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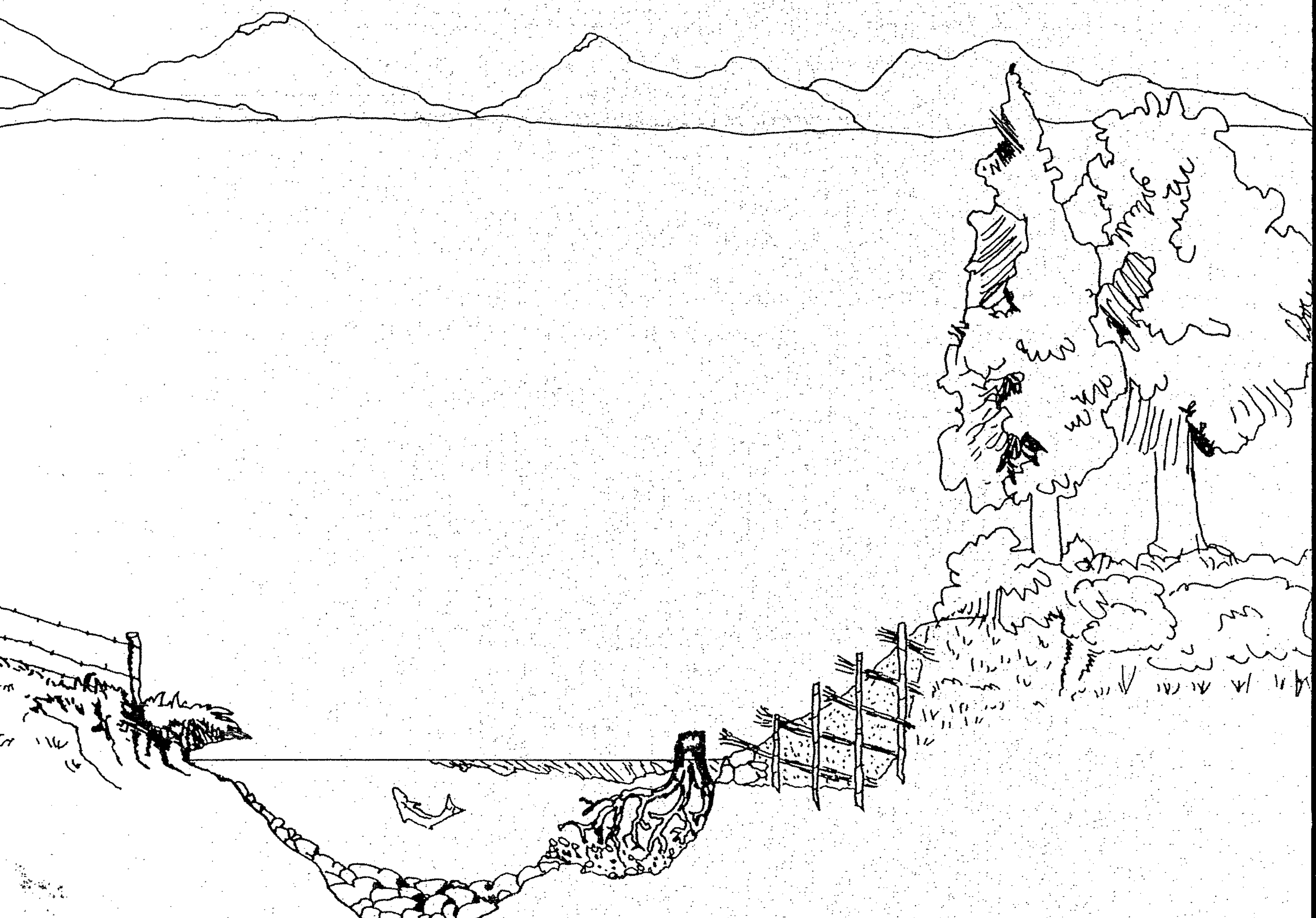
Ecological Restoration: A Tool To Manage Stream Quality



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ACRONYMS

BMP	best management practice
BOD	biochemical oxygen demand
CBO	Congressional Budget Office
CFR	Code of Federal Regulations
CSO	combined sewer overflow
CWA	Clean Water Act
DO	dissolved oxygen
DQO	data quality objective
EPA	U.S. Environmental Protection Agency
GAO	General Accounting Office
NPDES	National Pollution Discharge Elimination System
NRC	National Research Council
OMB	Office of Management and Budget
PCB	polychlorinated biphenyl
QAPP	Quality Assurance Project Plan
TMDL	total maximum daily load
WPA	watershed protection approach
WQ	water quality
WQS	water quality standard

FOREWARD

Water resource management under the Clean Water Act (CWA) has concentrated on limiting negative environmental impacts rather than creating positive ones. The U.S. Environmental Protection Agency, along with other federal agencies, is now moving toward the creation of positive impacts by encouraging the use of ecological restoration.

Rather than being a "how-to" document, this document is an initial attempt to provide information on the structure and function of natural elements of aquatic resources and the CWA.

The audience for this document is state water quality agency personnel and other water resource managers who have been implementing the CWA over the past twenty years. This document explains and clarifies CWA authorities for restoration and examines linkages between selected restoration techniques and parameters that are often addressed in state water quality standards. The document also presents a decision-making guide for water resource managers to determine when to pursue restoration as a management option and provides information on the cost effectiveness of restoration.

Aquatic ecosystems consist of the interacting streams, wetlands, lakes, uplands, and groundwater systems commonly thought of as watersheds. Although this document focuses on the restoration of streams, we believe that many of the document's underlying principles can be useful for restoring and maintaining a wide variety of water resource types.

Robert H. Wayland, III
Director, Office of Wetlands, Oceans and Watersheds

EXECUTIVE SUMMARY

Over the last 23 years, the Clean Water Act has produced large improvements in the water quality of the nation's surface waters, most of which were achieved through reductions in pollutants from point sources. Despite these achievements, however, many surface waters still have not attained CWA goals. Further reductions in pollutants from point sources likely will not achieve those goals, because factors that now limit attainment of those goals primarily are derived from land uses within a watershed which result in ecological degradation. To achieve significant additional improvements in the nation's waters will often require some type of ecological restoration.

Ecological restoration is a tool that can produce improvements in the quality of our water resources to support diverse, productive communities of plants and animals that provide significant ecological and social benefits. This document focuses on restoration as it applies to stream quality. *Ecological Restoration: A Tool to Manage Stream Quality* asserts that stream quality can often be managed by using restoration techniques in conjunction with more traditional management approaches, such as point source permitting. Many restoration techniques can serve as more natural options for meeting CWA goals when they are appropriately applied to restore the natural dynamics of a stream system.

Ecological Restoration: A Tool To Manage Stream Quality has four related objectives: (1) explaining and clarifying CWA authorities for restoration of streams, (2) examining and illustrating linkages between selected restoration techniques and parameters often addressed in state water quality standards, (3) providing water program managers with a helpful guide to determine when to pursue restoration, and (4) investigating the cost-effectiveness of restoration in comparison to traditional water quality management tools.

RESTORATION DEFINED (CHAPTER 1)

Academic and philosophical distinctions could be made between habitat restoration and ecological restoration. However, for the practical purposes of this document, the reader may find both terms used interchangeably.

In this report, ecological restoration is the restoration of chemical, physical, and/or biological components of a degraded system to a pre-disturbance condition and is also an important tool for preventing environmental degradation. Strengthening structural or functional elements through restoration can help increase a stream system's tolerance to stressors which lead to environmental degradation. By so doing, water quality and aquatic and terrestrial habitat will be improved, which, in turn, will lead to improvements in the aquatic and terrestrial communities that depend on that water.

For streams, then, restoration is an integral part of a broad, watershed-based approach for achieving federal, state, and local water resource goals. Specifically, restoration is the re-establishment of chemical, physical, and biological components of an aquatic ecosystem that have been compromised by stressors such as point or nonpoint sources of pollution, habitat degradation, hydromodification, and others.

This document emphasizes and endorses the use of natural restoration techniques. Natural techniques to restore ecosystem components are distinct from treatment technologies or artificial structures that are inserted into the system. Natural restoration techniques use materials indigenous to the ecosystem and are linked or incorporated into the dynamics of a river system in an attempt to create conditions in which ecosystem processes can withstand and diminish the impact of stressors.

Three categories of restoration techniques have been identified for stream management activities:

1. *Instream techniques* are applied directly in the stream channel (e.g., channel reconfiguration and realignment to restore geometry, meander, sinuosity, substrate composition, structural complexity, re-aeration, or stream bank stability).

2. *Riparian techniques* are applied out of the stream channel in the riparian corridor (e.g., re-establishment of vegetative canopy, increasing width of riparian corridor, or restrictive fencing).

3. *Upland, or surrounding watershed, techniques* are generally related to the control of nonpoint source inputs from the watershed, including hydrologic runoff characteristics from increased imperviousness of the watershed [e.g., urban, agricultural, and forestry best management practices (BMPs)].

Stream restoration can be a *mosaic* of instream, riparian, and upland techniques, including BMPs, to be used in combination to eliminate or reduce the impact of stressors (both chemical and nonchemical) on aquatic ecosystems and reverse the degradation and loss of ecosystem functions. Instream restoration practices often need to be accompanied by techniques in the riparian area and/or the surrounding watershed. For example, restoration may involve rebuilding the infrastructure of a stream system (e.g., reconfiguration of channel morphology, re-establishment of riffle substrates, re-establishment of riparian vegetation, and stabilization of stream banks, accompanied by control of excess sediment and chemical loadings within the watershed) to achieve and maintain stream integrity.

RESTORATION AND THE CLEAN WATER ACT (CHAPTER 2)

Restoration is a natural tool for meeting some CWA requirements. Water quality standards define specific objectives for restoring aquatic ecosystem integrity and are comprised of designated uses, numeric or narrative water quality standards to protect these uses, and an antidegradation provision.

Ecological restoration techniques can be effective in addressing water quality impairments that are typically characterized by state water quality standards. Water quality impairment is often indicated by excursions of numeric standards, which provide quantitative targets for particular parameters. Water quality impairment may also be identified based on narrative standards and designated uses, such as the ability to support a designated type of fishery.

The Watershed Protection Approach and its key technical component, the Total Maximum Daily Load (TMDL) process, provide an impetus for restoration activities. Restoration techniques can be applied as a management action within the context of the TMDL process in conjunction with traditional regulatory actions (such as point source permits) and voluntary programs (such as implementation of nonpoint source BMPs) to address any component of a water quality standard—a numeric or narrative criterion or a designated use. In the context of a TMDL, restoration can also address nonattainment of a designated use (e.g., a coldwater fishery) or a narrative criterion that refers explicitly to habitat quality or biological diversity. An optimal management strategy may combine some or all options involving point source load reductions, BMPs, and instream ecological restoration techniques.

LINKING RESTORATION PRACTICES TO WATER QUALITY PARAMETERS (CHAPTER 3)

Adequate understanding of the relationships among physical, chemical, and biological processes is critical for determining when habitat restoration can be used to improve stream quality and implement the CWA. The following discussion illustrates the relationship between several restoration techniques and specific water quality parameters.

- *Altered Stream Geomorphology:* In cases where habitat degradation is significant, restoring or improving the physical habitat can help attain the aquatic life designated use, while simultaneously improving water quality.

- *Sedimentation:* Upland, riparian, and instream restoration techniques that can restore equilibrium to sediment loads to streams include changes in land-use practices that reduce sediment loading (e.g., conservation tillage, contour farming, sodding or wildflower cover during construction activities), restoring off-stream wetlands to intercept nonpoint sources of sediments during wet-weather conditions, and modifying operations of dams and water diversion structures.

- *High Stream Flows:* Instream techniques that can reduce the effects of high stream flows include restoring natural stream meander and channel complexity, increasing substrate roughness, promoting growth of riparian vegetation (which provides refuge for fish during high flows), restoring wetlands to restore natural hydrologic regimes, and modifying operations of dams. Upland techniques include reducing the percent impervious surface in the watershed, which reduces "flash" runoff, through development of guidelines.

- *Low Stream Flows:* Impacts from low stream flows can be reduced by several instream restoration techniques, including restoring the stream channel in a channelized stream, controlling evaporation through restoration of the riparian canopy, replacing exotic riparian plant species that have high evapotranspiration rates with native species that have lower transpiration rates, creating pools through the use of drop structures providing protection of aquatic life during low flow periods, and increasing channel depth and re-establishing undercut banks to provide areas for protection of fish and other species during periods of low flow. Minimum flows can also be addressed by applying techniques in the surrounding watershed, such as managing watershed land and water use to prevent excessive dewatering.

- *Biological Integrity:* Improvements in water quality and habitat quality generally lead to increases in biodiversity and improvements in ecological functions such as nutrient cycling, trophic relationships, and predator-prey relationships.

- *Toxicity:* Practices that reduce ammonia toxicity would, through similar mechanisms, reduce the toxicity of other substances, including hydrogen sulfide. In addition, wetlands can help reduce the toxicity of some metals by reducing metal concentrations and bioavailability. Together, these practices would help reduce the total toxicity of the water and help attain narrative water quality standards.

- *Nuisance Algal Growths:* Restoration practices that can reduce nuisance algal growth include drop structures and riffles to create turbulence to reduce attached algal growth, constructing wetlands to reduce nutrient input and subsequent algal growths, planting trees and bushes to reduce the amount of sunlight available for algal growth, increasing channel depth, and re-establishing undercut banks to reduce the area available for algal growth.

- *Dissolved Oxygen:* Restoration practices that can increase dissolved oxygen (DO) concentrations include constructing small hydrologic drop structures that increase re-aeration rates, restoring wetlands to reduce nutrient inputs and plant growth, re-establishing trees and bushes along stream banks to reduce incident sunlight and water temperature, restoring stream depth and undercut banks to reduce aquatic plant growth and water temperatures, and restoring riffles to increase turbulence.

- *Water Temperature:* High water temperatures can be reduced by restoring trees and bushes along stream banks to reduce incident sunlight, restoring stream depth, re-establishing undercut banks, and narrowing stream width to reduce excessive solar warming.

- *pH:* pH levels can be increased by restoring wetlands to intercept acid mine drainage and neutralize acidity by converting sulfates associated with sulfuric acid to insoluble non-acidic metal sulfides that remain trapped in wetland sediments. In addition, all techniques discussed above for increasing DO concentrations can be used to decrease high pH levels caused by high rates of photosynthesis.

- *Ammonia:* Restoration practices that decrease high pH or temperature will also decrease the potential toxicity of ammonia to aquatic life.

- *Metals:* Restoration practices can decrease inputs of metals to streams or reduce the ionic, dissolved phases of metals, which are considered to be toxic. Particulate phases have much lower toxicities. Techniques include those mentioned above for increasing pH; decreasing metal bioavailability by increasing particulate metals; restoring existing wetlands to treat acid minedrainage; and re-establishing vegetation in riparian areas.

A Decision-Making Guide for Restoration (Chapter 4)

Chapter 4 presents a decision-making guide that includes decision points integrating a broad range of program responsibilities and activities. The process assumes that impaired or threatened water resources have already been identified in accordance with relevant sections of the CWA, as well as requirements of any other relevant water programs. The decision-making guide begins with a selected site where water quality standards, which may include numeric or narrative criteria or designated uses, are not being met or are threatened. In Step 1, an inventory of the watershed is conducted to assess the potential value of ecological restoration techniques for addressing water quality impairment. Steps 2 and 3 provide an analysis of the availability, applicability, and relative costs of ecological restoration techniques to assist regional and state personnel in making informed decisions. In Step 4, an ecological restoration approach is implemented, where appropriate. In Step 5, post-implementation monitoring, an essential part of the decision-making guide, is conducted to determine whether impairment has been mitigated. Additionally, several steps in the decision-making guide call for stakeholder involvement.

EVALUATING THE COST EFFECTIVENESS OF RESTORATION (CHAPTER 5)

Selecting the most cost-effective techniques is critical to the success of any restoration project. Two possible approaches for evaluating the cost effectiveness of water quality measures are cost minimization and benefit maximization. The most cost-effective restoration technique either achieves the water quality objective at the lowest cost (cost minimization) or produces the greatest benefits for the same cost (benefit maximization). The two primary economic reasons why restoration may be more cost effective than point source controls alone are that (1) restoration often has lower *marginal* costs (i.e., the incremental costs of removing an additional unit of a pollutant) and (2) restoration provides a wider range of ecological benefits. Cost calculations are relatively straightforward and are the same for cost minimization and benefit maximization analyses.

Determining the benefits of each project to be evaluated is critical prior to comparing costs and benefits. Benefits fall into three general categories: (1) prioritized benefits (i.e., those that are ranked by preference or priority, such as best, next best, and worst), (2) quantifiable benefits (i.e., those that can be quantified but not priced), and (3) monetary benefits (i.e., those that can be described in monetary terms).

If all benefits can be quantified monetarily, total costs can be compared to benefits in two ways. The first comparison is expressed as a cost-to-benefits ratio, from which the alternative with the lowest cost-to-benefits ratio is selected. The second comparison is expressed in terms of net value (i.e., subtracting costs from benefits), from which the alternative with the highest net value is selected. Neither approach is the most appropriate in all cases. In many cases, considering as many measures as practicable—cost per unit, cost-to-benefits ratios, and net present value—is advisable. A clear understanding of objectives is essential for the analysis.

Finally, cost effectiveness is relative and may change with location and circumstances. For example, a certain combination of restoration practices in one location may produce great benefits at a low cost, whereas others may produce few benefits at a large cost. Some water quality problems (e.g., loss of habitat) are not amenable to a point source treatment approach at any cost; and some water quality problems cannot be reduced through any reasonable degree of restoration.

CASE STUDIES (CHAPTER 6)

Chapter 6 presents seven case studies to demonstrate the effectiveness of using restoration techniques to achieve water quality goals. Common elements among the case studies that resulted in improvements to stream integrity are the reduction of stressors and the restoration of stream components (e.g., stream channel and riparian corridor). Each project does, however, offer unique lessons that may be beneficial in planning future projects. Presentation of case studies is therefore structured in accordance with the framework presented in this document to provide a common basis for evaluating individual examples and comparing different approaches. The following case studies are included in Chapter 6: Anacostia River, Metropolitan Washington, District of Columbia; Bear Creek, Iowa; Boulder Creek, Colorado; South Fork of the Salmon River, Idaho; Upper Grande Ronde River, Oregon; and Wildcat Creek, California.

CHAPTER 1

RESTORATION DEFINED

This document proposes restoration as an everyday management tool for streams whose chemical, physical, and biological habitats have been impaired, a focus that fills the conceptual gap between preservation and remediation. Chapter 1 defines restoration for use by water program managers within the context of the Clean Water Act (CWA) and takes into consideration current understanding of aquatic ecosystems. It is not intended to replace different, and equally valid, definitions that have been offered elsewhere. The restoration of streams fits within a continuum of activities that the U.S. Environmental Protection Agency (EPA) and other environmental organizations have conducted for many years. Activities range from preservation and protection (e.g., the designation and protection of biologically diverse areas as Outstanding National Resource Waters under 40 CFR 131.12[a][3]) to intense repair/recovery efforts (e.g., highly disturbed areas such as Superfund sites and waters or sediments contaminated with PCBs).

PERSPECTIVES ON RESTORATION

Restoration is not solely applicable to severely degraded streams. Although it can be used as an effective tool to return a degraded system to a pre-disturbance condition, restoration is also an important tool for preventing environmental degradation. Strengthening structural and functional elements through restoration can help improve a stream system's tolerance to stressors which lead to environmental degradation.

Restoration has been defined in a number of different ways. On the most basic level, restoration is the process of returning a damaged ecosystem to its condition prior to disturbance (Cairns 1991, Berger 1991, and Caldwell 1991). The long-term goal of restoration is to imitate an earlier natural, self-sustaining ecosystem that is in equilibrium with the surrounding landscape (Berger 1991). A National Research Council report (1992) defines restoration as a holistic process:

> *Restoration is ... the return of an ecosystem to a close approximation of its condition prior to disturbance. In restoration, ecological damage to the resource is repaired. Both the structure and the functions of the ecosystem are recreated .... The goal is to emulate a natural, functioning, self-regulating system that is integrated with the ecological landscape in which it occurs.*

What does it mean to restore an ecosystem to a *prior* or *pre-disturbance* condition? What condition should water resource scientists and managers use as a baseline goal (Westman 1991)? In many cases, restoring an ecosystem to an early pristine or pre-settlement condition would be impossible, because (1) data are insufficient to determine the original condition, (2) species representative of the original condition are extinct, or (3) human activities have changed the soil structure or hydrological characteristics of the ecosystem so extensively that the original condition would no longer be compatible with surrounding ecosystems and landscapes.

Restoration is not yet a perfected approach with accurate and precise predictive capabilities and, in fact, is still "... an exercise in approximation" (Cairns 1991). The practicality and attainability of restoration depend on many factors, including adequate tools (i.e., the state of science and technology), site-specific ecological conditions, social consent, legal authority, and availability of resources (i.e., personnel and funding) (Caldwell 1991). As with other water resource management alternatives, restoration must address questions concerning practicality, predictability of outcomes, and overall effectiveness of specific techniques. Additionally, because ecological systems are complex and may take years to reach equilibrium or fully demonstrate the effects of restoration and other management activities, seeing or measuring results of restoration efforts may take a long time.

Scope of Restoration

Restoration must consider all sources of stress on a stream and is therefore not restricted to instream mitigation of impacts. The health and protection of a waterbody cannot be separated from the watershed ecosystem, and restoration must address all watershed processes that degrade an ecological system, e.g., sediment loading from road cuts or development or increased polluted runoff from impervious areas. The intimate connection of rivers and watersheds is succinctly expressed by Doppelt et al. (1993):

> *Most people think of rivers simply as water flowing through a channel. This narrow view fails to capture the actual complexity and diversity of riverine systems, and is one of the reasons for failed policies. In the past 15 years many scientific studies and reports have documented that riverine systems are intimately coupled with and created by the characteristics of their catchment basins, or watersheds. The concept of the watershed includes four-dimensional processes that connect the longitudinal (upstream-downstream), lateral (floodplains-upland), and vertical (hyporheic or groundwater zone-stream channel) dimensions, each differing temporally.*

Restoration is an integral part of a broad, watershed-based approach for achieving federal, state and local water resource goals. Specifically, restoration is the re-establishment of chemical, physical, and biological components of an aquatic ecosystem that have been compromised by stressors such as point or nonpoint sources of pollution, habitat degradation, hydromodification, and others.

Restoration Techniques

This document emphasizes and endorses the use of natural restoration techniques. Natural techniques that restore a system's ability to approach a pre-disturbance condition are distinct from treatment technologies or structures that are inserted into the system to approximate equilibrium. Natural restoration techniques use materials indigenous to the ecosystem and are linked or incorporated into the dynamics of a river system in an attempt to create conditions in which ecosystem processes can withstand and diminish the impact of stressors.

While this document focuses on the use of natural restoration techniques to achieve water resource objectives, it also recognizes that restoration techniques must in part be selected based on existing landscape conditions. The mitigation of some conditions may necessitate the introduction of structures composed of material not indigenous to the ecosystem to mimic natural

CHAPTER 3

LINKING RESTORATION PRACTICES TO WATER QUALITY PARAMETERS

Because water resource quality is defined by *all* its components—the chemical, physical, and biological— adequate understanding of the relationships among physical, chemical, and biological processes is critical for determining when restoration can be used to improve stream quality. This chapter illustrates the relationship between several restoration techniques and a number of water quality parameters. Discussion in this chapter is based on two key concepts:

- Ecological restoration techniques can be *effective* in meeting water quality standards, including numeric and narrative criteria and designated uses, and

- Ecological restoration techniques can be *evaluated and implemented* within the framework of the TMDL process.

Chapter 3 describes how certain ecological restoration techniques affect numerous water quality parameters, thus illustrating how restoration can be used to address non-compliance with designated uses and numeric and narrative water quality criteria. Relative effects of selected stream habitat restoration techniques on several water quality parameters are summarized in Table 3–1.

ALTERED STREAM GEOMORPHOLOGY

Geomorphological characteristics such as pool-riffle ratios, width/meander length ratios, width/depth ratios, and substrate composition may impact stream ecology. Long-term trends in stream geomorphology may also exacerbate impairment caused by other sources. A stream can be characterized and classified based on its geomorphology, e.g., form and pattern, and channel behavior. In addition, classification "also can indicate how restoration might be approached if a reach of river becomes aberrant or different from its normal conditions" (Leopold 1994). For instance, in a stream where land-use changes have resulted in downcutting of the channel, increased suspended sediment loads may occur, as well as destruction of fish and wildlife habitat by erosion. In some cases, upland restoration techniques in the surrounding watershed (such as restoration of natural hydrologic regime and the re-establishment of wooded riparian buffers) may sufficiently allow a system's geomorphology to restore itself. Restoration techniques based on interpretation and control of stream geomorphology generally must take into account dynamics of flow and sediment transport throughout an entire watershed.

It is important to note that the restoration techniques listed below for altered stream geomorphology and the other parameters discussed in Chapter 3 cannot be developed or applied in isolation. As described in Chapter 4, a mosaic of restoration techniques must comprise a watershed approach mitigation plan. The following techniques could be considered for altered stream morphology:

- Reworking the stream channel to restore structural complexity (e.g., thalwag) and natural flow patterns (e.g., sinuosity and meander). For some of the most severely degraded channels, heavy equipment may be necessary to reconstruct the channel.

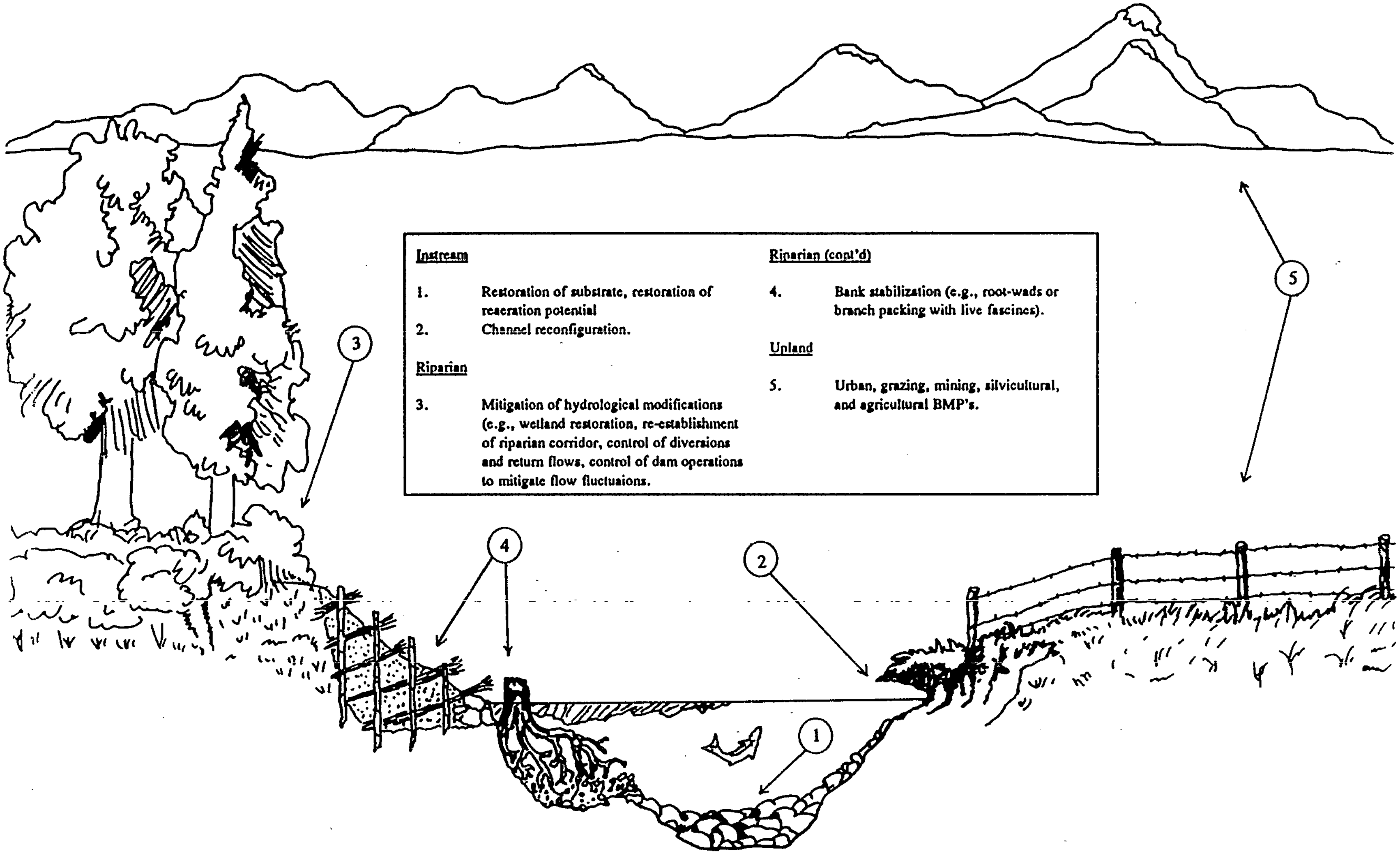

Figure 1-1. Examples of restoration techniques that can be applied to instream, riparian corridor, and upland zones.

Stream restoration can be a *mosaic* of instream, riparian, and upland techniques, including BMPs, to be used in combination to eliminate or reduce the impact of stressors (both chemical and nonchemical) on aquatic ecosystems and reverse the degradation and loss of ecosystem functions. Instream restoration practices often need to be accompanied by techniques in the riparian area and/or the surrounding watershed. For example, restoration may involve rebuilding the infrastructure of a stream system (e.g., reconfiguration of channel morphology, re-establishment of riffle substrates, re-establishment of riparian vegetation, and stabilization of stream banks, accompanied by control of excess sediment and chemical loadings within the watershed) to achieve and maintain stream integrity.

Balancing and integrating instream, riparian, and surrounding watershed approaches is essential. Any restoration plan could involve a combination of techniques, depending on environmental conditions and stressors to be addressed. Instream and riparian techniques directly restore the integrity of stream habitat, whereas surrounding watershed techniques focus on the elimination or mitigation of sources of stressors that cause the habitat degradation. Because surrounding watershed techniques tend to facilitate a system's ability to restore itself, instream techniques may not always be necessary. In addition, if instream and/or riparian techniques are selected to restore the integrity of the physical habitat, measures that eliminate or mitigate sources of stressors that caused the degradation should also be included; otherwise, the restoration effort may fail. Therefore, surrounding watershed techniques should, as a general rule, be considered prior to or in conjunction with the use of instream and riparian techniques. Because many projects need to address both causes and symptoms of stream degradation, combining instream, riparian, and surrounding watershed approaches is often appropriate.

These techniques and specific conditions for their application have been well described in the literature. Table 1-1 provides examples of restoration techniques that fall into these categories and their objectives. Table 1-2 lists selected references containing additional information on these and other techniques.

Table 1-1. Examples of Instream, Riparian, and Upland Restoration Techniques

Restoration Category	Description
Instream	Reconfiguration of stream bed: Dig a new channel for stream beds that have become braided or overly shallow. The new channel should increase depth and structural complexity (thalweg cross section).
Instream	Restoration of channel course natural meander pattern: Remove any manmade structure or stop dredging practices that maintain channelization; actively redirect stream into meander pattern appropriate to hydrologic conditions.
Instream	Root wad/tree revetment: A stump with roots still attached is placed horizontally into the stream bank with the root end extending into the stream.
Instream	Live stakes, live fascines, brush mattresses, branch packings, brush layering, vegetated geogrids, and live cribwall: These are all stream bank stabilization techniques that use vegetation bundles (e.g., willows) placed in stream banks in various patterns and means of attachment. A particular method is selected based on soil type, bank slope, and hydrologic conditions.
Instream	Channel deflector and channel constrictor: Deflectors and constrictors are triangular-shaped structures, constructed from rock, gabion, or logs that extend into the stream to narrow and deepen streams in selected locations. These techniques encourage meander, form pools, increase cover, and protect eroding banks.
Instream	Boulder cluster: Large boulders are placed strategically in the stream channel to increase structural complexity, including eddies and small pools.
Instream	Log drop structure: This example is one of many structures that alter flow conditions to create small drops and pools. The log drop consists of a log placed across the stream, with a V notch cut into the middle to direct flow. Characteristics of these structures (e.g., height of the drop and width of the log) are carefully designed to prevent the obstruction of fish migration.
Riparian	Wetland restoration
Riparian	Re-establishing vegetation in the riparian corridor with native species best suited to current hydrologic and soil conditions (e.g., forested riparian buffers).
Riparian	Controlling the timing, location, and extent of water diversions from and irrigation return flows to stream channel.
Riparian	Constructing fences and gates in riparian corridor to control access of grazing livestock and other agricultural activities to selected locations along the stream.
Upland	Urban BMPs: Retention devices (e.g., infiltration basins, trenches, dry wells, and porous pavement); vegetative controls (e.g., basin landscaping, filter strips, grassed swales, and wetlands); source controls (e.g., education regarding inappropriate discharges to storm drains and proper disposal of potential contaminants); erosion control (e.g., construction site management and controls); land-use planning (e.g., limiting direct connection of impervious area to waterbody); sewage overflow controls; urban stormwater retrofits.

Continued

Table 1-1. Continued

Restoration Category	Description
Upland	Agricultural and grazing BMPs: Erosion and sediment control (e.g., filter strips, grassed waterways, and conservation tillage); confined animal facility management (e.g., sediment basins); grazing management (e.g., livestock exclusion, alternative drinking locations, and stream crossings).
Upland	Forestry BMPs: Streamside management areas that contain canopy species to control temperature and increase bank stability; road decommissionings; erosion control (e.g., grass-seeding, hydromulch, installation of road drainage structures such as water bars, dips, or ditches).
Upland	Point source effluent controls

Table 1-2. References to Additional Information on Restoration Techniques

Anacostia Restoration Team. 1992. Watershed Restoration Source Book. Collected papers presented at ***Restoring Our Home River: Water Quality and Habitat in the Anacostia*****, held November 6–7, 1991, in College Park, MD. Department of Environmental Programs, Metropolitan Washington Council of Governments, Washington, DC.**
Gore, James A. (editor). 1985. *The Restoration of Rivers and Streams: Theories and Experience.* Butterworth, Stoneham, MA. 280 pp.
Hunter, Christopher J. 1991. *Better Trout Habitat: A Guide to Stream Restoration and Management.* Island Press, Washington, DC. 320 pp.
Woodward-Clyde Consultants. 1990. *Urban Targeting and BMP Selection: An Information and Guidance Manual for State Nonpoint Source Program Staff Engineers and Managers.* Prepared for the U.S. Environmental Protection Agency, Region V, Water Division and Office of Water Regulations and Standards, Office of Water Enforcement and Permits.
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Brooks, R.P., S.E. Gwin, C.C. Holland, A.D. Sherman, J.C. Sifneos. 1992. Restoration of Aquatic Ecosystems. NAS Report. *An Approach to Improving Decision-making in Wetland Restoration and Creation.* Kentula, ME. A.J. Hairston, ed. U.S. EPA, Environmental Research Laboratory, Corvallis, OR.
Rosgen, David L. 1994. A Classification of Natural Rivers. Catena. 22:169-199.
EPA. 1993a. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. EPA Report No. 840-B-92-002.

CHAPTER 2

RESTORATION AND THE CLEAN WATER ACT

The objective of the Clean Water Act, as stated in Section 101, is to "restore and maintain the chemical, physical and biological integrity of the Nation's waters." Restoration is a tool for meeting some CWA requirements. The CWA provides the broad and flexible authority needed to realize the nation's water resource goals. Most importantly, the CWA recognizes that water resource quality is defined by *all* its components—the chemical, physical, and biological, and that water resource integrity depends on complex interactions among all three components.

Numerous CWA programs encompass the concept of restoration. Because widespread loss of ecological function and biological diversity jeopardizes the health of many water resources, CWA programs must address all elements of water resource integrity in a more integrated manner and cannot work in isolation if the goals of the Act are to be met. Figure 2–1 illustrates EPA's emerging approach to harmonizing CWA programs and achieving the overall goal of aquatic ecosystem integrity. In addition, Table 2–1 on the following page provides some examples of restoration-related activities that have taken place within the framework of CWA programs.

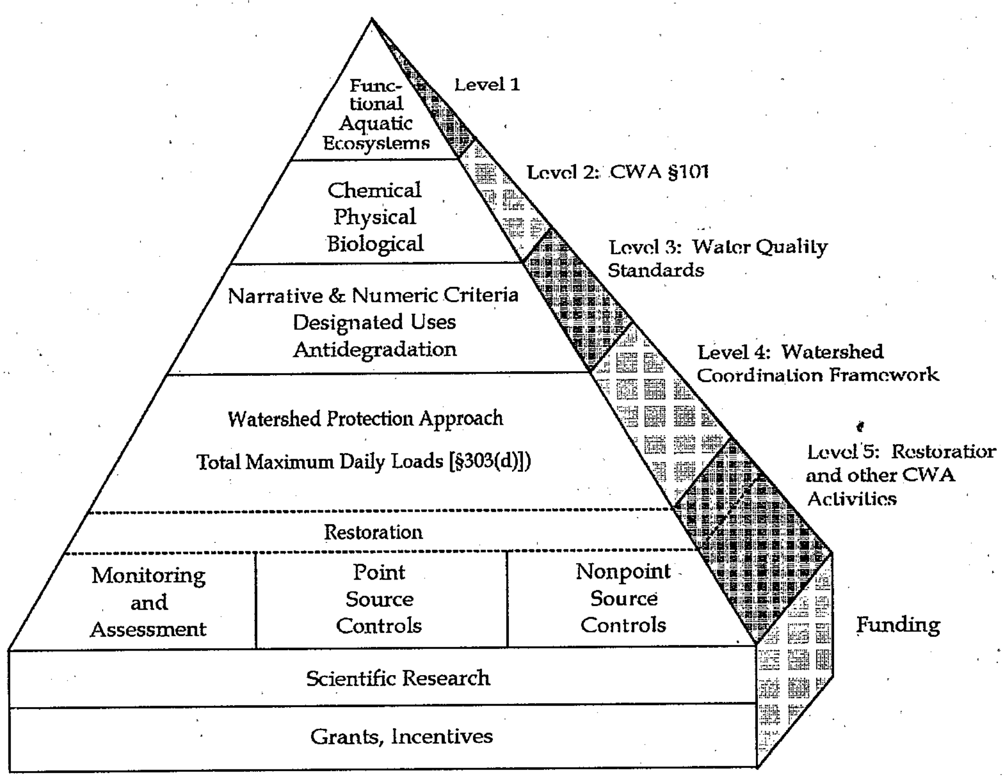

Figure 2-1. Integration of water quality management through the watershed protection approach and Clean Water Act activities.

Table 2-1. Restoration Activities within Clean Water Act Programs

CWA Section Number (Program Title)	Description of Program Activities
CWA Section 303(d) (TMDL Program)	Application of restoration techniques within the framework of the TMDL process. *TMDL Case Study #8, Boulder Creek, CO*, June 1993, EPA 841-F-93-006.
CWA Section 314 (Clean Lakes Program)	Guidance for lake and reservoir protection, management and restoration, including: *The Lake and Reservoir Restoration Guidance Manual*, August 1990, EPA 440/4-90-006; *Monitoring Lake and Reservoir Restoration*, August 1990, EPA 440/4-90-007; *Fish and Fisheries Management in Lakes and Reservoirs. Technical Supplement to the Lake and Reservoir Restoration Guidance Manual*, May 1993, EPA 841-R-93-002. Funding of Clean Lakes Program Phase II cooperative agreements to support lake and reservoir restoration projects. The Clean Lakes Program Management System maintains a database of Clean Lakes projects and provides capability for analysis of lake restoration and management techniques.
CWA Section 319 (Nonpoint Source Program)	Guidance recommending that ten percent of each State's overall work program go to support Watershed Resource Restoration. *Final Guidance on the Award of Nonpoint Source Grants Under Section 319(h) of the CWA for FY 94 and Future Years*, memorandum signed June 24, 1993.
CWA Section 320 (National Estuary Program)	Comprehensive Conservation and Management Plans to protect and improve water quality and enhance living resources of nationally significant estuaries.
CWA Section 402 (Stormwater Program)	Managing stormwater to restore degraded wetlands and urban wetlands that currently are not being maintained. *Wetlands and Stormwater Workshop: Summary of Topics*. Held January 8-10, 1992. Sponsored by EPA; State of Florida; Association of State Floodplain Managers, Inc., and Association of State Wetland Managers. May 6, 1992.
CWA Section 404 (Wetlands Program)	Wetlands mitigation banking, which allows for the restoration, creation, or enhancement of wetlands to compensate for future development activities. *Wetlands Fact Sheet Number 16, Wetlands Mitigation Banking*, EPA 843-F-95-001p. State Wetlands Grants Program [provided under CWA Section 104(b)(3)] to enhance existing and develop new wetlands protection programs, including State Wetland Conservation Plans and wetland monitoring programs. *Wetlands Fact Sheet Number 22, State Wetlands Grants Program*, February 1995, EPA 843-F-95-001v.

Level 1 of the water quality pyramid represents a primary goal of water quality programs established to support the CWA. Watershed planning is a multi-objective process with many stakeholder goals that must share equal status with the water quality goals. However, functional aquatic ecosystems are not exclusive of other goals, and the water quality planning process can often support other goals as well. Level 2 represents the components of aquatic ecosystems, identified in Section 101 of the Clean Water Act, whose integrity must be maintained to support a functioning aquatic ecosystem. It is important to note that Section 101 of the CWA places equal emphasis on each of these components (i.e., chemical, physical, and biological). Water quality standards (level three of the pyramid) define specific objectives for restoring aquatic ecosystem integrity and are comprised of designated uses, numeric or narrative water quality criteria to protect these uses, and an antidegradation provision (Table 2–2). Ecological restoration techniques can be effective in addressing water resource quality impairments that are characterized by state water quality standards.

Table 2-2. Components of Water Quality Standards

Water Quality Standards Component	Definition
Designated Uses	Those uses specified in water quality standards for each water body or segment whether or not they are being attained (40 CFR §131.3). Typical uses include public water supplies, propagation of fish and wildlife, recreation, agriculture, industry, or navigation.
Water Quality Criteria	Elements of State water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use (40 CFR §131.3)
Antidegradation	Antidegradation is a policy required in State water quality standards to protect their waters from degradation. At a minimum, States must maintain and protect the quality of waters to support existing uses. Antidegradation was originally based on the spirit, intent, and goals of the Clean Water Act, especially the clause "...restore and maintain the chemical, physical, and biological integrity of the Nation's waters".

[a] Adapted from: *Water Quality Standards Handbook: Second Edition.* 1994. EPA 823-B-94-005a. Office of Water.

The relationship between impairment and restoration techniques is often direct and obvious; the connection between restoration techniques and particular stressors contributing to stream impairment, however, is not always apparent. Therefore, distinguishing between *impairments* and specific *stressors and sources that cause impairments* will help to identify the stressors that are amenable to control using various restoration techniques. Water quality impairment is often indicated by excursions of numeric criteria, which provide quantitative targets for particular stressors. However, water quality impairment may also be identified based on narrative criteria and designated uses, such as the ability to support a designated type of fishery. For example, if a river does not meet water quality standards because it fails to support adequate salmonid spawning, it is first necessary to identify the stressors that reduce spawning (such as loading of fine sediment; which reduces available spawning habitat) before selecting a control or restoration technique. Chapter 3 presents the linkages between certain ecological restoration techniques and a number of water quality parameters, thus illustrating how restoration can be used to address excursions of both numeric and narrative water quality criteria.

