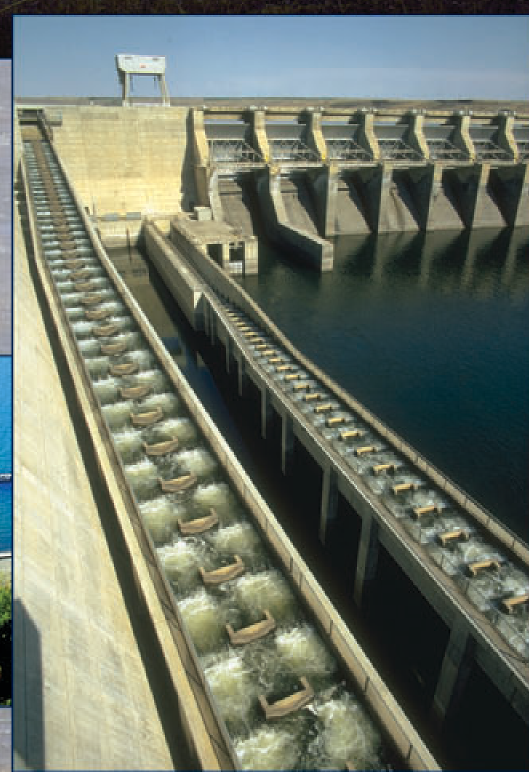
National Management Measures to Control Nonpoint Source Pollution from Hydromodification



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National Management Measures
to Control Nonpoint Source Pollution from Hydromodification

Nonpoint Source Control Branch
Office of Wetlands, Oceans and Watersheds
U.S. Environmental Protection Agency
Office of Water

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Disclaimer

This document provides technical guidance to states, territories, authorized tribes, and the public for managing hydromodification and reducing associated nonpoint source pollution of surface and ground water. At times, this document refers to statutory and regulatory provisions, which contain legally binding requirements. This document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus, it does not impose legally-binding requirements on EPA, states, territories, authorized tribes, or the public and may not apply to a particular situation based upon the circumstances. EPA, state, territory, and authorized tribe decision makers retain the discretion to adopt approaches to manage hydromodification and reduce associated NPS pollution of surface and ground water on a case-by-case basis that differ from this guidance where appropriate. EPA may change this guidance in the future.

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Chapter 1: Introduction

The Nation's aquatic resources are among its most valuable assets. Although environmental protection programs in the United States have improved water quality during the past 35 years, many challenges remain. Significant strides have been made in reducing the impacts of discrete pollutant sources, but some aquatic ecosystems remain impaired, due in part to complex pollution problems caused by nonpoint source (NPS) pollution.[1] Of special concern are the problems in our streams, lakes, estuaries, aquifers, and other water bodies caused by runoff that is inadequately controlled or treated. These problems include changes in flow, increased sedimentation, higher water temperature, lower dissolved oxygen, degradation of aquatic habitat structure, loss of fish and other aquatic populations, and decreased water quality due to increased levels of nutrients, metals, hydrocarbons, bacteria, and other constituents.

What is Hydromodification?

USEPA (1993) defines hydromodification as the "alteration of the hydrologic characteristics of coastal and non-coastal waters, which in turn could cause degradation of water resources." Examples of hydromodification in streams include dredging, straightening, and, in some cases, complete stream relocation. Other examples include construction in or along streams, construction and operation of dams and impoundments, channelization in streams, dredging, and land reclamation activities. Hydromodification can also include activities in streams that are being done to maintain the stream's integrity such as removing snags.[2] Some indirect forms of hydromodification, such as erosion along streambanks or shorelines, are caused by the introduction or maintenance of structures in or adjacent to a waterbody and other activities, including many upland activities, that change the natural physical properties of the waterbody.

EPA has grouped hydromodification activities into three categories: (1) channelization and channel modification, (2) dams, and (3) streambank and shoreline erosion. The following definitions are offered to clarify the hydromodification activities associated with these three categories:

> Channelization and channel modification include activities such as straightening, widening, deepening, and clearing channels of debris and sediment. Categories of channelization and channel modification projects include flood control and drainage, navigation, sediment control, infrastructure protection, mining, channel and bank instability, habitat improvement/enhancement, recreation, and flow control for water supply (Watson et al., 1999). Channelization activities can play a critical role in NPS pollution by increasing the timing and delivery of pollutants, including sediment, that enter the water. Channelization can also be a cause of higher flows during storm events, which potentially increases the risk of flooding.

