at time t)

z_0 = the elevation of the channel bed at t_0

a = the dimensionless coefficient, determined by regression and equal to the dimensionless elevation (z/z_0) when the equation becomes asymptotic, a>1 = aggradation, a<1 = degradation

b = the dimensionless coefficient, determined by regression and equal to the total change in the dimensionless elevation (z/z_0) when the equation becomes asymptotic

k = the coefficient determined by regression, indicative of the rate of change on the channel bed per unit time

t = the time since the year prior to the onset of the adjustment process, in years (t_0 =0)

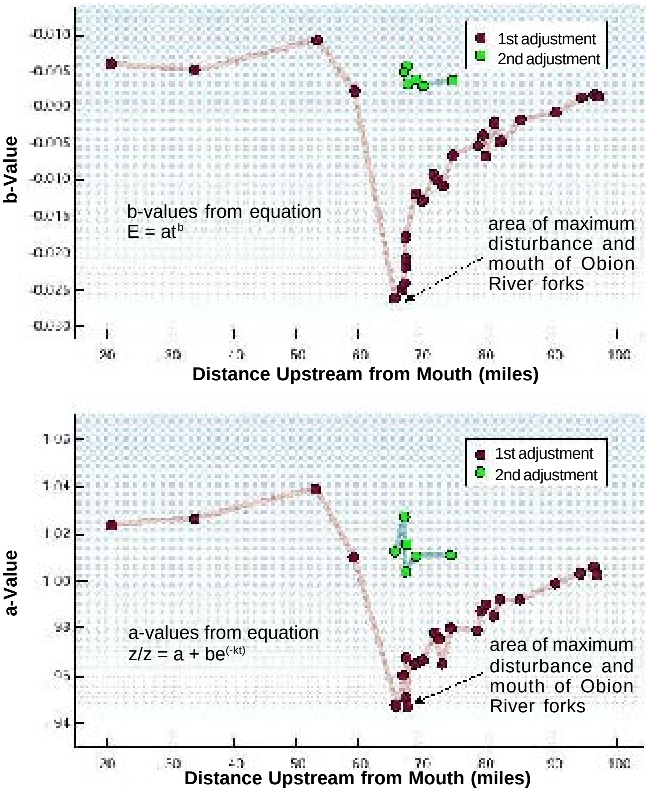


Figure 7.27: Coefficient a and b values for regression functions for estimating bed level adjustment versus ongitudinal distance ***along stream.*** *Future bed elevations can be estimated by using empirical equations.*
Source: Simon 1989, 992.

Future elevations of the channel bed can, therefore, be estimated by fitting the equations to bed elevations and by solving for the period of interest. Either equation provides acceptable results, depending on the statistical significance of the fitted relation. Statistical significance of the fitted curves improves with additional data. Degradation and aggradation curves for the same site are fit separately. For degrading sites, the equations will provide projected minimum channel elevations when the value of t becomes large and, by subtracting this result from the floodplain elevation, projected maximum bank heights. A range of bed adjustment trends can be estimated by using different starting dates in the equations when the initial timing of bed level change is unknown. Use of the equations, however, may be limited in some areas because of a lack of survey data.

Regression Functions for Aggradation

Once the minimum bed elevation has been obtained, that elevation can be used as the starting elevation at a new t_0 for the secondary aggradation phase that occurs during channel widening (see discussion of channel evolution above). Secondary aggradation occurs at a site after degradation reduces channel gradient and stream power to such an extent that sediment loads delivered from degrading reaches upstream can no longer be transported (Simon 1989a). Coefficient values for Si-

Figure 7.28: Bank erosion by undercutting. *Removal of toe slope support leads to instability requiring geotechnical solutions.*

mon's power function for estimating secondary aggradation can be obtained either from interpolating existing data or from estimating their values as about 60 percent less than the corresponding value obtained for the degradation phase.

The variation of the regression coefficients a and b with longitudinal distance along the channel can be used as an empirical model of bed level adjustment providing there are data from enough sites. Examples using both equations are provided for the Obion River system, West Tennessee (**Figure 7.27**). Estimates of bed-level change with time for unsurveyed sites can be obtained using interpolated coefficient a values and t_0. For channels downstream from dams without significant tributary sediment inputs, the shape of the a-value curve would be similar but inverted; maximum amounts of degradation (minimum a values) occur immediately downstream of the dam and attenuate nonlinearly with distance farther downstream.

Caution: If one of the above mathematical functions is used to predict future bed elevations, the assumption is made that no new disturbances have occurred to trigger a new phase of channel change. Downstream channelization, construction of a reservoir, formation of a large woody debris jam that blocks the channel, or even a major flood are examples of disturbances that can trigger a new period of rapid change.

The investigator is cautioned that the use of regression functions to compute aggradation and degradation is an empirical approach that might be appropriate for providing insight into the degradational and aggradational processes during the initial planning phases of a project. However, this procedure does not consider the balance between supply and transport of water and sediment and, therefore, is not acceptable for the detailed design of restoration features.

Sediment Transport Processes

This document does not provide comprehensive coverage of sedimentation processes and analyses critical to stream restoration. These processes include erosion, entrainment, transport, deposition, and compaction. Refer to standard texts and reference on sediment, including Vanoni (1975), Simons and Senturk (1977), Chang (1988), Richards (1982), and USACE (1989a).

Numerical Analyses and Models to Predict Aggradation and Degradation

Numerical analyses and models such as HEC-6 are used to predict aggradation and degradation (incision) in stream channels, as discussed in Chapter 8.

Bank Stability

Streambanks can be eroded by moving water removing soil particles or by collapse. Collapse or mass failure occurs when the strength of bank materials is too low to resist gravity forces. Banks that are collapsing or about to collapse are referred to as being geotechnically unstable (**Figure 7.28**). The physical properties of bank materials should be described to aid characterization of potential stability problems and identification of dominant mechanisms of bank instability.

The level of intensity of geotechnical investigations varies in planning and design. During planning, enough information must be collected to determine the feasibility of alternatives being considered. For example, qualitative descriptions of bank stratigraphy obtained during planning may be all that is required for identifying dominant modes of failure in a study reach. Thorne (1992) describes stream reconnaissance procedures particularly for recording streambank data.

Qualitative Assessment of Bank Stability

Natural streambanks frequently are composed of distinct layers reflecting the depositional history of the bank materials. Each individual sediment layer can have physical properties quite different from those of other layers. The bank profile therefore will respond according to the physical properties of each layer. Since the stability of stream-banks with respect to failures due to gravity depends on the geometry of the bank profile and the physical properties of the bank materials, dominant failure mechanisms tend to be closely associated with characteristic stratigraphy or succession of layers (**Figure 7.29**).

A steep bank consisting of uniform layers of cohesive or cemented soils generally develops tension cracks at the top of the bank parallel to the bank alignment. Slab failures occur when the weight of the soil exceeds the strength of the grain-to-grain contacts within the soil. As clay content or cementing agent decreases, the slope of the bank decreases; vertical failure planes become more flat and planar failure surfaces develop. Rotational failures occur when the bank soils are predominantly cohesive. Block-type failures occur when a weak soil layer is eroded away and the layers above the weak layer lose structural support.

The gravity failure processes described in Figure 7.29 usually occur after the banks have been saturated due to precipitation or high stream stages. The water adds weight to the

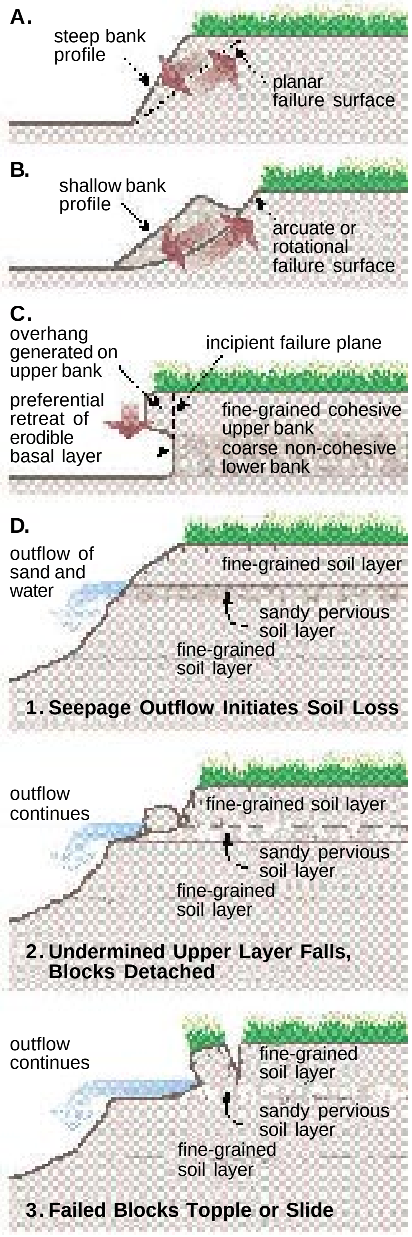


Figure 7.29:
Relationship of dominant bank failure mechanisms and associated stratigraphics.
(a) Uniform bank undergoing planar type failure
(b) Uniform shallow bank undergoing rotational type failure
(c) Cohesive upper bank, noncohesive lower bank leads to cantilever type failure mechanism
(d) Complex bank stratigraphy may lead to piping or sapping type failures.

Source: Hagerty 1991. In *Journal of Hydraulic Engineering*. Vol. 117 Number 8. Reproduced by permission of ASCE.

soil and reduces grain-to-grain contacts and cohesion forces while increasing the pore pressure. Pore pressure occurs when soil water in the pore spaces is under pressure from overlying soil and water. Pore pressure therefore is internal to the soil mass. When a stream is full, the flowing water provides some support to the streambanks. When the stream level drops, the internal pore pressure pushes out from within and increases the potential for bank failure.

The last situation described in Figure 7.29 involves ground water sapping or piping. Sapping or piping is the erosion of soil particles beneath the surface by flowing ground water. Dirty or sediment-laden seepage from a streambank indicates ground water sapping or piping is occurring. Soil layers above the areas of ground water piping eventually will collapse after enough soil particles have been removed from the support layer.

Quantitative Assessment of Bank Stability

When restoration design requires more quantitative information on soil properties, additional detailed data need to be collected (**Figure 7.30**). Values of cohesion, friction angle, and unit weight of the bank material need to be quantified. Because of spatial variability, careful sampling and testing programs are required to minimize the amount of data required to correctly characterize the average physical properties of individual layers or to determine a bulk average statistic for an entire bank.

Care must be taken to characterize soil properties not only at the time of measurement but also for the "worst case" conditions at which failure is expected (Thorne et al. 1981). Unit weight, cohesion, and friction angle vary as a function of moisture content. It usually is not possible to directly measure bank materials under worst-case conditions, due to the hazardous nature of unstable sites under such conditions. A qualified geotechnical or soil mechanics engineer should estimate these operational strength parameters.

Quantitative analysis of bank instabilities is considered in terms of force and resistance. The shear strength of the bank material represents the resistance of the boundary to erosion by gravity. Shear strength is composed of cohesive strength and frictional strength. For the case of a planar failure of unit length, the Coulomb equation is applicable

$$S_r = c + (N - \mu)\tan\phi$$

where S_r = shear strength, in pounds per square foot; c = cohesion, in pounds per square foot; N = normal stress, in pounds per square foot; μ = pore pressure, in pounds per square foot; and ϕ = friction angle, in degrees. Also:

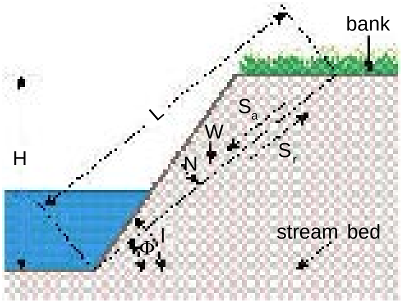
$$N = W\cos\theta$$

where W = weight of the failure block, in pounds per square foot; and θ = angle of the failure plane, in degrees.

The gravitational force acting on the bank is:

$$S_a = W\sin\theta$$

Factors that decrease the erosional resistance (S_r), such as excess pore pressure from saturation and the de-



Explanation
H = bank height
L = failure plane length
c = cohesion
Φ = friction angle
γ = bulk unit weight
W = weight of failure block
soil properties
I = bank angle
$S_a = W\sin\Phi$ (driving force)
$S_r = cL + N\tan\Phi$ (resisting force)
$N = W\cos\Theta$
$\Theta = (0.5\,I = 0.5\Theta)$ (failure plane angle)
for the critical case $S_a = S_r$ and:

$$H_c = \frac{4c\sin I\cos\Theta}{\gamma(1-\cos[I-\Theta])}$$

Figure 7.30: Forces acting on a channel bank assuming there is zero pore-water pressure. *Bank stability analyses relate strength of bank materials to bank height and angles, and to moisture conditions.*

velopment of vertical tension cracks, favor bank instabilities. Similarly, increases in bank height (due to channel incision) and bank angle (due to undercutting) favor bank failure by increasing the gravitational force component. In contrast, vegetated banks generally are drier and provide improved bank drainage, which enhances bank stability. Plant roots provide tensile strength to the soil resulting in reinforced earth that resists mass failure, at least to the depth of roots (Yang 1996).