Depicted at the fourth level of the pyramid are the Watershed Protection Approach and the Total Maximum Daily Load (TMDL) process, in which several CWA programs cooperate to meet the primary goal of functional aquatic ecosystems. The Watershed Protection Approach encourages water program managers to solve water quality problems by following a watershed-based approach. The approach encompasses all or most of the landscape in a well defined watershed (or other ecological, physiographic, or hydrologic unit) and addresses dynamic relationships that sustain aquatic resources and their beneficial uses. Significant threats to water resource integrity are prioritized based on a comparative analysis of ecological, economic, and human health risks; managers can then direct resources to high-risk problems. Watershed approaches also prioritize stressors within watersheds using water quality data, biological monitoring and habitat suitability data, and information on land use and location of critical resources.

A key technical component of the Watershed Protection Approach is the TMDL process required under CWA Section 303(d),[1] which determines the maximum allowable load of a pollutant or stressor that a water resource can assimilate without violating a water quality standard. Planning restoration activities within the context of a TMDL is helpful, because the TMDL process links stressors and their sources to the condition of the watershed and water resource. The process quantifies relationships among stressors, stressor sources, recommended controls, and ecological conditions. For example, a TMDL may mathematically show how a specified percent reduction of a stressor (such as elevated temperature that prevents the maintenance of a coldwater fishery) is necessary to meet a state water quality standard.

Restoration is located at Level 5 of the pyramid, and is grouped with other key CWA activities that are implemented within the TMDL process. Restoration techniques can be applied in conjunction with traditional regulatory actions (such as point source permits) and voluntary programs (such as implementation of nonpoint source BMPs) in addressing any component of a water quality standard—a numeric or narrative criterion or a designated use. For example, if a stream does not meet the numeric criterion for unionized ammonia, the restoration of riparian vegetation can lower stream temperature, thereby indirectly reducing instream concentrations of the pollutant. Restoration can also address nonattainment of a designated use (e.g., a coldwater fishery) or a narrative criterion that refers explicitly to habitat quality or biological diversity. For example, in a water resource where elevated sediment loadings impair spawning habitat, a TMDL might establish a specific percent fines by weight for substrate as a measurable endpoint. The success of instream, riparian, or surrounding watershed restoration efforts could then be evaluated by the measurement of percent fine sediment. An optimal management strategy may combine some or all options involving point source load reductions, BMPs, and instream ecological restoration techniques.

Table 2–3 lists several recent publications on ecological restoration that emphasize the importance of comprehensive watershed-scale projects that address both specific instream conditions and stressors in the watershed that caused the impairment. These publications consistently warn that the application of instream or channel-related techniques (e.g., re-aeration structures and channel reconfiguration) should be limited until stressors that created the impaired condition are understood and can be controlled. This approach is entirely consistent with and supportive of the watershed protection approach and TMDL process.

[1]Under Section 303(d), states are required to identify waters not meeting water quality standards, even after the implementation of existing required control, such as traditional technology-based controls. States then prioritize the list and develop TMDLs for high-priority waters.

Table 2-3. Recent Publications Endorsing Ecological Restoration within a Watershed Context

Doppelt, B., M. Scurlock, C. Frissell, and J. Karr. 1993. *Entering the Watershed: A New Approach to Save America's River Ecosystems.* The Pacific Rivers Council. Island Press, Washington, DC, and Covelo, CA.
Weaver, W.E., et al. 1987. *An Evaluation of Experimental Rehabilitation Work: Redwood National Park.* Redwood National Park Technical Report 19. National Park Service, Arcata, CA.
National Research Council. 1992. *Restoration of Aquatic Systems: Science, Technology, and Public Policy.* National Academy Press. Washington, DC.
Hunter, Christopher J. 1991. *Better Trout Habitat: A Guide to Stream Restoration and Management.* Montana Land Reliance. Island Press, Washington, DC, and Covelo, CA.

processes. For example, the urban landscape surrounding the South Platte River in Denver, Colorado, precluded more natural options for channel reconfiguration and alignment to restore the river's re-aeration potential. Instead, a large concrete drop structure was constructed to ameliorate low dissolved oxygen (DO) conditions. Although this structure uses natural forces associated with the flow of the river, the structure itself would not have developed as a result of natural hydrological processes.

This document recommends a comprehensive watershed perspective for restoration that considers interactions among stressors in developing effective long-term solutions. To facilitate assessment and the development of management strategies, three zones have been identified for categorizing stressors and restoration strategies. In actuality, however, the zones below are broadly connected ecologically.

1. The **instream zone** is generally the area that contains the stream's non-peak flows (i.e., the stream or river channel itself).

2. The **riparian corridor** includes the stream channel and also extends some distance out from the water's edge. Odum (1971) provides the following technical definition: Riparian habitats constitute an area of vegetation that exerts a direct biological, physical, and chemical influence on (and are influenced by) an adjacent stream, river, or lake ecosystem, through both above- and below-ground interactions. This area of association extends from the rooting systems and overhanging canopies of streamside flora outward to include all vegetation reliant on the capillary fringe characteristic of soils surrounding aquatic environments. Riparian ecosystems can vary to differences in local topography, stream bottom, soil type, water quality, elevation, climate, and surrounding vegetation.

3. The **upland zone** consists of those areas beyond the riparian corridor within a stream's watershed that generate nonpoint source runoff into the stream and whose infiltration and topographic characteristics control stream hydrology.

Figure 1-1 provides an example cross section of the three zones: instream, riparian corridor, and upland. Only a fraction of the upland zone is represented in this illustration, because this zone can extend far beyond the stream itself.

Three categories of restoration techniques have been identified for stream management activities that are consistent with the stream zones described above:

1. *Instream techniques* are applied directly in the stream channel (e.g., channel reconfiguration and realignment to restore geometry, meander, sinuosity, substrate composition, structural complexity, re-aeration, or stream bank stability).

2. *Riparian techniques* are applied out of the stream channel in the riparian corridor (e.g., re-establishment of vegetative canopy, increasing width of riparian corridor, or restrictive fencing).

3. *Upland, or surrounding watershed, techniques* are generally related to the control of nonpoint source inputs from the watershed, including hydrologic runoff characteristics from increased imperviousness of the watershed [e.g., urban, agricultural, and forestry best management practices (BMPs)].

Table 3-1. Relative Effect of Selected Stream Restoration Practices

	RESTORATION PRACTICE[a]				
	Create drop structures	Restore wetlands[1]	Plant trees and bushes along the stream bank	Increase channel depth; re-establish undercut banks; narrow stream width	Re-establish riffle substrate
Aquatic Life Designated Uses					
Altered Stream Geomorphology	↓	O	↓	↓	↓
Fine Sediment Loads	O	↓	↓	O	O
High Velocity/High Volume Flows	↓	↓	↓	↑	O
Low Flows	↓	↓	↓	↓	↓
Narrative Water Quality Parameters					
Biological Integrity	↑	↑	↑	↑	↑
Toxicity	↓	↓	↓	↓	↓
Nuisance Growths of Algae	↓	↓	↓	↓	↓
Settleable Solids	↓	↓	↓	O	↓
Numeric Water Quality Parameters					
DO	↑	↑	↑	↑	↑
Temperature	O	O	↓	↓	O
pH	↕	↕	↓	↓	↕
NH_3	↓	↓	↓	↓	↓
Suspended Solids	↑	↓	↓	O	O
Bioavailable Metals	↕[b]	↓	↕[b]	O	↕[b]

[a] ↑ means that the restoration technique increases water quality parameter; ↓ means that the restoration technique decreases water quality parameter; ↕ means that site-specific conditions can dictate increase or decrease in parameter; means that the restoration technique has a negligible effect on water quality parameter.

[b] Anoxic conditions could lead to the release of bioavailable metals from sediments.

[1] *Wetlands and 401 Certification: Opportunities and Guidelines for States and Indian Tribes.* (EPA 1993b) states that "wetlands are to be treated as waters in and of themselves for purposes of compliance with water quality standards, and not just as they relate to other surface waters."

CASE STUDY SUMMARY
SOUTH FORK OF THE SALMON RIVER, IDAHO

Overall Project Goal: Restore populations of resident and anadromous salmonid species by reducing sediment loadings.

Restoration Techniques and Parameters of Concern: See table below.

Restoration Technique/Functional Attribute	Parameter of Concern[a]		
	Fish Populations	Sediment Loadings	Cobble Embeddedness
Reduction in Ground-Disturbing Activities			
Road closures and land reclamation	↑	↓	↓
Road reconstruction and relocation	↑	↓	↓
BMPs for road building and forestry	↑	↓	↓
Stream Stabilization Activities			
Removal of sand from pools	↑	↓	↓
Instream gravel cleaning	↑	O	↓
Stream bank stabilization	↑	↓	↓
Monitoring			
Assessment of sediment reduction progress	↑	↓	↓

[a] ↑ means that the restoration technique increases water quality parameter; ↓ means that the restoration technique decreases water quality parameter; ↕ means that site-specific conditions can dictate increase or decrease in parameter; O means that the restoration technique has a negligible effect on water quality parameter.

Highlight on Techniques to Address Sediment Loadings with a Phased TMDL: Increased sediment loadings resulting from human activities had disrupted spawning sites for Chinook salmon and steelhead trout. Helping to restore those populations required reducing sediment loadings. The primary cause of sedimentation is road construction associated with forestry. An extensive data collection and modeling program was used to develop a numeric sediment criterion for the problem; then, a phased TMDL with an ongoing monitoring program was established. Initial projects are together expected to provide a 25-percent reduction in sediment yield, with goals for specific numeric sediment criteria specified. Additional sediment reduction projects have been identified for implementation if the first round of projects does not make sufficient progress toward restoration of spawning habitat.

For a more complete project description, including techniques to address additional parameters of concern, refer to Chapter 6.

- Strategically insert structures (e.g., log and gabion drop structures, large boulders) into the channel.

- Mitigate upland land use practices that result in damaging hydrological regimes.

- Evaluate operation of dams and other flow diversion structures to more closely simulate natural flow conditions.

FINE SEDIMENT LOADS

Excessive loads of fine sediments are detrimental to most stream systems because they can alter both substrate and water column conditions. Alterations in substrate conditions may contribute to a decline in fish spawning success, particularly salmonids. Fine sediment can trap fry that are attempting to emerge; deplete intergravel oxygen levels, smothering eggs that have been laid; limit the aquatic invertebrate populations used as a food source by predatory fish in rearing areas; and fill the pools and pockets between rocks and boulders on which young fish depend to protect themselves. Suspended fine sediments may also influence the survival of aquatic organisms by clogging and damaging respiratory organs. Increased turbidity increases water temperature (because turbid water absorbs heat more efficiently) and suppresses algal photosynthesis. Some aquatic ecosystems, however, where suspended solid concentrations were naturally high, such as the lower Colorado River system, have been adversely impacted by dams that reduced natural sediment transport.

For many streams, reduction in natural sediment loads can adversely affect channel stability and ecological conditions. When flowing waters have very low sediment concentrations or are devoid of sediments, they scour sediments from the stream banks and beds until an equilibrium load is suspended in the water. This scouring can degrade the morphology of the affected channel. Also, fine sediment is a natural, if not essential, part of most aquatic systems, except when present in excess. Beschta and Platts (1986), for example, note that the optimal spawning substrate appears to consist of gravel with a small amount of fine sediment and rubble to support egg pockets and stabilize the beds during high flows.

Reservoir construction, in particular, can cause unnaturally low downstream sediment loads and high flow energies. Both factors produce channel degradation downstream, characterized by increased stream depth and increased channel straightening; in contrast, upstream channels are affected by sediment aggradation, characterized by decreased stream depth and increased meander patterns. Erosion is always greater downstream of reservoirs than in natural streams having otherwise similar characteristics. Typically, this erosion begins in the stream reaches nearest the dam and continues until limited by natural factors within the channel (e.g., the accumulation of materials resistant to erosion, including large particulates and/or cohesive silts and clays that clog the streambed). Strongly established riparian plant communities also can be important deterrents of bank degradation.

Restoration techniques that can restore equilibrium to sediment loads to streams include:

- Changes in land-use practices that reduce sediment loading, such as conservation tillage, contour farming, sodding or wildflower cover during construction activities;

- Restoring wetlands to intercept sediments;

- For some systems, manipulating discharge depths from the reservoir to increase fine sediment discharges;
- Augmenting reservoir discharges with "silt runs" of added fine sediment (very limited application); and
- Removing the reservoir (a rarely used management option).

Natural tributary inflows to regulated streams downstream of reservoirs can contribute the necessary suspended materials to help the stream to achieve an equilibrium sediment load, hence reducing the erosive nature reservoir discharges.

Upland techniques may be applied in combination with instream techniques to mitigate instream sediment impacts, such as degraded substrate condition. Instream restoration, however, is unlikely to succeed unless sources and causes of excess suspended solid loading are addressed simultaneously.

Abnormally High Stream Flows

High-energy flows can erode substrate and bank materials, destabilize the physical structure of aquatic habitats, kill resident aquatic organisms, and destroy eggs incubating in the benthic environment. Seasonal cycles of high-energy flow events (e.g., spring floods) are typical in most aquatic systems; habitat alteration and degradation, however, may exacerbate impacts of high-energy flows and contribute to impairment of designated uses. For instance, in a channelized stream with minimal riparian vegetation, flow velocity and volume will likely be much greater than would be expected in a "natural stream", thereby increasing its erosive potential.

Instream and riparian techniques that can mitigate such impacts include

- Restoring natural stream meander and channel complexity;
- Increasing substrate roughness;
- Promoting growth of riparian vegetation, which serves as a drag on flows;
- Land use modification along buffers and other source areas; and
- Plunge pools and flow baffles to decrease the high energy of discharged waters.

These instream practices may need to be accompanied by techniques applied in the surrounding watershed, such as upland revegetation or the establishment of nonpoint source BMPs.

Low Flows

Maintaining flow is often essential to habitat protection. In many regions of the United States, stream segments are periodically dewatered from irrigation, industrial, and municipal withdrawals; diversion for hydroelectric power; evaporation; and groundwater infiltration. Additionally, during low-flow conditions, impacts from point source discharges of chemical stressors are typically greatest, because effluent constitutes a larger percentage of (sometimes all) stream

Case Study Summary
Wildcat Creek, California

Overall Project Goal: To implement an urban renewal plan to provide flood control, recreational opportunities, environmental quality, and enhanced economic development.

Restoration Techniques and Parameters of Concern: See table below.

Restoration Technique/Functional Attribute	Parameter of Concern[a]			
	Flooding	Wetlands Degradation	Elevated Temperature	Riparian Habitat Degradation
Construct low-flow channel				
Carry mean flows	↓	↓	O	↓
Transport and scour suspended sediment	↓	↓	O	↓
Spread high flows onto flood plain	↓	↓	O	↓
Plant trees along low-flow channels				
Provide shade	O	O	↓	↓
Reduce erosion	↓	↓	O	↓
Provide food for terrestrial and aquatic wildlife and organisms	O	↓	O	↓
Create pools/riffles	O	O	O	O
Fence and rotate grazing areas				
Promote plant growth	O	↓	↓	↓
Reduce erosion	↓	↓	O	↓

[a] ↑ means that the restoration technique increases water quality parameter; ↓ means that the restoration technique decreases water quality parameter; ↕ means that site-specific conditions can dictate increase or decrease in parameter; O means that the restoration technique has a negligible effect on water quality parameter.

Highlight on Techniques to Address Fine Sediment Loads/High Velocity Flows: Restoration techniques took into account dynamics of sediment transport and flow throughout the watershed. A key component of the project plan was transporting sediment past vulnerable marsh areas to diminish the impact of deposition. A meandering low-flow channel (10- to 15-feet wide) was designed to (1) carry mean flows; (2) scour and transport suspended sediment at higher velocities; and (3) allow high flows to spread onto the flood plains, lose velocity, and deposit sediment. A detention basin was also placed upstream to trap sediments. Trees were planted along banks to provide resistance to erosive forces of flowing water. Additionally, 312 acres of grazing lands were fenced and divided into four pastures. Livestock grazing is rotated through pastures to allow time for regrowth of vegetation, thereby protecting the watershed from soil erosion.

For a more complete project description, including techniques to address additional parameters of concern, refer to Chapter 6.

water at low flow, with increased pollutant concentration. NPDES permits based on low flow conditions (e.g., 7Q10) often cannot anticipate various combinations of climatic conditions and water demand that lead to exceedingly low flows.

Impacts attributable to minimum flows can be mitigated by several instream restoration techniques, including

- Reducing channelization,
- Restoring wetlands to store water and thereby restore natural hydrologic regimes,
- Controlling evaporation through restoration of the riparian canopy,
- Replacing exotic riparian plant species that have high evapotranspiration rates with native species that have lower transpiration rates,
- Constructing drop structures to create pools that provide protection for aquatic life during low-flow periods,
- Increasing channel depth and undercut banks to provide areas for protection of fish and other species during periods of low flow, and
- Increasing groundwater recharge to streams through increased infiltration (e.g., reduced imperviousness in recharge areas).

Minimum flows can also be addressed by applying techniques in the surrounding watershed, such as managing watershed land use to prevent excessive dewatering.

Resource management agencies, for example, can encourage or allow beavers to colonize stream segments; beaver dams create wetlands and retain water that supplements low flow during dry periods. Restored wetlands can have the same effect as a beaver dam. Local zoning authorities have begun to encourage the reduction of impervious area in watersheds through land-use ordinances. Increased infiltration and reduced peak flows from rapid runoff contributes to a more sustained base flow to the stream from groundwater discharge.

Restoration practices to mitigate low velocity/low-flow conditions often require close collaboration with other resource management agencies (e.g., USDA Forest Service), zoning authorities (e.g., county governments), and agricultural extension agencies. Several agricultural activities contribute to low velocity/low flow conditions. Agricultural extension agencies have developed specific techniques to modify the practices that impact streams and rivers in this manner. For example, irrigation plans can be optimized to reduce the demand for water that is diverted directly from the stream or dewatering by overdrafting an adjacent aquifer. Changing crop rotations and using less water-intensive crop alternatives are other tools that have been used effectively to address low velocity/low-flow situations.

BIOLOGICAL INTEGRITY

Practices that improve chemical and physical habitat quality will positively affect biological integrity, because improvements in water and habitat quality generally increase biodiversity and improve ecological functions such as nutrient and energy cycling, trophic relationships, and predator-prey relationships.

Toxicity

As discussed in the previous section, all of the restoration practices described in Table 3–1 potentially reduce ammonia toxicity. These same practices would, through similar mechanisms, reduce the toxicity of other substances (e.g., hydrogen sulfide). Wetlands can also help reduce the toxicity of some metals, by reducing metal concentrations and metal bioavailability. Together, all these practices would help reduce the total toxicity of the water and help attain this narrative water quality standard.

Algal Growth

Streams having slow flow waters, warm temperatures, and highly elevated nutrient concentrations can develop nuisance growth of algae (in general, concentrations of total inorganic nitrogen greater than about 0.25 mg/l and dissolved phosphate of about 0.02 mg/l are viewed as potentially leading to nuisance algal growth). Beyond the appearance, odor, and taste problems normally associated with nuisance algal growth, various instream problems can also result. For example, dense growths of filamentous algae in streams can block access to microhabitat features important for the growth and survival of many small or young aquatic species. Further, few aquatic species can use filamentous algae for food. The rapid and abundant growth of filamentous algae tend to competitively reduce the abundance of other algal forms that potentially provide favorable food sources for various aquatic species. Thus, nuisance algal growth tend to reduce available food supplies and, therefore, growth potential for many aquatic species.

Most importantly, both the high metabolic demands by the dense algal growths and the decay of the many dead algal filaments can drive down oxygen concentrations (especially at night-time) in the affected surface water. Often these demands can lead to depletion of dissolved oxygen concentrations. In turn, this can lead to severe stress or death of many species, loss of aquatic populations, and substantial shifts and simplification of aquatic communities. Generally, these changes also reduce the potential remaining assimilative capacities of receiving waters for other pollutants and reduce the resistance of the remaining stream community to other potential pollutant stressors. Additional concerns related to low dissolved oxygen concentrations are discussed in the next subsection.

In many streams, conditions promoting nuisance growth of algae can lead to stimulated growths of higher aquatic plants (macrophytes). Excessive growths of macrophytes can lead to many of the same problems caused by nuisance algal growths. In addition, dense macrophyte growths also can lead to additional slowing of flows and warming of waters, in some cases further intensifying the magnitude of these problems.

The following instream, riparian, and upland restoration practices can help to reduce excessive growth of algae and macrophyte.

- Drop structures and riffles would create turbulence that would reduce attached algal growth;

Case Study Summary
Bear Creek, Iowa

Overall Project Goal: Re-establishment of a healthy, functional riparian zone to improve aquatic habitat, water quality, and the aquatic community in the creek.

Restoration Techniques and Parameters of Concern: See table below.

Restoration Technique/Functional Attribute	Parameter of Concern[a]			
	Atrazine Loading	Sediment Loading	Nutrient Loading	Stream Bank Loading
Creation of Riparian Buffer Strip				
Increase uptake of nutrients	↓	O	↓	O
Trap sediments from croplands	↓	↓	↓	↑
Increase infiltration of water	↓	↓	↓	O
Plant trees, shrubs, and grasses	↓	↓	↓	↑
Monitoring and Data Collection				
Provide design specifications for other projects	↓	↓	↓	↑

[a] ↑ means that the restoration technique increases water quality parameter; ↓ means that the restoration technique decreases water quality parameter; ↕ means that site-specific conditions can dictate increase or decrease in parameter; O means that the restoration technique has a negligible effect on water quality parameter.

Highlight on Techniques to Address the Capture of Sediments and Agricultural Chemicals: The physical habitat in Bear Creek is adversely affected by high sediment loads; the water quality is also adversely affected by high concentrations of suspended solids, nutrients, and agricultural chemicals, particularly the herbicide, atrazine. Nitrogen levels in the creek exceed EPA limits in late spring and summer after fertilizer applications. Restoration of the riparian zone will be accomplished by helping farmers who own land along the creek to develop functioning riparian zones. These riparian zones will intercept surface runoff and subsurface flow and will remove or immobilize sediment and agricultural chemicals before they enter the creek. The restored riparian zone will also provide wildlife habitat, food for wildlife, and high-quality timber. The riparian buffer strip is specifically designed to capture nitrogen in agricultural runoff, with plants, trees, and shrubs selected for nutrient uptake characteristics. Rapidly growing tree species such as willow, poplar, silver maple, and green ash have been chosen for that purpose. They are harvested on 8- to 12-year rotations to remove sequestered nutrients from the site. Because these species regenerate from stump sprouts, the root systems stay intact and above-ground biomass is quickly re-grown.

For a more complete project description, including techniques to address additional parameters of concern, refer to Chapter 6.

- During some periods of the year, wetlands will reduce nutrient input into the stream, thereby reducing algal growths;
- Planting trees and bushes will reduce the amount of sunlight available for algal growth, thus leading to reductions in algal growth;
- Increased channel depth and undercut banks will reduce the area available for algal growth; and
- Nonpoint control of nutrient loading.

LOW DISSOLVED OXYGEN CONCENTRATIONS

Low dissolved oxygen (DO) concentrations can be detrimental to aquatic life. DO concentrations in surface waters are determined by many factors, including water temperature, salinity, biological respiration, chemical oxygen demand, sediment oxygen demand, photosynthesis, and transfer of oxygen into the water from the atmosphere (i.e., re-aeration). While DO concentrations are known to fluctuate throughout the day, minimum DO concentrations in streams typically occur at night when aquatic plants do not photosynthesize but aquatic organisms, including plants, respire. The lowest daily DO concentrations generally occur immediately before dawn.

In most streams that do not receive significant input of materials with high chemical and biological oxygen demand and nutrients that stimulate plant growth and respiration, natural re-aeration will maintain adequate DO concentrations to support a healthy aquatic community. Natural re-aeration rates in a stream are influenced by stream properties such as depth, turbulence, frequency of riffle areas, and natural drops (e.g., waterfalls and natural obstructions that create turbulence). Disturbances such as channelization and excessive erosion reduce channel complexity and thus re-aeration potential. Types of restoration practices that can increase DO concentrations include the following:

- Reintroducing or constructing small hydrologic drop structure or other structures (e.g., boulders, logs) that increase hydrological turbulence and mixing that increase re-aeration rates;
- Restoring existing degraded wetlands or re-establishing natural streamside vegetation to intercept nonpoint sources of nutrients to reduce aquatic plant growth and respiration demand within the stream;
- Re-establishing trees and bushes along stream banks to reduce incident sunlight and water temperature, and to trap nutrients and sediments, thereby reducing aquatic plant growth and respiration demands;
- Restoring stream depth and undercut banks and re-narrowing stream width to reduce aquatic plant growth and water temperatures, thereby reducing respiration demands; and
- Re-establishing or creating, shallow riffle substrates to increase turbulence, mixing, and the area of stream surface exposed to the atmosphere, which will increase re-aeration rates.

ALTERED TEMPERATURE

Abnormally high water temperatures may adversely impact aquatic life. Increased water temperature also increases toxicity of many chemicals such as un-ionized ammonia. High water temperatures reduce DO concentrations by increasing plant growth and respiration rates and decreasing the solubility of oxygen in water. Solar heating is the primary cause of abnormally high water temperatures. In some streams (e.g., warm water rivers downstream of dams with hypolimnetic discharges), abnormally low water temperatures may adversely affect warmwater aquatic life. Types of instream, riparian, and upland habitat restoration practices that can be used to manage water temperatures include:

- Re-establishing trees and bushes along stream banks to reduce incident sunlight;
- Restoring stream depth, re-establishing undercut banks, and narrowing stream width to reduce excessive solar warming; and
- Retrofit dams with multilevel intake to control temperatures.

EXTREME PH

Rapid fluctuations or sustained changes in pH outside the pH range that an organism has become accustomed to can create conditions that are stressful, or even toxic. In particular, aquatic organisms may suffer an osmotic imbalance under sustained exposures to low pH waters.

The concentration of hydrogen ions in aqueous solution is expressed as pH. The pH scale is a relative measure of the acidity of a solution, ranging from very acidic (pH of 1) to very alkaline (pH of 14). Neutrality occurs at a pH of 7. Most natural waters are circumneutral (i.e., near pH of 7), with pH values ranging from 6 to 8 (Stumm and Morgan 1981).

The carbonate buffering system controls the acidity of most streams. Carbonate buffering is an equilibrium between calcium, carbonate, bicarbonate, carbon dioxide, and hydrogen ions in the water and carbon dioxide in the atmosphere. The amount of buffering, also called alkalinity, is primarily determined by carbonate and bicarbonate concentration, which are introduced into the water from dissolved calcium carbonate (i.e., limestone) and similar minerals present in the watershed. In general, higher alkalinity makes water more resistant to acidification.

Acidification occurs when all alkalinity in the water is consumed by acids, a process often attributable to the input of strong mineral acids (e.g., sulfuric acid) from acid mine drainage and acidic precipitation or weak organic acids (e.g., humic and fulvic acids), which are naturally produced in large quantities in some types of soils, such as those associated with coniferous forests, bogs, and wetlands. In watersheds with relatively large amounts of limestone (or similar alkaline, rapidly weathered minerals), surface waters are well buffered and therefore resistant to acidification. Waters most susceptible to acidification are found in watersheds with minerals that weather slowly (e.g., granite) and have little or no limestone or other alkaline minerals.

Another characteristic of pH in some poorly buffered surface waters is high daily variability in pH levels attributable to biological processes that affect the carbonate buffering system. Extreme increases in pH may create conditions as detrimental to aquatic organisms as low-pH conditions

CASE STUDY SUMMARY
UPPER GRANDE RONDE RIVER, OREGON

Overall Project Goal: Conduct an analysis for selecting techniques to restore riparian zone and lower instream temperatures to sustain a healthy coldwater ecosystem, including habitat for salmon.

Restoration Techniques and Parameters of Concern: See table below.

Restoration Technique/Functional Attribute	Parameter of Concern[a]			
	Stream Temperature	Salmon Populations	Stability of Stream Banks	DO Levels
Riparian Zone Characterization Project				
Classify riparian zone vegetation patterns	↓	↑	↑	↑
Classify stream channel morphology	↓	↑	↑	↑
Provide input for basin temperature model	↓	↑	↑	↑
Temperature Modeling Project				
Predict stream temperatures	↓	↑	↑	↑
Identify priority locations for restoration	↓	↑	↑	↑

[a] ↑ means that the restoration technique increases water quality parameter; ↓ means that the restoration technique decreases water quality parameter; ↕ means that site-specific conditions can dictate increase or decrease in parameter; ○ means that the restoration technique has a negligible effect on water quality parameter.

Highlight on Techniques to Address Elevated Summer Water Temperatures: Widespread alteration and removal of riparian vegetation has caused elevated summer water temperatures on the Upper Grande Ronde River, resulting in impaired ability of the river to sustain a healthy coldwater ecosystem, including annual salmon runs and resident salmonid populations. The initial phase of the restoration project has two components. In the first, data on riparian vegetation patterns and stream channel morphology are gathered for input into the basin temperature model; a GIS database is also created. In the second phase, the temperature model is used to identify priority locations for stream restoration by predicting stream temperatures under various scenarios. To date, several potential restoration projects have been identified.

For a more complete project description, including techniques to address additional parameters of concern, refer to Chapter 6.

and contribute to the buildup of toxic concentrations of un-ionized ammonia (NH3), a toxic form of nitrogen. In waters with large standing crops of aquatic plants, uptake of carbon dioxide by plants during photosynthesis removes carbonic acid from the water, which can increase pH by several units. Conversely, pH levels may fall by several units during the night when photosynthesis does not occur and plants respire carbon dioxide, which is converted to carbonic acid in the water.

The following instream, riparian, and upland restoration practices can be used to reduce acidity or stabilize extreme fluctuations in pH levels:

- pH levels can be increased by restoring existing degraded wetlands that intercept acid inputs such as acid mine drainage and help neutralize acidity by converting sulfates associated with sulfuric acid to insoluble non-acidic metal sulfides that remain trapped in wetland sediments.

- Techniques discussed above for increasing DO concentrations also tend to stabilize highly variable pH levels attributable to high rates of photosynthesis.

Ammonia Toxicity

Ammonia can be toxic to aquatic life and has been found to be a source of toxic effects to aquatic life in some streams. Ammonia, an inorganic form of nitrogen, is a product of the metabolism of organic nitrogen and the biological conversion by bacteria of nitrate to ammonia in anaerobic waters and sediments. Inadequately treated municipal wastewater, agricultural runoff, groundwater contamination by fertilizer, stormwaters, and feedlots are potential sources of ammonia and nitrate to streams.

The un-ionized form of ammonia exists in equilibrium with the ammonia and hydroxide ions. The reaction occurs rapidly and is controlled by pH and temperature. Monitoring and water quality models usually report total ammonia, and the un-ionized fraction must be estimated. As weight per volume of N, un-ionized ammonia concentrations are determined from total ammonia (NH3+NH4+) as (Bowse et al. 1985):

$$pk_n = 0.09018 + \frac{2729.92}{T + 273.2}$$

where *A* is the measured total ammonia concentration and *pK*n is the hydrolysis constant, which depends on temperature:

where *T* is temperature in degrees Celsius.

Ammonia is present in water in two forms, un-ionized (NH3) and ionized (NH4+) ammonia. Of these two forms of ammonia, NH3 has relatively high toxicity and NH4+ has relatively negligible toxicity. The proportion of NH3 is determined by the pH and temperature of the water: As

Case Study Summary
Boulder Creek, Colorada

Overall Project Goal: Restore the full use of the creek reach as a warmwater fishery, create recreational opportunities, and ensure the effectiveness of capital improvements to the Boulder wastewater treatment plant in lowering un-ionized ammonia levels.

Restoration Techniques and Parameters of Concern: See table below.

Restoration Technique/Functional Attribute	Parameter of Concern[a]				
	DO Levels	Sediment Loadings	Temperature	pH	NH_3
Riparian Zone and Habitat Restoration					
Restore reaeration potential	↑	O	O	↕	↓
Stabilize stream banks	↑	↓	↓	↓	↓
Construct wetlands	↑	↓	O	↓	↓
Reroute irrigation flow	↑	↓	↓	↓	↓
Increase channel depth, undercut banks, and narrow stream width	↑	O	↓	↓	↓
Capital Improvements at Boulder WWTP					
Solid and liquid waste treatment	↑	O	O	O	↓
Nitrification trickling filter	↑	O	O	O	↓

[a] ↑ means that the restoration technique increases water quality parameter; ↓ means that the restoration technique decreases water quality parameter; ↕ means that site-specific conditions can dictate increase or decrease in parameter. O means that the restoration technique has a negligible effect on water quality parameter.

Highlight on Techniques to Address Degradation of Riparian Zone and In-Stream Habitat: A four-phase ecological restoration plan was necessary to ensure that capital improvements to the Boulder wastewater treatment plan were sufficient to reduce levels of un-ionized ammonia to meet state standards in the creek. The restoration plan had a number of complementary elements which reinforced one another. For example, the riparian zone in a cattle-grazing area was fenced off to allow revegetation efforts to take hold. A number of other stream-bank stabilization efforts were undertaken, such as construction of rock/willow jetties to break up erosive currents. The plan featured the construction of new wetlands and the protection of existing wetlands acreage to reduce the impact of irrigation return flows and lower sediment loadings from run-off.

For a more complete project description, including techniques to address additional parameters of concern, refer to Chapter 6.

pH or temperature increase, the proportion of un-ionized ammonia and the toxicity increases. For example, at pH 7 and 68 oF, only about 0.4% of the total ammonia is in the form of NH_3, while at pH 8.5 and 78 oF, 15% of the total ammonia is in the form of NH_3. Consequently, ammonia is over 35 times more toxic at pH 8.5 and 78 oF than at pH 7 and 68 oF.

Any instream, riparian, or upland restoration practice that decreases pH or temperature will decrease the potential toxicity of ammonia to aquatic life in streams:

- Restoring or enhancing the re-aeration potential of the stream can reduce ammonia concentrations by providing more DO for biological oxidation of ammonia to nitrate and by increasing the volatilization of ammonia into the atmosphere. The re-aeration potential can be increased by constructing small drop structures, riffles, and other structures that increase turbulence and mixing.

- Restoring wetlands that will intercept nutrients, thus reducing plant growth and photosynthesis in the stream, thereby decreasing pH levels, and also reducing ammonia concentrations, both of which will reduce ammonia toxicity.

- Re-establishing trees and bushes along stream banks to reduce incident sunlight and water temperature and trap nutrients, thereby reducing aquatic plant growth and photosynthesis; and

- Restoring stream depth and re-establishing undercut banks and narrowing stream width to reduce aquatic plant growth and decrease water temperatures.

- Reducing nonpoint source inputs of nutrients (e.g., nitrogen, phosphorus) to streams.

The decline of pH in response to these restoration measures is adequate to mitigate the accumulation of high concentrations of ammonia. However, the pH shift is generally not large enough to present a problem for increased mobilization of metals (e.g., aluminum, selenium, arsenic, mercury) from sediments. Generally, these metals are mobilized at a pH much lower than those associated with ammonia toxicity.

Toxic Concentrations of Bioavailable Metals

The uptake of metals by aquatic life is an active, rather than a passive, biological process. Because the primary pathway for most metal uptake by aquatic life is through respiratory organs of fish and aquatic invertebrates, and only ionic forms of metals can pass through cell membranes, the toxicity of most metals to aquatic life is a function of the concentration of dissolved ionic forms of metals in the stream. Consequently, particulate metals are not directly toxic to most forms of aquatic life.

Many toxic substances, including metals, have a tendency to leave the dissolved phase and attach to suspended particulate matter. The fractions of total metal concentration present in the particulate and dissolved phases depend on the partitioning behavior of the metal ion and the concentration of suspended particulate matter. The dissolved fraction may also be affected by complexing of metals with organic binding agents.

The primary mechanism for water column toxicity of most metals is adsorption at the gill surface. While some studies indicate that particulate metals may contribute to toxicity, perhaps because of factors such as desorption at the gill surface, the dissolved metal concentration more closely approximates the fraction of metal in the water column which is bioavailable.[1] Accordingly, the EPA's policy is that the use of dissolved metals to set and measure compliance with water quality standards is the recommended approach (EPA 1993c).

Conditions that partition metals into particulate forms (presence of suspended sediments, dissolved and particulate organic carbon, carbonates, bicarbonates, and other ions that complex metals) reduce potential bioavailability of metals. Also, calcium reduces metal uptake, apparently by competing with metals for active uptake sites on gill membranes. pH is also an important water quality factor in metal bio-availability. Metal solubilities, and therefore the proportion of ionic forms of most metals, are lower at circumneutral pH than in acidic or highly alkaline waters. In general, as concentrations of all these water quality factors increase, the proportion of less toxic particulate metal increases. Therefore, any restoration technique that increases the concentration of these water quality factors potentially reduces metal toxicities.

A number of instream, riparian, or upland restoration techniques can decrease the toxicity of metals to aquatic life by either reducing input of metals to streams or by altering appropriate chemical parameters in order to increase the proportion of less toxic particulate metals:

- Techniques mentioned above for stabilizing pH. These techniques decrease metal bioavailability by increasing particulate metals.

- Restoring existing wetlands to treat acid mine drainage is a good example of such a restoration practice. Wetlands can reduce metal inputs and increase inputs of dissolved organic carbon and alkalinity concentrations to streams, all of which reduce metal toxicities.

- Re-establishing trees in riparian areas and encouraging the growth of other riparian vegetation can also help reduce concentrations of bioavailable metals by trapping within or filtering metals from nonpoint sources and by contributing particulate and dissolved organic matter to the stream.

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[1]Certain metals, most notably mercury, also cause toxicity through other routes of exposure. Under anaerobic conditions, methanogenic bacteria in the sediment can produce methyl mercury, which is soluble and highly toxic and can accumulate through the food chain.

CHAPTER 4

A DECISION-MAKING GUIDE FOR RESTORATION

This chapter provides a conceptual framework for ecological restoration activities in water programs. Discussion focuses on important components and issues of decision-making for restoration, rather than a detailed step-by-step protocol for conducting ecological restoration. The decision-making guide is summarized in a series of *nested* flow charts. The first flow chart shows major components of the decision-making guide, without any complicating details (Figure 4–1); subsequent flow charts and text describe major components in greater detail.

This decision-making guide emphasizes the applicability of restoration techniques for water programs and includes decision points that integrate a broad range of program responsibilities and activities. The process assumes that impaired water resources have already been identified in accordance with the CWA and other requirements. The decision-making guide begins with a selected site where water quality standards, which may include numeric or narrative criteria or designated uses, are not being met or are threatened. In Step 1, an inventory of watershed conditions is used to scope promising opportunities for restoration. In some cases, ecological restoration will be the most effective response to impairment; in other cases, restoration may be one among many candidate tools for achieving water quality standards. Steps 2 and 3 provide an analysis of the availability, applicability, and relative costs of ecological restoration techniques to assist regional and state personnel in making an informed decision. In Step 4, an ecological restoration approach is implemented, where appropriate. Finally, post-implementation monitoring, an essential part of the decision-making guide, is conducted in Step 5 to determine whether impairment has been mitigated.

Several steps in the decision-making guide call for stakeholder involvement. Identification and recruitment of stakeholders may have been done as part of a Watershed Protection Approach or Total Maximum Daily Load (TMDL) process prior to the ecological restoration decision steps described below. If stakeholders have not already been identified and recruited, however, this important element of public participation should be addressed explicitly. Figure 4-1 illustrates recognition of the larger context of the restoration decision-making process by including an input arrow prior to Step 1. Each user should therefore view these steps as an example model and determine whether the public participation and other components need to be adapted to meet additional requirements.

STEP 1: INVENTORY THE WATERSHED

> **STEP 1: INVENTORY THE WATERSHED**
>
> - Characterize watershed conditions to determine nature of impairment
> - Determine feasibility of using restoration to meet waterbody goals

The decision-making process begins with a review or inventory of existing information, designed to yield a preliminary evaluation of the types of restoration activities which may be feasible and appropriate to address impairment. The accompanying Step 1 flow chart, which contains four numbered substeps and three decision points, lays out an example framework for determining when ecological restoration is of potential use (Figure 4–2).

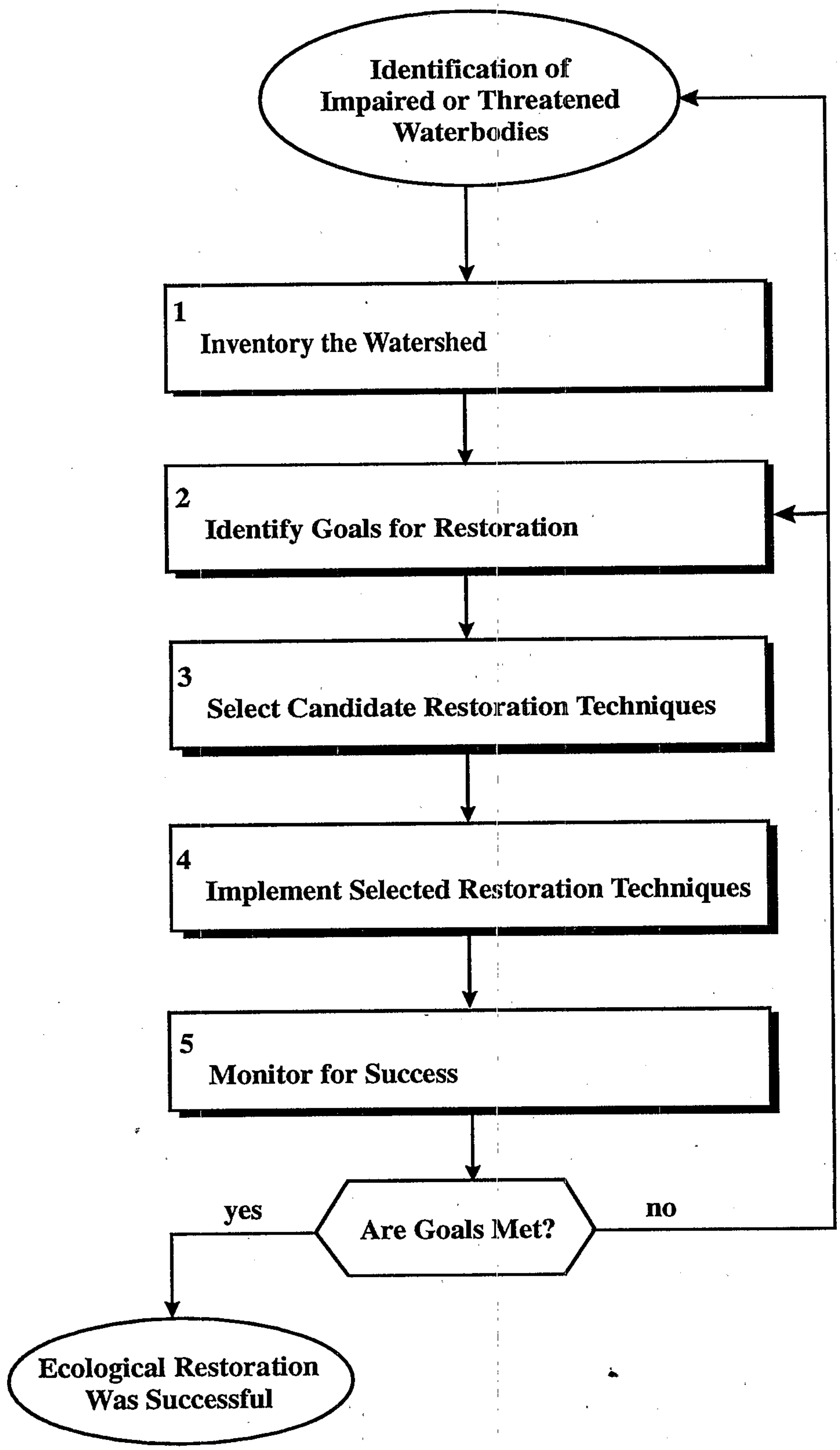


Figure 4-1. Major components of the ecological restoration decision framework.