[1] For more information on NPS pollution, go to EPA's website at http://www.epa.gov/owow/nps.
[2] A tree or branch embedded in a lake or stream bed and constituting a hazard to navigation; a standing dead tree.

Dams[3] are artificial barriers on waterbodies that impound or divert water and are built for a variety of purposes, including flood control, power generation, irrigation, navigation, and to create ponds, lakes, and reservoirs for uses such as livestock watering, municipal water supply, fish farming, and recreation. While these types of dams are constructed to provide benefits to society, they can contribute to NPS pollution. For example dams can alter flows, which ultimately can cause impacts to water quality (changes to temperature or dissolved gases) and biological/habitat (disruption of spawning or altering of plant and benthic communities) above and below the dam.

Streambank and shoreline erosion are the wearing away of material in the area landward of the bank along non-tidal streams and rivers. Streambank erosion occurs when the force of flowing water in a river or stream exceeds the ability of soil and vegetation to hold the banks in place. Eroded material is carried downstream and redeposited in the channel bottom or in point bars located along bends in the waterway. Shoreline erosion occurs in large open waterbodies, such as the Great Lakes or coastal bays and estuaries, when waves and currents sort coarser sands and gravels from eroded bank materials and move them in both directions along the shore away from the area undergoing erosion. While the underlying forces causing the erosion may be different for streambank and shoreline erosion, the results (erosion and its impacts) are usually similar. It is also important to note that streambank and shoreline erosion are natural processes and that natural background levels of erosion also exist. However, human activities along or adjacent to streambanks or shorelines may increase erosion and other nonpoint sources of pollution.

Why is NPS Guidance on Hydromodification Important?

Hydromodification is one of the leading sources of impairment in our nation's waters. According to the *National Water Quality Inventory: 2000 Report to Congress* (USEPA, 2002a), there are almost 3.7 million miles of rivers and streams[4] in the United States. Approximately 280,000 miles of assessed rivers and streams in the United States are impaired for one or more designated uses, which include aquatic life support, fish consumption, primary and contact recreation, drinking water supply, and agriculture. Many of the pollutants causing impairment are delivered to surface and ground waters from diffuse sources, such as agricultural runoff, urban runoff, hydrologic modification, and atmospheric deposition of contaminants. The leading causes of

[3] Dams are defined according to Title 33 of the Code of Federal Regulations, section 222.6(h) (2003) as all artificial barriers together with appurtenant works which impound or divert water and which (1) are 25-feet or more in height or (2) have an impounding capacity of 50 acre-feet or more. Barriers that are six-feet or less in height, regardless of storage capacity or barriers that have a storage capacity at maximum water storage elevation of fifteen acre-feet or less regardless of height are not included. Federal regulations define dams for the purpose of ensuring public safety. For example, 33 CFR 222.6 states objectives, assigns responsibilities, and prescribes procedures for implementation of a National Program for Inspection of Non-Federal Dams. Most states use this or a very similar definition, which creates a category of dams that requires some form of inspection to ensure that they are structurally sound. Dams smaller than those defined above, such as those used to create farm ponds, are authorized under the NRCS program.
[4] Approximately 700,000 miles (19%) of the total 3.7 million miles of rivers and streams in the United States were assessed for the *National Water Quality Inventory: 2000 Report to Congress* (USEPA, 2002a).

beneficial use impairment (partially or not supporting one or more uses) are nutrients, sediment, pathogens (bacteria), metals, pesticides, oxygen-depleting materials, and habitat alterations (USEPA, 2002a).

The *National Water Quality Inventory: 2000 Report to Congress* (USEPA, 2002a) identified hydrologic modifications (i.e., hydromodification) as a leading source of water quality impairment in assessed surface waters. Of the 11 pollution source categories listed in the report, hydromodification was ranked as the second leading source of impairment in assessed rivers, second in assessed lakes, and sixth in assessed estuaries (Table 1.1). Three major types of hydromodification activities—channelization and channel modification, dams, and streambank and shoreline erosion—change a waterbody's physical structure as well as its natural functions.