Bank Instability and Channel Widening

Channel widening is often caused by increases in bank height beyond the critical conditions of the bank material. Simon and Hupp (1992) show that there is a positive correlation between the amount of bed level lowering by degradation and amounts of channel widening. The adjustment of channel width by mass-wasting processes represents an important mechanism of channel adjustment and energy dissipation in alluvial streams, occurring at rates covering several orders of magnitude, up to hundreds of feet per year (Simon 1994).

Present and future bank stability may be analyzed using the following procedure:

- Measure the current channel geometry and shear strength of the channel banks.
- Estimate the future channel geometries and model worst-case pore pressure conditions and average shear strength characteristics.

For fine-grained soils, cohesion and friction angle data can be obtained from standard laboratory testing (triaxial shear or unconfined compression tests) or by in situ testing with a bore-hole shear test device (Handy and Fox 1967, Luttenegger and Hallberg 1981, Thorne et al. 1981, Simon and Hupp 1992). For coarse-grained, cohesionless soils, estimates of friction angles can be obtained from reference manuals. By combining these data with estimates of future bed elevations, relative bank stability can be assessed using bank stability charts.

Bank Stability Charts

To produce bank stability charts such as the one following, a stability number (N_s) representing a simplification of the bank (slope) stability equations is used. The stability number is a function of the bank-material friction angle (ϕ) and the bank angle (i) and is obtained from a stability chart developed by Chen (1975) (**Figure 7.31**) or from Lohnes and Handy (1968):

$$N_s = (4 \sin i \cos \phi) / [1 - \cos (i - \phi)]$$

The critical bank height H_c, where driving force S_a = resisting force S_r for a given shear strength and bank geometry is then calculated (Carson and Kirkby 1972):

$$H_c = N_s (c / \gamma)$$

where c =cohesion, in pounds per square foot, and γ = bulk unit weight of soil in pounds per cubic foot.

Equations are solved for a range of bank angles using average or ambient soil moisture conditions to produce the upper line "Ambient field conditions, unsaturated." Critical bank height for worst-case conditions (saturated banks and rapid decline in river stage) are obtained by solving the equations, assuming that ϕ and the frictional component of shear strength goes to 0.0 (Lutton 1974) and by using a saturated bulk-unit weight. These results are represented by the lower line, "saturated conditions."

The frequency of bank failure for the three stability classes (unstable, at-risk, and stable) is subjective and is based primarily on empirical field data (**Figure 7.32**). An unstable channel bank can be expected to fail at least annually and possibly after each major stormflow in which the channel banks are saturated, assuming that there is at least one major stormflow in a given year. At-risk conditions translate to a bank failure every 2 to 5 years, again assuming that there is a major flow event to saturate the banks and to erode toe material. Stable banks by definition do not fail by mass wasting processes. However, channel banks on the outside of meander bends may experience erosion of the bank toe, leading to oversteepening of the bank profile and eventually to bank caving episodes.

Generalizations about critical bank heights (H_c) and angles can be made with knowledge of the variability in cohesive strengths. Five categories of mean cohesive strength of channel banks are identified in **Figure 7.33**. Critical bank heights above the mean low-water level and saturated condi-

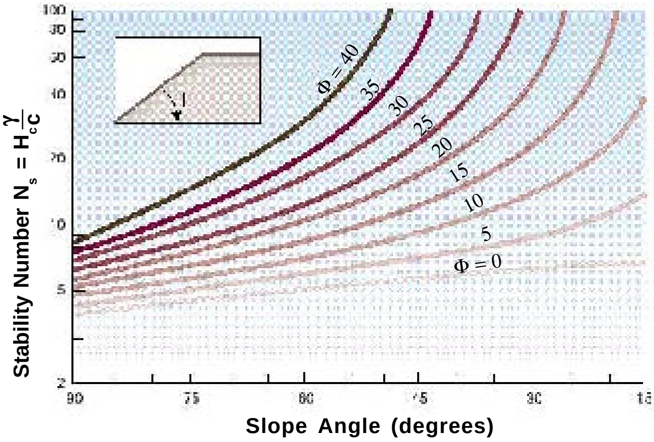


Figure 7.31: Stability number (NS) as a function of bank angle (i) for a failure surface passing through the bank toe. *Critical bank height for worst-case condition can be computed.*

Source: Chen 1975.

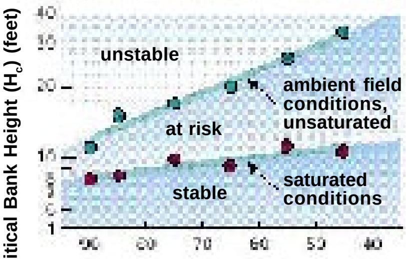


Figure 7.32: Example of a bank stability chart for estimating critical bank height (Hc). *Existing bank stability can be assessed, as well as potential stable design heights and slopes.*

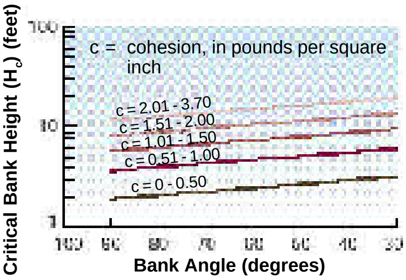


Figure 7.33: Critical bank-slope configurations for various ranges of cohesive strengths under saturated conditions. *Specific data on the cohesive strength of bank materials can be collected to determine stable configurations.*

tions were used to construct the figure because bank failures typically occur during or after the recession of peak flows. The result is a nomograph giving critical bank heights for a range of bank angles and cohesive strengths that can be used to estimate stable bank configurations for worst-case conditions, such as saturation during rapid decline in river stage. For example, a saturated bank at an angle of 55 degrees and a cohesive strength of 1.75 pounds per square inch would be unstable when bank heights exceed about 10 feet.

Predictions of Bank Stability and Channel Width

Bank stability charts can be used to determine the following:

- The timing of the initiation of general bank instabilities (in the case of degradation and increasing bank heights).
- The timing of renewed bank stability (in the case of aggradation and decreasing bank heights).
- The bank height and angle needed for a stable bank configuration under a range of moisture conditions.

Estimates of future channel widening also can be made using measured channel-width data over a period of years and then fitting a nonlinear function to the data (**Figure 7.34**). Williams and Wolman (1984) used a dimensionless hyperbolic function of the following form to estimate channel widening downstream from dams:

$$(W_i / W_t) = j_1 + j_2 (1 / t)$$

where:
W_i = initial channel width, in feet
W_t = channel width at t years after W_1, in feet
t = time, in years
j_1 = intercept
j_2 = slope of the fitted straight line on a plot of W_i / W_t versus 1/t

Wilson and Turnipseed (1994) used a power function to describe widening after channelization and to estimate future channel widening in the loess area of northern Mississippi:

$$W = x\ t^d$$

where:
W = channel width, in feet
x = coefficient, determined by regression, indicative of the initial channel width
t = time, in years
d = coefficient, determined by regression, indicative of the rate of channel widening.

7.C Chemichal Characteristics

Assessing water chemistry in a stream restoration initiative can be one of the ways to determine if the restoration was successful. A fundamental understanding of the chemistry of a given system is critical for developing appropriate data collection and analysis methods. Although data collection and analysis are interdependent, each has individual components. It is also critical to have a basic understanding of the hydrologic and water quality processes of interest before data collection and analysis begin. Averett and Schroder (1993) discuss some fundamental concepts used when determining a data collection and analysis program.

Data Collection

Constituent Selection

Hundreds of chemical compounds can be used to describe water quality. It is typically too expensive and too time-consuming to analyze every possible chemical of interest in a given system. In addition to selecting a particular constituent to sample, the analytical techniques used to determine the constituent also must be considered. Another consideration is the chemistry of the constituent; for example, whether the chemical is typically in the dissolved state or sorbed onto sediment makes a profound difference in the methods used for sampling and analysis, as well as the associated costs.

Often it is effective to use parameters that integrate or serve as indicators for a number of other variables. For instance, dissolved oxygen and temperature measurements integrate the net impact of many physical and chemical processes on a stream system, while soluble reactive phosphorus concentration is often taken as a readily

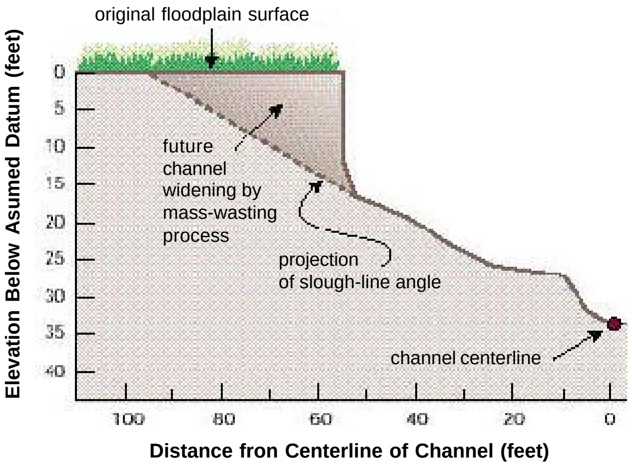


Figure 7.34: Method to estimate future channel widening (10-20 years) for one side of the channel. *The ultimate bank width can be predicted so that the future stream morphology can be visualized.*

available indicator of the potential for growth of attached algae. Averett and Schroder (1993) discuss additional factors involved in selecting constituents to sample.

Sampling Frequency

The needed frequency of sampling depends on both the constituent of interest and management objectives. For instance, a management goal of reducing average instream nutrient concentrations may require monitoring at regular intervals, whereas a goal of maintaining adequate dissolved oxygen (DO) during summer low flow and high temperature periods may require only targeted monitoring during critical conditions. In general, water quality constituents that are highly variable in space or time require more frequent monitoring to be adequately characterized.

In many cases, the concentration of a constituent depends on the flow condition. For example, concentrations of a hydrophobic pesticide, which sorbs strongly to particulate matter, are likely to be highest during scouring flows or erosion washoff events, whereas concentrations of a dissolved chemical that is loaded to the stream at relatively steady rates will exhibit highest concentrations in extremely low flows.

In fact, field sampling and water quality analyses are time-consuming and expensive, and schedule and budget constraints often determine the frequency of data collection. Such constraints make it even more important to design data collection efforts that maximize the value of the information obtained.

Statistical tools often are used to help determine the sampling frequency. Statistical techniques, such as simple random sampling, stratified random sampling, two-stage sampling, and systematic sampling, are described in Gilbert (1987) and Averett and Schroder (1993). Sanders et al. (1983) also describe methods of determining sampling frequency.

Site Selection

The selection of sampling sites is the third critical part of a sampling design. Most samples represent a point in space and provide direct information only on what is happening at that point. A key objective of site selection is to choose a site that gives information that is representative of conditions throughout a particular reach of stream. Because most hydrologic systems are very complex, it is essential to have a fundamental understanding of the area of interest to make this determination.

External inputs, such as tributaries or irrigation return flow, as well as output, such as ground water recharge, can drastically change the water quality along the length of a stream. It is because of these processes that the hydrologic system must be understood to interpret the data from a particular site. For example, downstream from a significant lateral source of a load, the dissolved constituent(s) might be distributed uniformly in the stream channel. Particulate matter, however, typically is stratified. Therefore, the distribution of a constituent sorbed onto particulate matter is not evenly distributed. Averett and Schroder (1993) discuss different approaches to selecting sites to sample both surface water and ground water. Sanders et al. (1983) and Stednick (1991) also discuss site selection.

Finally, practical considerations are an important part of sample collection. Sites first must be accessible, preferably under a full range of potential flow and weather conditions. For this reason, sampling is often conducted at bridge crossings, taking into consideration the degree to which artificial channels at bridge crossings may influence sample results. Finally, where constituent loads and concentrations are of interest, it is important to align water quality sample sites with locations at which flow can be accurately gauged.

Sampling Techniques

This section provides a brief overview of water quality sampling and data collection techniques for stream restoration efforts. Many important issues can be treated only cursorily within the context of this document, but a number of references are available to provide the reader with more detailed guidance.

Key documents describing methods of water sample collection for chemical analysis are the U.S. Geological Survey (USGS) protocol for collecting and processing surface water samples for determining inorganic constituents in filtered water (Horwitz et al. 1994), the field guide for collecting and processing stream water samples for the National Water Quality Assessment program (Shelton 1994), and the field guide for collecting and processing samples of streambed sediment for analyzing trace elements and organic contaminants for the National Water Quality Assessment program (Shelton and Capel 1994). A standard reference document describing methods of sediment collection is the USGS *Techniques for Water-Resource Investigations*, *Field Methods for Measurement of Fluvial Sediment* (Guy and Norman 1982). The USGS is preparing a national field manual that describes techniques for collecting and processing water quality samples (Franceska Wilde, personal communication, 1997).

Sampling Protocols for Water and Sediment

Stream restoration monitoring may involve sampling both water and sediment quality. These samples may be collected by hand (manual samples), by using an automated sampler (automatic samples), as individual point-in-time samples (grab or discrete samples), or combined with other samples (composite samples). Samples collected and mixed in relation to the measured volume within or flow through a system are commonly termed volume- or flow-weighted composite samples, whereas equal-volume samples collected at regular vertical intervals through a portion or all of the water column may be mixed to provide a water column composite sample.

Manual Sampling and Grab Sampling

Samples collected by hand using various types of containers or devices to collect water or sediment from a receiving water or discharge often are termed grab samples. These samples can require little equipment and allow recording miscellaneous additional field observations during each sampling visit.