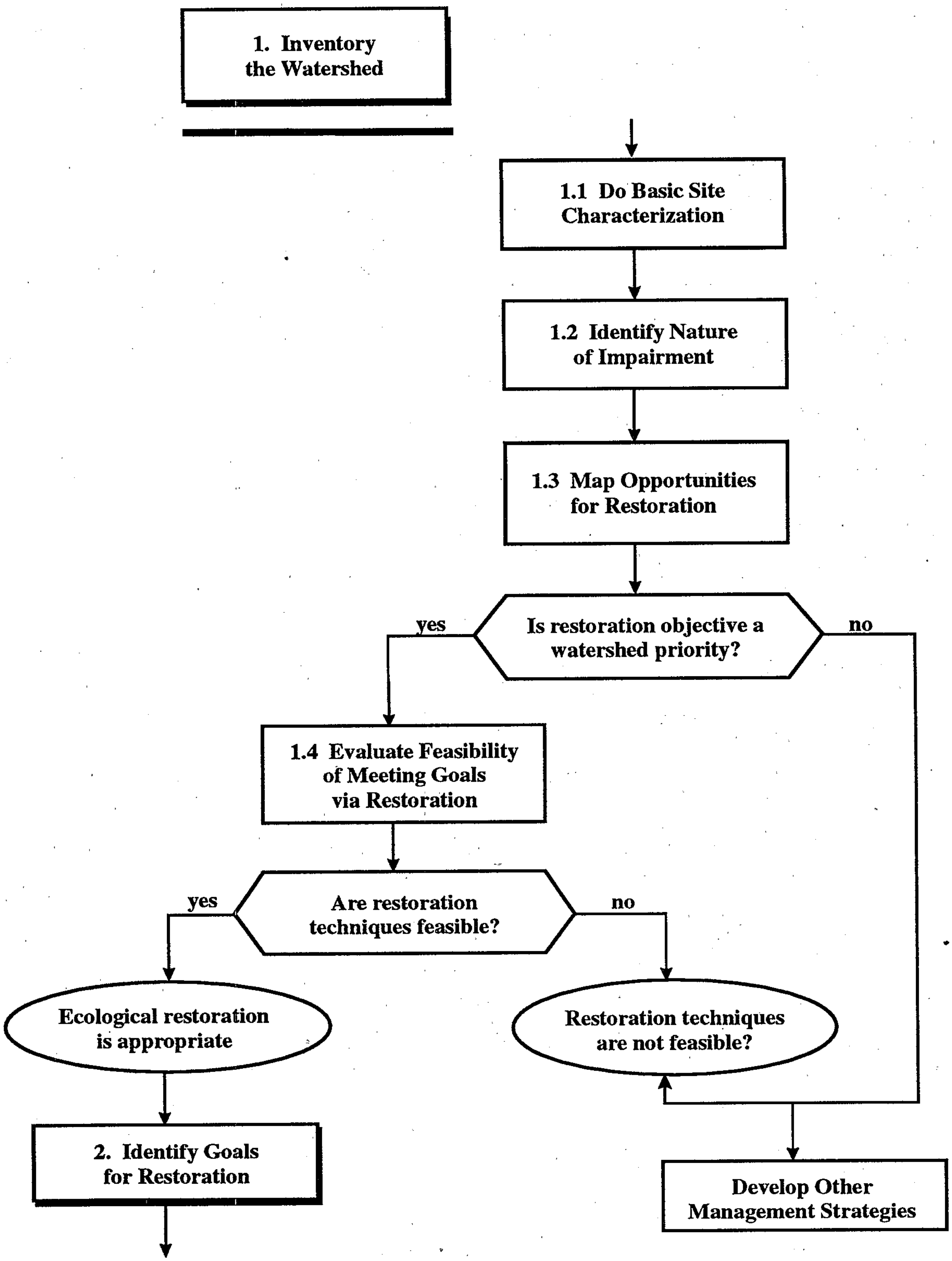


Figure 4-2. Step 1: Determine if restoration can be used to address waterbody impairment.

STEP 1.1: DO BASIC SITE CHARACTERIZATION

Basic site characterization and data collection are the first steps in inventorying a watershed. Characterization may include information on water quality; geochemistry; hydrology; fluvial geomorphology; substrate condition; flora; and fauna; and, to the greatest extent possible, identification of stressor sources in the watershed. In addition to traditional point source loading of pollutants, stressors may include nonpoint source pollutant loading and land-use effects, hydrological alterations, point source impacts causing physical habitat alterations, and mining, among others.

In addition to physical and chemical characteristics of the watershed, land ownership and regulatory jurisdictions play an important role in determining opportunities for restoration. Much of this information is geographically based, and amenable to storage and manipulation in a Geographic Information System (GIS). As part of the basic site characterization for potential restoration, managers may wish to consider (1) mapping other opportunities for related ecological improvement projects, such as parks, refuges, Nature Conservancy sites, heritage trust projects, etc.; (2) mapping other public lands, such as active and abandoned military bases, controlled flood protection areas, etc.; and (3) mapping regulatory jurisdictions. Such resource maps are valuable tools to foster public involvement, improve the coordination of restoration activities, and develop cooperative solutions to regulatory conflicts.

Also included in the basic site characterization is the acquisition of historical and current data on regional or landscape-scale habitat characteristics. This type of information is invaluable to planning and evaluating site characterization. It is also useful in later steps of the decision-making process for (1) setting realistic restoration goals and (2) identifying regional issues that must be addressed before undertaking a watershed or site-specific restoration project.

Data collected during site characterization, including both site and landscape-scale data, also provide a baseline for evaluating the performance of restoration projects. These data can be used to establish the environmental benchmarks to be used later (Step 5) to monitor for success of the restoration practices.

STEP 1.2: IDENTIFY NATURE OF IMPAIRMENT

In some watersheds, point and nonpoint sources of pollutant loads have direct and predictable relationships to waterbody impairment. In many cases, however, the connection between load sources and impairment is less obvious, and physical habitat variation may play an important role in the nature and occurrence of impairment. A spatial analysis of the specific nature and causes of impairments throughout the watershed is usually not feasible during the watershed inventory. Initial identification can, however, make use of available information, including databases and extant studies on physical habitat degradation and associated impairment of beneficial uses, such as §303(d) lists, §305(b) Reports, §319 Assessment Reports, Use Attainability Analyses, and other sources. Many studies provide detailed summaries of habitat suitability measures, water quality parameters related to habitat degradation, and associated excursions of water quality standards.

Identified impairments must be addressed within the appropriate regulatory context. In some cases, a narrative criterion or designated use component of the water quality standard may explicitly refer to a habitat use, such as the necessity of maintaining spawning habitat. In other cases, the water quality standard in question may not refer explicitly to a habitat goal or function, but rather to some numeric criterion. In these cases, ecological restoration techniques still have the potential to bring a water resource into compliance with the water quality criterion or standard. For example, a stream may not meet the criterion for un-ionized ammonia. Although in this case the water quality standard does not refer explicitly to a habitat use, restoration of riparian vegetation can lower stream temperature, which can reduce the instream concentration of un-ionized ammonia. Restoration may thus address numeric or narrative criteria. These two branches of the guide are separated at the decision point following Step 1.2.

Combining information on watershed physical characteristics, water quality, habitat, land ownership, and regulatory jurisdictions with the preliminary analysis of the nature of impairment allows selection of the best strategies to develop sustainable restoration sites, increase regional biodiversity, and, along the way, suggest the places appropriate for economic development.

STEP 1.3: MAP OPPORTUNITIES FOR RESTORATION

In mapping opportunities for restoration, it should be kept in mind that restoration approaches can have beneficial effects beyond the direct restoration of habitat. For instance, a stream segment might possess adequate functioning wetland habitat to support designated uses, but restoring degraded wetlands upstream might mitigate downstream excursions of numeric water quality criteria for metals. A cause-and-effect linkage is often difficult to prove; at this stage, however, only a preliminary, tentative assessment is needed for identifying the problem. Often, this will be based on assumptions and experience with similar sites.

STEP 1.4: EVALUATE FEASIBILITY OF MEETING GOALS VIA RESTORATION

Even where good opportunities exist for ecological restoration, establishing whether such techniques are appropriate for further consideration as management options must take into account the technical *feasibility* of restoration. That is, there will be cases in which ecological restoration opportunities are obvious, yet are not technically feasible with the current state of the science. When direct, instream ecological restoration does not appear feasible, however, riparian or upland restoration options (generally based on source control in the surrounding watershed) may improve habitat. When restoration by either instream, riparian, or upland techniques appears feasible, the decision process continues to Step 2, the identification of goals for restoration. Consideration of economic viability of candidate restoration techniques is addressed both in Step 3 and in Chapter 5.

STEP 2: IDENTIFY GOALS FOR RESTORATION

> **STEP 2: IDENTIFY GOALS FOR RESTORATION**
>
> - Develop specific restoration goals and candidate restoration techniques
> - Beginning stakeholder involvement at this stage is crucial

The screening analysis laid out in Step 1 is designed to indicate that ecological restoration should be considered as a management option whenever it has the potential to mitigate water resource impairment. Subsequent steps in the decision-making guide attempt to refine this analysis and provide a clear determination of which ecological restoration options, if any, should be pursued. Clarifying exactly what goals are appropriate for ecological restoration at a given site is critical to examining the worth of specific restoration techniques and is the emphasis of Step 2. A detailed flow chart for Step 2 containing six substeps is shown in Figure 4–3. As indicated on the right-hand side of the flow chart, public participation is an important element in identifying goals for any restoration project. Public participation not only improves the validity of restoration goals, but can be instrumental in finding necessary funding.

STEP 2.1: IDENTIFY SPECIFIC WATER QUALITY STANDARDS (I.E., CHEMICAL, PHYSICAL, AND BIOLOGICAL COMPONENTS) POTENTIALLY ADDRESSED BY RESTORATION

Problem identification and analysis in Step 1 focuses on the linkage between waterbody impairment and options for ecological restoration. As impairment is defined in terms of non-attainment of water quality standards, planning for restoration should be firmly based on specific water quality standards to be addressed, including criteria and designated uses. As in Step 1, standards may involve a specific reference to habitat use or other numeric or narrative criteria that are potentially addressed through ecological restoration.

STEP 2.2: BEGIN STAKEHOLDER INVOLVEMENT AND DEVELOP CONSENSUS OBJECTIVES

Participating programs, agencies, and stakeholders will develop consensus goals and objectives for the ecological restoration project, consistent with the Watershed Protection Approach and TMDL process. Figure 4–4, adapted from the Anacostia Restoration Team (1991), illustrates a matrix of watershed restoration goals and project objectives identified by participants. Goals and objectives should be directly related to meeting water quality standards in question. The matrix also shows which participants will contribute to individual project objectives. A key to stakeholder acronyms use in Figure 4-4 is included on page 4-10 following the table.

Following Step 2.2, the decision sequence varies depending on whether the waterbody impairment is defined directly in terms of ecological or habitat conditions or in terms of other types of water quality standards, such as non-attainment of numeric standards for chemical concentration, which may be mitigated through use of ecological restoration as a management tool.

STEP 2.3: CONDUCT ECOREGIONAL OR LANDSCAPE-LEVEL ANALYSIS

An ecoregional or landscape-level analysis can be used to determine the status of particular resource components of the aquatic ecosystem, describe existing reference sites, and identify any large-scale landscape condition that might inhibit achieving ecological restoration goals. Items addressed in a regional or landscape perspective include:

- Endangered species
- Critical resource type (e.g., wetland category)
- Reference conditions
- Large-scale problems

When using restoration to meet a numeric water quality criterion, this step could provide valuable information, but may not be necessary.

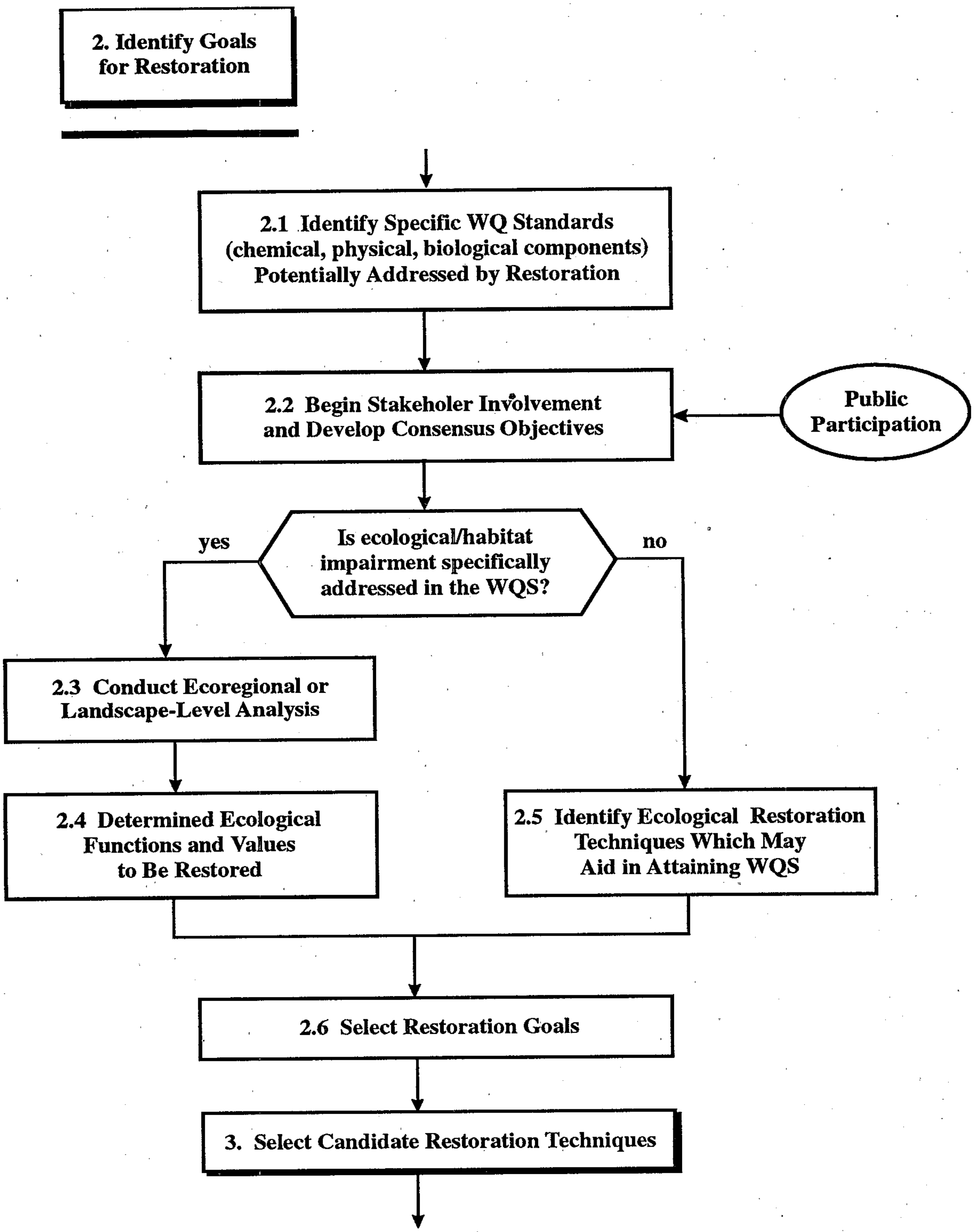


Figure 4-3. Step 2: Identify goals for restoration.

Figure 4-4. Matrix of watershed management goals, objectives, and stakeholders[a]

	MC-DEP	MNCPPC-MC	PG-DER	MNCPPC-PG	MDE	DNR	DC-DCRA	DC-DPW	WSSC	COG	ICPRB	EPA	USDA	NPS	COE
Goal 1—Stormwater: Dramatically reduce pollutant loads delivered to the tidal estuary to improve water quality conditions by the turn of the century															
Sewage Overflow Controls: Sharply reduce the volume of combined sewage overflow into the Anacostia from the District of Columbia's combined sewer system and the aging suburban sanitary sewer network in the tributaries							✓	✓	✓	✓		✓		✓	
Urban Stormwater Retrofits: Sharply reduce urban stormwater pollutant loadings from existing development in the watershed through the implementation of stormwater retrofit ponds, marsh, and filter systems	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	
Urban BMPs for New Development: Prevent increases in urban stormwater pollutant loadings from new development in the upland watershed through the use of stringent stormwater quality and sediment control regulations at new development sites	✓	✓	✓	✓	✓					✓		✓			
Control of Trash and Debris: Prevent trash and floatable debris from getting to the tidal river and remove the floatable debris that is currently trapped in the estuary	✓		✓					✓		✓	✓			✓	✓
Goal 2—Streams: Protect and restore the ecological integrity of urban Anacostia streams to enhance aquatic diversity and provide for a quality urban fishery															
Urban Stream Restoration: Comprehensively apply both stormwater management and instream restoration techniques to improve the habitat quality of severely degraded urban streams (Streambank stabilization methods include bioengineering, rip-rap, and instream restoration methods such as log check dams, boulder placement, and deflectors.)	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓
Urban Stream Protection: Apply land-use controls and stringent urban stormwater and sediment control practices at new development sites to protect receiving streams from the impacts of urbanization	✓	✓	✓	✓	✓	✓	✓			✓	✓		✓	✓	
Goal 3—Fish Passage: Restore the spawning range of anadromous fish to historical limits															
Removal of Fish Barriers: Strategically remove or modify fish barriers to expand the available spawning range for both anadromous and resident native fish		✓		✓		✓					✓	✓			✓
Improve Habitat Quality: Improve the quality of spawning habitat in the lower Anacostia through the installation of instream habitat improvement structures		✓		✓		✓					✓				✓

[a] Adapted from Anacostia Restoration Team (1991).

Continued

Figure 4-4. Continued

	MC-DEP	MNCPPC-MC	PG-DER	MNCPPC-PG	MDE	DNR	DC-DCRA	DC-DPW	WSSC	COG	ICPRB	EPA	USDA	NPS	COE
Goal 1—Wetlands: Increase the natural filtering capacity of the watershed by sharply increasing the acreage and quality of tidal and non-tidal wetlands															
Wetlands Protection: Prevent further net loss of wetlands in the watershed as a result of new development and other activities						✓	✓					✓			✓
Urban Wetland Restoration: Restore the ecological function of existing degraded wetland areas		✓						✓		✓		✓	✓	✓	✓
Urban Wetland Creation: Create several hundred acres of new wetlands throughout the basin to partially replace the natural filtering capacity lost over time	✓	✓	✓	✓				✓		✓	✓	✓	✓	✓	✓
Goal 5—Forests: Expand forest cover throughout the watershed and create a contiguous corridor of forest along the margins of its streams and rivers															
Forest Protection: Reduce the loss of forest cover associated with new development and other activities by local implementation of the 1991 Maryland Forest Conservation Act	✓	✓	✓	✓		✓				✓				✓	
Watershed Reforestation: Take full advantage of existing local, state, federal and private resources to extensively reforest suitable sites throughout the basin	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓
Riparian Reforestation: Reforest ten linear miles of riparian areas along the Anacostia over the next three years as a first step in creating an unbroken forest corridor from the tidal river to the uppermost headwater streams	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓
Goal 6—Stewardship: Make the public aware of its key role in the cleanup of the river and increase volunteer participation in watershed restoration activities															
Watershed Outreach and Education: Raise public awareness about the problems of the Anacostia River and restoration efforts; ask for sustained citizen commitment; educate the public, especially children, about the ecology of the river system and the role of the public in reducing urban pollution			✓		✓			✓		✓	✓	✓			✓
Restoration Stewardship: Encourage the development of an Anacostia stream constituency and grass-roots network of watershed residents to participate in a variety of ways: practicing good citizenship, joining environmental activist groups, adopting stream segments, and participating in small-scale habitat improvement projects	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓	

Key to Stakeholders Listed in Figure 4-4	
COE	Corps of Engineers (Baltimore District)
COG	Metropolitan Washington Council of Governments
DC-DCRA	District of Columbia Department of Consumer and Regulatory Affairs
DC-DPW	District of Columbia Department of Public Works
DNR	Maryland Department of Natural Resources
EPA	U.S. Environmental Protection Agency
ICPRB	Interstate Commission on the Potomac River Basin
MC-DEP	Montgomery County Department of Environmental Programs
MDE	Maryland Department of the Environment
MNCPPC-MC	Maryland National Capital Park and Planning Commission - Montgomery County
MNCPPC-PG	Maryland National Capital Park and Planning Commission - Prince George's County
NPS	National Park Service
PG-DER	Prince George's County Department of Environmental Regulation
USDA	U.S. Department of Agriculture
WASUA	Water and Sewer Utility Administration
WSSC	Washington Suburban Sanitary Commission

Step 2.4: Determine Ecological Functions and Values to Be Restored

When standards specifically mention ecological impairment, determining to what extent (and to what point in time) affected ecosystem functions and values can be restored is important. For some water resources, such as certain wild rivers impaired by recent disturbances, restoration to a pristine, pre-disturbance condition may be realistic. For water resources in areas that are long-settled or surrounded by development, specification of a pre-disturbance baseline may be unclear or irrelevant. In such cases, goals for restoration should be evaluated with respect to the water resource's designated uses in order to determine whether functions and values to be restored are reasonably *attainable* in the context of the existing surrounding landscape. This step is a refinement of the scoping analysis in Step 1.4, conducted at a more rigorous and detailed level.

Step 2.5: Identify Ecological Restoration Techniques that May Aid in Attaining Water Quality Standards

Restoration techniques are often useful to attain numeric criteria for chemical concentrations, which may indirectly relate to habitat conditions, or may be specified for protection of human health. Restoration techniques can also be applicable to attaining non-ecological narrative criteria, such as suitability for recreational use. Similar to Step 2.4, this step provides a more rigorous identification of exactly which restoration techniques (and associated ecosystem functions and values) are potentially available to reduce impairment.

Step 2.6: Select Restoration Goals

The previous steps yield a list of ecological functions and values, and stakeholder consensus objectives, for consideration for restoration. To complete Step 2, these results are summarized by selecting a set of potential ecological restoration goals for further consideration. Typical goals for restoration include meeting applicable water quality standards (consisting of the beneficial designated use or uses of a water resource, the numeric and narrative water quality criteria that are necessary to protect the use or uses of a particular water resource, and an antidegradation statement), maintaining a fishery, preserving specific habitat types, and so on. Such goals are closely related to ecological assessment endpoints, which are developed more formally in Step 5 (Monitor for Results) to determine the effectiveness of selected management options (EPA 1992a). (Table 4–1, page 4–22, summarizes information on assessment and measurement endpoints for ecological restoration.)

Step 3: Identify and Select Candidate Restoration Techniques

A key to identifying and selecting restoration techniques is to know *how much is enough.* That is, avoid unnecessary expenditure of resources trying to fix a problem that the system can fix on its own. The general decision framework for Step 3 is shown in Figure 4–5.

Step 3: Identify and Select Candidate Restoration Techniques

- Seek cost effective strategies
- A combination of instream and watershed techniques is often needed

While addressing water column issues is critical to the chemical, physical, and biological restoration of a stream, the focus of management options should include stressors that originate outside the stream channel and riparian zone as well. Management options considered in this step include instream techniques and techniques applied in the surrounding watershed (such as BMPs) that reduce loadings and allow the stream to reach a state of equilibrium with the landscape. State nonpoint source, point source, and wetlands programs can collaborate in the restoration effort to address stressors in the basin impacting the integrity of physical habitat.

Step 3.1: Identify Candidate Restoration Techniques

Building on the assessment conducted in Step 1, this step provides a more comprehensive list of feasible ecological restoration techniques. Instream, riparian, and upland techniques should be considered, individually and in combination. One form this step could take is listing categories of stressors or goals that must be addressed and associated restoration techniques that address the stressor to meet the goal. Table 3–1 provides example categories and candidate restoration techniques. There is a growing body of literature and professional expertise in designing restoration techniques to address a broad range of objectives and types of ecological settings.

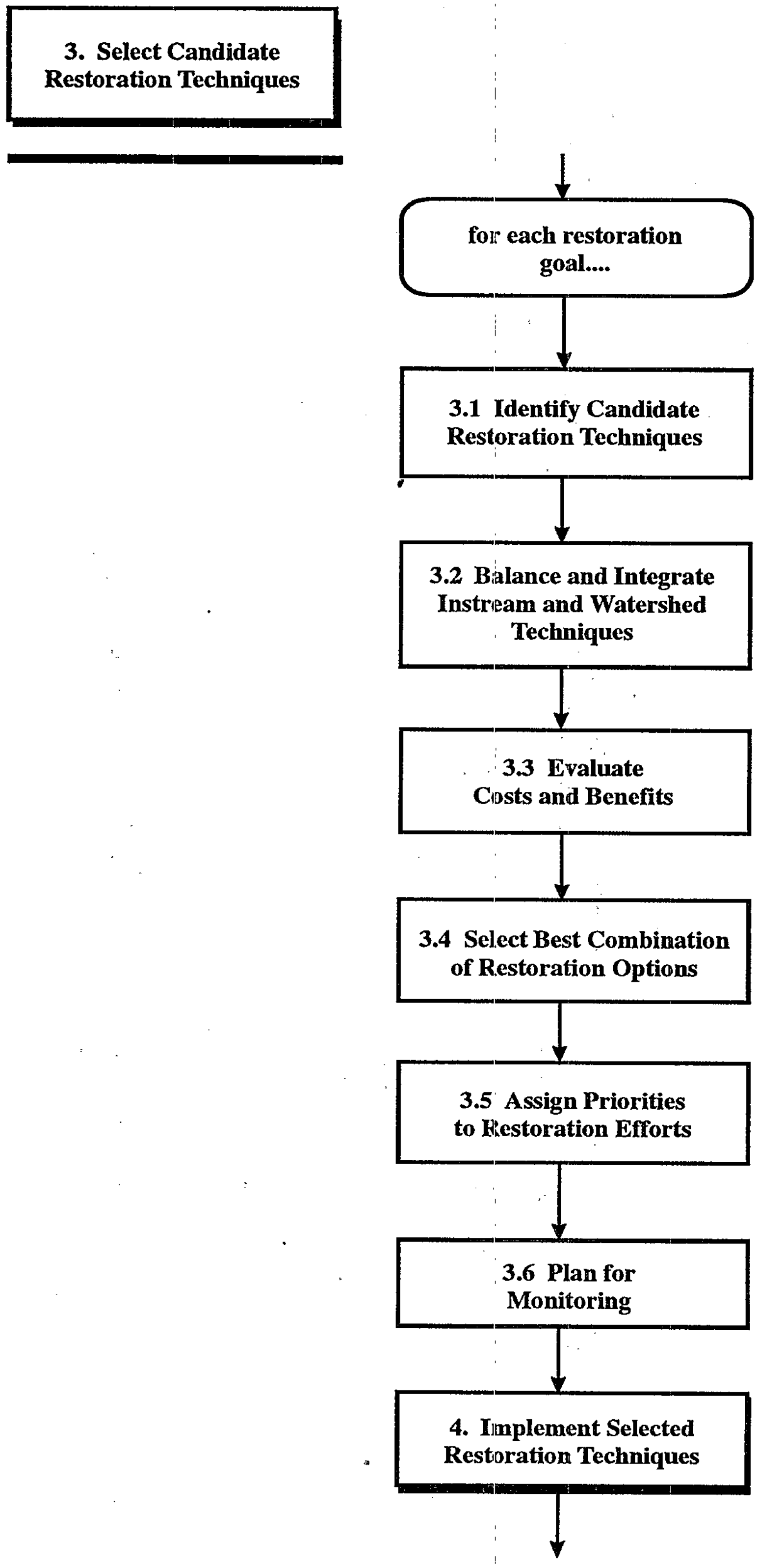


Figure 4-5. Step 3: Identify and select candidate restoration techniques.

STEP 3.2: BALANCE AND INTEGRATE INSTREAM AND WATERSHED TECHNIQUES

Restoration efforts can involve instream and riparian restoration of habitat and upland (watershed or source control) techniques. Achieving a balance among these components is important for many restoration projects. Addressing both symptoms (instream) and causes (in the watershed) is often desirable, but addressing only symptoms may be ineffective. For instance, a project involving channel modification to improve fish habitat in a river degraded by excessive sediment may be wasted effort if the watershed sources of sediment load are not also addressed. Also, once watershed sources of sediment load are addressed, instream techniques to restore habitat may not be needed. Often, a series of complementary management actions at different locations in the watershed will result in greater success.

STEP 3.3: EVALUATE COSTS AND BENEFITS

Selecting and prioritizing restoration efforts must take cost into account. A selected restoration technique should be cost-effective, in addition to resulting in major environmental benefits. Thus, economic criteria are part of the technical process to determine whether restoration techniques are reasonable. A growing number of ecological restoration examples in virtually every environmental setting provide baseline data for estimating economic impacts and costs; particularly detailed studies of relative cost effectiveness of BMPs and point source control technologies have been developed for the Chesapeake Bay basin study (Camacho 1992). Economic viability of nonpoint source BMPs has been demonstrated on many occasions. Restoration can be an extension of BMPs to include riparian physical habitat problems. Often, restoration leads to benefits that cannot be attained by more traditional water quality controls.

When management options that do not involve direct habitat restoration (e.g., point source controls alone) are also appropriate to address impairment, a relative evaluation of cost should be made. For instance, when a habitat restoration option is one among many options available to address an excursion of a water quality standard, the most cost-effective approach may be preferable. The economic assessment should include secondary economic impacts, such as any employment or recreational benefits of restoration activities. Finally, the economic evaluation will also aid in assigning priorities to restoration efforts where implementation must proceed in stages. Chapter 5 provides additional detail on cost evaluation of restoration activities.

STEP 3.4: SELECT BEST COMBINATION OF RESTORATION OPTIONS

Most restoration strategies will involve a combination of specific techniques. If more than one ecological restoration strategy is available for a restoration goal, the best restoration option or options should be selected based on technical and economic feasibility. The process is repeated for additional goals.

Selecting an optimal strategy generally requires some sort of quantitative prediction of the effectiveness for candidate restoration techniques. Evaluating technical ability and fine-tuning restoration options may involve the application of simulation models to predict results. Simple physical models of the water resource will be useful for some instream ecological restoration techniques. For instance, when evaluating the use of hydraulic drop structures to address DO problems, it may be necessary only to estimate the re-aeration associated with proposed structures for incorporation into a simple DO model. Similarly, relatively simple models of nonpoint loading can estimate the response to upland (watershed/source control) restoration techniques. On the other hand, quantitative prediction of the ability to attain narrative criteria and designated uses that reflect general ecological health of the water resource often present more challenging problems for analysis.

Simulation models of ecosystem responses to changes in physical and chemical conditions are research tools, which are difficult to implement and produce results of limited reliability (Fausch et al. 1988; Marcus et al. 1990). For this reason, it is generally necessary to work in terms of surrogate or indicator variables or combine a simulation and empirical approach to assess which restoration options are best. In a case where a designated use of salmonid habitat is impaired by the reduction of spawning substrate caused by fine sediment loads, building a model of salmonid population dynamics that incorporates sediment loading as a forcing variable is unlikely to be practical. A more sensible and cost-effective approach to the evaluation is the use of an empirical relationship between substrate embeddedness (which is governed by the loading of fines) and spawning success. This approach can be combined with simulations of sediment loading and transport, perhaps incorporating the potential effect of an instream restoration technique such as enhancing wetlands for sediment trapping and upland technique of watershed erosion control.

A phased approach to TMDL development that includes a schedule for implementation of controls and a monitoring plan that provides useful information for refining TMDLs is often appropriate when addressing nontraditional problems such as nonpoint sources or degraded habitat. The exact effects on water quality of many ecological restoration techniques are difficult to predict *a priori*. The phased approach provides for continuing efforts based on the success of previous efforts.

Step 3.5: Assign Priorities to Restoration Efforts

Restoration efforts can often address multiple ecological endpoints. Given limitations of funding and human resources, assigning priorities to restoration efforts is important so that efforts providing the greatest return, or addressing the most time-sensitive impairments, can be implemented first.

Step 3.6: Plan for Monitoring

In any restoration effort, monitoring is needed to evaluate progress in achieving goals. Planning for this monitoring must begin before the project is implemented and the waterbodies' characteristics are modified. Further details on monitoring are provided in Step 5.

Step 4: Implement Selected Restoration Techniques

Step 4: Implement Selected Restoration Techniques

- Address practical issues of implementation
- Achieving voluntary stakeholder participation may determine success

Implementation of selected restoration techniques (Figure 4–6) may present many challenges, including the following:

- *Collaboration Among Organizations:* Restoration projects may require information and resource contributions from several agencies that are often unaccustomed to working together. This can be remedied through early recruitment of stake-

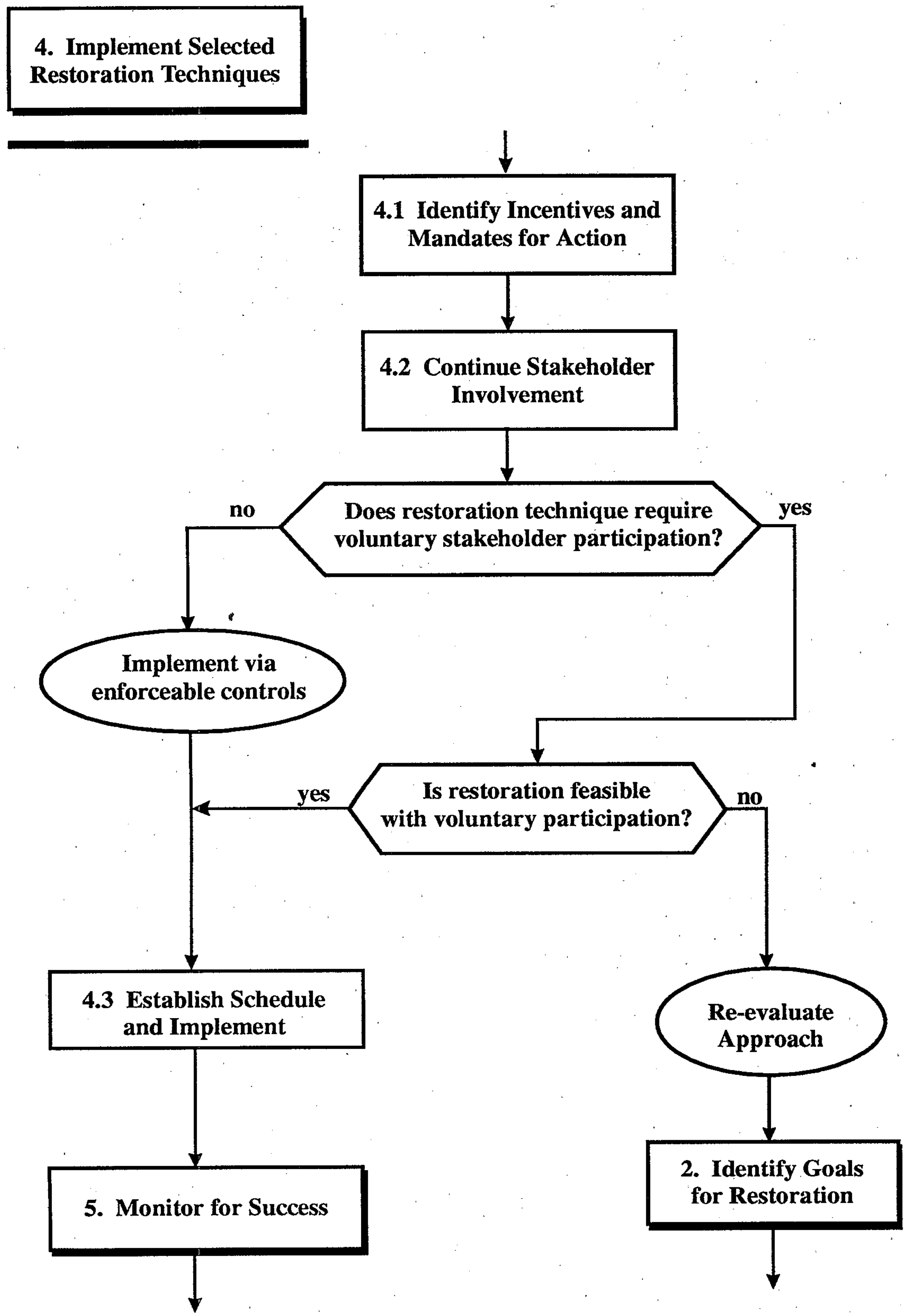


Figure 4-6. Step 4: Implement selected restoration techniques.

holders and the establishment of meaningful partnerships in the early phases of the project. Several states that are developing Watershed Protection Approaches are establishing formal relationships with other resource agencies to facilitate collaboration on projects.

- *Voluntary and Regulatory Approaches:* Flexibility is needed in the development of management strategies. In many cases, management strategies will combine enforceable point source controls with voluntary controls for nonpoint source dischargers. Managers will have to assess carefully the balance between voluntary and enforceable management options designed to meet water quality objectives. Methods for ensuring compliance, a key issue for both options, will vary from situation to situation.

- *Cost Effectiveness:* Cost incentives encourage the application of restoration techniques. In spite of indirect benefits associated with most restoration projects, the cost of restoration will need to be competitive with traditional control strategies. Accurate cost comparisons and justifications contribute greatly to effective implementation of restoration strategies.

- *Local Planning:* Many restoration projects will require consideration of BMPs and land-use restrictions, and water quality agencies will be required to collaborate with local land-use planning authorities. Involvement in local planning affairs will be a resource-intensive component that will require great sensitivity and is best accomplished through early and effective stakeholder participation.

STEP 4.1: IDENTIFY INCENTIVES AND MANDATES FOR ACTION

Ecological restoration requires cooperation among programs and agencies that have not traditionally worked together. Identifying incentives and mandates to form the basis of joint action plans will focus on scheduling activities, securing the commitment of resources, and eliminating barriers. Identifying incentives for a discharger may yield a more cost-effective approach to reducing the stressor. For a land owner (public or private), the incentive may involve, for example, sharing costs of the restoration project. The framework for both regulatory and voluntary control programs must be clearly delineated for all participants. In addition to supporting statutes and programs that are derived from the CWA, there are additional federal, state, and local mandates and agencies that can contribute to restoration efforts. For instance, timber permits could provide an important regulatory component of a restoration plan to reduce sediment loads. The Montana Streams Preservation and Protection Act is an excellent example of a state mandate that can be used to bolster ecological restoration efforts.

STEP 4.2: CONTINUE STAKEHOLDER INVOLVEMENT

Stakeholder involvement and buy-in is crucial to the success of most restoration efforts. Stakeholder involvement should begin *at least* as early as Step 2.2 in the decision process, and should continue throughout. The matrix illustrated in Figure 4–4 can be used as a planning tool for identifying roles and responsibilities of participants. A project plan that describes the contribution expected from each stakeholder can reinforce collaboration and cooperation. Ecological restoration projects have been excellent examples of coordination among agencies lending their own unique expertise. Many restoration projects are driven by local initiative with resource agencies playing a support role; state agencies should therefore look for opportunities for con-

Case Study Summary
Anacostia Watershed, District of Columbia

Overall Project Goal: Preserve and restore the chemical, physical, and biological integrity of the Anacostia Watershed by dramatically reducing pollutant loads to the tidal estuary, restoring and protecting the ecological integrity of the urban Anacostia streams, restoring the spawning range of anadromous fish, increasing the natural filtering capacity of the watershed, expanding the forest cover throughout the watershed, and making the public aware of their role in the Anacostia cleanup.

Restoration Techniques and Parameters of Concern: See table below.

Restoration Technique/Functional Attribute	Parameter of Concern[a]			
	Pollutant Loading	Sediment Loading	DO Levels	Fish Populations
Control of CSOs and urban storm water	↓	↓	↑	↑
Land-use controls	↓	↓	↑	↑
Stream channel stabilization	O	↓	↑	↑
Removal of key fish barriers	O	O	O	↑
Creation and protection	↓	↓	↑	↑
Riparian and upland	↓	↓	↑	↑
Public outreach program	↓	↓	↑	↑

[a] ↑ means that the restoration technique increases water quality parameter; ↓ means that the restoration technique decreases water quality parameter; ↕ means that site-specific conditions can dictate increase or decrease in parameter; O means that the restoration technique has a negligible effect on water quality parameter.

Highlight on Stakeholder Involvement: The decision-making process for the Anacostia project was broad based from the outset, involving numerous stakeholders to develop goals and management strategies and implement selected strategies. The first step was the formation of an intergovernmental partnership among the District of Columbia, the two counties of Montgomery and Prince George's, and the State of Maryland. The partnership agreement called for the creation of an Anacostia Watershed Restoration Committee (AWRC), which would be responsible for preparing the restoration plan. The Committee's membership was designed to be as broad as possible to maximize support among the 600,000 people inhabiting the watershed. As a result of the Committee's aggressive outreach program, over 60 public and private organizations have participated in the development and implementation of the restoration plan. The Committee was also responsible for soliciting public input during the plan's preparation, including the development of restoration goals. The restoration effort has been supported by two other groups: the Metropolitan Washington Council of Governments, which is providing administrative and technical support, and the Interstate Commission on the Potomac River, which is coordinating public education and participation in the restoration, as well as developing a living resource program for the watershed.

For a more complete project description, including techniques to address additional parameters of concern, refer to Chapter 6.

tributing to ongoing projects to achieve their own water quality objectives. The state is in a good position to encourage the collaboration among regulatory and voluntary programs and to integrate federal and local efforts. Many restoration projects have also been made the centerpiece of community revitalization programs, and state water quality agencies could play a leading stewardship role in recruiting and promoting local understanding and involvement in the process.

Most restoration projects will involve both regulatory and voluntary control programs. Regulatory controls are enforceable (e.g., NPDES permits), but voluntary controls require stakeholder participation. Success in obtaining sufficient stakeholder participation cannot be assumed *a priori.* In some cases, a restoration technique may not be feasible due to insufficient stakeholder buy-in.

The state can play a key role in promoting restoration projects and ensuring that participants commit the necessary resources to achieve restoration goals and objectives by clearly communicating the need and rationale for the project and by using grant resources, regulatory requirements, permit fees, and information management resources skillfully.

STEP 4.3: ESTABLISH SCHEDULE AND IMPLEMENT

A schedule should establish clear milestones to be completed in a realistic time frame. The schedule should be keyed to project objectives and endpoints. A growing number of restoration projects currently use a broad range of techniques from which to derive an estimate of project duration and time required for the project to yield results.