Many hydromodification activities are necessary because of human activities. For example, hardening of streambanks to correct headcutting and streambank erosion is often necessary because of changes in landuse that increase impervious surfaces. While hydromodification activities are intended to provide some form of benefit (e.g., levees for reducing flooding, electricity from hydroelectric dams, or bulkheads to reduce shoreline erosion and protect valuable property), there may be unintended consequences resulting from the activity. To illustrate, levees may provide local flood reduction by keeping storm flows from spreading onto flood plains. However, these same levees may alter riparian wetland habitat that once relied on seasonal flooding.

Table 1.1 Leading Sources of Water Quality Impairment Related to Human Activities for Rivers, Lakes, and Estuaries (USEPA, 2002a)

	Rivers and Streams	Lakes, Ponds, and Reservoirs	Estuaries
Sources[a]	Agriculture (48%)[b]	Agriculture (41%)	Municipal Point Sources (37%)
	Hydrologic Modification (20%)[c]	**Hydrologic Modification (18%)**	Urban Runoff/Storm Sewers (32%)
	Habitat Modification (14%)[d]	Urban Runoff/Storm Sewers (18%)	Industrial Discharges (26%)
	Urban Runoff /Storm Sewers (13%)	Nonpoint Sources (14%)	Atmospheric Deposition (23%)
	Forestry (10%)	Atmospheric Deposition (13%)	Agriculture (18%)
	Municipal Point Sources (10%)	Municipal Point Sources (12%)	**Hydrologic Modification (14%)**
	Resource Extraction (10%)	Land Disposal (10%)	Resource Extraction (12%)

[a] Excluding unknown, natural, and "other" sources.
[b] Values in parentheses represent the approximate percentage of surveyed river miles, lake acres, or estuary square miles that are classified as impaired due to the associated sources.
[c] Hydrologic modifications include flow regulation and modification, dredging, and construction of dams. These activities may alter a lake's habitat in such a way that it becomes less suitable for aquatic life (USEPA, 2002a).
[d] Habitat modifications result from human activities, such as flow regulation, logging, and land-clearing practices. Habitat modifications—changes such as the removal of riparian (stream bank) vegetation—can make a river or stream less suitable for the organisms inhabiting it (USEPA, 2002a).

Purpose and Scope of the Guidance

National summaries, such as those shown in Table 1.1, are useful in providing an overview of the magnitude of problems associated with hydromodification. Solutions, however, are usually applied at the local level. For example, in Maryland, the Shore Erosion Task Force, after investigating shore erosion in the state, published recommendations to be implemented under a Comprehensive Shore Erosion Control Plan. To initiate statewide planning, the Maryland Department of Natural Resources established partnerships with two coastal counties that were significantly affected by shoreline erosion. These state-local partnerships enable the state to better identify and correct shoreline erosion problems throughout Maryland (MDNR, 2001).

State and local elected officials and agencies, landowners, developers, environmental and conservation groups, and others play a crucial role in working together for protecting, maintaining, and restoring water resources that are impacted by hydromodification activities. These local efforts, in aggregate, form the basis for changing the status of hydromodification as a national problem.

This guidance document provides background information about NPS pollution and offers a variety of solutions for reducing NPS pollution resulting from hydromodification activities. The background information provided in Chapter 2 includes a discussion of sources of NPS pollution associated with hydromodification and how the generated pollutants enter the Nation's waters. Chapter 3 (Channelization and Channel Modification), Chapter 4 (Dams), and Chapter 5 (Streambank and Shoreline Erosion) present technical information about how certain types of NPS pollution can be reduced or eliminated.

Since hydromodification is not associated with localized impacts and solutions, Chapter 6 provides a discussion on the broad concept of assessing and addressing water quality problems on a watershed level. Chapter 7 provides detailed information for practices that can be used to implement the management measures presented in this guidance. Chapter 8 provides a discussion of available models and assessment approaches that could be used to determine the effects of hydromodification activities. Chapter 9 summarizes additional dam removal information, including permitting requirements, process, and techniques for dam removal. The primary goal of this guidance document is to provide technical assistance to states, territories, tribes, local governments, and the public for managing hydromodification and reducing associated NPS pollution.