Manual sampling has several advantages. These approaches are generally uncomplicated and often inexpensive (particularly when labor is already available). Manual sampling is required for sampling some pollutants. For example, according to *Standard Methods* (APHA 1995), oil and grease, volatile compounds, and bacteria must be analyzed from samples collected using manual methods. (Oil, grease, and bacteria can adhere to hoses and jars used in automated sampling equipment, causing inaccurate results; volatile compounds can vaporize during automated sampling procedures or can be lost from poorly sealed sample containers; and bacteria populations can grow and community compositions change during sample storage.)

Disadvantages of grab sampling include the potential for personnel to be available around the clock to sample during storms and the potential for personnel to be exposed to hazardous conditions during sampling. Long-term sampling programs involving many sampling locations can be expensive in terms of labor costs.

Grab sampling is often used to collect discrete samples that are not combined with other samples. Grab samples can also be used to collect volume- or flow-weighted composite samples, where several discrete samples are combined by proportion to measured volume or flow rates; however, this type of sampling is often more easily accomplished using automated samplers and flow meters. Several examples of manual methods for flow weighting are presented in USEPA (1992a). Grab sampling also may be used to composite vertical water column or aerial composite samples of water or sediment from various kinds of water bodies.

Automatic Sampling

Automated samplers have been improved greatly in the last 10 years and now have features that are useful for many sampling purposes. Generally, such sampling devices require larger initial capital investments or the payment of rental fees, but they can reduce overall labor costs (especially for long-running sampling programs) and increase the reliability of flow-weighted compositing.

Some automatic samplers include an upper part consisting of a microprocessor- based controller, a pump assembly, and a filling mechanism, and a lower part containing a set of glass or plastic sample containers and a well that can be filled with ice to cool the collected samples. More expensive automatic samplers can include refrigeration equipment in place of the ice well; such devices, however, require a 120-volt power supply instead of a battery. Also, many automatic samplers can accept input signals from a flowmeter to activate the sampler and to initiate a flow-weighting compositing program. Some samplers can accept input from a rain gauge to activate a sampling program.

Most automatic samplers allow collecting multiple discrete samples or single or multiple composited samples. Also, samples can be split between sample bottles or can be composited into a single bottle. Samples can be collected on a predetermined time basis or in proportion to flow measurement signals sent to the sampler.

In spite of the obvious advantages of automated samplers, they have some disadvantages and limitations. Some pollutants cannot be sampled by automated equipment unless only qualitative results are desired. Although the cleaning sequence provided by most such samplers provide reasonably separate samples, there is some cross-contamination of the samples since water droplets usually remain in the tubing. Debris in the sampled receiving water can block the sampling line and prevent sample collection. If the sampling line is located in the vicinity of a flowmeter, debris caught on the sampling line can also lead to erroneous flow measurements.

While automatic samplers can reduce manpower needs during storm and runoff events, these devices must be checked for accuracy during these events and must be regularly tested and serviced. If no field checks are made during a storm event, data for the entire event may be lost. Thus, automatic samplers do not eliminate the need for field personnel, but they can reduce these needs and can produce flow-weighted composite samples that might be tedious or impossible using manual methods.

Discrete versus Composite Sampling

Flow rates, physical conditions, and chemical constituents in surface waters often vary continuously and simultaneously. This presents a difficulty when determining water volumes, pollutant concentrations, and masses of pollutants or their loads in the waste discharge flows and in receiving waters. Using automatic or continuously recording flowmeters allows obtaining reasonable and continuous flow rate measurements for these waters. Pollutant loads can then be computed by multiplying these flow volumes over the period of concern by the average pollutant concentration determined from the discrete or flow-composited samples. When manual (instantaneous) flow measurements are used, actual volume flows over time can be estimated only for loading calculations, adding additional uncertainty to loading estimates.

Analyzing constituents of concern in a single grab sample collection provides the minimum information at the minimum cost. Such an approach, however, could be appropriate where conditions are relatively stable; for example, during periods without rainfall or other potential causes of significant runoff and when the stream is well-mixed. Most often, the usual method is to collect a random or regular series of grab samples at predefined intervals during storm or runoff events.

When samples are collected often enough, such that concentration changes between samples are minimized, a clear pattern or time series for the pollutant's concentration dynamics can be obtained. When sampling intervals are spaced too far apart in relation to changes in the pollutant concentration, less clear understanding of these relationships is obtained. Mixing samples from adjacent sampling events or regions (compositing) requires fewer samples to be analyzed; for some assessments, this is a reasonable approach. Sample compositing provides a savings, especially related to costs for water quality analyses, but it also results in loss of information. For example, information on maximum and minimum concentrations during a runoff event is usually lost. But compositing many samples collected through multiple periods during the events can help ensure that the samples analyzed do not include only extreme conditions that are not entirely representative of the event.

Even though analytical results from composited samples rarely equal average conditions for the event, they can still be used, when a sufficient distribution of samples is included, to provide reasonably representative conditions for computing loading estimates. In some analyses, however, considerable errors can be made when using analytical results from composited samples in completing loading analyses. For example, when maximum pollutant concentrations accompany the maximum flow rates, yet concentrations in high and low flows are treated equally, true loadings can be underestimated.

Consequently, when relationships between flow and pollutant concentrations are unknown, it is often preferable initially to include in the monitoring plan at least three discrete or multiple composite sample collections: during the initial period of increasing flow, during the period of the peak or plateau flow, and during the period of declining flow.

The most useful method for sample compositing is to combine samples in relation to the flow volume occurring during study period intervals. There are two variations for accomplishing flow-weighted compositing:

1. Collect samples at equal time intervals at a volume proportional to the flow rate (e.g., collect 100 mL of sample for every 100 gallons of flow that passed during a 10-minute interval) or
2. Collect equal-volume samples at varying times proportional to the flow (e.g., collect a 100-mL sample for each 100 gallons of flow, irrespective of time).

The second method is preferable for estimating load accompanying wet weather flows, since it results in samples being collected most often when the flow rate is highest.

Another compositing method is time-composited sampling, where equal sample volumes are collected at equally spaced time intervals (e.g., collect 100 mL of sample every 10 minutes during the monitored event). This approach provides information on the average conditions at the sampling point during the sampling period. It should be used, for example, to determine the average toxic concentrations to which resident aquatic biota are exposed during the monitored event.

Field Analyses of Water Quality Samples

Concentrations of various water quality parameters may be monitored both in the field and in samples submitted to a laboratory (**Figure 7.35**). Some parameters, such as water temperature, must be obtained in the field. Parameters such as concentrations of specific synthetic organic chemicals require laboratory analysis. Other parameters, such as nutrient concentrations, can be measured by both field and laboratory analytical methods. For chemical constituents, field measurements generally should be considered as qualitative screening values since rigorous quality control is not possible. In addition, samples collected for compliance with Clean Water Act requirements must be analyzed by a laboratory certified by the appropriate authority, either the state or the USEPA. The laboratories must use analytic techniques listed in the *Code of Federal Regulations* (CFR), Title 40, Part 136, "Guidelines Establishing Test Procedures for Analysis of Pollutants Under the Clean Water Act."

The balance of this subsection notes special considerations regarding those parameters typically sampled and analyzed in the field, including pH, temperature, and dissolved oxygen (DO).

pH

Levels of pH can change rapidly in samples after collection. Consequently, pH often is measured in the field using a hand-held pH electrode and meter. Electrodes are easily damaged and contaminated and must be calibrated with a standard solution before each use. During calibrations and when site measurements are conducted, field instruments should be at thermal equilibrium with the solutions being measured.

Temperature

Because water temperature changes rapidly after collection, it must be measured either in the field (using in situ probes) or immediately after collecting a grab sample. EPA Method 170.1 describes procedures for thermometric determination of water temperature. Smaller streams often experience wide diurnal variations in temperature, as well as pH and DO. Many streams also experience vertical and longitudinal variability in temperature from shading and flow velocity. Because of the effect of temperature on other water quality factors, such as dissolved oxygen concentration, tempera-

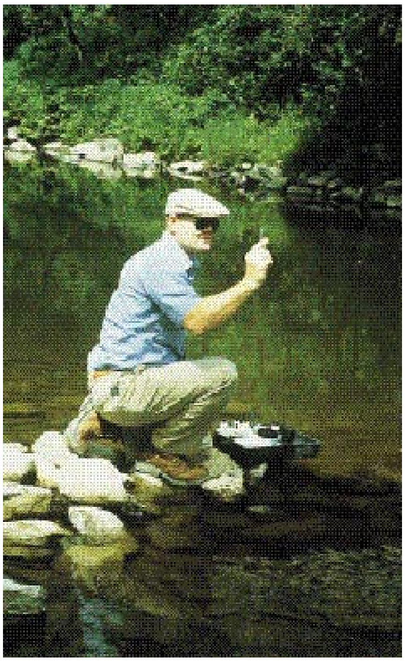


Figure 7.35: Field sampling. *Sampling can also be automated.*

tures always should be recorded when other field measurements are made.

Dissolved Oxygen

When multiple DO readings are required, a DO electrode and meter (EPA method 360.1) are typically used. To obtain accurate measurements, the Winkler titration method should be used to calibrate the meter before and after each day's use. Often it is valuable to recheck the calibration during days of intensive use, particularly when the measurements are of critical importance.

Oxygen electrodes are fragile and subject to contamination, and they need frequent maintenance. Membranes covering these probes must be replaced when bubbles form under the membrane, and the electrode should be kept full of fresh electrolyte solution. If the meter has temperature and salinity compensation controls, they should be used carefully, according to the manufacturer's instructions.

Water Quality Sample Preparation and Handling for Laboratory Analysis

Sample collection, preparation, preservation, and storage guidelines are designed to minimize altering sample constituents. Containers must be made of materials that will not interact with pollutants in the sample, and they should be cleaned in such a way that neither the container nor the cleaning agents interfere with sample analysis. Sometimes, sample constituents must be preserved before they degrade or transform prior to analysis. Also, specified holding times for the sample must not be exceeded. Standard procedures for collecting, preserving, and storing samples are presented in APHA (1995) and at 40 CFR Part 136. Useful material also is contained in the USEPA *NPDES Storm Water Sampling Guidance Document* (1992a).

Most commercial laboratories provide properly cleaned sampling containers with appropriate preservatives. The laboratories also usually indicate the maximum allowed holding periods for each analysis. Acceptable procedures for cleaning sample bottles, preserving their contents, and analyzing for appropriate chemicals are detailed in various methods manuals, including APHA (1995) and USEPA (1979a). Water samplers, sampling hoses, and sample storage bottles always should be made of materials compatible with the goals of the study. For example, when heavy metals are the concern, bottles should not have metal components that can contaminate the collected water samples. Similarly, when organic contaminants are the concern, bottles and caps should be made of materials not likely to leach into the sample.

Sample Preservation, Handling, and Storage

Sample preservation techniques and maximum holding times are presented in APHA (1995) and 40 CFR Part 136. Cooling samples to a temperature of 4 degrees Celsius (°C) is required for most water quality variables. To accomplish this, samples are usually placed in a cooler containing ice or an ice substitute. Many automated samplers have a well next to the sample bottles to hold either ice or ice substitutes. Some more expensive automated samplers have refrigeration equipment requiring a source of electricity. Other preservation techniques include pH adjustment and chemical fixation. When needed, pH adjustments are usually made using strong acids and bases, and extreme care should be exercised when handing these substances.

Bacterial analysis may be warranted, particularly where there are concerns regarding inputs of sewage and other wastes or fecal contamination. Bacterial samples have a short holding time and are not collected by automated sampler. Similarly, volatile compounds must be collected by grab sample, since they are lost through volatilization in automatic sampling equipment.

Sample Labeling

Samples should be labeled with waterproof labels. Enough information should be recorded to ensure that each sample label is unique. The information recorded on sample container labels also should be recorded in a sampling notebook kept by field personnel. The label typically includes the following information:

- Name of project.
- Location of monitoring.
- Specific sample location.
- Date and time of sample collection.
- Name or initials of sampler.
- Analysis to be performed.
- Sample ID number.
- Preservative used.
- Type of sample (grab, composite).

Sample Packaging and Shipping

It is sometimes necessary to ship samples to the laboratory. Holding times should be checked before shipment to ensure that they will not be exceeded. Although wastewater samples are not usually considered hazardous, some samples, such as those with extreme pH, require special procedures. If the sample is shipped through a common carrier or the U.S. Postal Service, it must comply with Department of Transportation Hazardous Material Regulations (49 CFR Parts 171-177). Air shipment of samples defined as hazardous may be covered by the requirements of the International Air Transport Association.

Samples should be sealed in leakproof bags and padded against breakage. Many samples must be packed with an ice substitute to maintain a temperature of 4 degrees C during shipment.

Plastic or metal recreational coolers make ideal shipping containers because they protect and insulate the samples. Accompanying paperwork, such as the chain-of-custody documentation, should be sealed in a waterproof bag in the shipping container.

Chain of Custody

Chain-of-custody forms document each change in possession of a sample, starting at its collection and ending when it is analyzed. At each transfer of possession, both the relinquisher and the receiver of the samples are required to sign and date the form. The form and the procedure document possession of the samples and help prevent tampering. The container holding samples also can be sealed with a signed tape or seal to help ensure that samples are not compromised.

Copies of the chain-of-custody form should be retained by the sampler and by the laboratory. Contract laboratories often supply chain-of-custody forms with sample containers. The form is also useful for documenting which analyses will be performed on the samples. These forms typically contain the following information:

- Name of project and sampling locations.
- Date and time that each sample is collected.
- Names of sampling personnel.
- Sample identification names and numbers.
- Types of sample containers.
- Analyses performed on each sample.
- Additional comments on each sample.
- Names of all those transporting the samples.