The project team should give careful consideration to an implementation schedule and associated recovery milestones. Project milestones and measures of success can be grouped into three general categories: near-term, mid-term, and long-term, in a phased project implementation schedule. The following is an example of such a schedule:

- *Near-Term Recovery—Improve Physical Habitat Quality:* Stream habitat quality sometimes can be improved quickly through the use of physical habitat restoration techniques, such as the placement of log drop structures, channel deepening and restoration, placement of boulders in the stream bed, and placement of boulders, logs, and/or brush along stream banks to restore bank stability, etc. BMPs, such as grazing enclosures and grass buffer strips placed along riparian areas and areas with high erosion potential, will enhance infiltration of surface runoff and reduce inputs of sediments, nutrients, and other chemicals to the stream. Restoration of riparian areas with woody vegetation is a longer-term goal. All of these measure can lead to significant, short-term improvements in habitat and water quality.

- *Mid-Term Recovery—Restore Benthic Macroinvertebrate Community*: The establishment of a diverse, productive benthic macroinvertebrate community indicates the restoration of a major component of a healthy functioning stream ecosystem. It is a mid-term measure of success that can be accomplished within a few years. The longer time required for establishment of a diverse, productive macroinvertebrate community, compared to the short-term restoration of physical habitat, is primarily a function of the time required to establish the more substantial, vegetative components of the restoration management plan, such as woody vegetation in riparian areas and buffer zones, and wetlands. These components, along with those established in the short-term, can greatly enhance water quality. If these short-term and mid-term milestones have been attained, then the ecosystem should be providing quality food resources, should be efficiently and effectively processing potentially toxic chemicals, nutrients, and sediments, and should be preventing temperature and pH extremes.

- *Long-Term Recovery—Restore Fish Community:* The restoration of a diverse, productive native fish community is, in most cases, a long-term measure of success. Because of their longer life cycles, fish populations require a longer time for recovery from adverse environmental effects than benthic macroinvertebrates, algae and macrophytes; therefore, for restoration of a fish community, the types of short-term and mid-term habitat restoration practices discussed above must have been accomplished on a watershed scale that will prevent or at least significantly reduce even fairly infrequent episodes of stress that may adversely affect the fish community, especially the more sensitive and vulnerable species. For example, an episode of high concentrations of sediment or a toxic chemical occurring just once a year or even once every several years may prevent the successful reproduction and recruitment of sensitive fish species.

Step 5: Monitor for Success

Step 5: Monitor for Success

- Determine whether goals of restoration are achieved
- Adequate monitoring is essential, and provides the opportunity to fine-tune the restoration effort

Determining whether the goals of a restoration project are being achieved can only be accomplished by a well-designed monitoring program that evaluates, with an acceptable degree of certainty, whether habitat restoration has caused a significant improvement in water resource quality and the biological community of the water resource. Although the potential benefits of restoration are many, some are not quantifiable, and the efficacy of an ecological restoration technique in achieving water quality standards at a given site is difficult to predict *a priori*. Further, many restoration projects will depend in part on voluntary (nonenforceable) stakeholder participation. It is therefore essential to monitor for results and, if desired results are not obtained, re-evaluate and adjust the restoration effort, as needed.

As first steps, monitoring for a restoration project should specify (1) assessment endpoints for the restoration project, (2) measurement endpoints, and (3) methods used to extrapolate from measurement endpoints to assessment endpoints. Then, the data collection program can be designed. Finally, data are collected and evaluated to determine the success of the project. General suggestions for structuring this step are shown in Figure 4–7.

Step 5.1: Identify Assessment and Measurement Endpoints

Assessment endpoints are ecological values to be restored such as quantity and quality of habitat and water quality standards (consisting of the beneficial designated use or uses of a water resource, numeric and narrative water quality criteria that are necessary to protect the use or uses of a particular water resource, and an antidegradation statement). They represent the final form of the restoration goals selected in Step 2. In many cases, these assessment endpoints are not readily quantifiable, so measurement endpoints, which are measurable responses that are related to the valued characteristics chosen as the assessment endpoints, should be selected (EPA 1992a). Measurement endpoints can be used to determine whether ecological values selected as

5. Monitor for Success

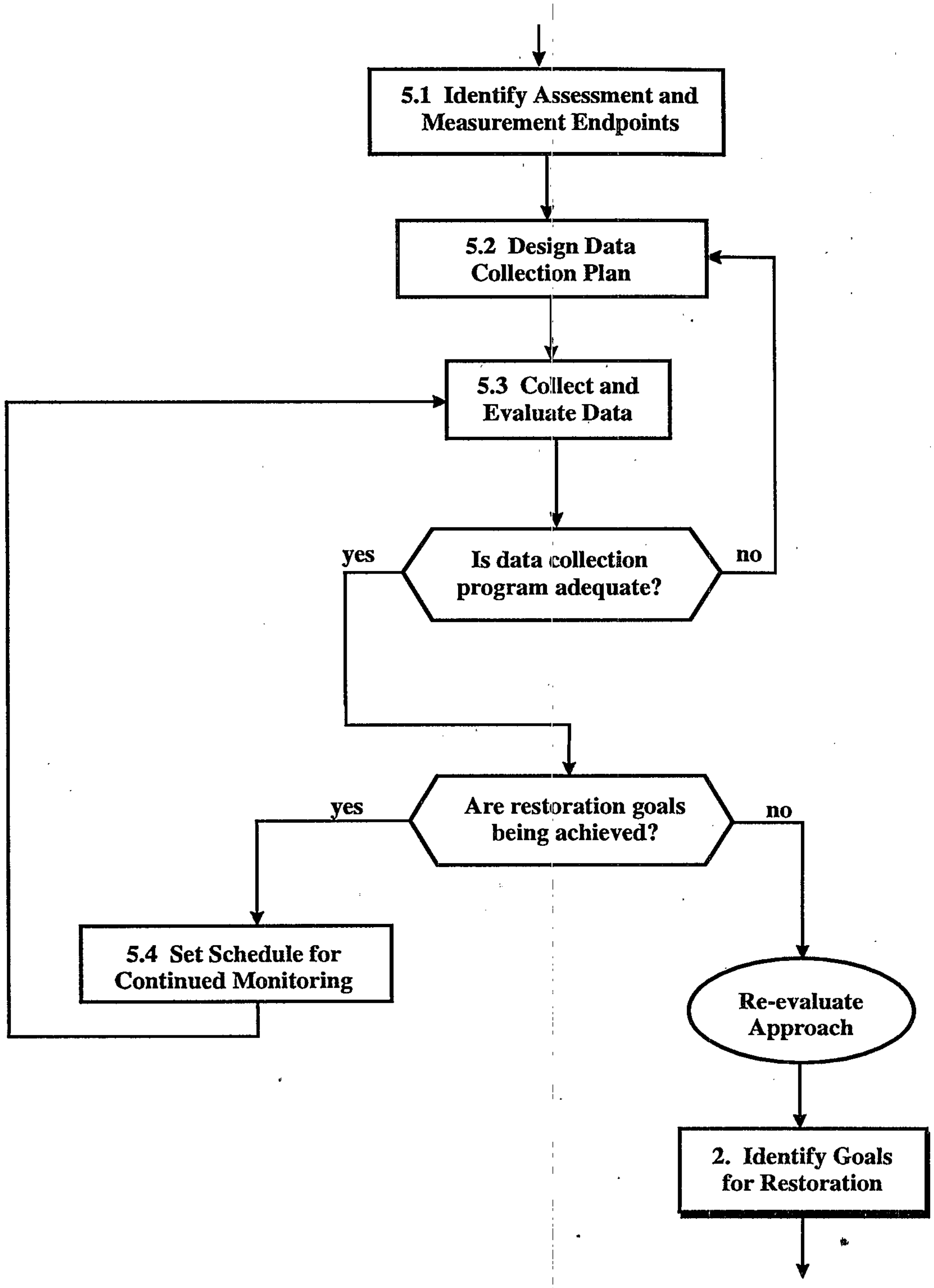


Figure 4-7. Step 5: Monitor for success.

assessment endpoints have been attained. In many cases, numeric water quality data will be emphasized as measurable indicators of the attainment of restoration goals. Table 4–1 summarizes information on assessment and measurement endpoints for ecological restoration.

Table 4-1. Example Assessment and Measurement Endpoints Applicable to Ecological Restoration of Streams

Stream Ecosystem Component	Assessment Endpoint	Measurement Endpoint
Physical Habitat	Increase habitat suitability for rainbow trout by 50%	Habitat Suitability Index for rainbow trout
Hydrology	Increase minimum stream flow to 10 cfs	Stream Flow
Population	Establish trout population of 50 kg/ha	Kg trout/ha
Ammonia	Eliminate exceedances of the water quality standard for ammonia	Concentration of ammonia
Ambient Toxicity	Eliminate acute and chronic ambient toxicity	96-h LC50s and 7-day IC25s of ambient stream water to fathead minnows and the benthic invertebrate, *Hyallela azteca.*

A clear relationship between assessment and measurement endpoints is essential. Avoid assessment endpoints that are vague or cannot be quantified. The best assessment endpoints, such as those listed in Table 4–1, are those for which there are well developed test methods, field measurements, and predictive models. Not all assessment endpoints meet these criteria, however. For example, if the assessment endpoint for an ecological restoration project is elimination of ambient toxicity to resident species, and the measurement endpoint is attainment of numeric water quality criteria, it is possible to attain all relevant numerical water quality criteria and still have ambient toxicity; conversely, it is possible to have exceedances of water quality criteria for toxic chemicals without ambient toxicity being present. As another example, if the assessment endpoint is restoration of biological integrity, it may be difficult to have both a reference condition and an index that can serve as an unambiguous, measurement endpoint.

Step 5.2: Design Data Collection Plan

Evaluation goals and standards for data accuracy should be specified *a priori* in data quality objectives (DQOs). High variability or uncertainty in results, however, often reduces the usefulness of field data, especially for ecological measurements. In designing data collection plans, the water quality manager is frequently forced to evaluate tradeoffs between an increase in uncertainty and the cost associated with reducing the uncertainty in the measured variables (Reckhow and Chapra 1983). Major components of uncertainty that can sometimes be controlled by a well specified survey design include variability, error, and bias:

- Variability can be caused by natural fluctuations in chemical and biological indicators over time and space;

- Error may be associated with inaccurate data acquisition, measurement errors, or errors in data reduction; and

- Bias occurs when samples are not representative of the population under review and frequently when samples are not randomly collected.

Sources of uncertainty should be evaluated prior to selecting a sampling design to minimize the effect of these factors on the decision-making process (Reckhow 1992). Good discussions of sampling designs applicable to ecological restoration projects are presented in Reckhow (1992) and Warren-Hicks et al. (1989).

STEP 5.3: COLLECT AND EVALUATE DATA

After the data collection plan is designed, data are collected and evaluated to determine whether desired benefits are being achieved. Data evaluation techniques depend on the design of the monitoring program and hypotheses to be evaluated (Step 5.2).

Evaluating data proceeds on two basic levels. First, evaluate whether the data collection plan is adequate to meet project DQOs and make necessary revisions (Step 5.2). When the data collection plan is judged to be adequate, analysis can proceed to the next level and inquire whether restoration goals are being achieved. If goals have not been achieved, the entire approach may need to be re-evaluated (indicated in the flow chart by a branch leading back to Step 2).

STEP 5.4: SET SCHEDULE FOR CONTINUED MONITORING

If restoration appears to be proceeding successfully and is meeting specified goals and milestones, the project will often enter a phase of assessing of water quality standards attainment, for which a program for continued monitoring should be established. This program will typically differ from the initial monitoring program, which has the burden of proving that the restoration technique can work in a given setting. Continued monitoring is designed to ensure that progress is ongoing and backsliding does not occur. The continued monitoring of a restoration site can often be incorporated into a state's Watershed Protection Approach.

CHAPTER 5

EVALUATING THE COST EFFECTIVENESS OF RESTORATION

Ecological restoration techniques expand the water quality manager's range of treatment options. Selecting the most cost-effective techniques is critical to the success of any restoration project. The two primary economic approaches for evaluating projects are cost-benefit analysis and cost-effectiveness analysis. Cost-benefit analysis is used to evaluate whether a project should be undertaken, by ensuring that its benefits are commensurate with its costs. Cost-effectiveness analysis is used to compare two or more alternatives that achieve the same objective and can also be used to evaluate whether benefits are commensurate with costs. This chapter focuses on cost-effectiveness analysis, which is the most appropriate analytical technique for projects in which project objectives have already been defined.

DEFINING COST EFFECTIVENESS: COST MINIMIZATION AND BENEFIT MAXIMIZATION

Two possible approaches for evaluating the cost effectiveness of restoration approaches are cost minimization and benefit maximization. The most cost-effective restoration technique either (a) achieves the water resource objective at the lowest cost (cost minimization) or (b) produces the greatest benefits for the same cost (benefit maximization).

Cost Minimization

Cost minimization evaluates the relative cost effectiveness of alternatives based solely on cost. This approach is appropriate for comparing point source controls alone with various alternative restoration techniques, if they all have the same objectives and benefits.

Benefit Maximization

Benefit maximization encompasses evaluations of benefits. Because ecological restoration has the potential to produce many additional ecological and social benefits compared to traditional point source controls alone (Table 5–1), benefit maximization analysis is often preferable for evaluating the cost effectiveness of restoration projects.

Current Limitations of Cost-Effectiveness Analysis

Cost-effectiveness analysis has only recently been applied to ecological restoration efforts, and several challenges must be surmounted, especially a general lack of information. Measures of stream restoration costs and benefits are not widely available, partly because the science of stream restoration is in its early stages. Although considerable restoration work has been done, much of the success of restoration either has not yet been realized or has not been properly documented. Additionally, restoration objectives and benefits are often not easily quantifiable, and alternative projects may vary widely in both the types of techniques used and benefits they may provide. Moreover, because restoration techniques often may complement rather than replace point source controls, assessing relative cost effectiveness can be a complex process.

Table 5–1. Comparison of the Ecological Benefits of Additional Point Source Controls and Ecological Restoration for Improving Water Quality

Point Source Controls	Restoration
• Higher DO	• Higher DO
• Lower water temperature	• Lower water temperature
• Lower levels of toxic chemicals	• Lower levels of toxic chemicals
• Lower nutrient levels	• Lower nutrient levels
• Lower turbidity	• Lower turbidity
• Increased recreational use	• Increased recreational use
• Increased faunal and floral diversity	• Increased faunal and floral diversity
• Increased faunal and floral abundance	• Increased faunal and floral abundance
• Higher property values	• Higher property values
	• Increased shading
	• Increased fish habitat
	• Increased wildlife habitat
	• Improved flood management
	• Increased social acceptance

CURRENT LIMITATIONS OF COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness analysis has only recently been applied to ecological restoration efforts, and several challenges must be surmounted, especially a general lack of information. Measures of stream restoration costs and benefits are not widely available, partly because the science of stream restoration is in its early stages. Although considerable restoration work has been done, much of the success of restoration either has not yet been realized or has not been properly documented. Additionally, restoration objectives and benefits are often not easily quantifiable, and alternative projects may vary widely in both the types of techniques used and benefits they may provide. Moreover, because restoration techniques often may complement rather than replace point source controls, assessing relative cost effectiveness can be a complex process.

Existing restoration studies provide some information that can be used to approximate costs and benefits, and more information will become available as restoration techniques are applied more widely.

WHY IS RESTORATION COST EFFECTIVE?

The two primary economic reasons why restoration may be more cost effective than point source controls are that (1) restoration often has lower *marginal* costs, and (2) restoration provides a wider range of ecological benefits. Marginal costs refer to the incremental costs of removing an additional unit (e.g., kilogram) of pollutant.

Because stringent controls of point source dischargers have been required for many years, the most cost-effective point source pollution reduction often has already been achieved. The incremental cost of removing remaining pollution with additional point source control will be greater than the average costs of existing point source controls on a per unit basis (e.g., per kilogram of BOD removed). For example, 80 percent of BOD may have been removed by secondary treatment at an average of $260 per metric ton removed. Removing an additional 10 percent by combining secondary treatment and nutrient removal may cost $560 per metric ton removed, or more than twice the cost per ton of secondary treatment. Using advanced secondary or tertiary treatment to remove an additional 5–8 percent, for a total reduction of 95–98 percent, may cost approximately $2,600 per metric ton removed, or ten times the cost per ton of secondary treatment (EPA 1978). By comparison, using ecological restoration techniques, such as wetlands, to remove BOD, will likely be far more economical per unit of pollutant removed. This comparison indicates that restoration has the potential to achieve water quality improvements for some parameters equivalent to new point source controls at a lower cost. Finally, because ecological restoration has not been extensively used to manage stream quality, many cost-effective restoration opportunities still exist.

Additionally, restoration generally achieves a broader range of benefits with additional value compared to additional point source controls (Table 5–1). Because the range of benefits is so broad, assessing the benefits of restoration will often rely on best professional judgment.

EVALUATING COST EFFECTIVENESS

Because procedures for cost minimization and benefit maximization analyses differ, the type of evaluation to be used must be selected early in the cost effectiveness assessment process (Figure 5–1). Benefit maximization includes a benefit estimate component that the cost minimization approach does not. However, the first step for each is identical. Estimating benefits for Step 2 of the benefit maximization approach can be complex and contains significant uncertainties.

Cost Categories: Costs are divided into two primary categories, capital costs and operating costs. Capital costs are all costs incurred to get a project underway, including planning, purchasing, land acquisition, construction, and financing. Operating costs are all costs incurred to continue operation of an ongoing project, including maintenance, monitoring, and equipment repair and replacement.

Cost Distribution: All potentially affected institutions should be identified to determine how costs might be apportioned fairly. The availability of financing is clearly a matter of practical concern for most projects, particularly projects with joint funding or cost-sharing arrangements. Adequate funds must be obtained from all potential sources to finance restoration projects, and public funding sources are frequently so constrained that only limited projects can be funded. Project managers should understand these limitations when planning how to obtain sufficient financing.

Timing: Different alternatives may incur costs and generate benefits in different years. These differences can be accounted for using a standard technique called net present value analysis, which converts future costs and benefits into present ones based on society's preference for the timing of cash flows. The key parameter in net present value analysis is the discount rate, a numeric expression of the preference for benefits in the present over benefits in the future. Selecting an appropriate discount rate is an important consideration, because the selected dis-

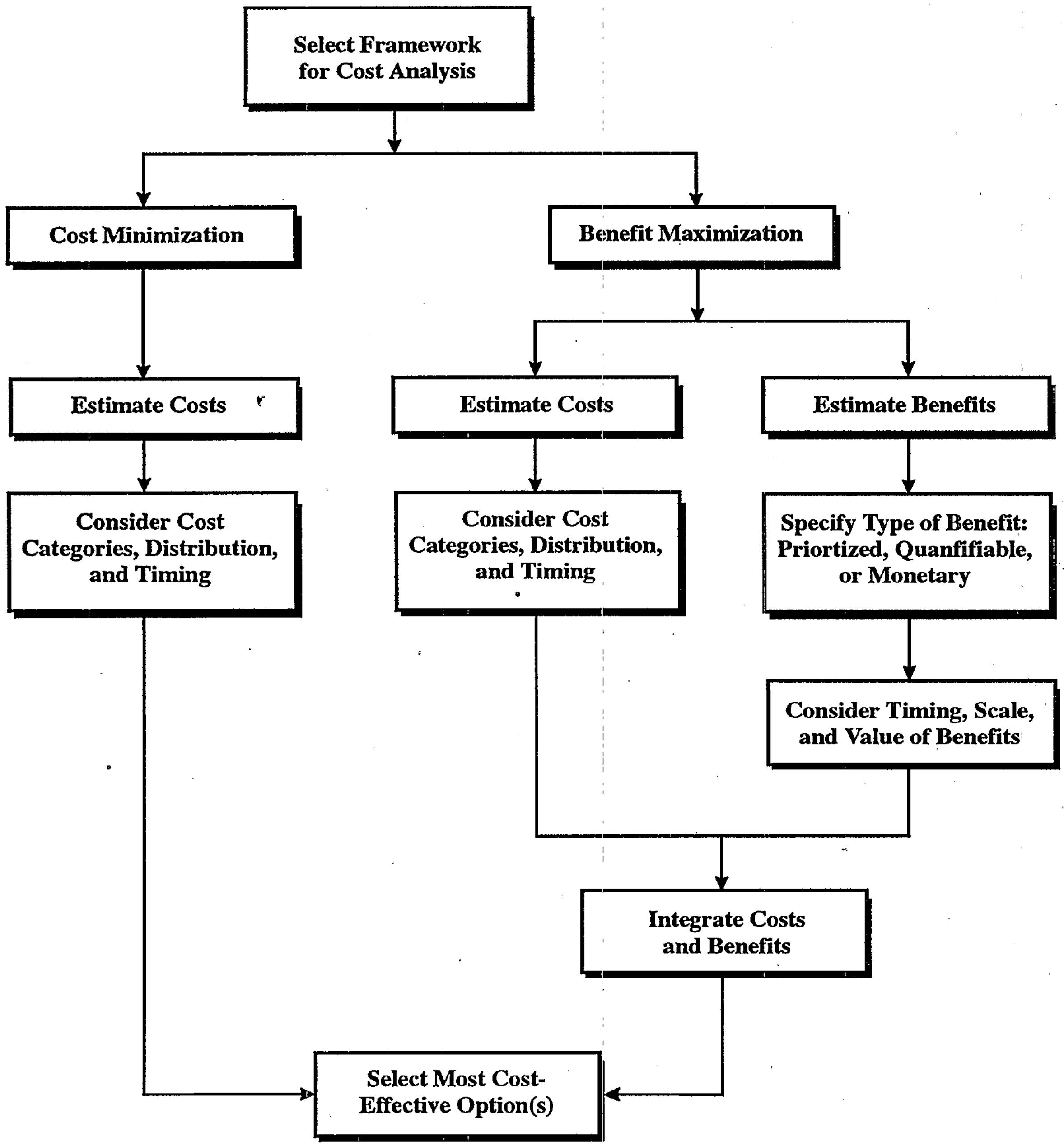


Figure 5-1. Cost effectiveness decision-making process.

count rate can dramatically affect the analysis. Individuals generally prefer to have benefits of value sooner rather than later and are less concerned about future costs than immediate costs. The discount rate used in project analysis attempts to quantify these preferences. Higher discount rates favor projects with more immediate benefits or costs incurred further into the future by effectively reducing future values. Lower discount rates increase the value of future benefits or costs. Federal agencies such as the Office of Management and Budget (OMB), Congressional

Budget Office (CBO), and General Accounting Office (GAO) have developed policies for selecting appropriate discount rates for evaluating government investments that are useful guides for restoration projects (OMB 1983 and 1986; Hartman 1990; and GAO 1983). In general, project managers use discount rates to reflect a project's cost of capital, or the interest rate on loans used to fund the project.

Estimating Benefits

Determining the benefits of each project to be evaluated is critical to comparing costs and benefits.

Types of Benefits: Benefits fall into three general categories:

1. Prioritized benefits are ranked by preference or priority, such as best, next best, and worst. In many cases, available information may be limited to qualitative descriptions of benefits and some indication of their magnitude; such information may be sufficient, however, to rank the benefits of the alternatives. Establishing priorities using this method requires only that results of comparing costs and benefits can be ranked.

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 can be devised that identifies the most *efficient* producer of benefits. If all options being considered can be applied at any one scale, then the best option is the most efficient one.

3. Monetary benefits can be described in monetary terms. Knowing the economic value of ecological benefits is desirable for evaluations of alternatives. For example, when restoration provides better fish habitat than point source controls, 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 may 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.

Considerations in Identifying Benefits—Timing, Scale, and Value: Key considerations in evaluating benefits include timing, scale, and value. The timing of benefits is an important consideration in both the cost minimization and benefit maximization analyses. For example, if a stream restoration project and a point source treatment approach produce comparable levels of reduction in BOD and suspended solids at comparable costs, then whichever project accomplishes the task sooner may be preferable. However, if associated social and ecological benefits are taken into account, then the restoration project, while not producing the quickest result, may be preferable. Although restoration may require more time before goals for BOD/suspended solids are realized, restoration may also bring long-term benefits (e.g., improved habitat or increased aquatic populations) that would not be realized through the point source treatment approach. Finally, restoration's benefits (improvements in habitat) may continue to increase over time relative to the benefits of point source controls (Figure 5–2). The restoration line extends below the point source control line because restoration can address conditions that have undermined the integrity of a stream that point source controls cannot. For example, discharging uncontaminated water into a channel with severely degraded physical habitat does not address the physical and biological integrity of the stream. However, restoration can mitigate and correct the degraded habitat allowing the stream to recover lost biological integrity.

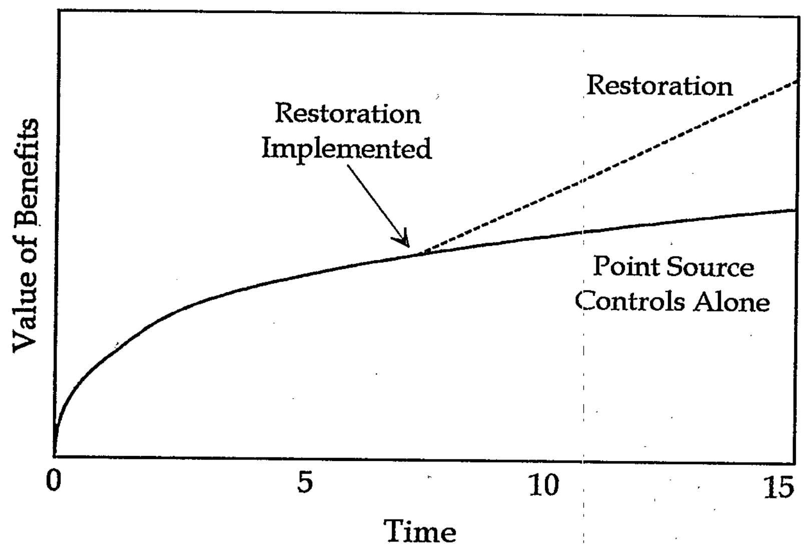


Figure 5-2. Benefits over time.

The scale of benefits and costs is an important consideration. Restoration projects may sometimes be small components of larger watershed restoration programs. Results of a project may be realized quickly only at the local level with relatively small results at the watershed level. Summing all potential benefits and costs across all projects within a watershed over a number of years provides a cumulative perspective through which the cost effectiveness of ecological restoration can be more realistically determined.

Value is also an important consideration in the identification of benefits. There are several ways to value the environment based on human use and appreciation. Commercial fish values can be calculated, recreational or sportfishing 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 local land or housing markets, and social values (such as wildlife, aesthetics, and biodiversity) can be estimated by surveying people to determine their willingness to pay for the achievement or maintenance of these values.

Integrating Costs and Benefits

If all benefits can be quantified monetarily, total costs can be compared to benefits in two ways. The first comparison is expressed as a cost-to-benefits ratio, from which the alternative with the lowest cost-to-benefits ratio is selected. The second comparison is expressed in terms of net value (i.e., subtracting costs from benefits), from which the alternative with the highest net value is selected. Neither approach is the most appropriate in all cases. In many cases, considering as many measures as practicable—cost per unit, cost-to-benefits ratios, and net present value—is advisable. A clear understanding of objectives is essential for the analysis. Moreover, cost effectiveness is relative and may change under different circumstances. For example,

- A specific combination of restoration practices in one location may produce great benefits at a low cost, whereas others may produce few benefits at a large cost (Schueler 1992);

- Some water quality problems (e.g., loss of habitat) are not amenable to point source treatment at any cost; and

- Some water quality problems cannot be reduced through any reasonable degree of restoration.

In summary, evaluating the cost effectiveness of restoration techniques requires considerable preparation, including the following:

- Identifying water quality objectives;

- Understanding how well each alternative achieves objectives and creates benefits;

- Understanding costs of alternatives for achieving objectives;

- Estimating prioritized, quantifiable, or monetary benefits obtained from each alternative;

- Estimating the value of the range of benefits created by each alternative;

- Understanding the appropriate scale of the analysis; and

- Selecting the method for comparing costs and benefits of alternatives.

Also, information on costs and benefits or outcomes should be carefully collected and organized by project managers. Sharing information on restoration efforts with other practitioners will help to establish a cost-effectiveness track record for restoration that will allow easier and more accurate evaluations in the future.

CHAPTER 6

CASE STUDIES

For many years, ecological restoration has been a valuable tool for fisheries biologists and other resource managers. Hundreds of restoration projects have resulted in improved fisheries, reduced flood potential, and increased recreational amenities. Ecological restoration has only recently been considered for use by water quality managers, and few projects are adequately documented. Although improving water quality is not always the primary objective for stream and river restoration projects described in this chapter, these case studies do demonstrate the effectiveness of using restoration techniques to achieve water quality goals.

Common elements among the case studies that resulted in improvements to stream integrity are the reduction of stressors and the restoration of stream components (e.g., stream channel and riparian corridor). None of the case studies demonstrate a framework entirely consistent with recommendations provided in this document; each project does, however, offer unique lessons that may be beneficial in planning future projects. Presentation of case studies is therefore structured in accordance with the framework presented in this document. This consistent format for all case studies provides a common basis for evaluating individual examples and comparing different approaches. The following categories are used to describe the case studies:

- *Considerations for Using Ecological Restoration:* The purpose of this section is to provide background information on the physical environment and location of the river or stream. This section also describes the administrative structure of the project team and the decision-making process for the restoration project.
- *Stressors of Concern:* This section describes the stressors acting on the river or stream and impacts of these stressors on water quality parameters of concern.
- *Project Goals:* Explicit and implicit goals of the restoration project are summarized and linked to specific stressors and measurements endpoints.
- *Restoration Techniques:* A description of techniques used for restoration provides evidence to establish the cause-and-effect relationship between the stressor and improvement offered by the restoration technique. That is, how does the restoration technique address project goals (e.g., measurement endpoints) and the water quality parameters of concern.
- *Issues of Cost:* To the extent possible, this section summarizes the cost of the restoration project and provides comparisons with alternative solutions.

Because the range of available information varies with each case study, presentation and content vary somewhat. Table 6-1 summarizes all seven case studies included in this chapter.

Table 6-1. Case Study Summary Table

Stream Name (Location)	Restoration Goals	Technique Category[a]	Restoration Techniques	Reference
Anacostia River (Metropolitan Washington, DC)	• Reduction in pollutant loading • Restoration of ecological integrity • Restoration of spawning range • Increased quality and quantity of wetlands • Expansion of forest cover • Public awareness	U I I I R U	• Control of CSOs and urban stormwater and land use controls • Stream channel restoration (e.g., channel geometry; streambank stabilization) • Removal of key fish barriers • Protection of existing and creation of new wetlands • Extensive riparian and upland reforestation • Public outreach program	Metropolitan Washington Council of Governments (1992)
Bear Creek (Iowa)	• Improve water quality, aquatic habitat, and the aquatic community in the creek • Provide design specifications for other projects	I U	• Create multi-species riparian buffer strip • Monitor and collect data	IStART (1993)
Boulder Creek (East slope, high plains in central Rocky Mountains, Boulder, CO)	• Restoration of aquatic life by reducing un-ionized ammonia concentrations and improving stream water quality conditions	I R I R U T	• Restoration of natural stream geometry and contour (i.e., replacing channelized berms, thalweg excavation, aeration structures) • Riparian zone revegetation and wetland creation • Streambank stabilization (biotechnical method using wattles and brush layering) • Improved timing and placement of irrigation diversion and return flows • Restrictive fencing and gating; grazing BMPs • Enhanced wastewater treatment facilities for removal of nitrate	EPA (1993b)

[a] Technique Categories: **I** = Instream; **R** = Riparian; **U** = Upland; **T** = Conventional Technology.

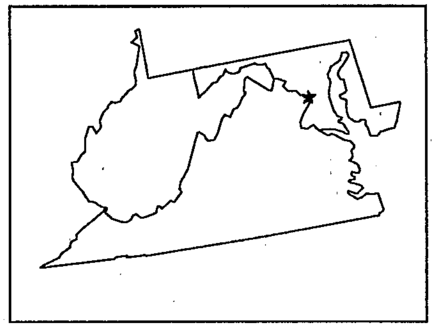
Continued

Table 6-1. Continued

Stream Name (Location)	Restoration Goals	Technique Category[a]	Restoration Techniques	Reference
Upper Grande Ronde River (NE Oregon)	• Characterization and modeling of restoration factors that will contribute to reduction of summer water temperatures to sustain a healthy coldwater ecosystem	I R	• Characterization and evaluation of impact of modified hydrology and sedimentation patterns attributable to land use on stream channel morphology and their effect on habitat suitability • Characterization and evaluation of the condition of riparian corridor vegetation and its ability to act as a sediment buffer and provide shade for the river	EPA (1994)
South Fork of the Salmon River (Idaho)	• Reduce sediment loads • Stabilize stream bank • Assess progress	I U	• Reduce ground-disturbing activities through land reclamation, road closures and reconstruction, and BMPs for forestry and roadbuilding • Remove sand from pools, in-stream gravel cleaning, and riparian restoration • Collect and analyze monitoring data such as core samples and fish populations	[Payette National Forest (1991) USDA (1989)
Wildcat Creek, San Francisco Bay tributary (Richmond, CA)	• Flood control and biological diversity • Preservation/enhancement of riparian habitat • Provision of recreation, education, and open space • Reduction in sediment loads and peak runoff	I R U U	• Restoration of natural stream channel geometry and contour • Planting of native species • Construction of regional trail system and educational facilities • Grazing management plan	Association of State Wetland Managers (1991)

[a] Technique Categories: **I** = Instream; **R** = Riparian; **U** = Upland; **T** = Conventional Technology.

ANACOSTIA RIVER WATERSHED, DISTRICT OF COLUMBIA



CONSIDERATIONS FOR USING ECOLOGICAL RESTORATION: A DEGRADED URBAN WATERSHED

The Anacostia River watershed is located in the metropolitan Washington, DC area. It is heavily urbanized with over 600,000 residents. The Anacostia River Watershed currently includes stakeholders of every socio-economic background, and every form of urban and suburban land use. The watershed is included in an area that represents the economic core of the region. These circumstances provided both significant incentives and barriers to the restoration initiative. For example, stream restoration can be an effective catalyst for revitalization of an economically depressed community.

Over the past three centuries, the landscape of the Anacostia watershed has been greatly transformed by successive waves of cultivation and urbanization. As a result of urban and suburban development in the late 19th and 20th centuries, the watershed underwent extensive change. Sediment deposition from agricultural fields was augmented by runoff from construction zones and impervious surfaces. Urbanization also brought increased flooding, further forest clearing and an influx of pollutants and toxins into the waters of the Anacostia. The sewage inputs to the tidal river added organic wastes, bacteria and debris to the deteriorating waters of the Anacostia.

To address the rapid deterioration of the river, an intergovernmental partnership was created by the landmark 1987 Anacostia Watershed Restoration Agreement, signed by the District of Columbia, Montgomery County, Prince George's County, and the State of Maryland. The Agreement formalized a cooperative partnership to restore the Anacostia River and its tributaries. To guide the restoration process, the Agreement called for the formation of an Anacostia Watershed Restoration Committee to develop a restoration plan. Membership on the committee is broadly based and an aggressive outreach program has extended participation in the development and implementation of the restoration plan to over 60 public and private organizations. Public and membership input has been substantial throughout, including the development of the restoration goals for the Anacostia River listed in the Restoration Tools section below. The Metropolitan Washington Council of Governments is responsible for providing administrative and technical support to facilitate the restoration activities of the Anacostia Watershed Restoration Committee. The Interstate Commission on the Potomac River is charged with coordinating and implementing public education and participation in the restoration effort, and developing a living resource program for the watershed.

Stressors of Concern

The Anacostia estuary has some of the poorest water quality recorded in the Chesapeake Bay system. It has a number of serious problems which have contributed to its degraded ecology and poor water quality:

- it is rapidly filling with sediment and debris from upstream;
- dissolved oxygen levels frequently violate water-quality standards;
- sediments are enriched with toxicants, hydrocarbons, trace metals and nutrients;
- many miles of stream habitats have been severely degraded by urbanization, which has profoundly altered the flow, shape, water quality, and ecology of these streams;
- anadromous fish migration has been blocked by numerous man-made fish barriers;
- over 98 percent of the tidal wetlands and nearly 75 percent of the freshwater wetlands within the watershed have been destroyed;
- nearly 50 percent of the forest cover in the basin has been lost to urbanization, including much of the riparian vegetation; and
- the approximately 600,000 residents are generally unaware that they live in the Anacostia watershed, and do not perceive the connection to the river and its unique natural features.

Project Goals and Restoration Techniques

The Anacostia Watershed Restoration Program is a six-point action plan intended to preserve and restore the chemical, physical and biological integrity of the river. The six goals, and the means of attaining them, are described below. Figure 6–1 presents a matrix that includes goals and general project objectives for the Anacostia River restoration program, and the agencies and organizations that are contributing to each objective.

Goal 1: Dramatically reduce pollutant loads in the tidal estuary to measurably improve water quality conditions by the turn of the century.

The most significant sources of pollutant loadings are combined sewer overflows (CSOs) and urban stormwater discharges. Therefore, to meet the goal of dramatically reducing pollutant loadings, a sharp reduction in the number of CSO events and stormwater pollutant loadings was necessary. This was accomplished by the installation of innovative swirl concentrators to treat CSOs, rehabilitation of aging sanitary sewer networks, construction of facilities to treat stormwater runoff from older developed areas, and requirements that new developments conform to stringent sediment and stormwater controls. Trash and floatable debris were removed from the estuary and its tributaries, and a widespread storm drain "Don't Dump" posting program was implemented to prevent the introduction of additional trash and debris.

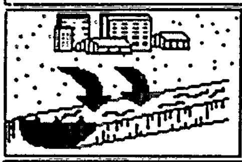
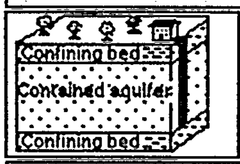
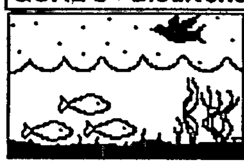
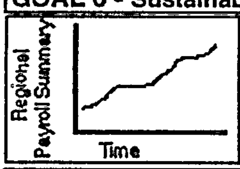
	Objective	Participating Programs, Agencies, and Other Stakeholders						
GOAL 1 - Control of Pollutant Inputs								
	Stormwater - Sewage Overflow Control							
	NPDES Permits							
	Point/NPS Trading Program							
	NPS BMPs							
GOAL 2 - Ecological Restoration								
	Channel Reconstruction							
	Water Flows							
	Redesign Diversion Structures							
GOAL 3 - Habitat Preservation								
	Wetlands/Forests							
	Conservation Easement Program							
	Wetlands Watershed Scale Advanced Identification*							
GOAL 4 - Public Health/Drinking Water								
	Comprehensive Groundwater Protection Policy							
GOAL 5 - Biodiveristy/Biological Integrity								
	Improve Timing for Diversions							
	Contiguous Habitat Corridors							
	Species Landscape Needs Analysis							
GOAL 6 - Sustainable Economic Development								
	Plan for Growth							
	Eliminate Excessive Soil Loss							
GOAL 7 - Stewardship								
	Public Outreach and Education							

Figure 6-1. Watershed Management Goals, Objectives, and Stakeholder Matrix [Adapted from Anacostia Restoration Team (1991)]

Goal 2: Restore and protect the ecological integrity of degraded urban Anacostia streams to enhance aquatic diversity and encourage a quality urban fishery.

Stream restoration techniques were applied to improve habitat in the most degraded streams. Eight major urban stream restoration projects were implemented to significantly improve almost 10 miles of river habitat. To prevent future degradation, land use controls and stringent stormwater and sediment practices were applied at new development sites in sensitive watersheds, to minimize impact on stream systems.

Goal 3: Restore the spawning range of anadromous fish to historical limits.

Annual migration of anadromous fish species had been stopped by as many as 25 unintentional man-made fish barriers along the lower portion of the Anacostia. Removal of key fish barriers is important to expanding the available spawning range for anadromous fish; improvement of the quality of the watershed's spawning habitat is also important. In the spring of 1991 a "bucket brigade" was begun that manually transports fish over barriers so that they can imprint the unique chemistry of the newly opened spawning range, and return to the same spots year after year.

Goal 4: Increase the natural filtering capacity of the watershed by sharply increasing the acreage and quality of tidal and non-tidal wetlands.

Local agencies have been empowered with new authority to protect all non-tidal wetlands, with a goal of no further net loss of wetlands within the watershed. Numerous projects have been initiated for restoring degraded tidal and non-tidal wetlands and marshes, and for creating hundreds of acres of new wetlands.

Goal 5: Expand the forest cover throughout the watershed and create a contiguous corridor of forest along the margins of its streams and rivers.

Riparian vegetation plays a critical role in maintaining stream water quality, preventing streambank erosion, and providing aquatic and terrestrial habitat. Extensive reforestation efforts have been implemented, both for upland areas and riparian zones, often with local agencies being provided with both trees and volunteers for tree planting. A new 1991 Maryland state law provides local authorities with the power to require reductions in the amount of forest cover lost during development, with specific mitigation requirements detailed in tree ordinances, buffer criteria, and Critical Area programs. The ultimate goal in the riparian reforestation efforts is to provide an unbroken forest corridor from the tidal river to the uppermost headwater streams.

Goal 6: Make the public aware of their role in the Anacostia cleanup, and increase their participation in restoration activities.

Many of the approximately 600,000 residents of the Anacostia watershed are unaware that they live in the watershed, and do not perceive a connection to the river. A strong public outreach program was therefore developed to raise public awareness about the problems of the Anacostia River and the ongoing restoration efforts. The program includes a quarterly newsletter, sub-basin coordinators, and educational publications and activities. Several environmental groups have responded to public outreach initiatives with cleanups, plantings, and stream walks. A

Table 6-2. Summary of Anacostia Restoration Blueprint

NOTE: This list is preliminary and is subject to change based on AWRC review.

***Stormwater Retrofits Projects:** Includes the creation of new best management practices or modifications of existing ponds or BMP's to improve the quality of urban runoff.*	
total number of projects	159
total area controlled	approximately 35 square miles
projects in-progress or completed to date	45 (28%)
estimated capital cost[1]	$27.6 million
***Stream Restoration Projects:** Includes bioengineering and other measures that stabilize eroding stream banks and create better fish habitat.*	
total number of projects[2]	60
total project length	approximately 20 stream miles
projects in-progress or completed to date	8 (13%)
projected capital cost[1]	$8.0 million
***Fish Passage Projects:** Includes projects to eliminate barriers to anadromous and resident fish migration.*	
total number of projects	31
projects in-progress or completed to date	6 (20%)
projected capital cost[1]	$1.1 million
***Riparian Reforestation:** Includes the reestablishment of forest habitats within 300 feet of the Anacostia and its tributaries.*	
total number of projects[2]	68
total project length	approximately 15 stream miles
projects in-progress or completed to date	25 (37%)
projected capital cost[1]	$800,000
***Wetland Creation:** Includes the creation of emergent wetlands in both tidal and non-tidal areas.[3]*	
total number of projects[2]	34
area	one square mile
projects in-progress or completed to date	10 (30%)
projected capital cost[1]	$7.3 million
***Small Habitat Improvement Program (SHIP):** Includes small scale restoration projects (excluding reforestation) suitable for implementation by citizens. These projects include storm drain stenciling, stream cleanups, wildflower plantings, etc.*	
total number of projects	400
projects in planning	72 (18%)
projects completed	12
projected capital cost[1]	$800,000
***Other Restoration Projects:** Includes CSO abatement, river dredging, sewer rehabilitation, reclamation and other activities that contribute to the restoration of the river.*	
total number of projects	17
projects in-progress or completed to date	3 (25%)
projected capital cost[1]	$70 million

NOTES:
1. Cost projections do not include costs for project planning, design, permitting, maintenance, and land acquisition (if any). Projections are based on 1990 dollars.
2. The total number of restoration projects in this category may increase as further field surveys are performed.
3. Does not include wetland acreage created by stormwater retrofits projects, which is significant.

Small Habitat Improvement Program was developed for implementation of small-scale restoration projects by citizen volunteers, and a number of tree-planting, wetland creation, storm drain stenciling, and stream cleanup projects have been completed.

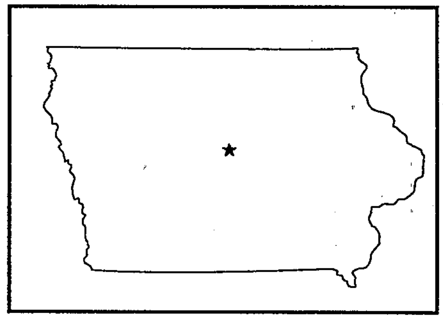
Issues of Cost

The Anacostia Watershed Restoration program provided coordination for spending by a large number of public and private organizations. Table 6–2 public and private organizations. Table 6–2, Summary of the Anacostia Restoration Blueprint, is taken from the Draft 1992 Anacostia Restoration Team "Blueprint for the Restoration of the Anacostia Watershed" (Metropolitan Washington Council of Governments 1992 draft). The figures in the table are estimates for capital and operating costs to be incurred over life of the program, and they provide an example of the scale of projects required to restore a severely degraded urban watershed.

The cost estimates are organized according to the watershed goals established for the Anacostia River watershed. The table allows a rough comparison of the relative costs for technology and construction intensive projects (e.g., sewage treatment, combined sewer overflow construction, other point source controls) versus habitat restoration measures (e.g., bioengineering, best management practices, reforestation). While a precise comparison is not possible it is clear that technology and construction objectives are responsible for the largest percentage of the estimated costs.

The estimated total cost for the entire project (including $70 million dollars for river dredging, sewer rehabilitation, reclamation, and other activities not assigned to a distinct goal) is $115,600,000 in 1990 dollars. Assuming a ten-year life span to for the project, the annual cost per household would be $68, given a population of 600,000 people, an average household size of 3.5 people, and no outside financial assistance. A potential measure of success for the Stewardship Goal (Goal 6) would be the willingness of Anacostia residents to pay this amount as an annual contribution towards restoration of the watershed.

BEAR CREEK, IOWA



CONSIDERATIONS FOR USING ECOLOGICAL RESTORATION: SEDIMENT AND POLLUTANT LOADINGS FROM AGRICULTURAL RUNOFF

The Bear Creek watershed is located in north-central Iowa within the Des Moines Lobe, the depositional remnant of the late Wisconsin glaciation in Iowa. Bear Creek runs 21.6 miles and empties into the Skunk River. The watershed drains 17,180 acres of farmland, most of which has been subjected to tile-drainage over the past 40 years; approximately 85 percent of the watershed is devoted to corn and soybean agriculture. Prairie vegetation originally dominated most of the watershed, except along the lower end of the creek where forests occurred. Roland, a town of 1,100 people, is the only community in the watershed, and no major recreational areas exist (IStART 1993).

The riparian zone along the creek has been severely degraded by past land use practices. This degradation has aggravated the effects of intensive agriculture on physical habitat and water quality in the creek, which have adversely affected aquatic life. Restoration and better management of the riparian zone should reduce the effects of non-point source pollution on the creek and improve stream habitat for aquatic life, as well as benefitting wildlife.

STRESSORS OF CONCERN

Physical habitat in Bear Creek is adversely affected by high sediment loads, while water quality has been degraded by high concentrations of suspended solids, nutrients, and agricultural chemicals, particularly the herbicide atrazine.

THE GOALS FOR RESTORATION

The long-term goal of the project is to restore functioning riparian zones along the creek, which will, in turn, improve aquatic habitat, water quality and the aquatic community in the creek.

RESTORATION TECHNIQUES

Restoration of the riparian zone will be done by helping farmers who own land along the creek develop functioning riparian zones. These riparian zones will intercept surface runoff and subsurface flow and will remove or immobilize sediment and agricultural chemicals before they enter the creek, and the restored riparian zone will also provide wildlife habitat, food for wildlife, and high quality timber.

Two different levels of restoration research activity are taking place in the Bear Creek watershed. The Leopold Center for Sustainable Agriculture Agroecology Issue Team is using the watershed to study the condition of the riparian zone at the watershed level. The team is identifying critical riparian reaches along Bear Creek that would benefit from modified restoration and management to reduce the impact of non-point source pollution on the creek.

The Iowa State Agroforestry Research Team is working on one farm in the watershed to develop a model for restoring a multi-species riparian buffer strip that could be used along the critical reaches of Bear Creek and other waterways in Iowa and the Midwest. The model Constructed Multi-species Riparian Buffer Strip site lies along a one kilometer reach of Bear Creek on a working farm approximately 1.5 miles north of Roland. The Constructed Multi-species Riparian Buffer Strip model will be used to help demonstrate the concept of the strip to farmers and to provide design specifications for similar buffer strips on their farms.

Constructed Multi-species Riparian Buffer Strip Design

Riparian buffer strips, such as Constructed Multi-species Riparian Buffer Strip, can be effective best management practices when designed to function similarly to natural riparian communities. Certain combinations of trees, shrubs, and grasses can function effectively as nutrient and sediment sinks for non-point source pollutants. Innovative designs use specially-selected, fast-growing tree species. If harvested for timber, their large root systems allow very rapid regrowth that provides continuity in water and nutrient uptake and physical stability of the soil throughout the life of the stand.

The Constructed Multi-species Riparian Buffer Strip design employs a three zone system that corresponds well to the new riparian forest buffer strip guidelines published by the Natural Resources Conservation Service. In the Natural Resources Conservation Service design, Zone 1 consists of a 4.5 meter-wide strip of undisturbed, existing or planted, forest whose major function is to maintain bank stability. Zone 2 consists of an 18 meter-wide strip of managed forest where nutrient sequestering is the major function and, therefore, requires vigorous growth and periodic removal of trees. Zone 3 contains a 6 meter-wide strip of grass that intercepts surface runoff and converts it to sheet flow or enhances infiltration so that runoff becomes shallow groundwater flow.

The Constructed Multi-species Riparian Buffer Strip consists of a 20 meter wide multi-species filter strip. Starting at the stream, five rows of trees, two rows of shrubs, and a 7 meter-wide band of switchgrass are used. In the strip design, the tree and shrub species act as a combined Natural Resources Conservation Service zone 1 and 2. The selection of rapidly growing species, such as willow, poplar, silver maple, and green ash, ensure rapid uptake of nutrients. The frequent removal of the stems of these species on 8 to 12 year rotations removes the sequestered nutrients from the site. Because these species regenerate from stump sprouts, the root systems stay intact and above-ground biomass is rapidly regrown. As a result, soil stability is maintained and the surface remains intact because neither site preparation or planting has to be done for a number of rotations. The grass strip in the Constructed Multi-species Riparian Buffer Strip functions as zone 3.

Constructed Multi-species Riparian Buffer Strip Effectiveness

Iowa State Agroforestry Research Team evaluated the hydrogeological, environmental, and economic effectiveness of various configurations of the Constructed Multi-species Riparian Buffer Strip along a one kilometer stretch of Bear Creek. The Iowa State Agroforestry Research Team is monitoring the site to test the ability of the strip system to trap sediment eroding from the cropped uplands, increase infiltration of water into the buffer strip soil, clean up contaminated water carrying chemicals that are moving through the buffer strip, stabilize streambanks to reduce streambank erosion, increase biodiversity for improved wildlife habitat, and provide diversification of farm products.

The researchers are also monitoring various water quality parameters. Nitrate and atrazine changes in the groundwater, surface water, soil, and plants are being observed to determine the fate of chemicals moving through the buffer strip. Alkalinity, conductivity, hardness, and pH data are collected in the tile and stream water. The researchers are also monitoring above- and below-ground growth of plants, physical and biological soil changes, and the presence of wildlife species.

The effectiveness of the Constructed Multi-species Riparian Buffer Strip appears to vary by aquifer system. The highest nitrate concentrations exist in the field tiles that drain cultivated fields. These tiles pass under the strip without plant-soil system interaction. Researchers are developing a small constructed wetland that will intercept this water before it enters the stream channel and reduce nitrate levels by means of denitrification. Nitrate concentrations are also elevated in the alluvial and shallow till groundwater systems during parts of the spring and summer. No measurable nitrate has been found in the limestone bedrock groundwater system. Creek water nitrate exceeds U.S. EPA limits during the late spring and summer after fertilizer application. At the confluence of Bear Creek and Skunk River, the Bear Creek watershed can deliver as much as 3.5 MT of nitrate-nitrogen per day during high discharge events in the summer. Although the exact impact of the Constructed Multi-species Riparian Buffer Strip on this loading has not been established, the strip does have a strong impact on the nitrate content of surface runoff.

Atrazine occurs in the alluvial and shallow till groundwater systems and in the field tiles, but does not exceed EPA limits. Atrazine concentrations are highest in the creek water, but only exceeded EPA limits during the heavy rains of June and July 1993. Metabolites of atrazine are found in each of the water systems just mentioned.

Nitrate and atrazine concentrations in the soils above the water table of the Constructed Multi-species Riparian Buffer Strip are very low and provide a buffer zone of low chemical concentrations along the creek. It is not yet known whether the low concentrations of nitrate and atrazine are completely attributable to plant-soil processes working through the agrichemicals moving through the strip or because no chemicals have been applied directly to the strip. A mini-piezometer system is being installed to clarify the cause of these low concentrations.

Over the three years of the project, the infiltration rates in Constructed Multi-species Riparian Buffer Strip soils have increased as much as eight times over rates of neighboring cultivated land on the same soil. Visual evidence shows that the strip is effective at trapping sediment from upslope surface runoff, but additional research is needed to quantify this observation. The researchers concluded that willow post bioengineering techniques placed along the entire length of Bear Creek could reduce the sediment load by as much as 50 percent.

Although many of the results of the project are preliminary, they successfully demonstrate that streamside buffer strips are an effective best management practice that will help make the agricultural landscape sustainable, and reduce non-point source inputs into surface waters, which in turn should produce improvements in surface water quality, aquatic habitat, and aquatic communities. The researchers concluded that similar buffer strips should be established along both sides of any perennial or intermittent stream, as well as around lakes and ponds in and near farming activities, to reduce the adverse effects of nonpoint source pollution on surface water quality and aquatic life. The design using trees, shrubs, and native, non-bunch warm-season grasses is superior to cool-season grass buffer strips at reducing non-point source pollution. The 20 meter width is effective and also provides wildlife habitat and the potential for tangible economic benefits from biomass and fiber products. Although fast-growing tree species provide the most rapid control of the site, high quality hardwood species can be grown as part of the design and provide additional product options.

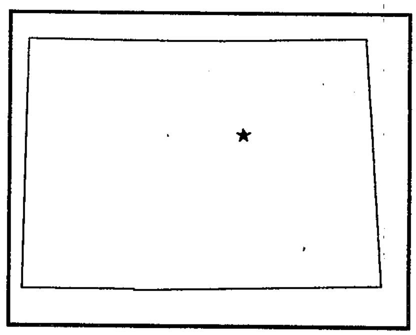
To date, most riparian zone research has been conducted either in existing naturally vegetated riparian zones or using cool-season grass buffer strips. The Iowa State Agroforestry Research Team project is the only one in the country that is conducting research on a constructed multi-species buffer strip that consists of both woody plants and native grass. The preliminary results have shown that this design is superior to the all-grass buffer strip.

Issues of Cost

The Leopold Center for Sustainable Agriculture and the Iowa Department of Natural Resources provided funding to the Iowa State Agroforestry Research Team to lead this project. Grants from these two agencies of $73,166 each covered the project from 1990 to 1993. Extensive cooperation was also received from several academic departments of Iowa State University.

Because the Constructed Multi-species Riparian Buffer Strip consists of a plant community that has to be established, all of the project objectives could not be completed within the allotted time frame of the project. However, the initial grant allowed enough time for this establishment of the strip to take place and provided leverage for obtaining additional funding from USDA's Cooperative State Research Service Special Grants - Water Quality Program and the USDA/EPA Agriculture in Concert with the Environment (ACE) program. These additional funds of $134,415 and $90,000 respectively allowed project research to continue through 1995.

BOULDER CREEK, COLORADO



CONSIDERATIONS FOR USING ECOLOGICAL RESTORATION: ELEVATED CONCENTRATIONS OF UN-IONIZED AMMONIA

From its headwaters in the Southern Rockies, Boulder Creek flows rapidly through narrow, relatively deep channels where its clear, cool waters provide ideal habitat for aquatic communities. As the creek flows west toward Boulder, Colorado, it enters the western high plains. On these plains, Boulder Creek assumes a shallow, meandering character and is relied on as a domestic and agricultural water supply, for swimming and other water-based recreation, and as habitat for warmwater aquatic life.

The City of Boulder's 75th Street wastewater treatment plant serves 95,000 inhabitants. On average, the plant discharges 17 million gallons per day into Boulder Creek. While base flow in the creek at the point of discharge ranges from 10 to 30 cubic feet per second over 9 months of the year (Rudkin and Wheeler 1989), during periods of high withdrawals (i.e., the summer months) the creek is wastewater-dominated. This has greatly influenced water quality.

In 1985, the city of Boulder Department of Public Works needed to renew the wastewater treatment plant's discharge permit. A total maximum daily load developed to determine a wasteload allocation for un-ionized ammonia indicated the need to tighten the plant's ammonia discharge limits, because monitoring downstream from the plant indicated that un-ionized ammonia concentrations increased as the creek flowed downstream and, at times, exceeded the state's standard of 0.06 mg/L for warm-water streams. The critical zone, in which the un-ionized ammonia concentration reached a maximum, occurred approximately 8.5 miles downstream from the plant (Rudkin and Wheeler 1989). In addition, a biological inventory of the 15.5-mile river segment below the wastewater treatment plant found that few of the 33 species of fish expected to inhabit this segment, including the greenback cutthroat trout, were present. The river segment was not fully supporting its aquatic life uses.

STRESSORS OF CONCERN

Wastewater treatment plant effluent data, collected monthly from January 1982 through March 1985, showed no violations of the total ammonia permit limit from November through May of each year and only three violations from June through October. Effluent data also showed no exceedance of pH effluent limits that would contribute to the ammonia problem. This indicated either that the wastewater treatment plant's permit limits were not stringent enough or that the wastewater treatment plant was not the only problem within the watershed (EPA 1993d).

Additional monitoring and analysis indicated that potential aquatic life uses could not be achieved, even if discharges at the wastewater treatment plant were improved, because of the already-degraded physical condition of the creek habitat. Runoff, erosion, agricultural return flows, channelization, destruction of the riparian zone, and mining discharge each contributed to the problem. For example, at the time, over 70 percent of the 15.5-mile stretch below the wastewater treatment plant was channelized. Ideally, a stream should contain about 50 percent riffle and 50 percent pool to support aquatic life uses, but channelization in Boulder Creek shifted this ratio to 97 percent riffle and 3 percent pool. The long riffle zones were smooth and shallow. With little or no canopy, the water temperature rose to extreme levels. The transition from riffle to pool also often involves a small drop that increases water turbulence. These drops had also been largely eliminated. This combination of conditions greatly reduced the ability of the stream to reaerate naturally. Channelization shortened the length of Boulder Creek below the wastewater treatment plant from 30 miles to 22 miles, changing the creek's hydrology and increasing erosion and sediment loading (Channel 28, 1990). In addition, the shallow water depth and lack of riparian shading encouraged a lush growth of photosynthesizing aquatic vegetation. This vegetation, in turn, caused higher water temperatures and increased pH, conditions that favor conversion of ammonia to its toxic un-ionized form. Low alkalinity permitted the relatively large pH fluctuations to occur.

These stressors had to be addressed in order to lower the creek's temperature and pH significantly, thereby reducing concentrations of un-ionized ammonia. A study to evaluate the effectiveness of best management practices and restoration measures concluded that best management practices would enhance the effects of advanced wastewater treatment (Windell and Rink 1987c). The study also indicated that aquatic life uses could be attained if the aquatic and riparian habitats were restored, nonpoint source pollution was controlled, and poor land use practices were corrected. As a result, resource managers decided to restore Boulder Creek first, then develop a total maximum daily load for un-ionized ammonia, basing the wastewater treatment plant's wasteload allocation on a properly functioning ecosystem rather than the existing degraded ecosystem.

Improving instream water quality by using restorative techniques in the riparian zone in conjunction with traditional treatment methods was appealing for several reasons. The estimated cost was far less than the cost of relying on wastewater treatment plant upgrades alone, and improving the physical condition of the stream and its riparian zone would enhance the aesthetics of the creek, making it more appealing and useful to property owners. Also, if part of the enhanced area could be acquired by the city for use as a public park or greenway, it would add a valuable asset to the community.

The Goals for Restoration

The goals of the Boulder Creek Enhancement Project are alleviating of the un-ionized ammonia problem, restoring of full use of the river reach as a warmwater fishery, and maximizing the impact of expensive modifications at the treatment facility.

RESTORATION TECHNIQUES

Controlling Point Sources to Restore Chemical Integrity

The first step of the project was to improve the quality of effluent at the wastewater treatment plant. This played an important role in restoring the chemical component of stream integrity. In 1991, the City of Boulder upgraded and expanded its 75th Street wastewater treatment plant to meet the stricter discharge limits required in its 1986 National Pollutant Discharge Elimination System permit. Solid and liquid waste treatment were improved to provide high-quality secondary effluent to the nitrification trickling filter, which was added to increase removal of ammonia from the liquid waste stream. The improvements also reduced total suspended solids and biological oxygen demand to levels significantly below permit requirements.

Riparian Zone and In-stream Habitat Restoration

The second and third steps of the Boulder Creek Enhancement Project improved the riparian zone along the river and restored instream habitats. These steps were completed in phases.

Phase I, which was completed in the spring of 1990, involved designing and implementing six best management practices over a 1.3-mile reach that passed through the center of a heavily grazed cattle ranch. These best management practices included constructing high-tensile, wildlife-compatible fencing to exclude cattle from the riparian habitat; stabilizing streambanks using log revetments; planting crack willow and cottonwood trees in the riparian zone; replacing channelized berms with sculpted or terraced streambanks; excavating one-half mile of the thalweg (i.e., the deepest part of the channel) on concave meander bends; and creating three boulder aeration structures (EPA 1992).

A monitoring program was established to evaluate the combined effect of the best management practices and the individual impact of each. Baseline data were collected prior to best management practice construction, during construction, and after implementation. Instream monitoring included monthly sampling for water quality, flow, and temperature, as well as fish inventories and evaluation of canopy density, ground water levels, and physical habitat.

Fencing off the riparian zone was critical. If cattle had not been excluded, the impact of all other best management practices would have been minimal. Under a protective easement from the landowner, 40 acres was fenced using stretched steel wire on hammered posts to provide a 120-foot-wide buffer between grazing land and the stream. Cattle crossings, designed as rigid, hinged double gates, excluded cattle entirely and could be opened to provide a temporary corridor across the creek. Sections of fencing, specifically the permanent cattle crossings, had to be redesigned since they were subject to water-borne debris and runoff. PVC mesh suspended from cables now allows debris and boaters to pass under the fence while acting as a visible barrier to cattle.

Phase II, which was completed in 1991, restored 1.1 miles of Boulder Creek. Phase II reduced the impact of return flow from an irrigation ditch by rerouting it through existing and constructed wetlands (EPA 1992). Although cattle grazing along the Phase II reach did not pose a serious problem, streambank revegetation was badly needed. Because the individual plantings used to revegetate Phase I were only moderately successful, Phase II tested "wattles" and "brush layering." Wattles are horizontal bundles of willow cuttings buried at or near the creek bank. Brush layering is the backfilling of willows into the streambank parallel to the water surface, with the growing tips projecting into the stream (Rudkin 1992). Construction of rock/willow jetties to break up erosive currents was also tested. This method was less expensive and time consuming than using riprap or other traditional construction methods.

Phase III added an additional one-half mile to the project. No cattle were trampling the creek and its banks in this section, and the channel was not as severely eroded, but the adverse effects of surface gravel mining posed a new challenge. The plan called for biotechnical streambank stabilization, revegetation, and creation of wetlands. A chief aspect of this phase was to reduce channel abrasion by creating low-flow channel over approximately 0.25 miles of the project area. In addition, the plant species and planting methods used in Phases I and II were reevaluated.

Phase IV of the demonstration project was under design in 1993. It involved a 1.7-mile reach that would bring the total length of restored creek to 4.6 miles. Phase IV plans included aspects of the first three phases and incorporated the design changes made after evaluating the effectiveness of previous methods. Results from the first three phases supported expanded use of riparian plantings combined with the use of rock buttresses placed to protect vegetation in the earlier stages of their development. A unique aspect of the Phase IV plan was the use of abandoned gravel mines to remove solids from runoff (EPA 1992). The basins would discharge to wetlands to polish the runoff water before it enters the stream.

Issues of Cost

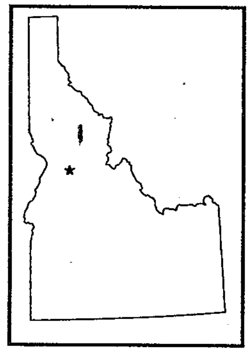
Overall project cost has included the costs of gathering data for planning and evaluating results, construction, materials, labor, and time. Funding for these activities has come from federal, state, city, local, and private organizations. The value of the project has also been augmented by donations of labor, time, and materials.

Monitoring is being conducted by a variety of agencies. U.S. EPA Region 8 is assisting the cities of Boulder and Longmont with instream monitoring costs. City officials authorized funding for two long-range planning studies, a use attainability study, two water quality studies, and a feasibility study. Two monitoring studies were funded by the University of Colorado Undergraduate Research Opportunities Participation Program (Windell and Rink 1992). The first was a $700 study on the interaction of riparian vegetation and water temperature. The second study, costing $2,500, covered follow-up monitoring of nonpoint source pollution controls after implementation. One study on the interaction of riparian vegetation, temperature, and fish population in Boulder Creek was funded for $2,500 by the W.L. Sussman Foundation (Windell and Rink 1992). Monitoring data are also provided by the U.S. Geological Survey and the Colorado Water Quality Control Division. The wastewater treatment plant monitors and reports effluent flows and concentrations as part of the permitting process. A portion of the funding for modeling was provided by U.S. EPA.

The 1991 upgrade of Boulder's 75th Street wastewater treatment plant was the largest capital project in the city's history, costing $23 million. 76 percent of the total improvement cost ($17.5 million) was expended to remove additional ammonia; the remainder was spent on sludge processing and disposal. Costs of the treatment plant upgrade were covered by the City of Boulder, with some assistance from the U.S. EPA Construction Grants program.

The total funding for Phase I of the demonstration project was $125,000. Colorado provided 60 percent of this amount under the state's nonpoint source control program; the remaining 40 percent was provided by the city of Boulder. With donated time, labor, and materials, the total worth of Phase I is estimated at $426,000 (Windell et al. 1991). Phase II funding, at $125,000, was similar to that of Phase I (Windell and Rink 1992). Phase III of the project was funded for $75,000 (Windell and Rink 1992), and Phase IV is estimated as having an on-the-ground budget of $225,000. The total cost of the completed enhancement project is currently estimated at $1.3 to $1.4 million (R.E. Williams, Assistant Director of Public Works for Utilities, City of Boulder, personal communication, March 28, 1991).

South Fork of the Salmon River, Idaho



Considerations for Using Ecological Restoration: Fine Sediment Loadings

The South Fork of the Salmon River (South Fork) is located in the forested, mountainous area of central Idaho. At lower elevations, the watershed is primarily forested with ponderosa pine and Douglas-fir. Lodgepole pine, grand fir, Engelmann spruce, and subalpine fir dominate as elevation increases. Meadows are found along the river, especially in its upper reaches.

The river and its tributaries flow on a granitic bedrock formation known as the Idaho Batholith, which is characterized by heavily dissected topography and highly erodible soils. Elevations range from 3,600 to 9,179 feet. Basin slopes are steep, with many over 70 percent. The South Fork, between its headwaters and the Secesh River confluence, drains 370 square miles.

Average annual precipitation varies with elevation from 20 to 60 inches per year. Summers are typically warm and dry, with warm-season precipitation occurring primarily during high-intensity thunderstorms. Winters are characterized by heavy snows and cold temperatures; most of the annual precipitation falls as snow. Long-duration, low-intensity storms are common in fall, winter, and spring; and winter and spring rain-on-snow events occur occasionally above 5,000 feet. The annual hydrograph reflects the winter precipitation pattern with snowpack accumulation and late spring snowmelt. The hydrograph, therefore, rises to a peak in mid to late May and gradually declines to base flows by early September. Base flows occur during the fall and winter.

The South Fork system supports populations of resident fish species, such as trout and char, and anadromous species, including salmon and steelhead. It is highly valued as a source of Chinook salmon and steelhead trout spawning and rearing habitat. The river once supported Idaho's largest run of summer Chinook salmon, estimated at approximately 10,000 returning adults; and runs of returning steelhead were estimated at 3,000 adults before logging began. These populations rely on just a few locations to spawn, however, since even under ideal conditions, spawning sites along the river are limited to the upper 35 miles and gradients along most of this channel length are too high to support required spawning conditions.

During its most recent statewide water quality assessment, the Idaho Division of Environmental Quality determined that three segments of the upper South Fork are water quality limited due to fine sediment, which has adversely affected salmonid spawning and the river's ability to support cold water biota. Nonpoint sources are responsible for most of this fine sediment. Reductions of sediment loadings from these sources should improve salmonid spawning habitat.

STRESSORS OF CONCERN

Using a computer model and professional judgment, the Forest Service has estimated that sources in the South Fork basin above Glory Hole deliver 18,550 tons of sediment to the river each year (Table 6-3). Glory Hole is approximately 3 miles above the Secesh River confluence. Over 85 percent of the sediment delivered has been attributed to natural background sources (EPA 1992b). This is not surprising given the erodible soils that exist in the basin.

Above the Secesh River confluence, the South Fork basin is primarily within the Boise and Payette National Forests. Timber harvesting has been the primary land use activity. Activities in the South Fork drainage prior to 1940 included intensive mining and grazing. Mining activities were responsible for significant deposits of sediment and chemicals to the stream system, while uncontrolled grazing contributed to increased sediment loads and degradation of riparian areas. From 1945 to 1965, intensive logging activities resulted in dense road networks and other sources of accelerated sedimentation.

Grazing activities ceased because of the Forest Service's moratorium on ground-disturbing activities in the basin took effect in the mid-1960s. Because they are no longer profitable, mining activities have also ceased, but sediment from tailings piles continues to be delivered to the river. These loadings are considered minor compared to the amount of sediment originating from current forestry activities.

Forestry roads appear to have been the major source of sediment from human activities. Early roads penetrated the South Fork basin during the 19th century; the South Fork Road was pioneered by the Civilian Conservation Corps during the 1930s; and road building associated with timber harvesting increased in the 1950s and early 1960s. Then, in the early 1960s, a large area of the canyon and adjacent slopes was burned by wildfire. As mitigation, the Forest Service benched (terraced) large areas of the burn, but during the winter of 1964-65 a series of rain-on-snow events in the basin caused road fills on unstable slopes and benched areas in the Poverty Burn to saturate and fail. This resulted in massive sedimentation of the river and inundated five primary critical salmonid spawning areas (Glory Hole, Krassel, Poverty Flats, Upper Stolle, and Lower Stolle Meadows) with coarse to fine sediments.

In recent years, the numbers of Chinook salmon and steelhead trout that are spawning on the South Fork have declined. This is partially because fine sediment has covered and infiltrated the larger bottom materials at spawning sites, which also function as areas of deposition because of their low gradient. The sediment may trap fry that are attempting to emerge; deplete intergravel oxygen levels, smothering eggs that have been laid; limit the aquatic invertebrate populations used as a food source by predatory fish in rearing areas; and fill the pools and pockets between rocks and boulders on which young fish depend to protect them from predators and to rest from swimming in fast currents.

In addition, some of the decline in salmonid population is due to the downstream influences of commercial and sport fishing, and the construction of eight mainstream hydroelectric dams on the Columbia and Snake Rivers. Dams can prevent salmonid smolts from safely leaving the river and can prevent adults from returning to spawn.

THE GOALS FOR RESTORATION

For salmonid spawning and cold water biota, no specific state numerical sediment criteria have been established. However, because of the problems associated with excess sediment in the South Fork, interim water quality criteria were set for the river and its tributaries by a consensus team composed of two hydrologists and one fisheries research scientist from the Intermountain Research Station, one forest hydrologist and one district fisheries biologist from Boise National Forest, one hydrologist and one district fisheries biologist from Payette National Forest, one representative from the Environmental Protection Agency (Region X), and two from the Idaho Division of Environmental Quality—one being from the Forest Service on a Interagency Personnel Agreement. The consensus team recognized that sediment input from human activities has to be reduced if full recovery of salmonid spawning potential and cold water biota uses of the South Fork can be expected.

The interim numeric sediment standards are as follows: the goal for cobble embeddedness, as measured by the Burns technique (Burns 1984), was set at a 5-year mean below 32 percent with no individual year above 37 percent. The goal for percent depth of fines, as measured with a McNeil core and percent of fines by weight analysis, was set at a 5-year mean of less than 27 percent with no individual year over 29 percent.

An interim objective is to provide habitat sufficient to support fishable populations of naturally spawning and rearing salmon and trout by 1997. This determination will be based on evaluation of fish populations, harvest of wild fish, cobble embeddedness, core sampling, photographs, and other pertinent data. Data must indicate that habitat is sufficient to sustain naturally producing populations of Chinook and steelhead tolerant of sustained recreational harvest. For now, the interim objective, which does t define fully restored habitat, is interpreted as follows:

1. A photographic record compiled during the recovery period will be used to document improvements along the river. Evidence of improvement can be

Table 6-3. Estimated Sediment Loading in the South Fork of the Salmon River Due to Various Sources in the Basin

Source	Sediment Delivered (ton/yr)	Percent Total
SFSR Road (Warm Lake Road to EF SFSR)	500	2.7
SFSR Road (Warm Lake Road to Cupp Cor)	50	0.3
Other (open roads, closed roads, logging)	2,000	10.8
Grazing	0	0.0
Poverty Burn Benches	100	0.5
Natural Sources	12,900	85.7

shown by such characteristics as duning and stringing sand, and changes from the existing conditions toward conditions more similar to those found in Chamberlain Creek, central reaches of the Secesh River, and other appropriate streams.

2. A 5-year mean of less than percent and no individual year greater than percent must be observed in locations where cobble embeddedness now exceeds 32 percent. Other locations must exhibit no increased sediment deposition beyond natural variation.

3. A 5-year mean of less than percent and no individual year greater than percent must be observed in locations where the percentage of fine sediment now exceeds 27 percent. Other locations must exhibit no increased sediment deposition beyond natural variation.

Annual project accomplishments and monitoring results are to be reported in the monitoring results documents prepared by the two National Forests. All sediment reduction projects will be completed by 1996. The interim goals for depth fines and cobble embeddedness are to be met by January 2001, or acceptable improving trends in other appropriate water quality parameters should be observed by then.

Targeting and Prioritizing: As a result of public interest in restoring the salmonid fishery, the State identified the South Fork as a priority for development of a total maximum daily load for sediment.

Monitoring and Data: The South Fork and its tributaries have been monitored extensively since 1965. The South Fork Monitoring Committee, composed of soil, water, and aquatic specialists from the Boise and Payette National Forests and the Intermountain Research Station, collected data on sediment load, depth fines, and cobble embeddedness over several years. These monitoring tasks were assumed by the two forests as part of their monitoring plans after their forest plans were implemented (Boise National Forest 1990; Payette National Forest 1990).

Data indicate that sediment yield peaked above 20,000 m3/yr in the late 1960s (162 percent of natural), with approximately 2x106 m3 being delivered to the river channel. By 1989 sediment yield had declined to 3,000-4,000 m3/yr.

After its gravel bottom was completely inundated with fine sand, the river began to carry excess sediment downstream as bedload. Core samples and embeddedness measurements indicate that surface and depth fines decreased from the late 1960s until 1977, remaining constant since then except for a slight increase in the early 1980s. There has been some fluctuation in later years, but they represent neither an improving nor declining trend. Graphical analysis showed that the amount of fine sediment at the sampling stations decreased sharply between 1966 and 1970. This improvement was attributed to the moratorium on ground-disturbing activity that began at that time. The amount of fine sediment leveled off after the mid-1970s, indicating that it is necessary to reduce sediment loading below current levels if the spawning areas are to improve any further.

Surface fines currently are between 10 percent and 15 percent, while depth fines are between 20 percent and 36 percent. Cobble embeddedness data have been collected in separate locations and with varied techniques for a much shorter period. These values vary from 14 percent to 56 percent (Platts et al. 1989; Ries and Burn 1989; Boise National Forest 1990).

Table 6-4. Projects that Together May Provide an Estimated 25 Percent Reduction in Sediment Yield

Project	Est. Yield Reduction (ton/yr)	Scheduled Implementation
Forest Highway 22 Fill Stabilization	12	1991
Close Miner's Peak Road	83	1991
SF Road Reconstruction	150	1992
Road Closures Upper SF	25	1992
Basin Road Stabilization	9	1992
Upper SF Road (Kline Mt Section) Obliteration/Spot Stabilization	54	1992
NF Dollar Creek Road Obliteration/Stabilization	28	1993
Curtis Creek Drainage Spot Stabilization	40	1994
Temp Closure of Buckhorn Road	200	1995
Two-Bit, Six-Bit Loop Road Stabilization	55	1995

Long-term stream flow data have been monitored in the South Fork drainage near the Krassel Ranger station. Information from this site has been collected in conjunction with the U.S. Geological Survey (gage 133-10700).

Modeling: Sediment loading estimates for the South Fork road, presented in Table 6-3, were calculated using analysis procedures that were developed during detailed research on erosion and sediment delivery from roads in the Silver Creek watershed, a tributary of the Middle Fork of the Payette River, in Boise National Forest (Payette National Forest 1990). All other sediment loading estimates were generated using the less rigorous BOISED model. The professional judgment of individuals having years of experience observing sedimentation processes in the river basin was invaluable in both cases (Megahan, personal communication).

BOISED is the operational sediment yield model that is used by the Boise and Payette National Forests to evaluate alternative land management scenarios. It is a local adaptation of the sediment yield model developed by the Northern and Intermountain Regions of the Forest Service for application on forested watersheds of approximately 1 to 50 square miles that are associated with the Idaho Batholith. To estimate cumulative average annual sediment yield using BOISED, the South Fork watershed was broken into land types, which are units of land with similar landform, geologic, soil, and vegetative characteristics. Dominant erosion processes, including surface and mass erosion, were then evaluated for each land type to estimate the sediment yield. When erosion and sediment yield data were missing, available research data were extrapolated to areas with similar characteristics to predict the effects of alternative watershed disturbances, including general road construction, timber harvest, and forest fire.
The model produced quantified estimates of average annual sediment yield for undisturbed conditions, past activities, and proposed future activities. While it was inappropriate to use the model as a highly reliable predictor of absolute quantities of sediment delivered to the river at a

specific time, it was appropriate to use model results for comparison of alternative management scenarios within the watershed.

Determining the Load Allocation Scheme: The consensus team devised a strategy to accomplish project goals based on information from the models, fisheries research, and the best professional judgement of members of the team.

The first step was to establish the interim numeric sediment criteria. While sediment transport into and out of water quality-limited segments of the South Fork is believed to be at equilibrium (Platts, et al. 1989; Platts and Megahan 1975), this does not mean that Chinook and steelhead spawning habitat has attained its pre-1964 spawning capabilities. Cobble embeddedness may, in fact, be higher than pre-1964 levels, making it reasonable to expect spawning/rearing habitat improvement only if sediment influx is reduced so that excess stream power can remove the stored sediment. The consensus team considered a 25 percent reduction in cobble embeddedness to be attainable within a reasonable time period through sediment yield reduction projects associated with the South Fork road reconstruction project (Payette National Forest 1990) and specific projects from the South Fork recovery plan (USDA 1989). It was also considered to be a starting point for a phased total maximum daily load based on load reduction, monitoring of effectiveness, and feedback of results for further load reduction decisions.

The sediment reduction projects have been planned and scheduled for implementation by the Forest Service. They are presented in Table 6-4.

Programmatic Issues: Because there is uncertainty that the numeric goals are stringent enough to restore salmonid spawning in the river and that the scheduled projects will reduce sediment loads sufficiently to achieve the numeric goals, the South Fork total maximum daily load is being developed in phases. Under this phased approach, sediment allocations are based on estimates which use available data and information, a schedule to implement various sediment reduction projects is developed, and additional data collection and analysis is scheduled to determine if load reductions lead to attainment of the narrative standard and interim numeric goals.

The lack of numeric State water quality standards was a challenge in developing the total maximum daily load. The standards and guidelines for the South Fork drainage that were established in the absence of specific State criteria have been specifically identified in both the Boise and Payette National Forest Plans.

Restoration Techniques

Implementing Nonpoint Source Controls: When ground-disturbing activity (timber harvesting and road building) resumes, best management practices will be required to guard against additional sedimentation. Since the South Fork is a concern in the State's antidegradation program because of forestry activities in its watershed, a local working committee prescribes site-specific best management practices for any forestry practice. The goal of these best management practices is to minimize additional sedimentation of the South Fork system.

Follow-up Monitoring: Monitoring is an important component of the phased total maximum daily load. It is necessary to determine whether the sediment load reduction required in the total maximum daily load effectively reestablishes spawning success.

The plan included in the South Fork total maximum daily load specifies monitoring of pollution sources, pollutant delivery to the river, and the status of beneficial use attainment. This requires (1) tributary sediment monitoring near the restoration and sediment reduction projects and photo-points to assess stabilization (Megahan and Nowlin 1976; Megahan 1982); and (2) monitoring of the status of the beneficial use (salmon and steelhead spawning habitat capability) at the five important spawning sites.

Each watershed improvement project developed by the Forest Service has been closely linked to coordinated research and monitoring activities. These activities are essential to document the relative effectiveness of the individual projects and to evaluate system-wide effects on erosion, sediment transport, and fish production.

Depth fines and cobble embeddedness data will be collected by the Boise and Payette National Forests. The Division of Environmental Quality or its contractors will be responsible for linking the depth fines and embeddedness data to determine whether the South Fork is supporting beneficial uses. Rearing habitat capability will be monitored using cobble embeddedness protocols (Burns 1984; Payette National Forest 1991).

If monitoring indicates that chinook and steelhead spawning capability has increased to acceptable limits by 2001, the level of effort expended to achieve the 25 percent reduction will be maintained. If spawning capability does not increase, additional recovery projects and/or an analysis of the level of beneficial use attainability will be required. Additional projects would be aimed at further sediment source reduction.

Results

Several sediment control measures have been undertaken, and additional sediment control measures continue to be attempted in the South Fork basin. The moratorium on ground-disturbing activity has been the most comprehensive effort to limit sedimentation of the river. The Payette and Boise National Forest Plans currently prohibit all but minor ground-disturbing activities, while permitting is designed to reduce the amount of sediment in and transport to the river. According to the plans, ground-disturbing activities can resume if a 5-year trend of improving sediment conditions is established. Such a trend would indicate that the river was successfully scouring the fines embedded in the substrate and could safely transport a specific amount of additional sediment through the system without adverse impacts.

A number of rehabilitation projects, covering over 350 acres, have been completed. Dragline removal of sand from some pools and in-stream gravel cleaning have been attempted. Retaining walls, mulching, and grass seeding have been used to stabilize cuts and fills on the South Fork road. Logging roads have been closed and reclaimed by ripping and grass seeding. Rehabilitation of areas where there have been recent fires has included water-barring fire lines, grass seeding, and contour felling of trees. The most recent mitigation actions proposed are to pave the South Fork road between the Warm Lake road and East Fork SFSR road, intensify cut and fill slope stabilization, and relocate a 4-mile segment of the road.

Issues of Cost

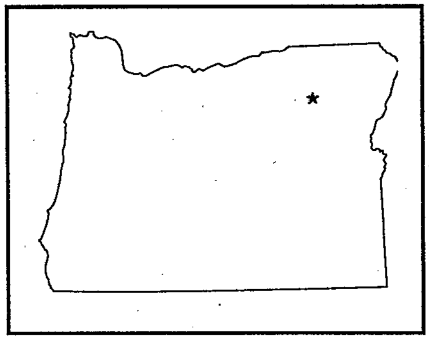
Funding levels and additional management factors will affect the ability of the Forest Service to implement these specific projects. Table 6-5 is a list of additional sediment reduction projects. Estimates of sediment reduction are not available for these projects. If monitoring results indicate that the 25 percent sediment reduction provided by the projects listed in Table 6-4 is insufficient to recover the beneficial uses, some or all of these projects could be implemented to attain further reductions. These projects may also be used to replace projects on the Table 6-4 list. Replacement may be allowed if accepted sediment reduction estimates indicate a reduction comparable to that of the replaced project.

The Forest Service, Idaho Division of Environmental Quality, and the Environmental Protection Agency are jointly working to secure the federal water pollution abatement funds necessary to complete the South Fork recovery projects required to meet the load reduction goal by 1996.

Table 6-5. Additional Sediment Reduction Projects

Project	Acreage to Treat	Scheduled Implementation
Jakie Creek Face	100	91-92
Martin Creek Face	60	91-92
Poverty Burn	72	91-96
Indian Creek Trail	6	91
Fitsum Creek	10	95
Cougar Creek	10	91
Backmere Creek Trail	10	91
Whit's Gully	5	91
Fitsum Creek Road	2	91
Cougar Creek Trail	25	91
Camp Creek	3	92
Jakie Creek Road Closure	30	91
Oxbow Breach	12	unknown
Sediment Removal (reaches with no spawning)	50	91-96
Spot Slide/Gully Stabilization	200	91-97
Bank Failure below Jakie Creek Bridge	1	91-93
Salmon Point Slide	5	91-95

Upper Grande Ronde River, Oregon



Background: Elevated Summer Water Temperatures

Riparian areas play a critical role in regulating the temperature of rivers and streams. Wide spread alteration and/or removal of riparian vegetation elevates summer water temperatures. This, in turn, affects the ability of many northwestern rivers to sustain a healthy coldwater ecosystem that includes annual salmon runs and resident salmonid populations. A maximum water temperature of 77 F is considered lethal to salmon, and adverse effects on spawning and juvenile growth can occur at lower temperatures.

Restoration Goals

The Oregon Department of Environmental Quality is currently developing a temperature total maximum daily load for the Upper Grande Ronde River because elevated water temperatures have impaired the river's ecosystem. Objectives set by the Oregon Department of Environmental Quality are as follows:

(1) set temperature target values for specific reaches,

(2) define riparian resource conditions to meet the temperature targets,

(3) develop watershed assessment methods, and

(4) ensure the transferability of the methods developed.

Restoration Techniques

Several activities are underway to meet these objectives. The Oregon Department of Environmental Quality has established a temperature monitoring network in the Upper Grande Ronde River, which has been collecting summer data since 1992. In addition to the Oregon Department of Environmental Quality temperature monitoring network, the Forest Service has funded a temperature monitoring project in the Upper Grande Ronde River through Oregon State University. Between the two monitoring projects, excellent coverage of the watershed has been obtained. In addition to the temperature monitoring efforts, meteorological and flow data have been collected. The data will be used, in conjunction with the data from the riparian characterization project, in temperature model simulation, calibration, and verification. The temperature model will help the Oregon Department of Environmental Quality establish target temperatures for specific reaches and define the resource conditions necessary to meet the targets.