Collecting and Handling Sediment Quality Samples

Sediments are sinks for a wide variety of materials. Nonpoint source discharges typically include large quantities of suspended material that settle out in sections of receiving waters having low water velocities. Nutrients, metals, and organic compounds can bind to suspended solids and settle to the bottom of a water body when flow velocity is insufficient to keep them in suspension. Contaminants bound to sediments may remain separated from the water column, or they may be resuspended in the water column.

Flood scouring, bioturbation (mixing by biological organisms), desorption, and biological uptake all promote the release of adsorbed pollutants. Organisms that live and feed in sediment are especially vulnerable to contaminants in sediments. Having entered the food chain, contaminants can pass to feeders at higher food (trophic) levels and can accumulate or concentrate in these organisms. Humans can ingest these contaminants by eating fish.

Sediment deposition also can physically alter benthic (bottom) habitats and affect habitat and reproductive potentials for many fish and invertebrates. Sediment sampling should allow all these impact potentials to be assessed.

Collection Techniques

Sediment samples are collected using hand- or winch-operated dredges. Although a wide variety of dredges are available, most operate in the following similar fashion:

1. The device is lowered or pushed through the water column by hand or winch.
2. The device is released to allow closure, either by the attached line or by a weighted messenger that is dropped down the line.
3. The scoops or jaws of the device close either by weight or spring action.
4. The device is retrieved to the surface.

Ideally, the device disturbs the bottom as little as possible and closes fully so that fine particles are not lost. Common benthic sampling devices include the Ponar, Eckman, Peterson, Orange-peel, and Van Veen dredges. When information is needed about how chemical depositions and accumulations have varied through time, sediment cores can be collected with a core sampling device. Very low density or very coarse sediments can be sampled by freeze coring. A thorough description of sediment samplers is included in Klemm et al. (1990).

Sediment sampling techniques are useful for two types of investigations related to stream assessments: (1) chemical analysis of sediments and (2) investigation of benthic macroinvertebrate communities. In either type of investigation, sediments from reference stations should be sampled so that they can be compared with sediments in the affected receiving waters. Sediments used for chemical analyses should be removed from the dredge or core samples by scraping back the surface layers of the collected sediment and extracting sediments from the central mass of the collected sample. This helps to avoid possible contamination of the sample by the sample device. Sediment samples for toxicological and chemical examination should be collected following method E 1391 detailed in ASTM (1991). Sediments for benthic population analyses may be returned in total for cleaning and analysis or may receive a preliminary cleaning in the field using a No. 30 sieve.

Sediment Analyses

There are a variety of sediment analysis techniques, each designed with inherent assumptions about the behavior of sediments and sediment-bound contaminants. An overview of developing techniques is presented in Adams et al. (1992). EPA has evaluated 11 of the methods available for assessing sediment quality (USEPA 1989b). Some of the techniques may help to demonstrate attainment of narrative requirements of some water quality standards. Two of these common analyses are introduced briefly in the following paragraphs.

Bulk sediment analyses analyze the total concentration of contaminants that are either bound to sediments or present in pore water. Results are reported in milligrams or micrograms per kilogram of sediment material. This type of testing often serves as a screening analysis to classify dredged material. Results of bulk testing tend to overestimate the mass of contaminants that will be available for release or for biological uptake because a portion of the contaminants are not biologically available or likely to dissolve.

Elutriate testing estimates the amount of contaminants likely to be released from sediments when mixed with water. In an elutriate test, sediment is mixed with water and then agitated. The standard elutriate test for dredge material mixes four parts water from the receiving water body with one part sediment (USEPA 1990). After vigorous mixing, the sample is allowed to settle before the supernatant is filtered and analyzed for contaminants. This test was designed to estimate the amount of material likely to enter the dissolved phase during dredging; however, it is also useful as a screening test for determining whether further testing should be performed and as a tool for comparing sediments upstream and downstream of potential pollutant sources.

Data Management

All monitoring data should be organized and stored in a readily accessible form. The potentially voluminous and diverse nature of the data, and the variety of individuals who can be involved in collecting, recording, and entering data, can easily lead to the loss of data or the recording of erroneous data. Lost or erroneous data can severely damage the quality of monitoring programs. A sound and efficient data management program for a monitoring program should focus on preventing such problems. This requires that data be managed directly and separately from the activities that use them.

Data management systems include technical and managerial components. The technical components involve selecting appropriate computer equipment and software and designing the database, including data definition, data standardization, and a data dictionary. The managerial components include data entry, data validation and verification, data access, and methods for users to access the data.

To ensure the integrity of the database, it is imperative that data quality be controlled from the point of collection to the time the information is entered into the database. Field and laboratory personnel must carefully enter data into proper spaces on data sheets and avoid transposing numbers. To avoid transcription errors, entries into a database should be made from original data sheets or photocopies. As a preliminary screen for data quality, the database design should include automatic parameter range checking. Values outside the defined ranges should be flagged by the program and immediately corrected or included in a follow-up review of the entered data. For some parameters, it might be appropriate to include automatic checks to disallow duplicate values. Preliminary database files should be printed and verified against the original data to identify errors.

Additional data validation can include expert review of the verified data to identify possible suspicious values. Sometimes, consultation with the individuals responsible for collecting or entering original data is required to resolve problems. After all data are verified and validated, they can be merged into the monitoring program's master database. To prevent loss of data from computer failure, at least one set of duplicate (backup) database files should be maintained at a location other than where the master database is kept.

Quality Assurance and Quality Control (QA/QC)

Quality assurance (QA) is the management process to ensure the quality of data. In the case of monitoring projects, it is managing environmental data collection to ensure the collection of high-quality data. QA focuses on systems, policies, procedures, program structures, and delegation of responsibility that will result in high-quality data. Quality control (QC) is a group of specific procedures designed to meet defined data quality objectives. For example, equipment calibration and split samples are QC procedures. QA/QC procedures are essential to ensure that data collected in environmental monitoring programs are useful and reliable.

The following are specific QA plans required of environmental monitoring projects that receive funding from EPA:

- State and local governments receiving EPA assistance for environmental monitoring projects must complete a quality assurance program plan acceptable to the award official. Guidance for producing the program plan is contained in USEPA (1983d).
- Environmental monitoring projects that receive EPA funding must file a quality assurance project plan, or QAPP, (40 CFR 30.503), the purpose of which is to ensure quality of a specific project. The QAPP describes quality assurance practices designed to produce data of quality sufficient to meet project objectives. Guidance for producing the QAPP (formerly termed the QAPjP) is contained in USEPA (1983e). The plan must address the following items:
    - Title of project and names of principal investigators.
    - Table of contents.
    - Project description.
    - Project organization and QA/QC responsibility.
    - Quality assurance objectives and criteria for determining precision, accuracy, completeness, representativeness, and comparability of data.
    - Sampling procedures.
    - Sample custody.
    - Calibration procedures.
    - Analytical procedures.
    - Data reduction, validation, and reporting.
    - Internal quality control checks.
    - Performance and system audits.
    - Preventive maintenance procedures.
    - Specific routine procedures to assess data precision, accuracy, representativeness, and comparability.
    - Corrective action.
    - Quality assurance reports.

Sample and Analytical Quality Control

The following quality control techniques are useful in assessing sampling and analytic performance (see also USEPA 1979b, Horwitz et al. 1994):

- *Duplicate samples* are independent samples collected in such a manner that they are equally representative of the contaminants of interest. Duplicate samples, when analyzed by the same laboratory, provide precision information for the entire measurement system, including sample collection, homogeneity, handling, shipping, storage, preparation, and analysis.
- *Split samples* have been divided into two or more portions at some point in the measurement process. Split samples that are divided in the field yield results relating precision to handling, shipping, storage, preparation, and analysis. The split samples may be sent to different laboratories and subjected to the same measurement process to assess interlaboratory variation. Split samples serve an oversight function in assessing the analytical por-

tion of the measurement system, whereas error due to sampling technique may be estimated by analyzing duplicate versions of the same sample.

- *Spiked samples* are those to which a known quantity of a substance is added. The results of spiking a sample in the field are usually expressed as percent recovery of the added material. Spiked samples provide a check of the accuracy of laboratory and analytic procedures.

Sampling accuracy can be estimated by evaluating the results obtained from blanks. The most suitable types of blanks for this appraisal are equipment, field, and trip blanks.

- *Equipment blanks* are samples obtained by running analyte-free water through sample collection equipment, such as a bailer, pump, or auger, after decontamination procedures are completed. These samples are used to determine whether variation is introduced by sampling equipment.
- *Field blanks* are made by transferring deionized water to a sample container at the sampling site. Field blanks test for contamination in the deionized water and contamination introduced through the sampling procedure. They differ from trip blanks, which remain unopened in the field.
- *Trip blanks* test for cross-contamination during transit of volatile constituents, such as many synthetic organic compounds and mercury. For each shipment of sample containers sent to the analytical laboratory, one container is filled with analyte-free water at the laboratory and is sealed. The blanks are transported to the site with the balance of the sample containers and remain unopened. Otherwise, they are handled in the same manner as the other samples. The trip blanks are returned to the laboratory with the samples and are analyzed for the volatile constituents.

Field Quality Assurance

Errors or a lack of standardization in field procedures can significantly decrease the reliability of environmental monitoring data. If required, a quality assurance project plan should be followed for field measurement procedures and equipment. If the QAPP is not formally required, a plan including similar material should be developed to ensure the quality of data collected. Standard operating procedures should be followed when available and should be developed when not.

It is important that quality procedures be followed and regularly examined. For example, field meters can provide erroneous values if they are not regularly calibrated and maintained. Reagent solutions and probe electrolyte solutions have expiration periods and should be refreshed periodically.

7.D Biological Characteristics

Nearly all analytical procedures for assessing the condition of biological resources can be used in stream corridor restoration. Such procedures differ, however, in their scale and focus and in the assumptions, knowledge, and effort required to apply them. These procedures can be grouped into two broad classes—synthetic measures of system condition and analyses based on how well the system satisfies the life history requirements of target species or species groups.

The most important difference between these classes is the logic of how they are applied in managing or restoring a stream corridor system. This chapter focuses on metrics of biological conditions and does not describe, for example, actual field methods for counting organisms.

Synthetic Measures of System Condition

Synthetic measures of system condition summarize some aspect of the structural or functional status of a system at a particular point in time. Complete measurement of the state of a stream corridor system, or even a complete census of all of the species present, is not feasible. Thus, good indicators of system condition are efficient in the sense that they summarize the health of the overall system without having to measure everything about the system.

Use of indicators of system condition in management or restoration depends completely on comparison to values of the indicator observed in other systems or at other times. Thus, the current value of an indicator for a degraded stream corridor can be compared to a previously measured preimpact value for the corridor, a desired future value for the corridor, a value observed at an “unimpacted” reference site, a range of values observed in other systems, or a normative value for that class of stream corridors in a stream classification system. However, the indicator itself and the analysis that establishes the value of the indicator provide no direct information about what has caused the system to have a particular value for the indicator.

Deciding what to change in the system to improve the value of the indicator depends on a temporal analysis in which observed changes in the indicator in one system are correlated with various management actions or on a spatial analysis in which values of the indicator in different systems are correlated with different values of likely controlling variables. In both cases, no more than a general empirical correlation between specific causal factors and the indicator variable is attempted. Thus, management or restoration based on synthetic measures of system condition relies heavily on iterative monitoring of the indicator variable and trial and error, or adaptive management, approaches. For example, an index of species composition based on the presence or absence of a set of sensitive species might be generally correlated with water quality, but the index itself provides no information on how water quality should be improved. However, the success of management actions in improving water quality could be tracked and evaluated through iterative measurement of the index.

Synthetic measures of system condition vary along a number of important dimensions that determine their applicability. In certain situations, single species might be good indicators of some aspect of a stream corridor system; in others, community metrics, such as diversity, might be more suitable. Some indicators incorporate physical variables, and others do not. Measurements of processes and rates, such as primary productivity and channel meandering rates, are incorporated into some and not into others. Each of these dimensions must be evaluated relative to the objectives of the restoration effort to determine which, if any, indicator is most appropriate.

Indicator Species

Landres et al. (1988) define an indicator species as an organism whose characteristics (e.g., presence or absence, population density, dispersion, reproductive success) are used as an index of attributes too difficult, inconvenient, or expensive to measure for other species or environmental conditions of interest. Ecologists and management agencies have used aquatic and terrestrial indicator species for many years as assessment tools, the late 1970s and early 1980s being a peak interest period. During that time, Habitat Evaluation Procedures (HEP) were developed by the U.S. Fish and Wildlife Service, and the U.S. Forest Service's use of management indicator species was mandated by law with passage of the National Forest Management Act in 1976. Since that time, numerous authors have expressed concern about the ability of indicator species to meet the expectations expressed in the above definition. Most notably, Landres et al. (1988) critically evaluated the use of vertebrate species as ecological indicators and suggested that rigorous justification and evaluation are needed before the concept is used. The discussion of indicator species below is largely based on their paper.