Riparian Zone Characterization Project

Many of the environmental changes that lead to temperature impairment are visible and measurable from the structure of the stream and its riparian zone. Riparian characterization involves documenting stream channel morphology and streamside vegetation patterns, including alteration by various land use practices. A variety of methods are involved, including aerial photointerpretation, mapping, field reconnaissance, and geographic information systems analysis. The first goal of the Riparian Zone Characterization Project was to gather and analyze data for use as input values to a temperature model. Temperature modeling is intended to quantify the relationship between stressor (removal of shade) and response (elevated water temperature) in the Upper Grande Ronde River watershed. The second goal was the creation of a riparian characterization geographic information systems database to support watershed management, risk assessment, and restoration planning. The geographic information systems database will be widely shared with the other state, federal, tribal, and private geographic information systems users working on the Upper Grande Ronde River. The data, measurements, and geographic information systems database are essential to both the temperature model and the temperature total maximum daily load.

Elevated temperatures in the Upper Grande Ronde River were monitored using a series of temperature recorders situated along the mainstem and several tributaries. These and other data were used to determine temperature loading along different stream segments. Other available data on factors influencing water temperature include soils, groundwater, and meteorology. The Riparian Characterization Project provided several of the modeling parameters necessary to run the basin-scale temperature model. Project objectives, methods, and products are summarized in Table 6-6.

Temperature Modeling Project

The Nonpoint Source Control Branch of EPA's Office of Water and the Office of Research and Development at the Environmental Research Laboratory in Athens, Georgia developed a temperature model for the Upper Grande Ronde River basin in cooperation with the state. The model associated several watershed parameters, including different riparian zone characteristics, with effects on water temperature. This watershed-scale continuous stream temperature modeling investigation can be used to predict the spatial and temporal stream temperature regimes under different riparian forest management scenarios and to identify priority locations for stream restoration.

Stream Bank Stabilization and Riparian Vegetation Projects

The first two activities allowed Oregon Department of Environmental Quality to identify a list of projects which would stabilize the stream banks and provide the shade necessary for lowering instream temperatures to acceptable levels. The following list of restoration and education projects are proposed for funding by the Oregon Watershed Health Program from 1994 to 1996:

Table 6-6. Riparian Characterization Project Methods and Products

Objective	Method	Product(s)	Date
Use airphotos and GIS to characterize riparian zone vegetation patterns and land uses	Photointerpretation by National Wetlands Inventory (NWI)	ARC/INFO GIS data set; GIS file copies; and map plot copies	Spring 1994
Provide input parameters to UGR basin temperature model	Transfer of GIS data sets to modeling project for extraction of different modeling parameters	Riparian land cover; average tree height; average canopy density; buffer width; offset; and average crown diameter	Spring 1994
Classify stream channel morphology using field, mapped, and photographic information	Rosgen classification of stream morphology of selected tributaries and the mainstem by Umatilla Tribe scientists	Digitized maps (1:24,000) of stream morphology classes	Spring 1994
Demonstrate uses of riparian characterization data for other protection and management projects	Evaluation of project's success in using GIS data on riparian zone land cover and stream morphology in the model and TMDL	Discussion paper and presentation with future opportunities identified	Summer 1994

- Riparian fencing (2.5 miles) on Beaver Creek;
- Riparian fencing and vegetation recovery on Burnt Coral Creek. Cost-share sought for 1994 implementation;
- Rehabilitation of Camp Carson mine;
- Water monitoring workshop;
- Seminar series on Watersheds: The Critical Link, sponsored by the Blue Mountain Natural Resource Institute. This series was televised via EDNET to over 22 locations throughout the northwest.

Issues of Cost

The Watershed Health program funds restoration projects on both private and federal lands. The funding comes from a state lottery whose proceeds are to be spent on economic development projects. To date, efforts have been primarily directed toward private landowners. The private landowners that apply for grants are not required to share costs, although they are required to show that the project is being maintained. Funding of projects on federal land requires a 50 percent cost-share. Currently, the Watershed Health Program staff in the Grande Ronde basin are working with the GR Model Watershed Program and the Northwest Power Planning Council to identify areas in which to do projects and to rank projects for funding.

WILDCAT CREEK, CALIFORNIA

CONSIDERATIONS FOR USING ECOLOGICAL RESTORATION: COMBINING FLOOD CONTROL AND ECOLOGICAL RESTORATION

North Richmond is in Contra Costa County about 14 miles northeast of San Francisco on San Pablo Bay. This unincorporated community was first established during World War II, when laborers who came to work in the growing shipbuilding industry settled on the flood plains of Wildcat and San Pablo Creeks. The location exposed North Richmond to routine flooding during the wet winter months.

Flooding in the 1940s and 1950s prompted the Contra Costa County Flood Control District to seek assistance for flood control, beginning a decades-long search for flood control alternatives which eventually resulted in the choice of ecological restoration. A 1960 U.S. Army Corps of Engineers (COE) flood control feasibility study suggested several alternatives, but none were considered economically feasible. In 1971, the U.S. Department of Housing and Urban Development developed an urban renewal plan for North Richmond under its Model Cities Program. The plan emphasized recreational opportunities along Wildcat and San Pablo Creeks and the San Pablo Bay shoreline, proposed the creeks as focal points for redevelopment, and spurred COE to conduct another flood control study. This COE study focused on the multiple objectives of the Model Cities Plan, incorporating social well-being, environmental quality, and economic redevelopment as project benefits. It recommended traditional flood control measures, such as concrete box culverts and channels, but also proposed fresh water ponds and an earthen trapezoidal channel and landscaping on lower Wildcat Creek. Congress authorized the project in 1976, but the community was unable to raise its required share of the costs and the project was not carried out.

In 1980, the Contra Costa County Board of Supervisors proposed a bare-bones structural flood control project with no environmental amenities. Presented to North Richmond as the only affordable alternative, the "Selected Plan" was not well received. In response, members of several community groups formed a coalition to develop an alternative flood control plan that recognized the value of Wildcat and San Pablo creeks. The coalition wanted to

- preserve and enhance Wildcat Creek's riparian habitat, one of the last remaining streams in the San Francisco Bay area with continuous riparian habitat along its length;

- reduce sediment loads, since sedimentation could damage wetlands, reduce channel capacity (and thus flood protection), creating costly maintenance requirements; and

- provide for recreation and open space.

The "Modified Plan" that was developed for Wildcat Creek by the coalition proposed modifying existing creek channels to simulate the natural hydraulic shape and processes of undisturbed streams, including features to deposit sediment in the upstream flood plain and to restore riparian vegetation. Regional trails and park facilities were also included.

In 1985, the County Board of Supervisors approved the Selected Plan, but left open the option to construct a multi-objective project if funding were to become available. Shortly thereafter, the U.S. Fish and Wildlife Service and the San Francisco Bay Conservation and Development Commission denied the permit applications for the Selected Plan because of concerns about possible impacts to wetlands and endangered species. Both agencies supported the Modified Plan as an alternative. A project design team was established to develop a consensus plan that would be environmentally sensitive but capable of conveying flows for the 100-year flood. Such a plan would address the concerns of both the general public and government agencies with regulatory authority over the project. The team met regularly for three years.

Stressors of Concern

Many of the stressors of concern in Wildcat Creek share a common point of origin. Development in the watershed has dramatically impacted the hydrological runoff characteristics. Intense storm flows had scoured the channel and caused extensive streambank destabilization and erosion. The flooding that resulted from the more rapid pattern had led to a management program of channelization and mowing of the riparian vegetation. Therefore, any restoration plan would need to address the amended hydrological regime which exists in the Wildcat Creek drainage area.

The Goals for Restoration

Wildcat Creek should safely convey 100-year flood flows past North Richmond using as much of the creek's natural character as possible. Restoration efforts should ensure such stressors as excessive sediment, high flows, elevated temperatures, and a damaged riparian zone be properly managed so they do not impair ecosystem functioning.

Restoration Techniques

Restoring Stream Geomorphology: Choosing a Natural Channel Design

The Consensus Plan modeled the channels according to natural channel geometry, rather than as hydraulic flumes. This allowed the project to remain within the narrow 180-foot right-of-way width specified by the Selected Plan, even with riparian vegetation along the channels, and provide the same level of flood protection as the Selected Plan.

A meandering or sinuous channel pattern more realistically reflects the stream channels in natural, undisturbed streams, and also reflects the original channel configuration that most likely existed prior to development. In natural systems, the degree of stream meandering depends largely on the channel gradient, with sinuous channels generally being associated with high gradient (greater than one percent) and meandering channels associated with lower gradients (less than one percent). The lower reaches of Wildcat Creek are lower gradient, and therefore naturally a meandering system. The natural channel design includes pools, riffles, and glides, which provide very different aquatic habitats.

Restoration techniques based on interpretation and control of stream geomorphology take into account dynamics of sediment transport, as well as flow, throughout the entire watershed. A key component of the plan was to transport sediment past vulnerable marsh areas, where its deposition would be harmful, and deposit it along the flood plain and in the Bay, where the impact of its deposition would be minimal. The Consensus Plan featured a 10- to 15-foot wide meandering low-flow channel designed to carry the creek's mean flows; to scour and transport sediment in suspension at higher flow velocities; and to allow higher flows to spread onto the flood plains, lose velocity, and deposit sediment. In addition, a detention basin was placed upstream to trap sediments.

Riparian Tree Restoration

A well-developed riparian corridor more closely reflects the natural habitat values of undisturbed streams. The Consensus Plan proposed planting trees along the low flow channels to guide channel formation and to shade the streams to prevent them from clogging with rushes, weeds, and sediment. Cuttings from nearby plants, seeds from native species, and some container stock were used as plantings along the stream.

Besides shading stream channels to prevent the growth of unwanted vegetation, a restored riparian zone can benefit aquatic habitats in many ways, including:

- roots of trees, grasses, and shrubs stabilize the stream bank by binding soil particles and providing resistance to the erosive forces of flowing water;
- stems and leaves of riparian vegetation provide shade that lowers water temperatures;
- leaves, stems, cones, fruit, and other plant parts that fall into the stream provide food for microbes, insects, and fish; and
- large woody debris that falls into a stream provides for the formation of pools and other habitat types.

The riparian sites were prepared by mowing and clearing the area where plantings would occur. Holes were dug for the plants, backfilled with existing soil with slow release fertilizer tablets, and covered with a layer of mulch. An automatic bubbler irrigation system was installed to allow vegetation to become established.

Initially, the use of chemical herbicides was prohibited, but competition from uncontrolled weed growth led to a low survival rate of the plantings. In addition, the weeds provided food for an enlarged pocket gopher population, which stressed the installed plants further. The project sponsors therefore recommended the initial use of chemical herbicides to reduce competition from opportunistic weeds.

An innovative vegetation maintenance plan was designed to keep the low flow channels free of vegetation until a riparian canopy could develop and shade out the unwanted, clogging reed growth expected in exposed, low-flow channels. Because the natural channel was designed to allow for a certain amount of sediment deposition, maintenance requirements were based on actual needs rather than annual schedules, reducing costs and environmental impacts.

Protecting Vegetative Cover throughout the Watershed

Implementation of this multi-objective flood control project aroused interest in the relationship between land uses, habitat, and water quality throughout the entire watershed. In contrast to the lower Wildcat Creek watershed, much of the upper watershed is undeveloped, consisting of the Wildcat Canyon Regional Park which owned and operated by the EBRPD. This park is used for grazing, recreation, open space, and vegetation and wildlife habitat.

While grazing can have positive effects such as preservation of open grassland habitat, fire protection, and food production, there can also be adverse impacts from over-grazing such as the loss of vegetation and erosion of disturbed areas and subsequent damage to wetlands and creeks from sedimentation. Therefore, the Wildcat Creek Grazing Management Demonstration Project was jointly designed and implemented by the EBRPD, the Contra Costa Resource Conservation District, a private rancher, and the University of California-Berkeley. The project was made possible by funding from the U.S. EPA through the San Francisco Estuary Project.

This project is intended to manage grazing activities over a portion of the 2,000 acre park. The specific objectives are to:

- rotate grazing to promote the growth of native perennial grasses and improve forage production;
- monitor plant species diversity and growth;
- protect riparian and wetland habitats;
- reduce soil erosion; and
- provide information about grazing management to ranchers, public land managers, environmental groups, and the general public.

Fencing will be constructed to divide 312 acres of grazed land within the watershed into four pastures. Appropriate "rest" periods will be scheduled to allow the vegetation to regrow without grazing pressure. This will improve forage production while protecting the watershed from soil erosion. Grazing will be scheduled to protect native perennial grasses during seed development, to reduce competition from annual grasses, and to ensure that adequate leaf area remains following livestock grazing to allow vigorous regrowth during the growing season. Additional fencing will be constructed around springs and wetlands to ensure the protection of this vegetation, and alternative water sources will be provided for the cattle.

Issues of Cost

By adding the objectives of public access and education, restoration of riparian habitat, and enhancement of aesthetic values to the original mission of flood control, a number of alternative sources of funding were available to implement the Consensus Plan that would not otherwise be available for single-purpose flood control projects. Table 6-7 lists contributors to the Consensus Plan.

Table 6-7. List of Contributors to the Consensus Plan

Contributor	Amount	Rationale for Funding
East Bay Regional Park District	$793,000 $19,000	Regional Trail System Educational activities at a creekside school
US Army Corps of Engineers	$793,000	Regional Trail System
CA State Lands Commission	$240,000[a]	Wetland transition zone
CA Coastal Conservancy	$578,000	Marsh restoration and riparian enhancement
CA Department of Water Resources	$100,000	Because the project involved design innova tions, citizen participation, and educational opportunities

[a]value of land purchase

CHAPTER 7

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CHAPTER 8

GLOSSARY

Acid neutralizing capacity (ANC): The equivalent capacity of a solution to neutralize strong acids.

Anaerobic: Without oxygen; water and sediment environments without oxygen produce, for example, chemical conditions that precipitate and permanently store many metals from water and that release dissolved phosphorus to the water.

Benefit maximization: The process of increasing benefits to the greatest extent possible within constraints such as limitation on financial resources.

Benefits: A good, service, or attribute of a good or service that promotes or enhances the well-being of an individual, an organization, or a natural system.

Bioavailable: The state of a toxicant such that there is increased physicochemical access to the toxicant by an organism. The less the bioavailability of a toxicant, the less its toxic effect on an organism.

Best management practice (BMP): A practice used to reduce impacts from a particular land use.

Channel: A conduit formed by the flow of water and debris. The time and volume characteristics of water or debris can be altered by man, by climate change, or by alterations in protective vegetal cover on the land of the watershed. The stream channel adjusts to the new set of conditions.

Channelization: The practice of straightening a waterway to remove meanders and make water flow faster. Sometimes concrete is used to line the sides and bottom of the channel.

Cost minimization: The process of reducing costs to the lowest possible amount given constraints such as requirements that a specified level of benefits or other resources be attained or provided.

CWA §101: The objective of the Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters.

CWA §303d: Requires States to identify waters that do not or are not expected to meet applicable water quality standards with technology-based controls alone. Waters impacted by thermal discharges are also to be identified. After the identification and priority ranking of water quality-limited waters are completed, States are to develop TMDLs at a level necessary to achieve the applicable State water quality standards.

CWA §314: Establishes the Clean Lakes Program, which supports activities from initial identification of potential water quality problems through post-restoration monitoring. Cooperative grants provide funding for these activities.

CWA §319: Requires States to develop nonpoint source control programs. EPA awards grants to implement approved programs that include, as appropriate, nonregulatory, and regulatory programs for enforcement, technical assistance, financial assistance, education, training, technology transfer, and demonstration projects.

CWA §320: Establishes that National Estuary Program (NEP), a demonstration program designed to show how estuaries and their living resources can be protected through comprehensive, action-oriented management. Participation in the NEP is limited to estuaries determined by the EPA Administrator to b of "national significant" after nomination by the Governors of the States in which the estuaries are located.

CWA §402: Establishes the National Pollutant Discharge Elimination System (NPDES), which provides for the issuance of point source permits to discharge any pollutant or combination of pollutants, after opportunity for public hearing.

CWA §404: The discharges of dredged or fill material into wetlands is regulated under this section of the CWA. Permits may be issued after notice and opportunity for public hearings.

Drop structure: A natural or man-placed structure that disrupts the continuous surface flow pattern in a river or stream by producing a pooling of water behind the structure and a rapid drop in the surface gradient for water flowing over the structure; used to improve habitat conditions for aquatic life and to increase the air (especially oxygen) content of water.u

Ecoregion: Ecological region that has broad similarities with respect to soil, relief, and dominant vegetation.

Energy cycling: The movement, or flow, and storage of energy among production and use components of ecological and physiological systems.

Evapotranspiration: The combined conversion of water to water vapor and loss resulting from both evaporation and transpiration.

Geomorphology: The geologic study of the evolution and configuration of land forms.

Marginal costs: The incremental cost of increasing output of a good or service by a small amount.

Pool: In streams, a relatively deep area with low velocity; in ecological systems, the supply of an element or compound, such as exchangeable or weatherable cations or adsorbed sulfate, in a defined component of the ecosystem.

Pool-riffle ratio: The ratio of stream surface area covering pools to stream surface area covering riffles in a given segment of stream.

Re-aeration: The rate at which oxygen is absorbed back into water. This is dependent, among other things, upon turbulence intensity and the water depth.

Respiration: The biological oxidation of organic carbon with concomitant reduction of external oxidant and the production of energy. In aerobic respiration, O2 is reduced to CO2. Anaerobic respiration processes utilize NO3- (denitrification), SO42- (sulfate reduction), or CO2 (methanogenesis).

Riffle: A shallow section in a stream where water is breaking over rocks or other partially submerged organic debris and producing surface agitation.

Site characterization: A location-specific or area-specific survey conducted to characterize physical, chemical, and/or biological attributes of an area; such surveys may be conducted at different times to provide information on how these attributes may change over time.

Solubility: The ability of a chemical (e.g., pollutant) to be dissolved into a solvent (e.g., water column).

Stream meander: The length of a stream channel from an upstream point to a downstream point divided by the straight line distance between the same two points.

Total Maximum Daily Load (TMDL): An estimate of the pollutant concentrations resulting from the pollutant loadings from all sources to a waterbody. The TMDL is used to determine the allowable loads and provides the basis for establishing or modifying controls on pollutant sources.

TMDL process: The approach normally used to develop a TMDL for a particular waterbody or watershed. This process consists of five activities, including selection of the pollutant to consider, estimation of the waterbody's assimilative capacity, estimation of the pollution from all sources to the waterbody, predictive analysis of pollution in the waterbody and determination of total allowable pollution load, and allocation of the allowable pollution among the different pollution sources in a manner that water quality standards are achieved.

Trophic state: The state of nutrition (e.g., amount of nutrients) in a body of water.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river or lake at a lower elevation.

Watershed Protection Approach (WPA): The U.S. EPA's comprehensive approach to managing water resource areas, such as river basins, watersheds and aquifers. WPA contains four major features — targeting priority problems, stakeholder involvement, integrated solutions, and measuring success.

Width/depth ratio: The width to depth ratio describes a dimension of bankfull channel width to bankfull mean depth. Bankfull discharge is defined as the momentary maximum peak flow which occurs several days a year and is related to the concept of channel forming flow.

Width/meander length ratio: The ratio of the average width of a stream or river over a reach divided by the average length over successive cycles of left and right bends of the stream or river.

APPENDIX A

ANNOTATED BIBLIOGRAPHY

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An experimental introduction of sand sediment into Hunt Creek in the northern Lower Peninsula of Michigan that increased the bed load 4-5 times resulted in a significant reduction of brook trout (*Salvelinus fontinalis*) numbers and habitat. The brook trout population declined to less than half its normal abundance. The growth rate of individual fish was not affected. Population adjustment to the poorer habitat was via a decrease in brook trout survival rates, particularly in the egg to fry to fall fingerling stages of their life cycle. Habitat for brook trout and their food organisms became much poorer, as judged by the drastic reductions of both. Stream morphometry changed considerably, the channel becoming wider and shallower and, sand deposition aggraded the streambed and eliminated most pools. The channel became a continuous run rather than a series of pools and riffles. Water velocities increased as well as did summer water temperatures. Relatively small sand bed-load concentrations of only 80 ppm had a profound effect on brook trout and their habitat.

American Fisheries Society. 1980. ***Position Paper on Management and Protection of Western Riparian Stream Ecosystems.*** **American Fisheries Society, Western Division, Tualatin, OR. 24 pp.**

The Western Division AFS presents this position statement to address the issue of management, maintenance, and protection of riparian stream ecosystems in the western United States. This paper was developed by the Riparian Habitat Committee of the WDAFS. It is the WDAFS intent that this paper be used not only by fisheries scientists, but also by those in other disciplines to develop an understanding of the relationships that exist between land uses, fish and wildlife habitat requirements, and stream ecology within riparian habitat zones. The WDAFS and the AFS urge objective consideration of the information presented herein. Includes information in grazing, mining, water development and irrigation, road construction, agriculture and urbanization, timber harvest, and recreational uses. Also includes a review of riparian stream ecosystem knowledge.

American Fisheries Society. 1982. ***The Best Management Practices for the Management and Protection of Western Riparian Stream Ecosystems.*** **American Fisheries Society, Western Division, Tualatin, OR. 45 pp.**

In 1976 streamside nutrient-enrichment experiments were conducted using wooden troughs. Triling of the PO4- concentration, with or without a similar increase of NO3-, increased algal biomass on the troughs by 8 times after 35 days. Increasing NO3- alone had no appreciable effect on algal growth. A sloughing of algal biomass in August 1976 is

believed to have been due to the instability of the heavy algal mat on the troughs and to the very poor light conditions that prevailed throughout August. Visual observation indicated that the relatively heavy algal population in Carnation Creek rapidly declined concurrent with the decline in the troughs, and *Frangilaria vaucheriae* replaced *Achnmanthes minutissima* as dominant on the phosphorus enriched trough. No shift to green or blue-green algal dominated assemblages occurred despite alteration of the N:P ratio. The dynamics of species succession, distribution, and growth, with and without nutrient addition, are discussed.

Aquatic and Wetland Consultants, Inc. 1991. *A Conceptual Habitat Restoration Design Plan for Boulder Creek - 55th Street to 61st Street.* Aquatic and Wetland Consultants, Inc., Boulder, CO, 7 pp. + appendices.

This report was prepared at the request of Mr. John Barnett, Tributary Greenway Coordinator, City of Boulder. It addresses Boulder Creed Reach 3-A extending between 55th Street and 61st Street. The intent of this project was to provide a design plan for a continuation of the Boulder Creek corridor project which was previously ended at 55th Street. The overall goal of this project was to produce a creative stream, riparian, and wetland conceptual design plan that could be implemented in the future when funds become available. Specific objectives included utilization of selected best management practices (BMPs) and techniques that would increase: 1) streambank stabilization, and thereby decrease bank erosion, channel downcutting, and sediment transport; 2) holding water carrying capacity and standing stock (numbers and biomass); 3) high quality pool habitat and provide over-winter and low flow aquatic life survival; 4) riffle substrate structure (roughness) that would favor increased invertebrate productivity (fish food); and 5) potential for establishment of a healthy and functional stream, riparian and wetland ecosystem. It was intended to meet these objectives by preparing: 1) a conceptual design plan identifying types and specific locations of recommended enhancements; 2) plan and cross section typical drawings; 3) preliminary cost estimates; and 4) details on nonstandard construction techniques.

Armour, C.L., D.A. Duff, and W. Elmore. 1991. The effects of livestock grazing on riparian and stream ecosystems. *Fisheries* 16(1):7-11.

An American Fisheries Society position statement on livestock grazing and its effects on riparian and streamside ecosystems, particularly on federally owned lands. Big game, small game, non-game habitats and 19,000 miles of sport fishery streams have declined in quality due to poor management practices, including overgrazing. This poor management can lead to actual elimination of riparian areas by channel widening, channel aggradation or lowering of the water table. Actions needed to alleviate this problem could include complete and accurate stream and riparian area inventories, an increase in grazing fees, and promotion of awareness of the ecology of aquatic-riparian ecosystems and the processes that regulate these ecosystems.

Arthur D. Little, Inc. 1973. *Report on Channel Modifications, Volume I & II*. Prepared for the Council on Environmental Quality, Washington, DC.

These volumes are a final report to assess environmental, economic, financial and engineering aspects of channel modifications, and the availability and use of alternatives, as planned and carried out by the Corps of Engineers, Soil Conservation Service, Tennessee Valley Authority and the Bureau of Reclamation. This assessment has drawn upon the public record and literature, observations in the field of 42 projects in 18 States, and discussions with at least 558 people in 30 public meetings throughout the Nation. The report is in three separate bindings. Volume I describes the procedures used in carrying out the assignment, summarized findings and presents nine chapters on the contractual elements of the work. Volume II, Part One, and Volume II, Part Two, each contain 21 field evaluation reports.

Avery, E.L. 1978. *The Influence of Chemical Reclamation on a Small Brown Trout Stream in Southwestern Wisconsin*. Department of Natural Resources, Madison, WI, Technical Bulletin No. 110.

The present study was initiated to more thoroughly quantify effects of chemical treatment and total fish removal on a domesticated brown trout population, the sport fisher, and the aquatic invertebrate community in a small southwestern Wisconsin trout stream. A culvert-type fish barrier was installed in the middle of the study zone prior to chemical treatment to determine its effectiveness in preventing reinvasion of forage fishes and to quantitatively document added benefits this practice might have over and above those derived from chemical treatment alone.

Babcock, W.H. 1982. *Tenmile Creek - A Study of Stream Relocation*. Colorado Division of Wildlife, Fisheries Research Section, Special Report No. 52, 22 pp.

After input from various interested agencies, three miles of creek were relocated to facilitate the construction of Interstate 70 through Tenmile Canyon west of Denver. The 0.5 million dollar project was designed to provide fish habitat of equal value to that present before construction or, if possible, to improve this habitat. Construction techniques were designed to minimize damage to flora and fauna. After the channels were excavated, rock and log fish habitat structures were constructed. Two years after construction, a 4 percent chance flood occurred at the project area which made almost 75 percent of the habitat structures ineffective. Pool- riffle ratios and quantity and quality of spawning areas remained essentially unchanged throughout the period. Population estimates indicated an increase in the number of fish in the postconstruction period compared to preconstruction numbers. Fish biomass estimates for the project area were comparable for the two periods. Aquatic invertebrate populations were unchanged as indicated by comparison of three pre- and postconstruction indices.

Baker, D.B. 1989. Environmental extension: a key to nonpoint-source pollution abatement. *Journal of Soil and Water Conservation* 44(1):8.

The importance on soil, water, and air resources to our future quality of life and prosperity cannot be overestimated. Continuing stewardship of these resources will involve ongoing

development of ever better best management practices and continuing assessment of the environmental impacts of ever more intensive land use activities. Environmental extension, by conveying to all of us state--of--the--art-and-science methods and current assessments of environmental conditions, will play increasingly important roles in environmental protection for the future. Article stresses cooperative education to abate nonpoint source pollution problems.

Beamish, F.W.H. and A. Tandler. 1990. Ambient ammonia, diet and growth in lake trout. *Aquatic Toxicology* 17:155-166.

Juvenile lake trout were exposed to ambient free (un-ionized) concentrations of 0, 99, 198 and 297 µg NH3N 1-1 for 60 days and fed one of two diets which were similar in energy concentration. Diet did not influence food intake at ammonia concentrations of 0, 99, and 198 µg NH3N 1-1. Food intake was unaffected by ammonia concentrations of 0 and 99 µg NH3N 1-1 and was only temporarily reduced when ammonia was 198 µg NH3N 101. Trout exposed to 297 µg NH3N 1-1 consumed significantly less food than fish exposed to the lower concentrations of ammonia. Food intake did not differ with diet during the first 30 days of exposure to 297 NH3N 1-1 but during the final 30 days, it was higher for trout fed the low protein diet. Growth, measured as a change in live body weight was not influenced by ammonia concentrations of 0, 99, and 198 µg NH3N 1-1 but declined significantly at 297 µg NH3N 10-1. Weight gain tended to be larger for trout fed the high protein diet. Efficiency of protein-N gain was greater for trout fed the low protein diet, presumably as a consequence of a sparing effect afforded by high dietary lipid. Efficiency of protein-N gain was significantly reduced among lake trout exposed to the highest concentration of ammonia. Mortalities were observed only among trout exposed to the highest concentration of ammonia.

Beaumont, P. 1978. Man's impact on river systems: a world-wide view. *Area* 10:38-41.

An analysis of dam building activity throughout the world since 1840 revealing the pre-eminent position of North America. Three periods of increasing activity are identified culminating in a remarkable spate of dam construction between 1950 and 1970.

Binns, N.A. 1986. *Stabilizing Eroding Stream Banks in Wyoming: A Guide to Controlling Bank Erosion in Streams*. Wyoming Game and Fish Department, Cheyenne, WY. 42 pp.

A non-technical booklet summarizing stream bank stabilization methods in a format useable by the average landowner. Topics include erosion, erosion mechanics, rock and rock devices, tree revetments, trout habitat, gabions, log cribs, unacceptable methods, alteration consequences, and sources of advice.

Bissonnette, P. 1985. Bellevue experiences with urban runoff quality control strategies. *Perspectives on Nonpoint Source Pollution: Proceedings of a Conference*. Kansas City, MO, May 19-22, 1985. pp. 279-280.

The Bellevue Storm and Surface Water (SSW) Utility was formed out of the city's and citizen's commitment to preserve it's network of streams and lakes. Established in 1974, the SSW Utility's mission is to manage the storm and surface water system in Bellevue to maintain a hydrologic balance, prevent property damage, and protect water quality for the health, safety, and enjoyment of citizens and for the preservation and enhancement of wildlife habitat. This mission has been impaired by urban runoff. It is essential that the state-of-the-art for runoff quality and treatment programs progress to the point that runoff pollution abatement strategies can be followed with confidence.

Bormann, F.H., G.E. Likens, and J.S. Eaton. 1969. Biotic regulation of particulate and solution losses from a forest ecosystem. *BioScience* 19(7):600-610.

Major losses of nutrients from terrestrial ecosystems result from two processes: particulate matter removal accomplished by erosion and transportation in surface drainage water, and solution removal accomplished by dissolution and transportation of solutes by surface and subsurface drainage water. Knowledge of these two processes is important to our understanding of the relationships between interconnected terrestrial and lotic ecosystems. In a larger sense, this information contributes to a more detailed understanding of fluvial denudation of the landscape and the relative importance of removal of solutes and particulate matter in this basic geologic phenomenon.

Boulder, City of - Department of Public Works/Utilities. 1990. *Boulder Creek Basin Planning to Reduce Nonpoint Source Pollution by Using Best Management Practices*. Department of Public Works/Utilities, City of Boulder, CO, 27 pp + appendices.

The City of Boulder proposed to control nonpoint source (NPS) pollution within the Boulder Creek Basin extending form the Indian Peaks Wilderness headwaters to the confluence with Coal Creek, a creek mainstem length of 40.8 miles. The objectives of the project include: 1) controlling NPS pollution using Best Management Practices (BMP's), 2) providing cost-effective water quality improvement singly and in combination with the 75th Street Waste Water Treatment Plant (WWTP), and 3) achieving the state use classification. The proposal follows initiation of a Phase I NPS Pollution Demonstration Project located downstream from the WWTP. Funding of $125,000 was split on a 60/40 basis by the State NPS Pollution Control Program and the City of Boulder. The project has generated high community interest, high NPS pollution visibility, and nearly a quarter million dollars of donated time, labor, and materials suggesting an approximate total project worth of $426,000. A Phase II Demonstration Project has been initiated as of 1 January 1990 and is funded similarly to Phase I. The Boulder Creek basin, for planning purposes, has been divided at the Boulder Canyon mouth into an upper (mountain) basin and a lower (plains) basin. Upper basin (upstream of City limits) NPS pollution includes: 1) 16 miles of State Highway sanding operations (3,000 tons/year including 7.5% salt), 2) mineral and gravel mining, and 3) sediment from a 1989 forest fire on Sugar Loaf Mountain. Lower basin NPS pollution includes: 1) highway street and road sanding operations (15,000 tons/year including 15% salt), 2) NPS drainage (18 sources) such as irrigation ditch return flows and 30 to 40 storm sewers, 3) channelization (70% requiring 7.8 miles of berm removal), 4) streambank erosion (72 locations totalling 2.1 miles), 5) overgrazing and gravel mining resulting in loss of the riparian canopy. The project has been divided into five one-year phases that include management, final design, construction, supervision and monitoring at an average yearly cost of $489,000 split on a 60/40 basis (state = 60% = @293,000; city = 40% = $195,600). Reported observations and documentation indicate that a final water quality management plan for the basin should include point source and

NPS pollution controls. Neither control type alone can result in a stream that consistently meets its intended uses or water quality standards. Recommended BMPs will permit NPS pollution control, result in physical, biological and chemical habitat reclamation, and facilitate attaining the aquatic life use in the lower basin.

Boulder, City of - Department of Public Works/Utilities. 1990a. *The Boulder Creek Watershed (Basin) Project for Nonpoint Source Pollution Control - Project Implementation Plan.* Department of Public Works/Utilities, City of Boulder, CO, 55 pp. + appendices.

The Boulder Creek Watershed Project Implementation Plan (PIP) is a proposal to reduce and control nonpoint source (NPS) pollution within the Boulder Creek Basin extending from the Indian Peaks Wilderness headwaters to the confluence with Coal Creek. Specific state-approved best management practices (BMPs) that have the capability of providing cost-effective water quality improvement individually and in combination have been selected for implementation. The Boulder Creek Watershed PIP calls for a dendritic (branching) approach to the identification and resolution of water quality issues. Because degraded quality conditions within Boulder Creek are due to both deficiencies of the main channel and to deficiencies within the drainage network entering the creek, Boulder Creek itself is the first order concern. Riparian enhancement efforts such as the City's Phase I and Phase II lower Boulder Creek restoration projects, have restored lost functions to the main channel of the creek and have reduced the impact of degraded riparian zones. When first-order impacts are reduced in this manner, the relative effect of second-order impacts can be assessed and quantified. In addition, tributary channels can be assessed in terms of riparian function loss and in relation to inputs from third-order systems (i.e., surface drainage and subsurface flows). Third order systems are more likely to involve non-riparian agricultural or urban use areas. Best Management Practices (BMPs) developed for these areas will differ from those required to address first-order impacts and will draw more heavily on the resources and knowledge of traditional land use management agencies within those areas.

Boulder, City of - Department of Public Works/Utilities. 1991. *Final Revised Project Implementation Plan (PIP) for Phase III Reach 5(a): The Boulder Creek Watershed Nonpoint Source Pollution Control Project.* Department of Public Works/Utilities, City of Boulder, CO, 26 pp.

The overall goal of the Boulder Creek Project Implementation Plan (PIP) is to improve the physical, chemical and biological integrity and beneficial uses of Boulder Creek in a cost effective manner. Specific objectives include: 1) controlling NPS pollution in the Boulder Creek basin using state-of-the-art BMPs, 2) providing cost effective water quality improvement singly and in combination with the WWTP, and 3) achieving the state use classification. Specific NPS pollution for Subreach 5(a) include: 1) sediment, nutrient, debris and other inputs caused by loss of riparian zone function (i.e., entrapment), 2) sediment, nutrient, debris and other inputs caused by destabilization and eroded streambanks following loss of riparian vegetation by long-term overgrazing, 3) unstable erodible streambank berms cause by channelization which support noxious weeds and preclude growth of functional riparian vegetation, 4) an overly wide, shallow channel following channelization, and 5) degradation of water quality by overheating and excessive aquatic plant growth within the overly wide, shallow channel.

Boulder, City of - Department of Public Works/Utilities. 1991a. *Project Implementation Plan (PIP) for Phase IV an V Reach 6 (a/b): The Boulder Creek Watershed Nonpoint Pollution Control Project.* Department of Public Works/Utilities, City of Boulder, CO, 29 pp.

The overall goal of the Boulder Creek Project Implementation Plan (PIP) is to improve the physical, chemical and biological integrity and beneficial uses of Boulder Creek in a cost effective manner. Specific objectives include: 1) controlling NPS pollution in the Boulder Creek basin using state-of-the-art BMPs, 2) providing cost effective water quality improvement singly and in combination with the WWTP, and 3) achieving the state use classification. Specific NPS pollution for Subreach 5(a) include: 1) sediment, nutrient, debris and other inputs caused by loss of riparian zone function (i.e., entrapment), 2) sediment, nutrient, debris and other inputs caused by destabilization and eroded streambanks following loss of riparian vegetation by long-term overgrazing, 3) unstable erodible streambank berms cause by channelization which support noxious weeds and preclude growth of functional riparian vegetation, 4) an overly wide, shallow channel following channelization, and 5) degradation of water quality by overheating and excessive aquatic plant growth within the overly wide, shallow channel.

Bradt, P.T., and G.E. Wieland, III. 1978. *The Impact of Stream Reconstruction and a Gabion Installation on the Biology and Chemistry of a Trout Stream.* Completion Report for Grant No. 14-34-0001-6225, U.S. Department of the Interior, Office of Water Research and Technology.

The purpose of this study was to evaluate the effect of a gabion installation and stream reconstruction in a 2 km section of rechanneled stream. The Bushkill Creek, supporting a naturally reproducing brown trout population in Northampton County, Pennsylvania, was sampled bi-weekly biologically, chemically and physically for sixteen months. Prior to the sampling, stream reconstruction efforts included both a gabion (rock current deflectors) installation to narrow an deepen the streambed and tree and shrub planting to cover bare banks and provide eventual shade. The stream bed was open to sunlight and primary productivity, as evidenced by larger algae populations, increased in the rechanneled area. The following benthic macroinvertebrate parameters significantly increased also through the rechanneled area: diversity index, biomass, total numbers, and number of taxa. The following chemical parameters increased significantly throughout the rechanneled area: conductivity, dissolved oxygen, percent oxygen saturation and alkalinity. Orthophosphate decreased significantly and flow velocity increased significantly. Limestone springs contributed to the increase in conductivity and alkalinity. Increased photosynthesis and turbulence contributed to the increase in dissolved oxygen and oxygen saturation. The gabions deepened and narrowed the stream channel resulting in a cooler stream in summer.

Brookes, A. 1988. *Channelized Rivers: Perspectives for Environmental Management.* John Wiley & Sons, New York, NY. 326 pp.

An introduction to and case studies of human impact on rivers. These impacts include channelization, engineering methods and designs, environmental legislation, the physical and biological effects of channelization, consequences to downstream reaches, new construction procedures, and mitigation, enhancement and restoration techniques (rehabilitation) of rivers.

Brouha, P. and R. Barnhart. 1982. Progress of the Brown's Creek Fish habitat development project. In: *R. Wiley (ed.) Proc. of Rocky Mt. Stream Habitat Management Workshop.* Sept. 7-10, 1982, Jackson, WY. Wyoming Game and Fish Department, Laramie, WY.

A direct and rapid restoration method is stream habitat improvement in major spawning and rearing tributaries. Various projects show that fish populations respond to an increase in shelter and food. This paper is a case study of the improvement of The Upper Browns Creek watershed in northwestern California 35 miles southwest of Redding in the Shasta-Trinity National Forest.

Brown, G.W. 1989. *Forestry and Water Quality*. O.S.U. Book Stores, Inc., Second Edition, Corvallis, OR.

A textbook for forestry management classes. The objective of this text is to illustrate the interaction between man and his management of the forest, the hydrologic cycle, and the quality of water in forest streams. It is intended as a text for use by students at the senior or graduate level in professional courses dealing with forestry, environmental sciences, or natural resources policy. Professional natural resource managers may also find it useful, especially the literature citations, in development of policy and operational guidelines or in preparation of environmental impact statements. Understanding how water quality is affected by natural factors and man's manipulation of the forest requires an understanding of hydrologic processes on forest land. Contains information on problems and solutions for the subjects of erosion and sedimentation, water temperature, dissolved nutrients, chemicals and water quality, dissolved oxygen, and pathogenic organisms.

Brown, G.W. and J.T. Krygier. 1967. Changing water temperature in small mountain streams. *Journal of Soil and Water Conservation* 22:242-244.

Land use effects on the water temperature of small mountain streams have been considered remote and inconsequential. Few investigations have been made to establish seasonal temperature patterns on forested streams and almost none of the effects of logging on water temperature. Results of such studies are important in the Pacific Northwest, where most of the land supplying the region's water is forested and subject to periodic harvest. Most municipal watersheds in the Northwest are forested. Anadromous and resident fish utilize forest streams extensively. Modification of vegetal cover along small streams may cause temperature changes as ecologically and economically significant as changes caused by reservoirs and thermal plants on large river systems. It is difficult, however, to economically control water temperature with reservoirs on small streams. If control is important, it must be accomplished by watershed management.

Burgess, S.A. 1985. Some effects of stream habitat improvement on the aquatic and riparian community of a small mountain stream. Pp. 223-246 in: J.A. Gore, ed., *The Restoration of Rivers and Streams*. Theories and Experience. Butterworth, Stoneham, MA. 280 pp.

A study was conducted to determine the effectiveness of a relatively simple habitat improvement program in increasing trout biomass in an experimental section of a small mountain stream. The intention of the study was to use relatively simple techniques with

low cost and labor requirements. In addition to monitoring the effects of the habitat improvements on the trout population, the responses of other members of the aquatic and riparian community, notably crayfish and mink, were also investigated.

Cairns, J. Jr. 1991. The status of the theoretical and applied science of restoration ecology. *The Environmental Professional* 13:186-194.

Restoration ecology is evolving rapidly, but the field is still experimental activity. At this stage, every restoration project should be used to improve the status of both theoretical and applied science. The course of a restoration project should be sufficiently flexible to incorporate changes as a result of the feedback of scientific and societal information. Unfortunately, experiments on large systems such as the Kissimmee River are not amenable to replication, Nevertheless, simultaneous measurements in a nonmanipulated reference system provide information about large-scale trends that otherwise may confound evaluation. Finally, the resilience of natural systems is so impressive that even a beginning field can make major contributions to the condition of the planet's ecosystems.

Cairns, J. Jr., B.R. Niederlehner, and J.R. Pratt. 1990. Evaluation of joint toxicity of chlorine and ammonia to aquatic communities. *Aquatic Toxicology* 16:87-100.

Periphytic communities on artificial substrates were exposed to chlorine and ammonia, alone and in combinations. The species richness of protozoans decreased with increasing toxicant concentrations. Species richness was reduced by 20% in 2.7 μg/L chlorine, 15.4 μg/L un-ionized ammonia, and a combination of 1.2 μg/L chlorine and 16.9 μg/L ammonia. Interaction between toxicants was significant and effects of mixtures were less-than-additive, especially at higher concentrations. Multiple regression was used to derive a response surface model accounting for 73.4% of the variation in species richness. Algal biomass and community metabolism measures were less sensitive to stress and showed different patterns of joint action.

Canada, Government of - Department of Fisheries and Oceans. 1980. *Stream Enhancement Guide*. Government of Canada, Department of Fisheries and Oceans, Vancouver, BC. 82 pp. + appendices.

This guide provides an introduction to the various approaches and methods suitable for salmonid production stream enhancement in British Columbia. It has been prepared to assist both the interested public and government agency staff, having limited technical background in this field, to plan and implement projects. Contains information on project planning, streamside and watershed improvements, stream channel improvements, side channel development, stream flow control, nutrient enrichment, and project assessment.

Clary, W.P. and B.F. Webster. 1990. Riparian grazing guidelines for the intermountain region. *Rangelands* 12(4):209-212.

Excessive livestock impacts, through heavy grazing and trampling, affect riparian-stream habitats by reducing or eliminating riparian vegetation, changing streambank and channel morphology, and increasing stream sediment transport. Often there is a lowering of the surrounding water tables. Thus livestock are perceived as a major cause of habitat disturbance in many Western riparian areas. This perception has resulted in accelerated concerns from various resource users because riparian areas generally represent the epitome of multiple use. In addition to the livestock forage, riparian areas and the associated streams often have high to very high values for fisheries habitat, wildlife habitat, recreation, production of wood fiber, transportation routes, precious metals, water quality, and timing of water flows. Includes information on recommended grazing management practices.

Coffin, P.D. 1982. Northeastern Nevada stream and riparian habitat improvement projects. In: R. Wiley (ed.) *Proc. of Rocky Mt. Stream Habitat Management Workshop*. Sept. 7-10, 1982, Jackson, WY. Wyoming Game and Fish Department, Laramie, WY.

A synopsis of various stream and riparian habitat improvement projects in Nevada. Costs, techniques, and results are included for eight projects dating from 1963 through 1981.

Columbia Basin System Planning. 1990. *Salmon and Steelhead Production Plans*. Columbia Basin System Planning, Northwest Power Planning Council, Portland, OR.

Fish production plans dated 9/1/90, lead-written by either the Oregon Department of Fish and Wildlife or the Washington State Department of Fisheries in conjunction with other State Agencies and Indian Tribal Governments. The documents include information on habitat improvement projects, constraints and opportunities for habitat protection, and habitat protection objectives and strategies. Our library contains this information for the following areas: Willamette River subbasin (Coast Range, Molalla & Pudding Rivers, Tualatin River, Clackamas River, Willamette Mainstem, Coast Fork & Long Tom Rivers, Middle Fork of the Willamette River, McKenzie River, and Santiam & Calapooia Rivers), Yakima River subbasin, Upper Columbia River subbasin (Priest Rapids Dam to Chief Joseph Dam), Lower Columbia River subbasin (Mouth to Bonneville Dam), Mid Columbia River subbasin (Bonneville Dam to Priest Rapids Dam), Deschutes River subbasin, Snake River subbasin (Mainstem from mouth to Hells' Canyon Dam), Sandy River subbasin, Wenatchee River subbasin, Walla Walla River subbasin, Umatilla River subbasin, Tucannon River subbasin, Wind River subbasin, Imnaha River subbasin, Hood River subbasin, Klickitat River subbasin, John Day River subbasin, White Salmon River subbasin, Little White Salmon River subbasin, Salmon River subbasin, Methow and Okanogan River subbasin, Grays River subbasin, Kalama River subbasin, Elochoman River subbasin, Cowlitz River subbasin, Washougal River subbasin, Entiat River subbasin, Fifteenmile Creek subbasin, and Grande Ronde River subbasin.

Contor, C.R. and W.S. Platts. 1991. *Assessment of COWFISH for Predicting Trout Populations in Grazed Watersheds of the Intermountain West*. USDA Forest Service, Intermountain Research Station, Ogden, UT, Gen. Tech. Rep. INT-278, 28 pp.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. *Classification of Wetlands and Deepwater Habitats of the United States*. Office of Biological Services, U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC. FWS/OBS/79/31, 103 pp.

This classification, to be used in a new inventory of wetlands and deepwater habitats of the United States, is intended to describe ecological taxa, arrange them in a system useful to resource managers, furnish units for mapping, and provide uniformity of concepts and terms. Wetlands are defined by plants (hydrophytes), soils (hydric soils), and frequency of flooding. Ecologically related areas of deep water, traditionally not considered wetlands, are included in the classification as deepwater habitats. Systems form the highest level of the classification hierarchy (Marine, Estuarine, Riverine, Lacustrine, and Palustrine), followed by Subsystem, Class, and Dominance Type, plus modifying terms. Regional differences important to wetland ecology are described through a regionalization that combines a system developed for inland areas by G.R. Bailey in 1976 with our Marine and Estuarine provinces. The structure of the classification allows it to be used at any of several hierarchical levels. Special data required for detailed application of the system are frequently unavailable, and thus data gathering may be prerequisite to classification. Development of rules by the user will be required for specific map scales. Dominance Types and relationships of plant and animal communities to environmental characteristics must also be developed by users of the classification. Keys to the Systems and Classes are furnished as a guide, and numerous wetlands and deepwater habitats are illustrated and classified. The classification system is also compared with several other systems currently in use in the United States.

DeBano, L.F. and B.H. Heede. 1987. Enhancement of riparian ecosystems with channel structures. *Water Resources Bulletin* 23(3):463-470.

Naturally occurring and man-made structures can be used for enhancing the development of riparian zones. Naturally occurring structures are cienagas, beaver dams, and log steps. Man-made structures include large and small channel structures and bank protection devices. All these structures affect streamflow hydraulics and sedimentation and can create a more favorable environment for riparian zone establishment. However, when they are used improperly, they can be destructive to existing riparian zones. Since stream processes are generally slow, long-time spans may pass before the effects of management action, good or bad, become visible. Also, the effects of large dam installations may appear a long distance down-stream from the dam. Therefore, investigations must be of a wide scope. Interactions between riparian site, channel, and streamflow may be so complex that an interdisciplinary approach is required.

DeBano, L.F. and L.J. Schmidt. 1989. *Improving Southwestern Riparian Areas through Watershed Management*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, General Technical Report No. RM-182.

This paper reviews opportunities and watershed restoration techniques available for rehabilitating and enhancing riparian ecosystems in southwest environments. As such it is intended to serve as a state-of-the- art report on riparian hydrology and improvement in both naturally occurring and man-made riparian areas throughout the Southwest.

Delong, M.D. and M.A. Brusven. 1991. Classification and spatial mapping of riparian habitat with applications toward management of streams impacted by nonpoint source pollution. ***Environmental Management*** **15(4):565-571.**

Management of riparian habitats has been recognized for its importance in reducing instream effects of agricultural nonpoint source pollution. By serving as a buffer, well structured riparian habitats can reduce nonpoint source impacts by filtering surface runoff from field to stream. A system has been developed where key characteristics of riparian habitat, vegetation type, height, width, riparian and shoreline bank slope, and land use are classified as discrete categorical units. This classification system recognizes seven riparian vegetation types, which are determined by dominant plant type. Riparian and shoreline bank slope, in addition to riparian width and height, each consist of five categories. Classification by discrete units allows for ready digitizing of information for production of spatial maps using a geographic information system (GIS). The classification system was tested for field efficiency on Tom Beall Creek watershed, an agriculturally impacted third-order stream in the Clearwater River drainage, Nez Perce County, Idaho, USA. The classification system wa simple to sue during field applications and provided a good inventory of riparian habitat. After successful field tests, spatial maps were produced for each component using the Professional Map Analysis Package (pMAP), a GIS program. With pMAP, a map describing general riparian habitat condition was produced by combining the maps of components of riparian habitat, and the condition map was integrated with a map of soil erosion potential in order to determine areas along the stream that are susceptible to nonpoint source pollution inputs. Integration of spatial maps of riparian classification and watershed characteristics has a great potential as a tool for aiding in making management decisions for mitigating off-site impacts of agricultural nonpoint source pollution.

Duff, D.A. and N. Banks. 1988. ***Indexed Bibliography on Stream Habitat Improvement.*** **USDA Forest Service Intermountain Region, Wildlife Management Staff, Ogden, UT.**

Not available.

Elmore, W. and R.L. Beschta. 1987. Riparian areas: Perceptions in management. ***Rangelands*** **9(6):260-265.**

Riparian areas can be the most important part of a watershed for a wide range of values and resources. They provide forage for domestic animals and important habitat for approximately four-fifths of the wildlife species in eastern Oregon. Where streams are perennial, they provide essential habitat for fish and other aquatic organisms. When overbank flows occur, riparian areas can attenuate flood peaks and increase groundwater recharge. This paper presents information on issues and problems like, flooding, vegetation, streamflow, and grazing.

Ferguson, B.K. 1991. Urban stream reclamation. ***Journal of Soil and Water Conservation*** **46(5):324-328.**

In urban areas, streams represent potential wildlife corridors, wetland multipliers of ecosystem integrity, scenic resources, recreational facilities close to home, and greenway links among neighborhoods and parks. The materials, vegetation, shape, stability, and spatial composition of the stream channel and riparian landscape govern the corridor's effectiveness as a resource. Such characteristics can be managed through landscape design. Projects to implement such values have been undertaken in several areas; some examples are California's Urban Stream Restoration Program, The Boulder Creek Corridor Project in Colorado, and San Antonio's Riverwalk.

Froelich, P.N. 1988. Kinetic control of dissolved phosphate in natural rivers and estuaries: a primer on the phosphate buffer mechanism. *Limnology and Oceanography* 33(4, part 2):649-668.

The primary mode of interaction of dissolved phosphate with fluvial inorganic suspended particles is via a reversible two-step sorption process. The first step is adsorption/desorption on surfaces has fast kinetics (minutes-hours). The second step, solid-state diffusion of adsorbed phosphate from the surface into the interior of particles, has slower kinetics (days-months) and is dependent on the time history of the previous surface sorption and the chemistry of the solid diffusional layer. Natural clay particles with a surface of iron and aluminum hydroxyoxides resulting from chemical weathering of rocks and soils, have a high capacity for absorbing phosphate and for maintaining low "equilibrium phosphate concentrations" in solution. Extrapolation of laboratory experiments suggest that phosphate concentrations of unperturbed turbid rivers are controlled near the dynamic equilibrium phosphate concentration and that fluvial suspended particles "at equilibrium" contain phosphate that is desorbable. Release of this phosphate from particles entering the sea produces the characteristic shape and magnitude of input profiles of dissolved phosphate observed in unperturbed estuaries. On a global scale, fluvial particulates could transport some 2.5 times more than that in the dissolved load alone.

Gammon, J.R. 19??. *Biological Monitoring in the Wabashi River and Its Tributaries.* Department of Bio. Sci., DePauw University, Greencastle, IN.

The aquatic communities of the middle Wabash River and its tributaries have been studied annually since 1967. Initial assessments of thermal effects at two power plants were expanded in 1973 to include 160 miles of mainstem. D.C. electrofishing proved to be most effective for the greatest number of large species in the Wabash River. Fish are collected 3 times each summer from 63 stations, each of which is 0.5 km long. Most stations are sited in relatively fast-water with good cover and depths of 1.5 m. or less. Several important tributaries have also been investigated. Some macrobenthic, periphyton, and phytoplankton work has been undertaken, but the fish community has been studied most intensively. In recent years improvements have been documented along the Wabash River itself, but it has been simultaneously observed that marked negative changes from agricultural activities in tributaries have occurred.

Gore, J.A. 1985. Mechanisms of colonization and habitat enhancement for benthic macroinvertebrates in restored river channels. Pp. 81-101 in: J.A. Gore, ed., *The Restoration of Rivers and Streams. Theories and Experience.* Butterworth, Stoneham, MA. 280 pp.

Benthic macroinvertebrates comprise a large and diverse faunal community in most undisturbed running water ecosystems. These invertebrates represent a critical pathway for the transport and utilization of energy within that ecosystem. Alterations habitat, such as diversions, channel restructuring, or dredging of substrate material, have the potential of changing the energy dynamics of downstream faunal communities as well. Restoration of the benthic macroinvertebrate community to duplicate adjacent unstressed communities is essential to the maintenance of a stable restored system. This article provides the manager with information on the dispersal mechanisms of aquatic invertebrates, measurements of optimum habitat for invertebrates, and a synopsis of some typical reclamation efforts designed for macroinvertebrate habitat.

Gore, J.A. (Ed.). 1985. *The Restoration of Rivers and Streams: Theories and Experience.* Butterworth, Stoneham, MA, 288 pp.

The restoration or rivers and streams differs from land reclamation projects in that it involves the process of recovery enhancement, that is, restoration of the ecosystem at a faster rate than through natural development. This effort requires the knowledge and involvement of a number of professionals, including biologists, hydrologists, engineers and others working as stream managers. This book is for these professionals any anyone else concerned about the reclamation and restoration of damaged streams and ecosystems. It is a unique interdisciplinary survey of theories and techniques used in river and stream restoration, from maintenance of the hydrologic balance to assessment of the successful restoration project.

Gunderson, D.R. 1968. Floodplain use related to stream morphology and fish populations. *Journal of Wildlife Management* 32(3):507-514.

For two contiguous sections of a Montana stream, the agricultural use of the floodplain was related to cover, stream morphology, and fish populations. In one section the vegetation of the floodplain had been reduced by clearing and intensive livestock grazing; in the other section, which had received light use by livestock, vegetation was relatively unchanged. This ungrazed section had 76% more cover (undercut banks, debris, overhanging brush, and miscellaneous) per acre of stream than the grazed section. Brown trout (+6 inches) were estimated to be 27% more numerous and to weigh 44% more per acre in the ungrazed section of the stream, although their rate of growth was similar in the two stream sections.

Gurtz, M.E. and T.W. La Point (eds.). 1989. *North American Benthological Society Technical Information Workshop "Stream Rehabilitation and Restoration".* May 18, 1989, University of Guelph, Guelph, Ontario, Canada.

Papers presented at a workshop in Guelph, Ontario. Include information on river ecosystem rehabilitation, water quality restoration, riparian revegetation, invertebrate response to restoration, and evaluation of salmonid habitat for stream restoration. The water quality restoration paper is very general, showing overall concepts only, not specifics.

Hasfurther, V.R. 1985. The use of meander parameters in restoring hydrologic balance to reclaimed stream beds. Pp. 21-40 in: J.A. Gore, ed., *The Restoration of Rivers and Streams*. Theories and Experience. Butterworth, Stoneham, MA. 280 pp.

A river or stream is dynamic through time. Change is one of the most common features associated with river and stream channels. In general, this change is very slow, however, and only over long periods of time is it actually noticeable to most individuals. As a result, engineers, ecologists, and others involved with the hydrologic balance of a stream often treat the stream system as static. Humans often induce change upon the system without taking the necessary steps to restore the quasi-steady situation and thus set in motion a response by the stream system to adjust to this change, which results in the propagated response along great distances from the human- induced action. This paper discusses methods and techniques for restoring a stream channel to its natural inclinations after a human-induced change. The main emphasis will be on meander parameters and their importance in stream channel stability.

Haugen, G.N. 1983. Riparian best management practices. *Fisheries* 8(1):2 and 9.

The Western Division of the American Fisheries Society has been active in increasing an awareness of riparian habitat management on State, Federal, and Provincial land throughout the west. We should recognize existing situations, describe the fishery potential under optimum management conditions, and then develop alternatives that have specific objectives as well as monitoring to insure that these objectives are met. In developing a plan for a riparian area, it is important that not only fisheries and wildlife expertise be involved but also those who manage the range, the watershed, and the soil. A multidisciplinary team approach is essential if riparian areas are to abe managed to the benefit of all dependent resources.

Heede, B.H. and J.N. Rinne. 1990. Hydrodynamic and fluvial morphologic processes: implications for fisheries management and research. *North American Journal of Fisheries Management* 10(3):249-268.

Past work has not sufficiently integrated the sciences of hydrology and fisheries. Therefore, streamflow, sediment transport, and channel morphology were used to describe the present state of our knowledge of interactions between physical and biological (fishery) processes. These three physical factory (and others) dictate both habitat quantity and quality for different life states of fishes, and their inclusion in habitat assessments will enhance the quality of investigations. Interaction of hydraulic and morphologic factors creates either dynamic equilibrium or disequilibrium, and indicators are given for determination of the type of equilibrium condition. Thus, stream reaches in disequilibrium can be avoided for enhancement or channel stabilization projects, while neglect of the equilibrium condition increases the probability of failure of enhancement projects. Investigators are also urged to use additional hydrodynamic parameters, such as the Froude or Reynolds number, go quantify objectively the type of flow for improved mathematical-statistical analysis of fish-flow relationships. Land managers and researchers are encouraged to design future projects to improve the understanding of the very complex interactions between fish and their hydraulic and morphologic environment. Characteristics of fish habitat must be modified with great care, and then only if (1) the causes for an undesirable condition are known and (2) the measures will be compatible with future stream development. In such an evaluation of fish habitat, the inclusion of hydrodynamic and fluvial morphologic variables should provide more precise quantification of habitat characteristics.

Henderson, J.E. 1986. Environmental designs for streambank protection projects. *Water Resources Bulletin* 22(4):549-558.

Streambank protection projects are intended to prevent streambank erosion, thereby preventing streambank failure and maintaining a desirable channel alignment. Streambank erosion is a natural process of unaltered, dynamic river systems, and protection projects seek to impose stability on this natural system. The environmental impacts of such projects are primarily changes to terrestrial and aquatic habitats and to aesthetics. Adverse environmental impacts have been minimized and enhancement of existing habitat an d aesthetics have been achieved through the development of new, innovative designs or modifications to existing designs and through use of construction and maintenance practices that promote habitat and aesthetics. Designs based on channel flow characteristics, e.g., revetments using a variety of structural materials, can result in preservation of wildlife habitat by reducing the use of structural protection by matching the erosion potential of flow at the bank with the protection capability of the materials used. Designs based on streambed stabilization prevent bank failure caused y bank undermining, result in preservation or establishment of streamside vegetation, and enhance aesthetics. Protection schemes that manage and preserve floodplains, berms, and riparian areas preserve the natural condition of the floodplain area. Designs based on deflection of erosive flows, e.g., dikes, minimize disturbance to the bank vegetation and create low-velocity aquatic habitats. Use of vegetation for bank protection is most effective when used in combination with structural components. Construction and maintenance practices can be scheduled and modified to minimize impacts to floodplain areas and to enhance wildlife habitat while preserving the integrity of the protection structure.

Henszey, R.J., T.A. Wesche, and Q.D. Skinner. 1989. *Evaluation of the State-of-the-Art Streambank Stabilization*. Prepared for Water Quality Division, Wyoming Department of Environmental Quality, Cheyenne, WY, 224 pp.

An evaluation of structural, non-structural, and vegetative streambank stabilization methods, with comments on description, application (how and where), advantages, limitations, and relative cost of approximately 50 techniques. Also includes a large bibliography of references for individual projects, and streambank stabilization overall.

Herricks, E.E. and L.L. Osborne. 1985. Water quality restoration and protection in streams and rivers. Pp. 1-20 in: J.A. Gore, ed., *The Restoration of Rivers and Streams*. Theories and Experience. Butterworth, Stoneham, Ma. 280 pp.

The following discussion of restoration and protection of water quality in streams and rivers recognizes the role water plays in the ecosystem process. Water quality cannot easily be discussed from a single disciplinary perspective because issues span a number of disciplines and relate to physical, chemical, and biological components of the ecosystem.

In addition, the separation of purely technical issues from economic, political, and social factors is impossible when constraints on restoration or protection efforts are considered. In this discussion of the restoration and protection of water quality in streams, the authors felt it important to first review the context in which restoration and protection of water quality is viewed, identify uses and impacts, and then discuss the general approaches to restoration and protection which are available to water quality managers.

Hughes, R.M. 1985. Use of watershed characteristics to select control streams for estimating effects of metal mining wastes on extensively disturbed streams. *Environmental Management* 9(3):253-262.

Impacts of sediments and heavy metals on the biota of streams in the copper-mining district of southwestern Montana were examined by comparing aquatic communities of impacted streams with those of control streams. Control streams were chosen through the use of a technique that identifies similar streams based on similarities in their watershed characteristics. Significant differences between impacted and control sites existed for surface substrate, riparian vegetation, and the number of macroinvertebrates taxa. These results revealed that (a) chemical and physical habitats at the impacted sites were disrupted, (b) the presence of trout was an inadequate measure of ecological integrity for these sites, and (c) watershed classification based on a combination of mapped terrestrial characteristics provided a reasonable method to select control sites where potential control sites upstream and downstream were unsuitable.

Hughes, R.M., T.R. Whittier, and C.M. Rohm. 1990. A regional framework for establishing recovery criteria. *Environmental Management* 14(5):673-683.

Effective assessments of aquatic ecosystem recovery require ecologically sound endpoints against which progress can be measured. Site-by-site assessments of end points and potential recovery trajectories are impractical for water resource agencies. Because of the natural variation among ecosystems, applying a single set of criteria nation-wide is not appropriate either. This article demonstrates the use of a regional framework for stratifying natural variation and for determining realistic biological criteria. A map of ecoregions, drawn from landscape characteristics, forms the framework for three statewide case studies and three separate studies at the river basin scale. Statewide studies of Arkansas, Ohio, and Oregon, USA, streams demonstrated patterns in fish assemblages corresponding to ecoregions. The river basin study in Oregon revealed a distinct change at the ecoregion boundary; those in Ohio and Montana demonstrated the value of regional reference sites for assessing recovery. Ecoregions can be used to facilitate the application of ecological theory and to set recovery criteria for various regions of states or of the country. Such a framework provides an important alternative between site- specific and national approaches for assessing recovery rates and conditions.

Hunt, R.L. 1976. A long-term evaluation of trout habitat development and its relation to improving management-related research. *Transactions of the American Fisheries Society* 105(3):361-364.

Responses of a wild brook trout (*Salvelinus fontinalis*) population to instream habitat development in a 0.7 km reach of Lawrence Creek were monitored for 7 years and compared to population data for the 3-year period prior to development. Mean annual biomass of trout, mean annual number of trout over 15 cm (legal size), and annual production increased significantly during the 3 years following development, abut more impressive response were observed during the second 3 years. Maximum number and biomass and number of legal trout did not occur until 5 years after completion of development. The peak number of brook trout over 20 cm was reached the sixth year after development. Where long-term studies of aquatic systems are needed to evaluate effects of environmental perturbations, it may be desirable to deliberately delay collection of posttreatment data. Such a start-pause-finish sequence of research would provide more valid and less costly evaluations and utilize the time of researchers more efficiently.

Hunt, R.L. 1988. *A Compendium of 45 Trout Stream Habitat Development Evaluations in Wisconsin During 1953-1985.* Wisconsin Department of Natural Resources, Madison, WI, Technical Bulletin No. 162.

A standard case history format was devised to summarize 45 trout stream habitat evaluations carried out by Wisconsin Department of Natural Resources (DNR) fishery management and research biologists on 41 streams distributed among 29 counties during 1953-85. Thirty-three of these case histories are based on unpublished documents supplied from files of fish managers. Data were gathered from 55 treatment zones (TZs) averaging 0.84 mile long and 20 reference zones (RZs) averaging 0.74 mile long. Wild trout were dominant or solely present in 59 of the 55 TZs. "Success" of each project was judged on the basis of percentage changes within TZs for each of 6 possible variables standardized to "per mile" quantities. These 6 variables were: total number of trout, number 6 inches or larger (legal size), number 10 inches or larger (quality size), total biomass, angler hours, and angler harvest. The habitat development techniques employed were grouped into six categories based on the predominant techniques. Of these 6 categories, the "Wisconsin-style" bank cover and current deflector category generally produced the best success rates regardless of the species of trout present in the 10TZs represented. Stream bank debrushing, sometimes in combination with installation of brush bundles, was very effective in a few TZs but scored low in overall success rates for all 9 TZs. More attention should be given in future evaluations to improve experimental design by including several annual observations of selected variables in paired RZs and TZs before and after habitat development in the TZs. Special emphasis is needed on more frequent inclusion of season-long creel census studies, despite their high cost, so that changes in trout carrying capacity after habitat development can be more accurately assessed.

Hunter, C.J. 1991. *Better Trout Habitat: A Guide to Stream Restoration and Management.* Montana Land Reliance, Island Press, Washington, 321 pp.

This book was written in response to an explosion of interest in habitat restoration in general, and trout-stream habitat restoration in particular. The intent was to synthesize state-of-the-art technical information and present it in such a way that it would be readable and informative for both the lay and professional reader. Chapters 1 - 6 provide the historical context and technical background necessary to understanding the theory behind trout stream restoration and management. Chapters 7 through 9 examine 14 case histories showing how theory has, and has not, been put into practice. Chapter 10 provides some concluding thoughts on stream restoration management and protection.

Inter-Fluve, Inc. 1990. *Placer Mining Reclamation Guidance Document* (Draft). U.S. Environmental Protection Agency, Region VIII, Montana Office, Helena, MT, 78 pp. + appendices.

The principal objective if this report is to facilitate informed participation in placer mine reclamation. Due to the technical nature of the information contained herein, the primary audience for this report is intended to be resource agency personnel. However, it should be accessible to a wide audience, including miners, operators, consultants, law makers, and administrators. In cases where placer mine activities involve the modification or reconstruction of stream environments, it is desirable to reclaim aquatic resources. This report outlines the steps required for fundamental channel reconstruction, focusing on techniques to preserve or create channel forms commonly associated with good aquatic habitat.

Jensen, S.E. and W.S. Platts. 1989. Restoration of degraded riverine/riparian habitat in the Great Basin and Snake River regions. P. 367-404 in: J.A. Cusler and M.E. Kentula, eds., *Wetland Creation and Restoration: The Status of the Science*. Vol. I: Regional Reviews. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR. EPA600/3-89/038A, 473 pp.

Riverine/riparian habitat (RRH) includes interdependent aquatic (riverine) and streamside (riparian) resources that are valuable for fish and wildlife habitat, flood storage and desynchronization, nutrient cycling and water quality, recreation, and heritage values. RRH includes resources both wetter and drier than stipulated for wetlands. Whereas the "natural or achievable state" of a riparian habitat may be wetland, the "existing state" may be non-wetland because of natural or anthropogenically induced changes in the hydrologic character of RRH. There are many different types of RRH, each with distinctive structure, function and values. Restoration commonly requires: (1) planning to identify preliminary goals and a general approach, (2) baseline assessments and inventories, (3) designs from which the feasibility of accomplishing goals can be assessed, (4) evaluation to assure compliance with designs, and (5) monitoring of variables important to goals and objectives. The goals, approach and design of restoration projects must be tailored to each type or RRH. Some general elements important to restoration of degraded RRH are: (1) establishment of hydrologic conditions compatible with project goals, (2) efficient handling of soil and substrates in construction, (3) selection and propagation of plants suited to the site and project goals, (4) evaluation of features to enhance habitat for target species, (5) maintenance and control of impacts, and (6) scheduling construction to reflect site constraints and goals. Perhaps the most universally applicable recommendation is "don't fight the river" but, rather, encourage it to work for you.

Kanaly, J. 1975. *Stream Improvement Evaluation in the Rock Creek Fishway, Carbon County, Wyoming*. Wyoming Game and Fish Department, Fish Division, Administrative Report, Project 5075-08-6602.

With the advent of Highway I-80 from Laramie, Wyoming to Walcott Junction, Wyoming, a 1,200-foot channel change on Rock Creek near Arlington was deemed necessary by the Wyoming Highway Department. Confronted by the virtual loss of 1,200 feet of good fish habitat which supported populations of rainbow, brook and brown trout, the Wyoming Game and Fish Department and the Wyoming Highway Department agreed to attempt restoration of this reach of stream. The cost of the restoration was included as part of highway construction expenditures for I-80. This report reviews the success of the project.

Karr, J.R. and D.R. Dudley. 1982. Ecological perspective on water quality goals. ***Environmental Management*** **5(1):55-68.**

The central assumption of nonpoint source pollution control efforts in agricultural watersheds is that traditional erosion control programs are sufficient to insure high quality water resources. We outline the inadequacies of that assumption, especially as they relate to the goal of attaining ecological integrity. The declining biotic integrity of our water resources over the past two decades is not exclusively due to water quality (physical/chemical) degradation. Improvement in many aspects of the quality of our water resources must be approached with a much broader perspective than improvement of physical/chemical conditions. Other deficiencies in nonpoint pollution control programs are discussed and a new approach to the problem is outlined. Includes broad comments on habitat structure as a primary determinant of the quality of a water resource.

Keeney, D.R. 1982. Nitrogen management for maximum efficiency and minimum pollution. Ch. 16 in: ***Nitrogen in Agricultural Soils - Agronomy Monograph No. 22*****, pp. 605-649.**

Agriculture must evolve towards conserving nonrenewable energy resources and minimizing adverse environmental impacts. Of the essential plant nutrients which can be realistically managed, N undoubtedly has the greatest potential environmental and health impact. Further, while small relative to total U.S. energy use, N fertilizer manufacturing has the largest energy requirement for any single facet of production agriculture. The objectives of this chapter are twofold: (1) to consider the impacts of N in the environment, and (2) to examine various management systems for conservation of N (and, hence, minimization of pollution) in agro-ecosystems.

Key, J.W. 1987. ***Small Instream Structure Construction for Meadow Restoration in Clark Canyon, California.*** **Proceedings of the California Watershed Management Conference, November 18- 20, 1986, West Sacramento, CA, p. 161.**

The project area in Clark Canyon Creek covers approximately four stream miles within the East Walker River subbasin, Mono County, California. This perennial stream receives most of its subsurface flow throughout Clark Canyon. Heavy algal growth has occurred in the meadow sections of the stream due to the elimination of undercut banks, widening of stream beds, and large amounts of nutrients added from livestock grazing and trailing. Naturally occurring erosion in the upper stream reaches contributes a large amount of sediment from the upper watershed to lower riparian areas. As a result, an increase of suspended sediments and turbidity has occurred in the lower stream reaches where available population of rainbow trout is found. Small instream structures have been constructed using inexpensive materials and simple techniques to (1) stabilize active erosion, (2) restore wet meadow riparian areas, (3) improve aquatic habitat, and (4) improve wildlife cover and downstream fish habitat.

Kiefling, J. 1981. *Snake River Investigations.* Federal Aid Project Completion Report F-37-R.

Habitat improvement procedures were conducted on Flat Creek, Lower Bar BC Spring Creek, Three-Channel Spring Creek, and the Gros Ventre River. Compacted gravels and a decided lack of suitable gravels in the tributaries of the Snake River had reduced the spawning potential significantly and contributed to increased numbers of superimposed redds. The mechanical rejuvenation of gravels, stocking of commercial gravels, and development of protected resting sites has been instrumental in significantly increasing the numbers of spawning cutthroat trout in all areas. The eyed egg stocking program initiated in 1972 (in combination with habitat improvement projects), has been extremely successful. The significant return of spawners has been largely attributed to the egg stocking program and points out the limited availability of gravels as being a major limiting factor in the Snake River Fishery. In addition, this program is an economical method for returning imprinted cutthroat trout to specific tributaries. The drought conditions of 1977-78 and resultant flows exhibited little difference from those flows experienced since this period due to restricted storage levels in Jackson Lake Dam. Creel census data indicate the average length of cutthroat harvested and fishing success rates have changed very little since 1975. These data did note a significant decrease in non-resident use which relates to the national economy and increased license fees. Over-exploitation of the fishery during a period of reduced flows did not materialize at this time.

Kusler, J.A. and M.E. Kentula (Eds.). 1989. *Wetland Creation and Restoration: The State of the Science, Volume I - Regional Reviews.* U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR, EPA 600/3-89/038A, 473 pp.

Not available.

Larsen, D.P., M. Omernik, R.M. Hughes, D.R. Dudley, D.M. Rohm, T.R. Whittiers, A.L. Kinney, and A.L. Gallant. 1986. The correspondence between spatial patterns in fish assemblages in Ohio streams and aquatic ecoregions. *Environmental Management* 10:815-828.

Land classification systems can be useful for assessing aquatic ecosystems if relationship among them exist. Because the character of aquatic ecosystems depends to a large extent upon the character of the landscape it drains, spatial patterns in aquatic ecosystems should correspond to patterns in the landscape. To test this hypothesis, the US state of Ohio was divided into four aquatic ecoregions based on an analysis of spatial patterns in the combination of land-surface form, land use, potential natural vegetation, and soil parent material. During the period July-October 1983, fish assemblages were examined relative to the ecoregions; distinct regional differences were identified. The assemblages differed most between the Huron/Erie Lake Plain region and the Western Allegheny Plateau region; assemblages in the Eastern Corn Belt Plains and the Erie/Ontario Lake Plain-Interior Plateau regions were intermediate. This pattern also reflects the gradient in landscape character as one moves from the northwest to the southeast of Ohio.

Lisle, T.E. 1986. Stabilization of a gravel channel by large streamside obstructions and bedrock bends, Jacoby Creek, northwestern California. ***Geological Society of America Bulletin*** **97:999-1011.**

Jacoby Creek (bed width = 12m; bankfull discharge = 32.6 m3/s) contains stationary gravel bars that have forms and positions controlled by numerous large streamside obstructions (bedrock outcrops, large woody debris, and rooted bank projections), and bedrock bends. Bank-projection width and bar volume measured in 104 channel segments 1 bed-width long are significantly cross-correlated at lags of -1, 2, and 4, indicating the tendency for large obstructions and bends to form bars 3 to 4 bed-widths downstream and 1 bed-width upstream. All of the 18 bars downstream of large obstructions or bends in the study reach were along the obstruction side of the channel or outside bank of the bend. Most of the pools (85%) were next to large obstructions or in bends; conversely, 92% of large obstructions or bends had pools. Comparison of the volume of four bars with volumetric bar changes and volume of bedload transported during four high-flow events suggests that rates of sediment transport were sufficient to cause major changes in bars during bankfull events. The only important channel changes observed in 4 yr, however, have been associated with the movement of large woody debris and with changes in the angle at which the flow approaches the obstruction. A general model is proposed that large obstructions and non- alluvial bends stabilize the form and location of gravel bars. Bars are stabilized by two related mechanisms: 1) Large obstructions and bends cause intense, quasi-steady secondary circulation in scour holes that terminate upstream bars at fixed locations. Obstruction width, channel deflection, scour-hole width, and bed width were measured at 26 obstructions. These data show that obstructions wider than approximately one-third of the bed form "pools" spanning the entire channel and, thus, terminating bars; smaller obstructions form "scour-holes" contained within a single bar, and 2) Bars are deposited upstream of large obstructions and sharp bends because of backwater reductions in stream power. Bars are deposited downstream because flow energy is expanded around obstructions and bends and because the flow expands downstream of constrictions that result from large obstructions. The formation of bars and pools inherent in many gravel channels can, thus, be enhanced and fixed in position by flow structures set up around large obstructions and bends formed of resistant materials.

Madsen, B.L. 1987. Restoration of Danish streams and insect habitats. ***Entomologiske Meddelelser*** **55(2-3):85-90.**

Change in the use of land during recent decades has resulted in a deterioration of the biological environment in most Danish streams. A good indicator is the drastic decline in well known stream insect communities. The main causes have been pollution, ochre depositions, and physical changes in stream channels and surroundings. Because of the maintenance procedures the high physical diversity inherent in streams has vanished. Recent legislation and administrative practices are reversing the past trend. Most important is the Danish Water Course Act of 1982 which is supposed to be implemented within a decade. This law states, e.g., that maintenance procedures must be planned and undertaken in such a way that the former diverse physical template can be restored. Recent reports from the local Water Authorities show evidence of improvements in the stream biota.

Marcus, M.D., M.K. Young, L.E. Noel, and B.A. Mullen. 1990. *Salmonid-Habitat Relationships in the Western United States*. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. Gen. Tech. Report RM-188, 84 pp.

This report includes a general review and analysis of the literature summarizing the available information relevant to salmonid-habitat relationships, particularly as it pertains to the central Rocky Mountains. Also included is a comprehensive indexed bibliography. Indexed subjects include: beaver, channel morphology, grazing, habitat enhancement, nutrients, organic materials, riparian, sediments, streamflow, temperature, urbanization, and water development.

Marston, R.A. 1982. The geomorphic significance of log steps in forest streams. *Annals of the Association of American Geographers* 72(1):99-108.

A functional account of log steps in forest streams is provided by field surveys of 163 kilometers of streams in the central Oregon Coast Range. Natural treefall, rather than silvicultural activities, accounts for the majority of log steps. During low-flow conditions, dissipation of potential stream energy by log steps amounts to 6 percent, approximately equal to that by falls. There are no statistically significant differences regarding spatial distribution of log steps between study basins with contrasting silvicultural and natural stream inputs of large woody debris. However, significant spatial differences are revealed between streams of various orders, a finding that points to channel flushing capacity and stream- adjacent topography as dominant controls on log step development. Application of thermodynamic principles to stream systems demonstrates that neither falls nor log steps cause a statistically significant difference in equilibrium conditions of stream networks. The volume of sediment stored behind log steps in third-, fourth-, and fifth-order streams is 123 percent of the mean annual sediment discharge (suspended load and bed-load). Depriving some streams of log steps by stream clean-out or repeated harvest of stream-adjacent trees may initiate an episode of progressive erosion by not dissipating stream energy in excess of that needed to transport imposed sediment supplies. Addition of log steps to streams with energy already insufficient to balance sediment inputs and outputs may only serve to accentuate progressive deposition. Functions of instream large woody debris not incorporated as log steps must also be addressed in forest management decisions.

Meyer, J.L. and G.E. Likens. 1979. Transport and transformation of phosphorus in a forest stream ecosystem. *Ecology* 60(6):1255-1269.

A phosphorus budget was constructed to examine P retention and processing during 1 yr. (1974-1975) in Bear Brook, an undisturbed headwater stream in the Hubbard Brook Experimental Forest, New Hampshire, USA. Year-to -year variation in the P mass balance was also estimated for a 13-yr period using an empirical model of the annual budget. In the model, fluvial inputs and exports of P were calculated using the 13-year record of streamflow and the regressions between P concentration and discharge developed from measurements made during 1974-1976. Precipitation and streamflow were average in the 1974-75 water year, and the relative importance of P input vectors during this year were: tributary streams (62%) > falling and blowing litter (23%) > subsurface water (10%) > precipitation (5%). Geologic export of P in stream water was the only export vector of consequence. Under these average hydrologic conditions, there was no annual net retention of P in the stream: annual inputs of 1.25 g P/m2 were essentially balanced by exports of 1.30 g P/m2. However, during most days of this year inputs exceeded exports: P accumulated, was processed in the ecosystem, and was exported during episodes of high stream discharge. Because of the pulsed nature of P flux, a mass balance provides an overestimate of the P entering functional pathways of a stream ecosystem. Over the 13-yr period (1963-1975), annual mass balances calculated with the model were variable; the ratio of P exports to inputs varied from 0.56 to 1/6 and was directly related to annual streamflow. Thus monthly transport patterns or annual mass balances generated from only 1 yr of record may lead to erroneous conclusions on stream ecosystem function. Although variability characterizes most aspects of P dynamics in Bear Brook, processing of P is consistent. Inputs of dissolved P (DP, < 0.45 μm-1 mm) and coarse particulate P (CPP, > 1 mm) exceeded exports, while exports of fine particulate P (FPP, 0.45 μm-1 mm) exceeded inputs. Thus there was a net conversion of other forms of P to the FPP fraction, which was the predominant form (62% of the total) exported downstream.

Moore, K.M.S. and S.V. Gregory. 1988. Response of young-of-the-year cutthroat trout to manipulation of habitat structure in a small stream. *Transactions of the American Fisheries Society* 117:162-170.

In Mack Creek, a third-order stream flowing through a 450-year-old coniferous forest in Oregon's Cascade Mountains, population size of young-of-the-year cutthroat trout (*Salmo clarki*) was positively correlated with length of stream edge and area of lateral habitat. Lateral habitats included backwaters and eddies at the margin of the channel that made up 10-15% of total stream area. Lateral habitat area was reduced at higher or lower streamflow, but the length of channel perimeter formed by lateral habitats was never less than twice the length of the reach. In an experimental manipulation of lateral habitat before the emergence of young fish from the redd, an increase in lateral habitat area of 2.4 times the area observed in the control reaches resulted in a 2.2 times greater density of age-0 cutthroat trout. Young-of-the-year fish were virtually eliminated from stream sections with reduced area of lateral habitat. Growth was not effected by the greater density of fish in reaches with enhanced lateral habitat.

Morrison, S.W. 1988. The Percival Creek corridor plan. *Journal of Soil and Water Conservation*, 43(6):465467.

Within the shadow of the Washington State Capitol dome, Percival Creek and the Black Lake Drainage Ditch flow 3.3 miles form Black Lake throughout Thurston County and the cities of Tumwater and Olympia to Capitol Lake at Percival Cove. Within this short distance, the corridor contains three distinct creek reaches. Each reach is abundant in water, wetlands, and related natural resources. These resources and amenities survive in an urban area experiencing rapid population growth and development. Because of these pressures, conflicts have arisen between upland activities and the future maintenance of the creek's natural integrity. In 1984, public controversy surrounding construction of the West Olympia Bridge indicated that current land use and shoreline regulations were inadequate to address the unique conditions within the Percival Creek corridor. The upshot of this controversy has been the development of a corridor plan that strives to achieve a balance between environmental protection and economic development.

Mullaney, R.J. and J.T. Windell. 1989. *A Proposal for Control of Non-point Source Pollution with Best Management Practices on Dry Creek, Boulder County, Colorado.* Clean Water Act Section 319 Program, Non-point Source Pollution Control, Colorado Department of Health.

The City of Boulder Department of Public Works was awarded a matching grant by the Colorado Department of Health, Water Quality Control Commission, Section 319 Program, in January 1989. The grant was based on a proposed project "A Proposal for Control of Nonpoint Source Pollution in Boulder Creek with Best Management Practices - A Demonstration Project" dated November 4, 1988. All of the grant money is to be spent on construction of six best management practices designed to reduce and control nonpoint source pollution. Specific BMP's were selected that will not only control NPS pollution, but facilitate aquatic and riparian zone habitat restoration and ecosystem function over time. Dry creek, a tributary that connects with Boulder Creek contributes significant amounts of NPS pollution to Boulder Creek. This proposal has been prepared to compliment the Boulder Creek proposal. Includes information in aquatic habitat improvement, (especially fisheries), revegetation, and some ditch repair.

Munther, G.L. 1982. *Beaver Management in Grazed Riparian Ecosystems.* In: R. Wiley (ed.) Proceedings of Rocky Mt. Stream Habitat Management Workshop, Sept. 7-10, 1982, Jackson, WY. Wyoming Game and Fish Department, Laramie, WY.

Beaver activity has substantially influenced the structure of many low gradient streams and associated valley bottoms in western Montana. These areas, with their flat valley bottoms and low gradient streams, have high wildlife, fisheries , and livestock values. Because riparian zones are in delicate equilibrium with their surroundings, the removal of beaver through the elimination of habitat or overharvest often leads to dramatic changes in the valley bottom and its stream channel. Reductions in wildlife and fisheries habitat can result. Continued livestock grazing in the absence of beaver in some valley bottom types eliminates shrubs, causes stream channel changes, and lowers water tables. Once the channel has degraded, and the water table lowered, livestock forage production is usually reduced, and vegetative type changes result in a less diverse wildlife community. The lower vegetative productivity in combination with a more active stream channel inhibit riparian recovery and necessitates substantial livestock management changes for recovery. Several riparian management practices, depending in individual site analysis, are available to increase the quality of this zone. These include using grazing systems that favor shrub production, shrub plantings, regulation of beaver harvest, beaver transplants into favorable habitat, and reduction of livestock grazing in sensitive areas following loss of beaver.

Myers, T.J. and S. Swanson. 1991. Aquatic habitat condition index, stream type, and livestock bank damage in northern Nevada. *Water Resources Bulletin* 27(4):667-677.