The Good and Bad of Indicator Species

Indicator species have been used to predict environmental contamination, population trends, and habitat quality; however, their use in evaluating water quality is not covered in this section. The assumptions implicit in using indicators are that if the habitat is suitable for the indicator it is also suitable for other species (usually in a similar ecological guild) and that wildlife populations reflect habitat conditions. However, because each species has unique life requisites, the relationship between the indicator and its guild may not be completely reliable, although the literature is inconsistent in this regard (see Riparian Response Guilds subsection below). It is also difficult to include all the factors that might limit a population when selecting a group of species that an indicator is expected to represent. For example, similarities in breeding habitat between the indicator and its associates might appear to group species when in fact differences in predation rates, disease, or winter habitat actually limit populations.

Some management agencies use vertebrate indicators to track changes in habitat condition or to assess the influence of habitat alteration on selected species. Habitat suitability indices and other habitat models are often used for this purpose, though the metric chosen to measure a species' response to its habitat can influence the outcome of the investigation. As Van Horne (1983) pointed out, density and other abundance metrics may be misleading indicators of habitat quality. Use of diversity and other indices to estimate habitat quality also creates problems when the variation in measures yields an average value for an index that might not represent either extreme.

Selecting Indicators

Landres et al. (1988) suggest that if the decision is made to use indicators, then several factors are important to consider in the selection process:

- Sensitivity of the species to the environmental attribute being evaluated. When possible, data that suggest a cause-and-effect relationship are preferred to correlates (to ensure the indicator reflects the variable of interest and not a correlate).
- Indicator accurately and precisely responds to the measured effect. High variation statistically limits the ability to detect effects. Generalist species do not reflect change as well as more sensitive endemics. However, because specialists usually have lower populations, they might not be the best for cost-effective sampling. When the goal of monitoring is to evaluate on-site conditions, using indicators that

Stream Visual Assessment Protocol

This is another assessment tool that provides a basic level of stream health evaluation. It is intended to be the first level in a four-part hierarchy of assessment protocols that facilitate planning stream restorations. Scores are assigned by the planners for the following:

- Channel condition
- Hydrologic alteration
- Riparian zone width
- Bank stability
- Canopy cover
- Water appearance
- Nutrient enrichment
- Manure presence
- Salinity
- Barriers to fish movement
- Instream fish cover
- Pools
- Riffle quality
- Invertebrate habitat
- Macroinvertebrates observed

The planning assessment concludes with narratives of the suspected causes of observed problems, as well as recommendations or further steps in the planning process (USDA-NRCS 1998).

occur only within the site makes sense. However, although permanent residents may better reflect local conditions, the goal of many riparian restoration efforts is to provide habitat for neotropical migratory birds. In this case, residents such as cardinals or woodpeckers might not serve as good indicators for migrating warblers.

- Size of the species home range. If possible, the home range should be larger than that of other species in the evaluation area. Management agencies often are forced to use high-profile game or threatened and endangered species as indicators. Game species are often poor indicators simply because their populations are highly influenced by hunting mortality, which can mask environmental effects. Species with low populations or restrictions on sampling methods, such as threatened and endangered species, are also poor indicators because they are difficult to sample adequately, often due to budget constraints. For example, Verner (1986) found that costs to detect a 10 percent change in a randomly sampled population of pileated woodpeckers would exceed a million dollars per year.
- Response of an indicator species to an environmental stressor cannot be expected to be consistent across varying geographic locations or habitats without corroborative research.

Riparian Response Guilds

Vertebrate response guilds as indicators of restoration success in riparian ecosystems may be a valuable monitoring tool but should be used with the same cautions presented above. Croonquist and Brooks (1991) evaluated the effects of anthropogenic disturbances on small mammals and birds along Pennsylvania waterways. They evaluated species in five different response guilds, including wetland dependency, trophic level, species status (endangered, recreational, native, exotic), habitat specificity, and seasonality (birds).

They found that community coefficient indices were better indicators than species richness. The habitat specificity and seasonality response guilds for birds were best able to distinguish those species sensitive to disturbance from those which were not affected or were benefited. Neotropical migrants and species with specific habitat requirements were the best predictors of disturbance. Edge and exotic species were greater in abundance in the disturbed habitats and might serve as good indicators there. Seasonality analysis showed migrant breeders were more common in undisturbed areas, which, as suggested by Verner (1984), indicates the ability of guild analysis to distinguish local impacts. Mammalian response guilds did not exhibit any significant sensitivity to disturbance and were considered unsuitable as indicators.

In contrast, Mannan et al. (1984) found that in only one of the five avian guilds tested was the density of birds consistent across managed and undisturbed forests. In other words, population response to restoration might not be consistent across different indicator guilds. Also, periodically monitoring restoration initiatives is necessary to document when, during the recovery stage, the more sensitive species outcompete generalists.

Aquatic Invertebrates

Aquatic invertebrates have been used as indicators of stream and riparian health for many years. Perhaps more than other taxa, they are closely tied to both aquatic and riparian habitat. Their life cycles usually include periods in and out of the water, with ties to riparian vegetation for feeding, pupation, emergence, mating, and egg laying (Erman 1991).

It is often important to look at the entire assemblage of aquatic invertebrates as an indicator group. Impacts to a stream often decrease diversity but might increase the abundance of some species, with the size of the first species to be affected often larger (Wallace and Gurtz 1986). In summary, a good indicator species should be low on the food chain to respond quickly, should have a narrow tolerance to change, and should be a native species (Erman 1991).

Diversity and Related Indices

Biological diversity refers to the number of species in an area or region and includes a measure of the variety of species in a community that takes into account the relative abundance of each species (Ricklefs 1990). When measuring diversity, it is important to clearly define the biological objectives, stating exactly what attributes of the system are of concern and why (Schroeder and Keller 1990). Different measures of diversity can be applied at various levels of complexity, to different taxonomic groups, and at distinct spatial scales. Several factors should be considered in using diversity as a measure of system condition for stream corridor restoration.

Levels of Complexity

Diversity can be measured at several levels of complexity—genetic, population/species, community/ecosystem, and landscape (Noss 1994). There is no single correct level of complexity to use because different scientific or management issues are focused on different levels (Meffe et al. 1994). The level of complexity chosen for a specific stream corridor restoration initiative should be determined based on careful consideration of the biological objectives of the project.

Subsets of Concern

Overall diversity within any given level of complexity may be of less concern than diversity of a particular subset of species or habitats. Measures of overall diversity include all of the elements of concern and do not provide information about the occurrence of specific elements. For example, measures of overall species diversity do not provide information about the presence of individual species or species groups of management concern.

Any important subsets of diversity should be described in the process of setting biological objectives. At the community level, subsets of species of interest might include native, endemic, locally rare or threatened, specific guilds (e.g., cavity users), or taxonomic groups (e.g., amphibians, breeding birds, macroinvertebrates). At the terrestrial landscape level, subsets of diversity could include forest types or seral stages (Noss 1994). Thus, for a specific stream corridor project, measurement of diversity may be limited to a target group of special concern. In this manner, comparison of diversity levels becomes more meaningful.

Spatial Scale

Diversity can be measured within the bounds of a single community, across community boundaries, or in large areas encompassing many communities. Diversity within a relatively homogeneous community is known as alpha diversity. Diversity between communities, described as the amount of differentiation along habitat gradients, is termed beta diversity. The total diversity across very large landscapes is gamma diversity. Noss and Harris (1986) note that management for alpha diversity may increase local species richness, while the regional landscape (gamma diversity) may become more homogeneous and less diverse overall. They recommend a goal of maintaining the regional species pool in an approximately natural relative abundance pattern. The specific size of the area of concern should be defined when diversity objectives are established.

Measures of Diversity

Magurran (1988) describes three main categories of diversity measures—richness indices, abundance models, and indices based on proportional abundance. Richness indices are measures of the number of species (or other element of diversity) in a specific sampling unit and are the most widely used indices (Magurran 1988). Abundance models account for the evenness (equitability) of distribution of species and fit various distributions to known models, such as the geometric series, log series, lognormal, or broken stick. Indices based on the proportional abundance of species combine both richness and evenness into a single index. A variety of such indices exist, the most common of which is the Shannon-Weaver diversity index (Krebs 1978):

$$H = -\Sigma p_i \log_e p_i$$

where

H = index of species diversity

S = number of species

p_i = proportion of total sample belonging to the ith species

Results of most studies using diversity indices are relatively insensitive to the particular index used (Ricklefs 1979). For example, bird species diversity indices from 267 breeding bird censuses were highly correlated ($r = 0.97$) with simple counts of bird species richness (Tramer 1969). At the species level, a simple measure of richness is most often used in conservation biology studies because the many rare species that characterize most systems are generally of greater interest than the common species that dominate in diversity indices and because accurate population density estimates are often not available (Meffe et al. 1994).

Simple measures of species richness, however, are not sensitive to the actual species composition of an area. Similar richness values in two different areas may represent very different sets of species. The usefulness of these measures can be increased by considering specific subsets of species of most concern, as mentioned above. Magurran (1988) recommends going beyond the use of a single diversity measure and examining the shape of the species abundance distribution as well. Breeding bird census data from an 18-hectare (ha) riparian deciduous forest habitat in Ohio (Tramer 1996) can be used to illustrate these different methods of presentation (**Figure 7.36**). Breeding bird species richness in this riparian habitat was 38.

Pielou (1993) recommends the use of three indices to adequately assess diversity in terrestrial systems:

- A measure of plant species diversity.
- A measure of habitat diversity.
- A measure of local rarity.

Other indices used to measure various aspects of diversity include vegetation measures, such as foliage height diversity (MacArthur and MacArthur 1961), and landscape measures, such as fractal dimension, fragmentation indices, and juxtaposition (Noss 1994).

Related Integrity Indices

Karr (1981) developed the Index of Biotic Integrity to assess the diversity and health of aquatic communities. This index is designed to assess the present status of the aquatic community using fish community parameters related to species composition, species richness, and ecological factors. Species composition and richness parameters may include the presence of intolerant species, the richness and composition of specific species groups (e.g., darters), or the proportion of specific groups (e.g., hybrid individuals). Ecological parameters may include the proportion of top carnivores, number of individuals, or proportion with disease or other anomalies. Key parameters are developed for the stream system of interest, and each parameter is assigned a rating. The overall rating of a stream is used to evaluate the quality of the aquatic biota.

Rapid Bioassessment

Rapid bioassessment techniques are most appropriate when restoration goals are nonspecific and broad, such as improving the overall aquatic community or establishing a more balanced and diverse community in the stream corridor. Bioassessment often refers to use of biotic indices or composite analyses, such as those used by Ohio EPA (1990), and rapid bioassessment protocols (RBP), such as those documented by Plafkin et al. (1989). Ohio EPA evaluates biotic integrity by using an invertebrate community index (ICI) that emphasizes structural attributes of invertebrate communities and compares the sample community with a reference or control community. The ICI is based on 10 metrics that describe different taxonomic and pollution tolerance relationships within the macroinvertebrate community. The RBP established by USEPA (Plafkin et al. 1989) were developed to provide states with the technical information necessary for conducting cost-effective biological assessments. The RBP are divided into five sets of protocols (RBP I to V), three for macroinvertebrates and two for fish (**Table 7.8**).

Species Sequence	Species	Abundance in 18-ha Plot
1	American robin	18.5
2	House wren	13
3	Gray catbird	10.5
4	Song sparrow	9.5
5	Northern cardinal	7.5
6	Baltimore oriole	7
7	Warbling vireo	8
8	Wood thrush	4.5
9	Common grackle	4.5
10	Eastern wood-pewee	4
11	Red-eyed vireo	4
12	Indigo bunting	4
13	Red-winged blackbird	4
14	Mourning dove	3
15	Northern flicker	3
16	Blue jay	3
17	Tufted titmouse	3
18	White-breasted nuthatch	3
19	American redstart	3
20	Rose-breasted grosbeak	3
21	Downy woodpecker	2
22	Great crested flycatcher	2
23	Black-capped chickadee	2
24	Carolina wren	2
25	European starling	2
26	Yellow warbler	2
27	Brown-headed cowbird	2
28	American goldfinch	2
29	Wood duck	1
30	Ruby-throated hummingbird	1
31	Red-bellied woodpecker	1
32	Hairy woodpecker	1
33	Tree swallow	1
34	Blue-gray gnatcatcher	1
35	Prothonotary warbler	1
36	Common yellowthroat	1
37	Eastern phoebe	1
38	N. rough-winged swallow	1

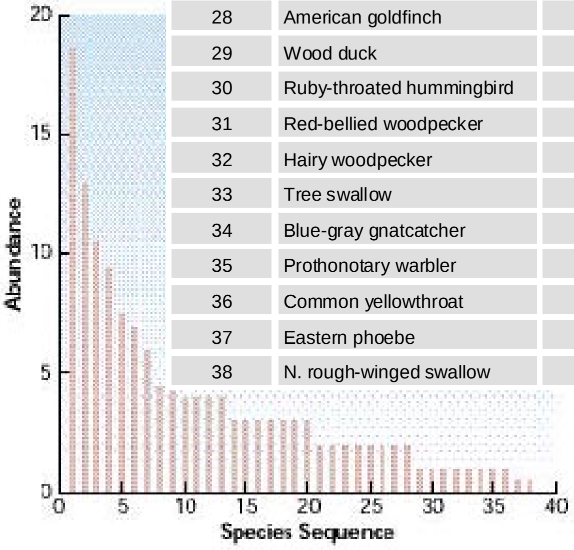


Figure 7.36: Breeding bird census data. *Species abundance curve in a riparian deciduous forest habitat.*
Source: Tramer 1996.

Algae

Although not detailed by Plafkin et al. (1989), algal communities are useful for bioassessment. Algae generally have short life spans and rapid reproduction rates, making them useful for evaluating short-term impacts. Sampling impacts are minimal to resident biota, and collection requires little effort. Primary productivity of algae is affected by physical and chemical impairments. Algal communities are sensitive to some pollutants that might not visibly affect other aquatic communities. Algal communities can be examined for indicator species, diversity indices, taxa richness, community respiration, and colonization rates. A variety of nontaxonomic evaluations, such as biomass and chlorophyll, may be used and are summarized in Weitzel (1979). Rodgers et al. (1979) describe functional measurements of algal communities, such as primary productivity and community respiration, to evaluate the effects of nutrient enrichment.

Although collecting algae in streams requires little effort, identifying for metrics, such as diversity indices and taxa richness, may require considerable effort. A great deal of effort may be expended to document diurnal and seasonal variations in productivity.

Benthic Macroinvertebrates

The intent of the benthic rapid bioassessment is to evaluate overall biological condition, optimizing the use of the benthic community's capacity to reflect integrated environmental effects over time. Using benthic macroinvertebrates is advantageous for the following reasons:

- They are good indicators of localized conditions.
- They integrate the effects of short-term environmental variables.
- Degraded conditions are easily detected.
- Sampling is relatively easy.
- They provide food for many fish of commercial or recreational importance.
- Macroinvertebrates are generally abundant.
- Many states already have background data.

As indicated above, the RBP are divided into three sets of protocols (RBP I to III) for macroinvertebrates. RBP I is a "screening" or reconnaissance-level analysis used to discriminate obviously impaired and nonimpaired sites from potentially affected areas requiring further investigation. RBP II and III use a set of metrics based on taxon tolerance and community structure similar to the ICI used by the state of Ohio. Both are more labor-intensive than RBP I and incorporate field sampling. RBP II uses family-level taxonomy to determine the following set of metrics used in describing the biotic integrity of a stream:

- Taxa richness.

Table 7.8: Five tiers of the rapid bioassessment protocols. *RBPs are used to conduct cost-effective biological assessments.*
Source: Plafkin et al. 1989.

Level or Tier	Organism Group	Relative Level of Effort	Level of Taxonomy /Where Performed	Level of Expertise Required
I	Benthic invertebrates	Low; 1-2 hr per site (no standardized sampling)	Order, family/field	One highly-trained biologist
II	Benthic invertebrates	Intermediate; 1.5-2.5 hr per site (all taxonomy performed in field)	Family/field	One highly-trained biologist and one technician
III	Benthic invertebrates	Most rigorous; 3-5 hr per site (2-3 hr of total are for lab taxonomy)	Genus or species/laboratory	One highly-trained biologist and one technician
IV	Fish	Low; 1-3 hr per site (no fieldwork involved)	Not applicable	One highly-trained biologist
V	Fish	Most rigorous; 2-7 hr per site (1-2 hr per site are for data analysis)	Species/field	One highly-trained biologist and 1-2 technicians

- Hilsenhoff biotic index (Hilsenhoff 1988).
- Ratio of scrapers to filtering collectors.
- Ratio of Ephemeroptera/Plecoptera/Trichoptera (EPT) and chironomid abundances.
- Percent contribution of dominant taxa.
- EPT index.
- Community similarity index.
- Ratio of shredders to total number of individuals.

RBP III further defines the level of biotic impairment and is essentially an intensified version of RBP II that uses species-level taxonomy. As with ICI, the RBP metrics for a site are compared to metrics from a control or reference site.

Fish

Hocutt (1981) states "perhaps the most compelling ecological factor is that structurally and functionally diverse fish communities both directly and indirectly provide evidence of water quality in that they incorporate all the local environmental perturbations into the stability of the communities themselves."

The advantages of using fish as bioindicators are as follows:

- They are good indicators of long-term effects and broad habitat conditions.
- Fish communities represent a variety of trophic levels.
- Fish are at the top of the aquatic food chain and are consumed by humans.
- Fish are relatively easy to collect and identify.
- Water quality standards are often characterized in terms of fisheries.
- Nearly one-third of the endangered vertebrate species and subspecies in the United States are fish.

The disadvantages of using fish as bioindicators are as follows:

- The cost.
- Statistical validity may be hard to attain.
- It is difficult to interpret findings.

Electrofishing is the most commonly used field technique. Each collecting station should be representative of the study reach and similar to other reaches sampled; effort between reaches should be equal. All fish species, not just game species, should be collected for the fish community assessment (**Figure 7.37**). Karr et al. (1986) used 12 biological metrics to assess biotic integrity using taxonomic and trophic composition and condition and abundance of fish. Although the Index of Biological Integrity (IBI) developed by Karr was designed for small midwestern streams, it has been modified for many regions of the country and for use in large rivers (see Plafkin et al. 1989).

Establishing a Standard of Comparison

With stream restoration activities, it is important to select a desired end condition for the proposed management action. A predetermined standard of comparison provides a benchmark against which to measure progress. For example, if the chosen diversity measure is native species richness, the standard of comparison might be the maximum expected native species richness for a defined geographic area and time period.

Historical conditions in the region should be considered when establishing a standard of comparison. If current conditions in a stream corridor are degraded, it may be best to establish the standard at a period in the past that represented more natu-

Figure 7.37: Fish samples. *Water quality standards are often characterized in terms of fisheries.*

ral or desired conditions. Knopf (1986) notes that for certain western streams, historical diversity might have been less than current due to changes in hydrology and encroachment of native and exotic riparian vegetation in the floodplain. Thus, it is important to agree on what conditions are desired prior to establishing the standard of comparison. In addition, the geographic location and size of the area should be considered. Patterns of diversity vary with geographic location, and larger areas are typically more diverse than smaller areas.

The IBI is scaled to a standard of comparison determined through either professional judgment or empirical data, and such indices have been developed for a variety of streams (Leonard and Orth 1986, Bramblett and Fausch 1991, Lyons et al. 1996).

Evaluating the Chosen Index

For a hypothetical stream restoration initiative, the following biological diversity objective might be developed. Assume that a primary concern in the area is conserving native amphibian species and that 30 native species of amphibians have been known to occur historically in the 386 m^2 watershed. The objective could be to manage the stream corridor to provide and maintain suitable habitat for the 30 native amphibian species.

Stream corridor restoration efforts must be directed toward those factors that can be managed to increase diversity to the desired level. Those factors might be the physical and structural features of the stream corridor or possibly the presence of an invasive species in the community. Knowledge of the important factors can be obtained from existing literature and from discussions with local and regional experts.

Diversity can be measured directly or predicted from other information. Direct measurement requires an actual inventory of the element of diversity, such as counting the amphibian species in the study area. The IBI requires sampling fish populations to determine the number and composition of fish species. Measures of the richness of a particular animal group require counts. Determining the number of species in a community is best accomplished with a long-term effort because there can be much variation over short periods. Variation can arise from observer differences, sampling design, or temporal variation in the presence of species.

Direct measures of diversity are most helpful when baseline information is available for comparing different sites. It is not possible, however, to directly measure certain attributes, such as species richness or the population level of various species, for various future conditions. For example, the IBI cannot be directly computed for a predicted stream corridor condition, following management action.

Predictions of diversity for various future conditions, such as with restoration or management, require the use of a predictive model. Assume the diversity objective for a stream corridor restoration effort is to maximize native amphibian species richness. Based on knowledge of the life history of the species, including requirements for habitat, water quality, or landscape configuration, a plan can be developed to restore a stream corridor to meet these needs. The plan could include a set of criteria or a model to describe the specific features that should be included to maximize amphibian richness. Examples of indirect methods to assess diversity include habitat models (Schroeder and Allen 1992, Adamus 1993) and cumulative impact assessment methods (Gosselink et al. 1990, Brooks et al. 1991).

Predicting diversity with a model is generally more rapid than directly measuring diversity. In addition, predictive methods provide a means to analyze alternative future conditions before implementing specific restoration plans. The reliability and accuracy of diversity models should be established before their use.

Classification Systems

Classification is an important component of many of the scientific disciplines relevant to stream corridors—hydrology, geomorphology, limnology, plant and animal ecology. **Table 7.9** lists some of the classification systems that might be useful in identifying and planning riverine restoration activities. It is not the intent of this section to exhaustively review all classification schemes or to present a single recommended classification system. Rather, we focus on some of the principal distinctions among classification systems and factors to consider in the use of classification systems for restoration planning, particularly in the use of a classification system as a measure of biological condition. It is likely that multiple systems will be useful in most actual riverine restoration programs.

The common goal of classification systems is to organize variation. Important dimensions in which riverine classification systems differ include the following:

- *Geographic domain*. The range of sites being classified varies from rivers of the world to local differences in the composition and characteristics of patches within one reach of a single river.
- *Variables considered.* Some classifications are restricted to abiotic variables of hydrology, geomorphology, and aquatic chemistry. Other community classifications are restricted to biotic variables of species composition and abundance of a limited number of taxa. Many classifications include both abiotic and biotic variables. Even purely abiotic classification systems are relevant to biological evaluations because of the important correlations (e.g., the whole concept of physical habitat) between abiotic structure and community composition.
- *Incorporation of temporal relations.* Some classifications focus on describing correlations and similarities across sites at one, perhaps idealized, point in time. Other classifications identify explicit temporal transitions among classes, for example, succession of biotic communities or evolution of geomorphic landforms.
- *Focus on structural variation or functional behavior.* Some classifications emphasize a parsimonious description of observed variation in the classification variables. Others use

classification variables to identify types with different behaviors. For example, a vegetation classification can be based primarily on patterns of species co-occurrence, or it can be based on similarities in functional effect of vegetation on habitat value.

- The extent to which management alternatives or human actions are explicitly considered as classification variables. To the extent that these variables are part of the classification itself, the classification system can directly predict the result of a management action. For example, a vegetation classification based on grazing intensity would predict a change from one class of vegetation to another class based on a change in grazing management.

Use of Classification Systems in Restoring Biological Conditions

Restoration efforts may apply several national and regional classification systems to the riverine site or sites of interest because these are efficient ways to summarize basic site description and inventory information and they can facilitate the transference of existing information from other similar systems.

Most classification systems are generally weak at identifying causal mechanisms. To varying degrees, classification systems identify variables that efficiently describe existing conditions. Rarely do they provide unequivocal assurance about how variables actually cause the observed conditions. Planning efficient and effective restoration actions generally requires a much more mechanistic analysis of how changes in controllable variables will cause changes toward desired values of response variables. A second limitation is that application of a classification system does not substitute for goal setting or design. Comparison of the degraded system to an actual unimpacted reference site, to the ideal type in a classification system, or to a range of similar systems can provide a framework for articulating the desired state of the degraded system. However, the desired state of the system is a management objective that ultimately comes from outside the classification of system variability.

Analyses of Species Requirements

Analyses of species requirements involve explicit statements of how variables interact to determine habitat or how well a system provides for the life requisites of fish and wildlife species. Complete specification of relations between all relevant variables and all species in a stream corridor system is not possible. Thus, analyses based on species requirements focus on one or more target species or groups of species. In a simple case, this type of analysis may be based on an explicit statement of the physical factors that distinguish good habitat for a species (places where it is most likely to be found or where it best reproduces) from poor habitat (places where it is unlikely to be found or reproduces poorly). In more complicated cases, such approaches incorporate variables beyond those of purely physical habitat, including other species that provide food or biotic structure, other species as competitors or predators, or spatial or temporal patterns of resource availability.

Analyses based on species requirements differ from synthetic measures of system condition in that they explicitly incorporate relations between "causal" variables and desired biological attributes. Such analyses can be used directly to decide what restoration actions will achieve a desired result and to evaluate the likely consequences of a proposed restoration action. For example, an analysis using

Table 7.9: Selected riverine and riparian classification systems. *Classification systems are useful in characterizing biological conditions.*

Classification System	Subject	Geographic Domain	Citation
Riparian vegetation of Yampa, San Miguel/Dolores River Basins	Plant communities	Colorado	Kittel and Lederer (1993)
Riparian and scrubland communities of Arizona and New Mexico	Plant communities	Arizona and New Mexico	Szaro (1989)
Classification of Montana riparian and wetland sites	Plant communities	Montana	Hansen et al. (1995)
Integrated riparian evaluation guide	Hydrology, geomorphology, soils, vegetation	Intermountain	U.S. Forest Service (1992)
Streamflow cluster analysis	Hydrology with correlations to fish and invertebrates	National	Pott and Ward (1989)
River Continuum	Hydrology, stream order, water chemistry, aquatic communities	International, national	Vannote et al. (1980)
World-wide stream classification	Hydrology, water chemistry, substrate, vegetation	International	Pennak (1971)
Rosgen's river classification	Hydrology, geomorphology: stream and valley types	National	Rosgen (1996)
Hydrogeomorphic wetland classification	Hydrology, geomorphology, vegetation	National	Brinson (1993)
Recovery classes following channelization	Hydrology, geomorphology, vegetation	Tennessee	Hupp (1992)

the habitat evaluation procedures might identify mast production (the accumulation of nuts from a productive fruiting season which serves as a food source for animals) as a factor limiting squirrel populations. If squirrels are a species of concern, at least some parts of the stream restoration effort should be directed toward increasing mast production. In practice, this logical power is often compromised by incomplete knowledge of the species habitat requirements.