The quality of stream habitat varies for a variety of natural and anthropogenic reasons not identified by a condition index. However, many people use condition indices to indicate management needs or even direction. To better sort natural from livestock influences, stream types and levels of ungulate bank damage were regulated to estimates of aquatic habitat condition index and stream width parameters in a large existing stream inventory database. Pool/riffle ratio, pool structure, stream bottom materials, soil stability, and

vegetation type varied significantly with ungulate bank damage level. Soil and vegetation stability were highly cross-correlated. Riparian area width did not vary significantly with either stream type or ungulate bank damage. Variation among stream types indicates that riparian management and monitoring should be stream type and reach specific.

National Research Council (NRC). 1991. ***Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy*****. Prepublication copy, National Research Council, 11 pp.**

This report describes the status and functions of surface water ecosystems; the effectiveness of aquatic restoration efforts; the technology associated with those efforts; and the research, policy, and institutional reorganization required to begin a national strategy for aquatic ecosystem restoration.

National Research Council (NRC). 1992. ***Water Transfers in the West: Efficiency, Equity, and the Environment*****. National Academy Press, Washington, DC.**

Not Available.

Nelson, R.W., G.C. Horak, and J.E. Olson. 1978. ***Western Reservoir and Stream Habitat Improvements Handbook: Guide to the Performance of Fish and Wildlife Habitat and Population Improvement Measures Accompanying Water Resource Development*****. U.S. Department of the Interior, Fish and Wildlife Service, Biological Services Program, FWS/OBS-78/56.**

This book is a guide to the performance of habitat and population improvement measures. It is designed to be a handbook of guidance for selecting more effective measures to recommend and negotiate among administrators, biologists and engineers of fish and game and construction agencies. The guide is based primarily on measures shown to be effective in the past at a representative selection of 90 dam and reservoir projects in 19 western States. The major effort in preparing the guide was devoted to investigation into the historical success of approximately 286 individual improvement measures within 60 categories. Secondarily, the guide presents measures believed to be potentially effective by investigators involved in current research or authors of recent literature.

Nelson, W.R., J.R. Dwyer, and W.E. Greenberg. 1987. Regulated flushing in a gravel-bed river channel habitat maintenance: a Trinity River fisheries case study. ***Environmental Management*** **11(4):479-493.**

The operation of Trinity and Lewiston Dams on the Trinity River in northern California in the U.S., combined with severe watershed erosion, has jeopardized the existence of prime salmonid fisheries. Extreme streamflow depletion and stream sedimentation below Lewiston have resulted in heavy accumulation of coarse sediment on riffle gravel and filling of streambed, causing the destruction of spawning, nursery, and overwintering habitat for prized chinook salmon (*Salmo gairdnerii*) and steelhead trout (*Oncorhynchus tschawytscha*). Proposals to restore and maintain the degraded habitat include controlled one-time remedial peak flows or annual maintenance peak flows designed to flush the spawning gravel and scour the banks, deltas, and pools. The criteria for effective channel

restoration or maintenance by streambed flushing and scouring are examined here, as well as the mechanics involved. The liabilities of releasing mammoth scouring-flushing flows approximating the magnitude that preceded reservoir construction make this option inviable. The resulting damage to fish habitat established under the postproject streamflow regime, as well as damage to human settlements in the floodplain, would be unacceptable, as would the opportunity costs to hydroelectric and irrigation water users. The technical feasibility of annual maintenance flushing flows depends upon associated mechanical and structural measures, particularly instream maintenance dredging of deep pools and construction of a sediment control dam on a tributary where watershed erosion is extreme. The cost effectiveness of a sediment dam with a limited useful economic life, combined with perpetual maintenance dredging, is questionable.

Oberts, G.L. 1977. *Water Quality Effects of Potential Urban Best Management Practices: A Literature Review*. Department of Natural Resources, Madison WI, Tech. Bull. No. 97, 25 pp.

This paper presents a review of the literature regarding the water quality effects of all readily available urban management practices commonly used to alleviate or control pollution from such sources as construction, street runoff, litter, combined sewer overflows, and all predominantly urban activities that potentially add pollutants to streams. Three alternative management approaches for dealing with pollution from urban runoff are discussed: source control, collection system control, and discharge treatment.

Osborne, L.L., B. Dickson, and D. Kovacic. 1989. *Water Quality Restoration: A Perspective and Some Methods*. Paper presented at the North American Benthological Society's Technical Information Workshop on "Stream Rehabilitation and Restoration", May 18, 1989, Guelph, Ontario, Canada.

The purpose of this paper is to provide an individualistic, and hopefully realistic, perspective on water quality restoration, address fundamental issues involved with any restoration effort, provide a general overview of available water quality restoration strategies, and discuss some limited methods available for streams degraded by diffuse source impacts.

Packer, P.E. 1957. Management of forest watersheds and improvement of fish habitat. *Transactions of the American Fisheries Society* 87:392-397.

Management of forest watersheds in the western United States for protection against floods and sediment and to improve water yields can also be very beneficial in fishery management. Some of the important hydrologic processes that operate on watersheds are discussed. The principal kinds of watershed protection and water yield improvement problems are outlined and discussed in relation to maintenance of desirable fish habitat. Need for research to determine quantitative hydrologic relationships on watersheds and develop methods of forest management for better regulated and higher quality stream flow is emphasized.

Pennington, C.H., S.S. Knight, and M.P. Farrell. 1985. Response of fishes to revetment placement. *Arkansas Academy of Science Proceedings* 39:95-97.

Routine fish sampling with hoop nets was conducted monthly from April through December 1978 along natural and revetted riverbanks of the lower Mississippi River near Eudora, Arkansas, to monitor changes in fish populations affected by placement of new revetment for bank protection. Eighteen species of fish were collected with four species comprising over 75%of the total catch. During the months prior to revetment placement, freshwater drum, (*Aplodinotus grunniens*), was the most abundant (32.7% of the catch) species collected. Following in abundance were the flathead catfish (*Pylodictis olivaris* - 9.8%), common carp (*Cyprinus carpio* - 7.8%), and blue catfish, (*Ictalurus furcatus* - 3.3%). After revetment placement in August 1978, the freshwater drum was again the most abundant component, comprising 9.7% of the catch. Gizzard shad (*Dorosoma cepedianum*), flathead catfish, and blue catfish followed in abundance and comprised 8.9, 4.1, and 3.4% of the total catch, respectively. Catch per effort data indicated that fish were generally more abundant at natural bank stations than revetted bank stations but the difference was not significant. The study suggests that fish inhabiting natural riverbank habitat recover quite rapidly from bank perturbation caused by the placement of revetment.

Phillips, J.D. 1989. Nonpoint source pollution control effectiveness of riparian forests along a coastal plain river. *Journal of Hydrology* 110:221-237.

A detention-time model of water quality buffer zones is used to evaluate the nonpoint source pollution control effectiveness of riparian forests in a two-county area of the lower Tar River basin, North Carolina. Soil map units, which represent specific combinations of soil, topography, and vegetation characteristics, are compared in terms of their relative ability to filter nitrate in agricultural runoff. All typical riparian forests provide significant water quality protection, but there is a wide variation in buffer effectiveness. This suggests a need for flexibility in determining buffer widths. A range of 15-80 m is appropriate for the soil- landform-vegetation complexes found in riparian zones within the study area. Buffer widths of 60 m - and after much less - are generally adequate on the soils likely to be used for agricultural production.

Platts, W.S. and J.N. Rinne. 1982. *Riparian-Stream Protection and Enhancement Research in the Rocky Mountains*. In: R. Wiley (ed.) Proc. of Rocky Mt. Stream Habitat Management Workshop, Sept. 7-10, 1982, Jackson, WY. Wyoming Game and Fish Department, Laramie, WY.

Artificial change of watershed condition whether by logging, road construction, livestock grazing, or mining can effectively override climatic and geologic controls and maintain a stream in an artificial state. Such an artificial unstable state will persist until natural stabilizing forces can override the disturbing factory. Presently, many streams in the Rocky Mountains are functioning in a recently-imposed, artificial state which fishes have difficulty adapting their life requirements to. In addition, some natural streams, because of innate geologic and climatic control, do not offer the necessary environmental conditions that provide suitable habitat for certain specie of fish, especially salmonids. These two stream conditions (artificial stressed and naturally having an innately low habitat quality) are the situations that fishery biologists must address when attempting stream enhancement

projects to improve fish habitat. As biologists plan and construct these enhancement projects they will find that research in the Rocky Mountains concerning stream and riparian enhancement is very limited. This report attempts to summarize what is available under one cover and make recommendations for further research direction in this area. Contains some reference to the influence of restoration on chemical factors (see p. 16).

Platts, W.S. and J.N. Rinne. 1985. Riparian and stream enhancement management and research in the Rocky Mountains. *North American Journal of Fisheries Management* 5:115-125.

This report reviews past stream enhancement research int he Rocky Mountains, its adequacy, and research that should be done to improve the effectiveness of future stream enhancement projects. Research is lacking on stream improvement in a watershed context on a long-term basis. Not all streams can be enhanced. Enhancement should be attempted only after techniques described in the literature have been carefully considered and judged to be appropriate for the selected site. Contains some mention of improvement to the water column (physical dimensions and physiochemical factors such as dissolved oxygen, temperature and pH) by grazing restriction, channelization techniques and stream improvement structures, natural enhancement, and control of agricultural runoff from adjacent lands. Mentions that brush and tree cover lowers stream temperatures, and techniques that attempt to improve the water column.

Richards, C., P.J. Cernera, M.P. Ramey, and D.W. Reiser. 1992. *Development of Off-channel Habitat for use by Juvenile Chinook Salmon.* Manuscript in publication.

Fisheries habitat improvement frequently requires the exploitation of existing or man-made features of stream channels and associated floodplains. In the Yankee fork of the Salmon River, a series of off-channel dredge ponds were connected to the river by excavating connecting channels and construction of surface-water control structures. This habitat was created to increase available rearing habitat for juvenile chinook salmon. The dredge ponds had been left as a result of past mining activities. Highest fish densities in the newly constructed pond series were in connecting channel habitats. These densities are higher than those reported in other streams and may be related to the hatchery origin of the stocked fish. Densities observed in the ponds were similar to those reported in natural habitats. Addition of habitat through incorporation of dredge ponds increases management options for rebuilding chinook populations in the stream.

Roseboom, D., R. Twait, and D. Sallee. 1989. *Habitat Restoration for Fish and Wildlife in Backwater Lakes of the Illinois River.* Proceedings of the Second Conference on the Management of the Illinois River System: The 1990's and Beyond, Peoria, IL, Oct. 3-4, 1989, pp. 65-68.

The Lake Peoria Habitat Restoration project was sponsored by the Illinois Department of Conservation with Sport Fish Restoration funds to create fish habitat. The Illinois River and Lake Peoria were the greatest fishing and hunting areas in Illinois. Excessive rates of sedimentation are destroying Lake Peoria and all backwater lakes of the Illinois River. Concurrently with increased sedimentation, much of the aquatic vegetation disappeared between 1950 and 1965. High rates of sedimentation buried aquatic vegetation beneath thick layers of fluid sediments. Wave action prevents natural revegetation by uprooting young plants from the fluid sediments. When the aquatic vegetation died off, populations of waterfowl and gamefish declined quickly. The Lake Peoria Restoration project has developed low cost techniques to restore aquatic vegetation. When placed behind a tire breakwater, arrowhead and pondweed plantings have been successful in 1987, 1988, and 1989. Both the breakwater and plant beds have survived two winters after the initial plantings. The breakwater also serves as an artificial reef. Gamefish response has been quick and dramatic. The number of fish species has doubled and the numbers of fish have quadrupled. The vegetated area serves as a nursery for young bluegill, channel catfish, and bass. In 1989, large bluegill were found on the vegetated site only. In fact, the number and total weight of bluegill and channel catfish in the vegetated area exceeded the number and weight of all fish (mainly carp) in the control area.

Rost, R.A., J.C. Brand, R.M. Bruch, D.H. Crehore, S.I. Dodson, R.L. Fassbender, L.J. Herman, T.F. Rasman, and A.M. Stranz. 1989. *Water Quality and Restoration of the Lower Oconto River, Oconto County, Wisconsin.* Wisconsin Department of Natural Resources, Madison, WI, Technical Bulletin No. 164, 37 pp.

The purpose of the Oconto River Restoration Project (1979-83) was to develop and implement a plan to restore the water quality, aquatic environment, and fish habitat of the lower Oconto River in Oconto County, Wisconsin. This river segment had been severely degraded for over 70 years by pulp mill effluent. Because of noncompliance with federal and state water quality standards, the mill was closed in 1978. The owner paid a court-ordered settlement, part of which was allocated to the Wisconsin Department of Natural Resources for development of a remedial plan. The principal elements of the plan were: 1) an extended drawdown of the Machickanee Flowage to change the physical consistency of the accumulated sediment; 2) chemical treatment of fish populations in the Machickanee Flowage to eradicate rough fish; 3) fish stocking to establish game fish and panfish following chemical treatment; 4) access development; 5) establishment of contingency funds for habitat improvement and additional fish stocking if necessary; 6) continuous monitoring for a three-year period to determine the effectiveness of the management techniques applied; and 7) an intensive public relations program conducted throughout the project. Because of the drawdown the character of the sediment changed such that both numbers and species of aquatic plants and aquatic macroinvertebrates greatly increased. The amount of substrate for fish spawning also increased. A creel census and other surveys conducted after the management plan was implemented indicated that the aquatic ecosystem was more favorably balanced.

Rowe, M., S. Spaulding, J.M. Gunderman, and K. Bacon. 1989. *Salmon River Habitat Enhancement - Annual Report.* Shoshone-Bannock Tribes Annual Report, Bonneville Power Administration, Portland, OR, Project No. 83-359.

Fine sediments from an inactive dredge mine in the headwaters of Bear Valley Creek (BVC) contributed to degradation of spawning and rearing habitat of chinook salmon and steelhead trout in a 55 km section of stream. Major construction efforts targeted at decreasing recruitment of fine sediments in the mined area were completed in the fall of 1988. In 1989 a completed revegetation program has finalized enhancement efforts in the mined area. Biological monitoring evaluation of project efficacy continued throughout the length of Bear Valley Creek during the summer of 1989. Physical habitat features were monitored only in the mined area and the strata directly below this area in 1989. Baseline floodplain cover measurements were also initiated this year. In June, densities of Age 0+ chinook salmon were highly variable according to location and time of year. Age 0+ chinook salmon densities were highest in the mid-portion of BVC at 25 fish/100m2pool compared to upper BVC where densities ranged from 0.8 - 8.0 fish/100m2pool. By late August, however, we documented high chinook salmon densities in upper BVC of 77 to 118 fish/100m2pool compared to less than 1 fish/100m2pool in lower BVC. It was found that sloughs play an important role in early season chinook salmon rearing in upper BVC where high flow conditions likely preclude most fish from channel habitat. In early July, chinook salmon densities of 134 and 59 fish/100m2 were estimated in slough areas of the two upper BVC strata. By August, chinook densities in these sloughs were less than July densities, as well as late season stream densities. Most fish move out of the sloughs by August and this movement may be partially responsible for the high number of chinook observed in upper BVC by late August. Various physical parameters have responded favorably to the project. The percentage of fine sediments in the mined area has decreased from a high of 34.4% in 1987 to a low of 23.5% in 1989; this difference, however, was not significant. The stream area directly below the mined section has undergone a similar decrease in fine sediments, from 50.1% in 1987 to 37.9% in 1989. Amount of riparian cover has continually increased since 1984 in the mined area with 1989 measures significantly greater. The mean percentage of vegetative cover ranged from 8.4% in lower floodplain of the mined area (seeded in 1988) to 34.6% in the upper floodplain region (seeded in 1986). The present cover in the 1986 plot was significantly ($P<0.05$) greater than cover in the 1988 plot. The grasses (*Pla pratensis*, Agropyron spp. and *Phleum pretensis*) were the primary cover constituents in the three plots. Annual reports from 1987 and 1988 are also available, but this is the most recent on this project as they are approximately 3 years behind in publication.

Sedell, J.R. and J.L. Froggatt. 1984. Importance of streamside forests to large rivers: the isolation of the Willamette River, Oregon, U.S.A., from its floodplain by snagging and streamside forest removal. *Verh. Internat. Verein. Limnol.* 22:1828-1834.

The river continuum concept (Vannote et al. 1980) stressed the point that the influence of the terrestrial system on a stream diminishes as the stream gets larger. The role of floodplains in the river continuum concept was limited to decomposition of particulate organic material during periods of low water and the subsequent return of organic materials by flood waters and surface runoff. The river continuum concept emphasizes some functions of streamside forest in inferring a downstream decrease in influence, but does not give attention to other functions related to overbank flow that increase in importance downstream as outlined by Welcomme (1979). The influence of the floodplains has been reduced by local activities such as snagging the mainstem, diking and improved drainage of floodplains for agriculture or urbanization, and the reduction of the extent of flooding because of upstream activities such as flood control dams. These alterations within the stream and on the floodplain have modified the relationship between mainstem and floodplain by changing the composition and structure of the floodplain vegetation and changing the sources and sinks for organic matter along large rivers. The combined effects isolate a river system from the influence its floodplain has on the structure and nutrient capital of

the aquatic ecosystem. This report describes the pristine and present streamside forest, channel geomorphology, and role of downed trees in the Willamette River, Oregon, U.S.A. From this case history, a modification of the river continuum concept is presented.

Seehorn, M.E. 1982. *Trout Stream Improvements Commonly Used on Southeastern National Forests*. In: R. Wiley (ed.) Proc. of Rocky Mt. Stream Habitat Management Workshop, Sept. 7-10, 1982, Jackson, WY. Wyoming Game and Fish Department, Laramie, WY.

"Structural" improvement in itself is a broad term encompassing habitat needs such as fish passageways, fish barriers, fencing, spawning structures, and cover devices. With only limited anadromous fisheries on southeastern forests, emphasis is for the most part, oriented towards instream cover needs, and construction of fish barriers to preclude upstream migration of undesirable fish species. The following accounts describe structures most commonly used on Southeastern National Forests. Cost estimates, given in crew days, are based on a 4- to 6-man crew working in relatively accessible areas, using hand tools and cutting logs on site.

Seehorn, M.E. 1985. *Fish Habitat Improvement Handbook*. U.S. Department of Agriculture, Forest Service, Southern Region, Technical Publication R8-TP 7.

This handbook provides fishery managers with structural designs that may be used to correct stream fish habitat deficiencies over a broad range of existing conditions. With the exception of the fish barrier, the primary objective of the designs is to improve instream conditions by creating deeper water and overhead cover. The designs in this handbook are for structures that can be installed using hand labor with little or no heavy equipment.

Shields, F.D., Jr. 1982. Environmental features for flood control channels. *Water Resources Bulletin* 18(5):779-784.

The environmental effects of flood control channel modifications such as clearing and snagging, straightening, enlargement, and/or paving can be quite severe in some cases. Information review reveals that several environmental features have been incorporated into the design, construction, operation, or maintenance of recent flood control channel projects to avoid adverse environmental impacts and enhance environmental quality. Typically, these features have been proposed by conservation agencies and designed with minimal quantitative analysis. Environmental features for channel projects include selective clearing and snagging techniques, channel designs with nonuniform geometry such as single bank modification and floodways, restoration and enhancement of aquatic habitat, improved techniques for placement of excavated material, and revegetation.

Simpson, P., J.R. Newman, M.A. Keirn, R.M. Matter, and P.A. Guthrie. 1982. *Manual of Stream Channelization Impacts on Fish and Wildlife*. U.S. Department of the Interior, Fish and Wildlife Service. FWS/OBS-82/24, 155 pp.

To control flooding and flood damage, increase available land for agriculture, improve navigability, and maintain hydraulic efficiency of streams, many channelization or stream

modification activities have been performed in the last several years. Channelization activities associated with small streams include clearing and snagging, riprapping, widening, deepening, realignment, and lining. This manual describes the impacts of these activities on the physical, chemical, and biological environments of streams. Associated impacts are identified based on existing literature. Relevant literature was used to assess probable impacts where studies had not been performed. Historic and current legislation governing channelization activities is also addressed. A step-by-step procedure to assess channelization projects is recommended.

Skinner, Q.D., J.L. Dodd, J.D. Rodgers, and M.A. Smith. 1985. *Antidesertification of Riparian Zones and Control of Nonpoint Source Pollution.* Perspectives on Nonpoint Source Pollution: Proceedings of a Conference, Kansas City, MO, May 19-22, 1985, pp. 382-386.

Overgrazing by domestic livestock and periodic flooding are often cited as sources for increasing nonpoint source pollution in streams within semi-arid rangelands. Riparian zones along streams may help decrease nonpoint pollution if maintained in a healthy ecological condition. This paper will address two research programs designed to reverse desertification of streamside zones along cold desert streams in Wyoming by: (1) manipulating livestock grazing; (2) promoting regrowth of desirable vegetation; (3) willow planting; (4) using instream flow structures to store water in channel banks and trap sediment; and (5) encouraging beaver damming. Research theory as well as monitoring protocol will be discussed and related to ease of use by management agencies and producer groups affiliated with western rangelands.

Sparks, R.E., P.B. Bayley, S.L. Kohler, and L.L. Osborne. 1990. Disturbance and recovery of large floodplain rivers. *Environmental Management* 14(5):699-709.

Disturbance in a river-floodplain system is defined as an unpredictable event that disrupts structure or function at the ecosystem, community, or population level. Disturbance can result in species replacements or losses, or shifts of ecosystems from one persistent condition to another. A disturbance can be a discrete event or a graded change in a controlling factor that eventually exceeds a critical threshold. The annual flood is the major driving variable that facilitates lateral exchanges of nutrients, organic matter, and organisms. The annual flood is not normally considered a disturbance unless its timing or magnitude is "atypical". As an example, the record flood of 1973 had little effect on the biota at a long-term study site on the mississippi river. In contrast, the Illinois river has been degraded by a gradual increase in sediment input and sediment resuspension that changed a formerly productive 320-km reach of the river from clear, vegetated areas to turbid, barren basins. Traditional approaches to experimental design are poorly suited for detecting control mechanisms and for determining the critical thresholds in large river-floodplains. Large river-floodplain systems cannot be manipulated or sampled as easily as small streams, and greater use should be made of man-made or natural disturbances and environmental restoration as opportunistic experiments to measure thresholds and monitor the recovery process.

Stern, D.H. and M.S. Stern. 1980a. *Effects of Bank Stabilization on the Physical and Chemical Characteristics of Streams and Small Rivers: A Synthesis*. Eastern Energy & Land Use Team, Office of Biological Services, Fish and Wildlife Service, USDOI, Kearneysville, WV.

This report is a synthesis of available literature relating the effects of bank stabilization to the physical and chemical characteristics of streams. A companion document contains the references to the literature which formed the basis for the synthesis. The synthesis provides guidelines for planning bank protection and stabilization activities. Contains information on temperature, suspended solids, bed materials, and dissolved substances among other subjects.

Stern, D.H. and M.S. Stern. 1980b. *Effects of Bank Stabilization on the Physical and Chemical Characteristics of Streams and Small Rivers: An Annotated Bibliography*. Eastern Energy & Land Use Team, Office of Biological Services, Fish and Wildlife Service, USDOI, Kearneysville, WV.

Companion document to ER73. This annotated bibliography provides a source of information on the impacts of bank stabilization on the physical and chemical characteristics of streams and small rivers. The bibliography has 213 references, and is indexed by 26 key subject headings. Papers range from technical documents to general discussions addressing the physical and chemical changes that result from various type of bank stabilization activities. Many of the annotations provide a thorough summary of pertinent information contained in the respective references.

Stockner, J.G. and K.R.S. Shortreed. 1978. Enhancement of autotrophic production by nutrient addition in a coastal rainforest stream on Vancouver Island. *J. Fish. Res. Board Can.* 35:28-34.

In 1976 streamside nutrient-enrichment experiments were conducted using wooden troughs. Triling of the PO4- concentration, with or without a similar increase of NO3-, increased algal biomass on the troughs by 8 times after 35 days. Increasing NO3- alone had no appreciable effect on algal growth. A sloughing of algal biomass in August 1976 is believed to have been due to the instability of the heavy algal mat on the troughs and to the very poor light conditions that prevailed throughout August. Visual observation indicated that the relatively heavy algal population in Carnation Creek rapidly declined concurrent with the decline in the troughs, and *Frangilaria vaucheriae* replaced *Achnmanthes minutissima* as dominant on the phosphorus enriched trough. No shift to green or blue-green algal dominated assemblages occurred despite alteration of the N:P ratio. The dynamics of species succession, distribution, and growth, with and without nutrient addition, are discussed.

Thomas, R.B. 1990. Problems in determining the return of a watershed to pretreatment conditions: techniques applied to a study at Caspar Creek, California. *Water Resources Research* 26(9):2079-2087.

Using a previously treated basin as a control in subsequent paired watershed studies requires the control to be stable. Basin stability can be assessed in many ways, some of

which are investigated for the South Fork of Caspar Creek in northern California. This basin is recovering from logging and road building in the early 1970s. Three storm-based discharge characteristics (peak discharge, quick flow, and total storm flow), daily flows, and concentration of suspended sediment were studied to see of the South Fork can be used as a control in a second experiment. Mean sediment concentration in three discharge classes and regression parameters for the other data were tested to estimate remaining treatment effects relative to the North Fork. Patterns of change were similar for most data, with rises in response followed by returns toward pretreatment conditions. The storm and sediment data showed few significant differences, but tests on daily flows indicated that differences still exist. The overall evidence suggests that the South Fork has returned to near pretreatment conditions. Better sediment data are needed for studies of the effects of land management.

Thurston, R.M., G.R. Phillips, R.C. Russo, and S.M. Hinkins. 1981. Increased toxicity of ammonia to rainbow trout (*Salmo gairdneri*) resulting from reduced concentrations of dissolved oxygen. *Can. J. Fish. Aquat. Sci.* 38:983-988.

The medial lethal concentration (LC50) of aqueous ammonia at reduced dissolved oxygen (D.O.) concentrations was tested in acute toxicity tests with rainbow trout (*Salmo gairdneri*) fingerlings. Fifteen 96-h flow- through tests were conducted over the D.O. range 2.6 - 8.6 mg/L, the former concentration being the lowest at which control fish survived. There was a positive linear correlation between LC50 (milligrams per liter un-ionized ammonia) and D.O. over the entire D.O. range tested; ammonia toxicity increased as D.O. decreased. Ammonia LC50 values were also computed for 12, 24, 48, and 72 h; the correlation with D.O. was greater the shorter the time period.

U.S. Department of Interior, National Park Service. 1991. *A Casebook in Managing Rivers for Multiple Uses*. U.S. Department of Interior, National Park Service, Washington, DC.

This report presents eight case studies that illustrate innovative and successful strategies for multi-objective river corridor planning and management. Rivers from throughout the country were chosen to represent a variety of physiographic an climatic zones and include both urban and rural communities. Case studies include Charles River, South Platte River, Chattahoochee River, Kickapoo River, Boulder Creek, Kissimmee River, Wildcat & San Pable Creeks, and Mingo Creek. Also includes contact list and bibliography.

U.S. Department of the Interior, Bureau of Land Management. 1991. *Riparian-Wetland Initiative for the 1990's*. U.S. Department of the Interior, Bureau of Land Management, Washington, DC. BLM/WO/GI-91/001+4340, 50 pp.

This Riparian-Wetland Initiative for the 1990's provides a blueprint for management and restoration or riparian-wetland areas encompassing 23.7 million acres of BLM lands. This overall national strategy complements other plans such as Waterfowl Habitat Management on Public Lands, A Strategy for the Future; Fish and Wildlife 2000; Range of Our Vision; and Recreation 2000 in an interdisciplinary, multi-program, cooperative effort. Nationwide riparian-wetland goals have been established along with broad- based implementation strategies to achieve these goals. This Initiative does not establish specific objectives or priorities for actions. Most actions will be taken at the field level. Each state, through their individual strategic plans, establishes specific objectives and priorities to implement this Initiative consistent with laws, regulations, policy, and funding.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1986. *Development and Evaluation of Habitat Suitability Criteria for Use in the Instream Flow Incremental Methodology: Instream Flow* Information Paper No. 21. U.S. Department of the Interior, Fish and Wildlife Service, Fort Collins, CO, Biological Report (86)7.

Accurate and comprehensive suitability criteria are critical to the effective use of the Instream Flow Incremental Methodology. Five major topic areas relating to the development and evaluation of microhabitat suitability criteria are discussed in this paper: (1) study and planning design, (2) development of criteria by professional judgement and consensus, (3) field methods for fitting data to curves or mathematical functions, and (5) methods for evaluating criteria accuracy and transferability. The discussion of each technique includes a brief summary of the advantages, limitations, and potential sources of error and bias. The paper also provides a foundation for the development of regionalized microhabitat suitability criteria by a strategy of complementary study planning and mathematical convergence.

U.S. Environmental Protection Agency. 1988. *The Lake and Reservoir Restoration Guidance Manual.* U.S. Environmental Protection Agency, Criteria and Standards Division, Nonpoint Source Branch, Washington, DC, EPA 440/5-88-002.

The Lake and Reservoir Restoration Guidance Manual represents a landmark in this nation's commitment to water quality, as it brings to the lake user practical knowledge for restoring and protecting lakes and reservoirs. More than an explanation of restoration techniques, this Manual is a guide to wise management of lakes and reservoirs. The purpose of this manual is to provide guidance to the lake manager, lake homeowner, lake association and other informed laypersons on lake and reservoir management, restoration and protection.

Van Haveren, B.P. and W.L. Jackson. 1986. *Concepts in Stream Riparian Rehabilitation.* Transactions of the 51st North American Wildlife and Natural Resources Conference, March 21-26, 1986, Reno, NV, pp. 280-289.

The purpose of this paper is to discuss interrelationships between riparian systems and the hydrologic and geomorphic processes operating in the associated stream channels. We show how the proper hydrologic function of the floodplain, stream-dependent water table, and stream channel erosion an deposition processes are all necessary for a healthy riparian ecosystem. These factors and interrelationships are brought to bear in a discussion of rehabilitation principles and approaches for use on degraded riparian areas. Proper identification of the causes of degradation and stage of channel evolution is required before developing a rehabilitation plan. We stress that stream riparian systems undergoing major geomorphic or hydrologic adjustments should not be treated with habitat improvements until the channel has reached a new dynamic equilibrium. We consider the stream riparian zone to be the entire active channel area, including that portion of the floodplain that supports a riparian vegetation community.

Wesche, T.A. 1974. ***Habitat Evaluation and Subsequent Rehabilitation Recommendations for the Laramie River Channel Change Area in Laramie, Wyoming.*** **Water Resources Research Institute, Laramie, WY, 35 pp.**

The relocation of the U.S. Highway 130-230 bridge across the Laramie River in Laramie, Wyoming will require the channelization of 1,330 feet of the present channel by the Wyoming Highway Department. The objectives of this report were to describe the habitat which presently exists in the river reach to be affected, define the adverse impacts to this habitat which will be realized by the channelization project, and recommend suitable habitat improvement measures for the new channel.

Wesche, T.A. 1985. Stream channel modifications and reclamation structures to enhance fish habitat. Pp. 103-163 in: J.A. Gore, ed., ***The Restoration of Rivers and Streams.*** **Theories and Experience. Butterworth, Stoneham, MA. 280 pp.**

The process of channel modification has played a major, although not always beneficial, role in the development of this country. Dredging, land drainage, channel realignment and redesign and overgrazing of riparian areas have all had an effect on our streams and rivers. In 1972 it was estimated that over 200,000 miles of stream channel had been modified in the United States. Given the sheer magnitude of such river manipulations and an increasing awareness by the public of the environmental ramifications of such acts, it is little wonder that engineers and biologists find themselves continually debating the pros and cons of channel modification. In recent years the concept of river restoration has become widespread. The underlying tenet of the river restoration approach is that by thorough planning done before modification activity begins, a design simulating that of nature as closely as possible can be developed that not only alleviates the problem causing the needed modification, but also preserve many of the other valued reach characteristics. After a brief review of the basic in-stream components of fish habitat (for brevity, this will focus on the salmonid family), the impacts of various channel modification activities on habitat diversity will be discussed. The concluding section of the chapter will then concentrate on channel restoration procedures and structures to enhance fish habitat, from a planning aspect as well as from a design and installation approach.

Wesche, T.A. and D.W. Reiser. 1976. ***A Literature Summary on Flow-related Trout Habitat Components.*** **Paper presented at Forest Service - Region 5, Earth Science Symposium, Fresno, CA, November 8-12, 1976.**

Four fundamental components of salmonid habitat include; water quality, food-producing areas, spawning-egg incubation areas, and cover. To provide a suitable habitat for salmonid population, no matter how large or how small the stream, a proper range of flows is required through the channel configuration which the stream itself has formed. Each habitat constituent directly influences the type and quality of salmonid fisheries that are able to exist under a given set of conditions. A careful look at each of the components will lead to a better understanding of its importance in comprising salmonid habitat. Contains information on water temperature, dissolved oxygen, pH, and total suspended solids.

Whittier, T.R., D.P. Larsen, R.M. Hughes, C.M. Rohm, A.L. Gallant, and J.M. Omernik. 1988. *Project Summary - The Ohio Stream Regionalization: A Compendium of Results.* U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR, EPA/600/S3-87/025.

Regional patterns in terrestrial characteristics can be used as a framework to monitor, assess and report the health of aquatic ecosystems. In ohio, five ecological regions were delineated using spatial patterns in land- surface form, land use, soil and potential natural vegetation. We evaluated this framework by studying the water quality, physical habitat, and fish and macroinvertebrate assemblages of 109 minimally impacted representative streams. Water quality and fish assemblages showed clear regional differences. The highest quality water and fish assemblages were consistently found in the southeast ecoregion, and the lowest quality in the northwest ecoregion. We found no clear regional patterns in macroinvertebrate assemblages and limited regional patterns in physical habitat.

Wiley, M.J., L.L. Osborne, and R.W. Larimore. 1990. Longitudinal structure of an agricultural prairie river system and its relationship to current stream ecosystem theory. *Canadian Journal of Fisheries and Aquatic Sciences* 47:373-384.

The largescale structure of an agriculturally developed prairie river system in central Illinois was examined and compared with predictions from current stream ecosystem theory. High rates of primary productivity were characteristic of the watershed, although longitudinal patterns in riparian vegetation, stream temperature, and primary productivity were inverted relative to typical streams in forested uplands. Empirical models of gross primary production and community respiration were developed. Light availability, mediated by both channel shading and turbidity, appeared to be the principal factor limiting primary productivity. Both nitrate and orthophosphorus were found in high concentrations throughout the watershed. Largescale patterns in nutrient availability suggest that landuse patterns, and particularly urbanization, strongly affected spatial and temporal distributions of both nutrients. Differences between prairie river systems and "prototype" structures envisioned by the River Continuum Concept (RCC) derive from the descriptive nature of the RCC, and its inability to incorporate nonstandard distributions of key driving variables. The use of empirical modelling in stream ecosystem studies is discussed.

Wiley, R. (ed.). 1982. *Proceedings: Rocky Mountain Stream Habitat Management Workshop*, September 7-10, 1982, Jackson, Wyoming. Wyoming Game and Fish Department, Laramie, WY.

Enthusiasm for habitat management has increased in the last 50 years and continues to occupy the minds of fishery biologists throughout North America and internationally as well. This meeting is the third in the series and this proceeding represents contemporary reports provided by the participants. Please use the contents of the proceedings as appropriate. Apply and modify the ideas and techniques to fit your needs and advance the state of the art. Included are various case studies which contain techniques, costs, and historical records.

Wilkin, D.C. and S.J. Hebel. 1982. Erosion, redeposition, and delivery of sediment to midwestern streams. *Water Resources Research* 18(4):1278-1282.

While sediment in surface waters may be one of our more serious water quality problems, the sources of this sediment are not well defined. Sediment control programs for water quality are presently concentrating on the application of best management practices (BMPs) across the watershed with little regard to location. The authors have studied sediment movement patterns in a midwestern watershed using fallout cesium-137 techniques and have concluded these programs may be largely ineffective. The implications from this work are that cropped floodplains are the most severely eroded lands in the watershed, followed by cropped lands bordering the floodplains. Most of the eroded sediment either originates on or is delivered directly to the active floodplain and hence to the stream. The authors conclude that the majority of cropped uplands may bet be nearly as important in determining sediment levels in streams as generally thought.

Wilzbach, M.A., K.W. Cummins, and J.D. Hall. 1986. Influence of habitat manipulation on interactions between cutthroat trout and invertebrate drift. *Ecology* 67(4):898-911.

The objectives of this study were to examine the interactions of the riparian setting (logged vs. forested) and prey availability on the prey capture efficiency and growth of cutthroat trout, and to determine of the riparian setting influences the impact of trout predation on drift composition. Short-term relative growth rates of cutthroat trout, experimentally confined in stream pools, were greater in a logged than in a forested section of stream. Differences in growth rates were attributed to differences among pools in invertebrate drift density, and to differences in trout foraging efficiency that were related to differences between sections in the amount of overhead shading and substrate crevices. Mean percentages of introduced prey captured by trout were greater in logged control pools and pools of both sections whose bottoms were covered with fiberglass screening to eliminate substrate crevices than in forested control pools and logged pools that were artificially shaded. A logarithmic relationship was found between trout foraging efficiency and surface light of pools. Drift density significantly increased relative to controls in pools from which trout were removed in the logged reach, but not in the forested section. This may result from habitat features in the logged section that favor greater trout foraging success and the occurrence of behaviorally drifting prey taxa, which represent a predictable food supply for the trout.

Windell, J.T., L.P. Rink, and C. Rudkin. 1991. Compatibility of stream habitat reclamation with point source and nonpoint source controls. *Water Environment and Technology*, Jan. 1991.

A series of studies done under contract with the city of Boulder (Colo.) Public Works was completed recently. The studies concluded that implementation of state-approved stream-management practices downstream of the city's wastewater treatment plant (WWTP) could potentially eliminate the need for future denitrification towers, resulting in long-term cost savings for WWTP capital construction, operation, and maintenance. Stream management practices included: fencing to exclude cattle from riparian habitat; restoration of streambank stability using log revetments; planting 9000 willow and cottonwood cuttings to regenerate riparian habitat; removing streambank berms so vegetation would be closer to the water table and could grow; excavation of 0.5 miles of thalweg (low flow channel) to concentrate and deepen water flow and reduce the amount of photosynthesizing aquatic vegetation; and creating three boulder aeration structures to increase instream oxygen and carbon dioxide concentrations. Project costs are also mentioned.

Windell, J.T., L.P. Rink, and C.F. Knud-Hansen. 1987a. ***A One Year, Biweekly, 24-Hour Sampling Study of Boulder Creek and Coal Creek Water Quality.*** **Aquatic and Wetland Consultants, Inc., Boulder, CO, 63 pp. + appendices.**

The City of Boulder is in the process of a $12-14 million dollar upgrade and expansion of the 75th Street Wastewater Treatment Plant in order to meed NPDES permit requirements. Expansion and upgrading includes installation of one nitrification tower for ammonia removal costing $1.3 million dollars with three additional towers possibly required during the next twenty years. Present studies funded by the City concluded that Boulder creek segments 9 and 10 were impaired by non-water quality factors that preclude attainment of the designated Class 1 Warm Water Aquatic Life use regardless of improvements in water quality. It was suggested that future Class 1 Warm Water Aquatic Life use could not be attained without implementation of aquatic and riparian zone best management practices and improvements to the stream ecosystem. Physical and biological impairments could be mitigated by aquatic and riparian zone restoration to achieve the designated use, and could result in significant financial savings for the City by potentially eliminating the need for additional nitrification towers. Restoration would have the effect of reducing daily temperature and pH excursions and thus reduce average un-ionized ammonia levels in Boulder Creek downstream of the WWTP. The purpose of this study was to collect diurnal water quality data each hour on a bi-weekly basis for one year (providing 26 data sets) on Boulder Creek and Coal Creek. This information was used to analyze those factors influencing ammonia dynamics, understand more fully ammonia dynamics specific to Boulder Creek, and to estimate the effects of Coal Creek on Boulder Creek.

Windell, J.T., L.P. Rink, and C.F. Knud-Hansen. 1988. ***A 24-Hour Synoptic Water Quality Study of Boulder Creek Between the 75th Street Wastewater Treatment Plant and Coal Creek.*** **Aquatic and Wetland Consultants, Inc., Boulder, CO, 98 pp. + appendices.**

Excessive livestock impacts, through heavy grazing and trampling, affect riparian-stream habitats by reducing or eliminating riparian vegetation, changing streambank and channel morphology, and increasing stream sediment transport. Often there is a lowering of the surrounding water tables. Thus livestock are perceived as a major cause of habitat disturbance in many Western riparian areas. This perception has resulted in accelerated concerns from various resource users because riparian areas generally represent the epitome of multiple use. In addition to the livestock forage, riparian areas and the associated streams often have high to very high values for fisheries habitat, wildlife habitat, recreation, production of wood fiber, transportation routes, precious metals, water quality, and timing of water flows. Includes information on recommended grazing management practices.

Windell, J.T., and L.P. Rink. 1987. *A Use Attainability Analysis of Lower Boulder Creek, Segments 9 and 10*. Aquatic and Wetland Consultants, Inc., Boulder, CO, 23 pp.

The City of Boulder is in the process of a $12-14 million dollar upgrade and expansion of the 75th Street Wastewater Treatment Plant in order to meed NPDES permit requirements. Expansion and upgrading includes installation of one nitrification tower for ammonia removal costing $1.3 million dollars with three additional towers possibly required during the next twenty years. Present studies funded by the City concluded that Boulder creek segments 9 and 10 were impaired by non-water quality factors that preclude attainment of the designated Class 1 Warm Water Aquatic Life use regardless of improvements in water quality. It was suggested that future Class 1 Warm Water Aquatic Life use could not be attained without implementation of aquatic and riparian zone best management practices and improvements to the stream ecosystem. Physical and biological impairments could be mitigated by aquatic and riparian zone restoration to achieve the designated use, and could result in significant financial savings for the City by potentially eliminating the need for additional nitrification towers. Restoration would have the effect of reducing daily temperature and pH excursions and thus reduce average un-ionized ammonia levels in Boulder Creek downstream of the WWTP. The purpose of this study was to determine if non-water quality related factors preclude attainment of the Class I Warm Water Aquatic Life use classification. This purpose was based on recognition that non-water quality factors are an important standard setting consideration.

Windell, J.T., and L.P. Rink. 1992. *Boulder Creek Nonpoint Source Pollution Control Project: A Bibliography of Reports, Proposals, Publications, Videos, Presentations, Preliminary Data/draft Monitoring Reports, and Abstracts*. Aquatic and Wetland Consultants, Inc., Boulder, CO, 10 pp.

A bibliography of all references and materials used in the Boulder Creek project. Contains reports, proposals, publications, preliminary data/draft monitoring reports, and abstracts.

Yount, J.D. and G.J. Niemi, eds. 1990. Recovery of lotic communities and ecosystems from disturbance: Theory and application. *Environmental Management* 14(5):515-762.

The September/October issue of Environmental Management is devoted to lotic ecosystem recovery. Some of the topics covered by various authors are case study reviews, life history and behavioral characteristics of ecosystem communities, the problem of spatial-temporal variability, ecosystem and landscape constraints on community recovery, theoretical bases for defining and predicting community recovery, and research needs and priorities.

EPA
United States
Environmental Protection Agency
(4503F)
Washington, DC 20460