The complexity of these methods varies along a number of important dimensions, including prediction of habitat suitability versus population numbers, analysis for a single place and single time versus a temporal sequence of spatially complex requirements, and analysis for a single target species versus a set of target species involving trade-offs. Each of these dimensions must be carefully considered in selecting an analysis procedure appropriate to the problem at hand.

The Habitat Evaluation Procedures (HEP)

Habitat evaluation procedures (HEP) can be used for several different types of habitat studies, including impact assessment, mitigation, and habitat management. HEP provides information for two general types of habitat comparisons— the relative value of different areas at the same point in time and the relative value of the same area at different points in time. Potential changes in wildlife (both aquatic and terrestrial) habitat due to proposed projects are characterized by combining these two types of comparisons.

Basic Concepts

HEP is based on two fundamental ecological principles—habitat has a definable carrying capacity, or suitability, to support or produce wildlife populations (Fretwell and Lucas 1970), and the suitability of habitat for a given wildlife species can be estimated using measurements of vegetative, physical, and chemical traits of the habitat. The suitability of a habitat for a given species is described by a habitat suitability index (HSI) constrained between 0 (unsuitable habitat) and 1 (optimum habitat). HSI models have been developed and published by the U.S. Fish and Wildlife Service (Schamberger et al. 1982; Terrell and Carpenter, in press), and USFWS (1981) provides guidelines for use in developing HSI models for specific projects. HSI models can be developed for many of the previously described metrics, including species, guilds, and communities (Schroeder and Haire 1993).

The fundamental unit of measure in HEP is the Habitat Unit, computed as follows:

$$HU = AREA \times HSI$$

where HU is the number of habitat units (units of area), AREA is the areal extent of the habitat being described (units of area), and HSI is the index of suitability of the habitat (unitless). Conceptually, an HU integrates the quantity and quality of habitat into a single measure, and one HU is equivalent to one unit of optimal habitat.

Use of HEP to Assess Habitat Changes

HEP provides an assessment of the net change in the number of HUs attributable to a proposed future action, such as a stream restoration initiative. A HEP application is essentially a two-step process—calculating future HUs for a particular project alternative and calculating the net change as compared to a base condition.

The steps involved in using and applying HEP to a management project are outlined in detail in USFWS (1980a). However, some early planning decisions often are given little attention although they may be the most important part of a HEP study. These initial decisions include forming a study team, defining the study boundaries, setting study objectives, and selecting the evaluation species. The study team usually consists of individuals representing different agencies and viewpoints. One member of the team is generally from the lead project planning agency and other members are from resources agencies with an interest in the resources that would be affected.

One of the first tasks for the team is to delineate the study area boundaries. The study area boundaries should be drawn to include any areas of direct impact, such as a flood basin for a new reservoir, and any areas of secondary impact, such as a downstream river reach that might have an altered flow, increased turbidity, or warmer temperature, or riparian or upland areas subject to land use changes as a result of an increased demand on recreational lands. Areas such as an upstream spawning ground that are not contiguous to the primary impact site also might be affected and therefore should be included in the study area.

The team also must establish project objectives, an often neglected aspect of project planning. Objectives should state what is to be accomplished in the project and specify an endpoint to the project. An integral aspect of objective setting is selecting evaluation species, the specific wildlife resources of concern for which HUs will be computed in the HEP analysis. These are often individual species, but they do not have to be. Depending on project objectives, species' life stages (e.g., juvenile salmon), species' life requisites (e.g., spawning habitat), guilds (e.g., cavity-nesting birds), or communities (e.g., avian richness in riparian forests) can be used.

Instream Flow Incremental Methodology

The Instream Flow Incremental Methodology (IFIM) is an adaptive system composed of a library of models that are linked to describe the spatial and temporal habitat features of a given river. IFIM is described in Chapter 5 under *Supporting Analysis for Selecting Restoration Alternatives*.

Physical Habitat Simulation

The Physical Habitat Simulation (PHABSIM) model was designed by the U.S. Fish and Wildlife Service primarily for instream flow analysis (Bovee 1982). It represents the habitat evaluation component of a larger instream flow incremental methodology for incorporating fish habitat consideration into flow management, presented in Chapter 5. PHABSIM is a collection of computer programs that allows evaluation of available habitat within a study reach for various life stages of different fish species. The two basic components of the model are hydraulic simulation (based on field-measured cross-sectional data) and several standard hydraulic methods for predicting water surface elevations and velocities at unmeasured discharges (e.g., stage vs. discharge relations, Manning's equation, step-backwater computations). Habitat simulation integrates species and life-stage-specific habitat suitability curves for water depth, velocity, and substrate with the hydraulic data. Output is a plot of weighted usable area (WUA) against discharge for the species and life stages of interest. (**Figure 7.38**)

The stream hydraulic component predicts depths and water velocities at unobserved flows at specific locations on a cross section of a stream. Field measurements of depth, velocity, substrate material, and cover at specific sampling points on a cross section are taken at different observable flows. Hydraulic measurements, such as water surface elevations, also are collected during the field inventory. These data are used to calibrate the hydraulic simulation models. The models then are used to predict depths and velocities at flows different from those measured.

The habitat component weights each stream cell using indices that assign a relative value between 0 and 1 for each habitat attribute (depth, velocity, substrate material, cover), indicating how suitable that attribute is for the life stage under consideration. These attribute indices are usually termed habitat suitability indices and are developed from direct observations of the attributes used most often by a life stage, from expert opinion about what the life requisites are, or a combination. Various approaches are taken to factor assorted biases out of these suitability data, but they remain indices that are used as weights of suitability. In the last step of the habitat component, hydraulic estimates of depth and velocity at different flow levels are combined with the suitability values for those attributes to weight the area of each cell at the simulated flows. The weighted values for all cells are summed to produce the WUA.

There are many variations on the basic approach outlined above, with specific analyses tailored for different water management phenomena (such as hydropeaking and unique spawning habitat needs), or for special habitat needs (such as bottom velocity instead of mean column velocity) (Milhous et al. 1989). However, the fundamentals of hydraulic and habitat modeling remain the same, resulting in a WUA versus discharge function. This function should be combined with the appropriate hydrologic time series (water availability) to develop an idea of what life states might be affected by a loss or gain of available habitat and at what time of the year. Time series analysis plays this role and also factors in any physical and institutional constraints on water management so that alternatives can be evaluated (Milhous et al. 1990).

REVERSE

Review Chapter 5's

Supporting Analysis for Selecting Restoration Alternatives

Several things must be remembered about PHABSIM. First, it provides an index to microhabitat availability; it is not a measure of the habitat actually used by aquatic organisms. It can be used only if the species under consideration exhibit documented preferences for depth, velocity, substrate material, cover, or other predictable microhabitat attributes in a specific environment of competition and predation. The typical application of PHABSIM assumes relatively steady flow conditions such that depths and velocities are comparably stable within the chosen time step. PHABSIM does not

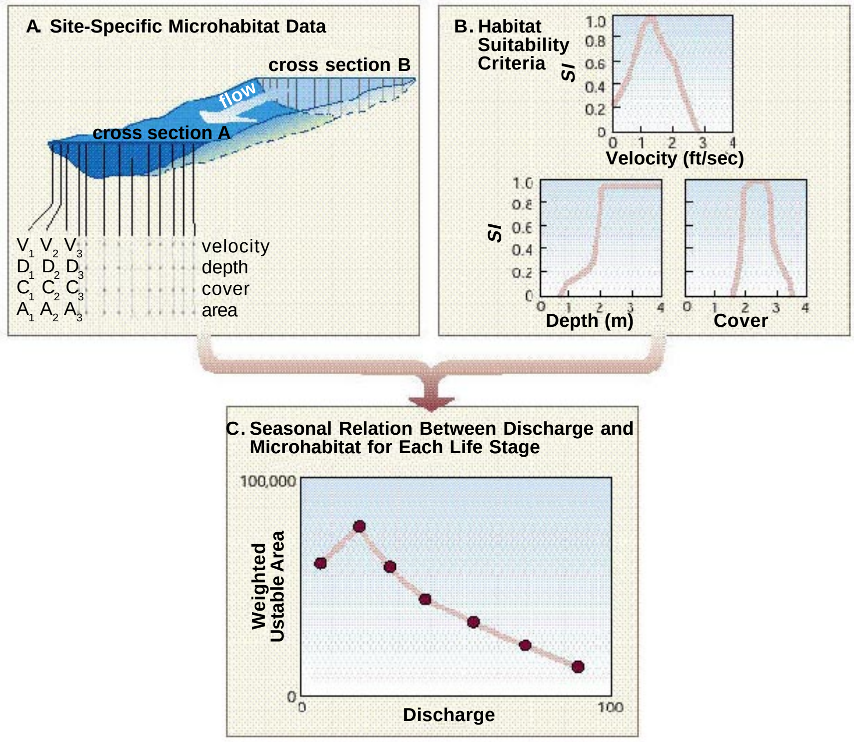


Figure 7.38: Conceptualization of how PHABSIM calculates habitat values as a function of discharge. *A. First, depth (Di), velocity (Vi), cover conditions (Ci), and area (Ai) are measured or simulated for a given discharge. B. Suitability index (SI) criteria are used to weight the area of each cell for the discharge. The habitat values for all cells in the study reach are summed to obtain a single habitat value for the discharge. C. The procedure is repeated for a range of discharges.*

Modified from Nestler et al. 1989.

predict the effects of flow on channel change. Finally, the field data and computer analysis requirements can be relatively large.

Two-dimensional Flow Modeling

Concern about the simplicity of the one-dimensional hydraulic models used in PHABSIM has led to current research interest in the use of more sophisticated two-dimensional hydraulic models to simulate physical conditions of depth and velocity for use in fish habitat analysis. A two-dimensional hydraulic model can be spatially adjusted to represent the scale of aquatic habitat and the variability of other field data. For example, the physical relationship between different aquatic habitat types is often a key parameter when considering fish habitat use. The spatial nature of two-dimensional flow modeling allows for the analysis of these relationships. The model can also consider the drying and wetting of intermittent stream channels.

Leclerc et al. (1995) used two-dimensional flow modeling to study the effect of a water diversion on the habitat of juvenile Atlantic salmon *(Salmo salar*) in the Moisie River in Quebec, Canada. Average model error was reduced when compared with traditional one-dimensional models. Output from the two-dimensional modeling was combined with habitat suitability indexes with finite element calculation techniques. Output from the analysis included maps displaying the spatial distribution of depth, velocity, and habitat suitability intervals.

Physical data collection for this modeling tool is intensive. Channel contour and bed material mapping is required along with discharge relationships and the upstream and downstream boundaries of each study reach. Velocity and water-surface measurements for various discharges are required for model calibration. Two-dimensional modeling does not address all of the issues related to hydrodynamics and flow modeling. Mobile bed systems and variability in Manning's coefficient are still problematic using this tool (Leclerc et al. 1995). Moderate to large rivers with a stable bedform are most suited to this methodology.

Riverine Community Habitat Assessment and Restoration Concept Model (RCHARC)

Another modeling approach to aquatic habitat restoration is the Riverine Community Habitat Assessment and Restoration (RCHARC) concept. This model is based on the assumption that aquatic habitat in a restored stream reach will best mimic natural conditions if the bivariate frequency distribution of depth and velocity in the subject channel is similar to a reference reach with good aquatic habitat. Study site and reference site data can be measured or calculated using a computer model. The similarity of the proposed design and reference reach is expressed with three-dimensional graphs and statistics (Nestler et al. 1993, Abt 1995). RCHARC has been used as the primary tool for environmental analysis on studies of flow management for the Missouri River and the Alabama-Coosa-Tallapoosa Apalachicola-Chatta-hoochee-Flint Basin.

Time Series Simulations

A relatively small number of applications have been made of time series simulations of fish population or individual fish responses to riverine habitat changes. Most of these have used PHABSIM to accomplish hydraulic model development and validation and hydraulic simulation, but some have substituted time-series simulations of individual or population responses for habitat suitability curve development and validation, and habitat suitability modeling. PHABSIM quantifies the relationship of hydraulic estimates (depth and velocity) and measurements (substrate and cover) with habitat suitability for target fish and invertebrate life stages or water-related recreation suitability. It is useful when relatively steady flow is the major determinant controlling riverine resources. Use of PHABSIM is generally limited to river systems in which dissolved oxygen, suspended sediment, nutrient loading, other chemical aspects of water quality, and interspecific competition do not place the major limits on populations of interest. These limitations to the use of PHABSIM can be abated or removed with models that simulate response of individual fish or fish populations.

Individual-based Models

The Electric Power Research Institute (EPRI) program on compensatory mechanisms in fish populations (CompMech) has the objective of improving predictions of fish population response to increased mortality, loss of habitat, and release of toxicants (EPRI 1996). This technique has been applied by utilities and resource management agencies in assessments involving direct mortality due to entrainment, impingement, or fishing; instream flow; habitat alteration (e.g., thermal discharge, water-level fluctuations, water diversions, exotic species); and ecotoxicity. Compensation is defined as the capacity of a population to self-mitigate decreased growth, reproduction, or survival of some individuals in the population by increased growth, reproduction, or survival of the remaining individuals. The CompMech approach over the past decade has been to represent in simulation models the processes underlying daily growth, reproduction, and survival of individual fish (hence the classification of individual-based models) and then to aggregate over individuals to the population level.

The models can be used to make short-term predictions of survival, growth, habitat utilization, and consumption for critical life stages. For the longer term, the models can be used to project population abundance through time to assess the risk that abundance will fall below some threshold requiring mitigation. For stream situations, several CompMech models have been developed that couple the hydraulic simulation method of PHABSIM directly with an individual-based model of reproduction and young-of-year dynamics, thereby eliminating reliance on the habitat-based component of PHABSIM (Jager et al. 1993). The CompMech model of smallmouth bass is being used to evaluate the effects of alternative flow regimes on nest success, growth, mortality, and ultimately year class strength in a Virginia stream to identify instream flows that protect fisheries with minimum impact on hydropower production.

A model of coexisting populations of rainbow and brown trout in California is being used to evaluate alternative instream flow and temperature scenarios (Van Winkle et al. 1996). Model predictions will be compared with long-term field observations before and after experimental flow increases; numerous scientific papers are expected from this intensive study.

An individual-based model of smolt production by Chinook salmon, as part of an environmental impact statement for the Tuolumne River in California, considered the minimum stream flows necessary to ensure continuation and maintenance of the anadromous fishery (FERC 1996). That model, the Oak Ridge Chinook salmon model (ORCM), predicts annual production of salmon smolts under specified reservoir minimum releases by evaluating critical factors, including influences on upstream migration of adults, spawning and incubation of eggs, rearing of young, and predation and mortality losses during the downstream migration of smolts. Other physical habitat analyses were used to supplement the population model in evaluating benefits of alternative flow patterns. These habitat evaluations are based on data from an instream flow study; a stream temperature model was used to estimate flows needed to maintain downstream temperatures within acceptable limits for salmon.

SALMOD

The conceptual and mathematical models for the Salmonid Population Model (SALMOD) were developed for Chinook salmon in concert with a 12-year flow evaluation study in the Trinity River of California using experts on the local river system and fish species in workshop settings (Williamson et al. 1993, Bartholow et al. 1993). SALMOD was used to simulate young-of-year production, assuming that the flow schedules to be evaluated were released from Lewiston Reservoir in every year from 1976 to 1992 (regardless of observed reservoir inflow, storage, and release limitations).

The structure of SALMOD is a middle ground between a highly aggregated classical population model that tracks cohorts/size groups for a generally large area without spatial resolution, and an individual-based model that tracks individuals at a great level of detail for a generally small area. The conceptual model states that fish growth, movement, and mortality are directly related to physical hydraulic habitat and water temperature, which in turn relate to the timing and amount of regulated streamflow. Habitat capacity is characterized by the hydraulic and thermal properties of individual mesohabitats, which are the model's spatial computational units.

Model processes include spawning (with redd superimposition), growth (including maturation), movement (freshet-induced, habitat-induced, and seasonal), and mortality (base, movement-related, and temperature-related). The model is limited to freshwater habitat for the first 9 months of life; estuarine and ocean habitats are not included. Habitat area is computed from flow/habitat area functions developed empirically. Habitat capacity for each life stage is a fixed maximum number per unit of habitat available. Thus, a maximum number of individuals for each computational unit is calculated for each time step based on streamflow and habitat type. Rearing habitat capacity is derived from empirical relations between available habitat area and number of individual fish observed.

Partly due to drought conditions, most of the flow alternatives to be evaluated did not actually occur during the flow evaluation study. When there is insufficient opportunity to directly observe and evaluate impacts of flow alternatives on fish populations, SALMOD can be used to simulate young-of-the-year production that may result from proposed flow schedules to be released or regulated by a control structure such as a reservoir or diversion.

Other physical habitat analyses can be used to supplement population models in evaluating benefits of alternative flow patterns. In the Trinity River Flow Study, a stream temperature model was used to estimate flows needed to maintain downstream temperatures within acceptable limits for salmon. Both the ORCM (FERC 1996) and SALMOD models concentrated on development, growth, movement, and mortality of young-of-year Chinook salmon but with different mechanistic inputs, spatial resolution, and temporal precision.

Vegetation-Hydroperiod Modeling

In most cases, the dominant factor that makes the riparian zone distinct from the surrounding uplands, and the most important gradient in structuring variation within the riparian zone, is site moisture conditions, or hydroperiod (**Figure 7.39**). Hydroperiod is defined as the depth, duration, and frequency of inundation and is a powerful determinant of what plants are likely to be found in various positions in the riparian zone. Formalizing this relation as a vegetation-hydroperiod model can provide a powerful tool for analyzing existing distributions of riparian vegetation, casting forward or backward in time to

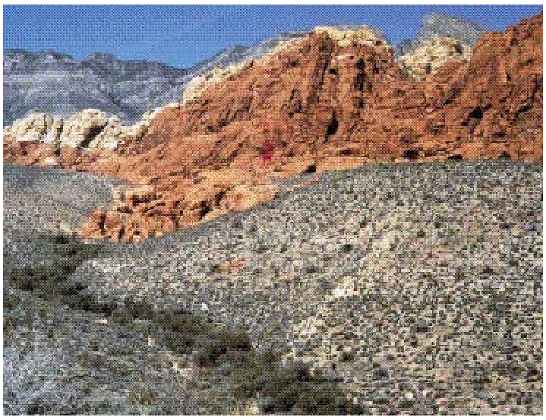


Figure 7.39: Vegetation/water relationship. *Soil moisture conditions often determine the plant communities in riparian areas.*
Source: C. Zabawa.

FAST FORWARD
Preview Chapter 8's Information on vegetation-hydroperiod model.

alternative distributions, and designing new distributions. The suitability of site conditions for various species of plants can be described with the same conceptual approach used to model habitat suitability for animals. The basic logic of a vegetation-hydroperiod model is straightforward. How wet a site is has a lot to do with what plants typically grow on the site. It is possible to measure how wet a site is and, more importantly, to predict how wet a site will be based on the relation of the site to a stream. From this, it is possible to estimate what vegetation is likely to occur on the site.

Components of a Vegetation-hydroperiod Model

The two basic elements of the vegetation- hydroperiod relation are the physical conditions of site moisture at various locations and the suitability of those sites for various plant species. In the simplest case of describing existing patterns, site moisture and vegetation can be directly measured at a number of locations. However, to use the vegetation- hydroperiod model to predict or design new situations, it is necessary to predict new site moisture conditions. The most useful vegetation-hydroperiod models have the following three components:

- *Characterization of the hydrology or pattern of streamflow.* This can take the form of a specific sequence of flows, a summary of how often different flows occur, such as a flow duration or flood frequency curve, or a representative flow value, such as bankfull discharge or mean annual discharge.
- *A relation between streamflow and moisture conditions at sites in the riparian zone.* This relation can be measured as the water surface elevation at a variety of discharges and summarized as a stage vs. discharge curve. It can also be calculated by a number of hydraulic models that relate water surface elevations to discharge, taking into account variables of channel geometry and roughness or resistance to flow. In some cases, differences in simple elevation above the channel bottom may serve as a reasonable approximation of differences in inundating discharge.
- *A relation between site moisture conditions and the actual or potential vegetation distribution.* This relation expresses the suitability of a site for a plant species or cover type based on the moisture conditions at the site. It can be determined by sampling the distribution of vegetation at a variety of sites with known moisture conditions and then deriving probability distributions of the likelihood of finding a plant on a site given the moisture conditions at the site. General relations are also available from the literature for many species.

The nature and complexity of these components can vary substantially and still provide a useful model. However, the components must all be expressed in consistent units and must have a domain of application that is appropriate to the questions being asked of the model (i.e., the model must be capable of changing the things that need to be changed to answer the question). In many cases, it may be possible to formulate a vegetation-hydroperiod model using representations of stream hydrology and hydraulics that have been developed for other analyses such as channel stability, fish habitat suitability, or sediment dynamics.

Identifying Non-equilibrium Conditions

In altered or degraded stream systems, current moisture conditions in the riparian zone may be dramatically unsuitable for the current, historical, or desired riparian vegetation. Several conditions can be relatively easily identified by comparing the distribution of vegetation to the distribution of vegetation suitabilities.

- The hydrology of the stream has been altered; for example, if streamflow has diminished by diversion or flood attenuation, sites in the riparian zone may be drier and no longer suitable for the historic vegetation or for current long-lived vegetation that was established under a previous hydrologic regime.
- The inundating discharges of plots in the riparian zone have been altered so that streamflow no longer has the same relation to site moisture conditions; for example, levees, channel modifications, and bank treatments may have either increased or decreased the discharge required to inundate plots in the riparian zone.
- The vegetation of the riparian zone has been directly altered, for example, by clearing or planting so that the vegetation on plots no longer corresponds to the natural vegetation for which the plots are suitable.

In many degraded stream systems all of these things have happened. Understanding how the moisture conditions of plots correspond to the vegetation in the current system, as well as how they will correspond in the restored system, is an important element of formulating reasonable restoration objectives and designing a restoration plan.

Vegetation Effects of System Alterations

In a vegetation-hydroperiod model, vegetation suitability is determined by streamflow and the inundating discharges of plots in the riparian zone. The model can be used to predict effects of alteration in streamflow or the relations of streamflow to plot moisture conditions on the suitability of the riparian zone for different types of vegetation. Thus, the effects of flow alterations and changes in channel or bottomland topography proposed as part of a stream restoration plan can be examined in terms of changes in the suitability of various locations in the riparian zone for different plant species.

Extreme Events and Disturbance Requirements

Temporal variability is a particularly important characteristic of many stream ecosystems. Regular seasonal differences in biological requirements are examples of temporal variability that are often incorporated into biological analyses based on habitat suitability and time series simulations. The need for episodic extreme events is easy to ignore because these are so widely perceived as destructive both of biota and of constructed river features. In reality, however, these extreme events seem to be essential to physical channel maintenance and to the long-term suitability of the riverine ecosystem for disturbance- dependent species. Cottonwood in western riparian systems is one well-understood case of a disturbance-dependent species. Cottonwood regeneration from seed is generally restricted to bare, moist sites. Creating these sites depends heavily on channel movement (meandering, narrowing, avulsion) or new flood deposits at high elevations. In some western riparian systems, channel movement and deposition tend to occur infrequently in association with floods. The same events are also responsible for destroying stands of trees. Thus maintaining good conditions for existing stands, or fixing the location of a stream's banks with structural measures, tends to reduce the regeneration potential and the long-term importance of this disturbance-dependent species in the system as a whole.

Flooding Tolerances of Various Species

There is a large body of information on the flooding tolerances of various plant species. Summaries of this literature include Whitlow and Harris (1979) and the multivolume Impact of Water Level Changes on Woody Riparian and Wetland Communities (Teskey and Hinckley 1978, Walters et al. 1978, Lee and Hinckley 1982, Chapman et al. 1982). This type of information can be coupled to site moisture conditions predicted by applying discharge estimates or flood frequency analyses to the inundating discharges of sites in the riparian zone.

The resulting relation can be used to describe the suitability of sites for various plant species, e.g., relatively flood-prone sites will likely have relatively flood-tolerant plants. Inundating discharge is strongly related to relative elevation within the floodplain. Other things being equal (i.e., within a limited geographic area and with roughly equivalent hydrologic regimes), elevation relative to a representative water surface line, such as bankfull discharge or the stage at mean annual flow, can thus provide a reasonable surrogate for site moisture conditions. Locally determined vegetation suitability can then be used to determine the likely vegetation in various elevation zones.

Zonation of Vegetation

There are a number of statistical procedures for estimating the frequency and magnitude of extreme events (see flood frequency analysis section of chapter 8) and describing various aspects of hydrologic variation.

Changing these flow characteristics will likely change some aspect of the distribution and abundance of organisms.

Analyzing more specific biological changes generally requires defining the requirements of target species; defining requirements of their food sources, competitors, and predators; and considering how those requirements are influenced by episodic disturbance events.

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PART II

STREAM CORRIDOR RESTORATION

In Italia, nella gestione dei corsi d'acqua, prevale ancora un approccio ingegneristico strettamente monodisciplinare; la rinaturazione degli ambienti fluviali è propugnata da pochi, considerati con sufficienza come utopisti o sognatori. Perfino l'ingegneria naturalistica, sebbene volta a sostituire il cemento con vegetali vivi, è ancora applicata essenzialmente per le sue funzioni di consolidamento, con scarsa attenzione alle funzioni naturalistiche ed è spesso ridotta al mero ruolo di cosmetico ambientale di opere idrauliche, per altri versi devastanti.

Il principale ostacolo al superamento di questo approccio è la diffusa arretratezza culturale, che inchioda i progettisti idraulici alla comoda inerzia delle tecniche ingegneristiche tradizionali.

Con la pubblicazione del volume *Stream Corridor Restoration*, il CISBA intende scuotere la pigrizia dei progettisti, mettere allo scoperto i profondi limiti delle pratiche attuali e mostrare la ricchezza culturale di un approccio interdisciplinare che fornisce a ciascuno stimoli di crescita professionale.

Il volume, redatto da 15 agenzie governative americane con la collaborazione dei più autorevoli esperti di numerose discipline, presenta i principi e la pratica del ripristino dei corridoi fluviali.

Per la completezza della trattazione, il ricco e curato corredo d'illustrazioni, l'autorevolezza delle fonti, l'utilità dei consigli pratici, degli approfondimenti, dei casi-studio, il volume rappresenta un prezioso contributo all'affermazione di una cultura della riqualificazione fluviale nel nostro paese. (Parte 2 di 3)