Document Organization

This document is divided into the following chapters:

- Chapter 1: Introduction
- Chapter 2: Background
- Chapter 3: Channelization and Channel Modification
- Chapter 4: Dams
- Chapter 5: Streambank and Shoreline Erosion

- Chapter 6: Guiding Principles
- Chapter 7: Practices for Implementing Management Measures
- Chapter 8: Modeling Information
- Chapter 9: Dam Removal Requirements, Process, and Techniques
- References Cited
- Additional Resources
- Appendix A: Federal, State, Nonprofit, and Private Financial and Technical Assistance Programs
- Appendix B: U.S. Environmental Agency Contacts

Activities to Control NPS Pollution

Historical Perspective

During the first 15 years of the national program to abate and control water pollution (1972–1987), EPA and the states focused most of their water pollution control activities on traditional point sources, which are stationary locations or fixed facilities from which pollutants are discharged; any single identifiable source of pollution (e.g., a pipe, ditch). EPA and the states have regulated these point sources through the National Pollutant Discharge Elimination System (NPDES) permit program established by section 402 of the Clean Water Act (CWA).[5] The NPDES program functions as the primary regulatory tool for assuring that state water quality standards are met. NPDES permits, issued by an authorized state or EPA, contain discharge limits designed to meet water quality standards and national technology-based effluent regulations.

In 1987, in view of the progress achieved in controlling point sources and the growing national awareness of the increasingly dominant influence of NPS pollution on water quality, Congress amended the CWA to focus greater national efforts on nonpoint sources.

Federal Programs and Funding

The CWA establishes several reporting, funding, and regulatory programs that address pollutants carried in runoff that is not subject to confinement or treatment. These programs relate to watershed management and nonpoint source control. Readers are encouraged to use the information contained in this guidance to develop nonpoint source management programs/plans that comprehensively address the following EPA programs:

- *Section 319 Grant Program*. Under section 319 of the CWA, EPA awards funds to states and eligible tribes to implement NPS management programs. These funds can be used for projects that address nonpoint source related sources of pollution, including hydromodification.[6]

- *Clean Water State Revolving Fund*. The Clean Water State Revolving Fund (CWSRF) program is an innovative method of financing environmental projects. Under the

[5] For more information on the NPDES program, refer to EPA's NPDES website at http://cfpub.epa.gov/npdes.
[6] More information about the section 319 program is provided at http://www.epa.gov/owow/nps/cwact.html.

program, EPA provides grants or "seed money" to all 50 states plus Puerto Rico to capitalize state loan funds. The states, in turn, make loans to communities, individuals, and others for high-priority water quality activities. As money is paid back into the revolving fund, new loans are made to other recipients. When funded with a loan from this program, a project typically costs much less than it would if funded through the bond market. Many states offer low or no interest rate loans to small and disadvantaged communities. In recent years, state programs have begun to devote an increasing volume of loans to nonpoint source, estuary management, and other water-quality projects. Eligible NPS projects include almost any activity that a state has identified in its nonpoint source management plan. Such activities include projects to control runoff from agricultural land; conservation tillage and other projects to address soil erosion; development of streambank buffer zones; and wetlands protection and restoration.[7]

- *Total Maximum Daily Loads*. Under section 303(d) of the CWA, states are required to compile a list of impaired waters that fail to meet any of their applicable water quality standards. This list, called a 303(d) list, is submitted to Congress every 2 years, and states are required to develop a Total Maximum Daily Load (TMDL) for each pollutant causing impairment for waterbodies on the list.[8]

- *Water Quality Certification.* Section 401 of the CWA requires that any applicant for a federal license or permit to conduct any activity that "may result in any discharge" into navigable waters must obtain a certification from the state or tribe in which the discharge originates that the discharge will comply with various provisions of the CWA, including sections 301 and 303. The federal license or permit may not be issued unless the state or tribe has granted or waived certification. The certification shall include conditions, e.g., "effluent limitations or other limitations" necessary to assure that the permit will comply with the state's or tribe's water quality standards or other appropriate requirements of state or tribal law. Such conditions must be included in the federal license or permit.

- *National Estuary Program.* Under the National Estuary Program, states work together to evaluate water quality problems and their sources, collect and compile water quality data, and integrate management efforts to improve conditions in estuaries. To date, 28 estuaries have been accepted into the program. Estuary programs can be an excellent source of water quality data and can provide information on management practices.[9]

- *Safe Drinking Water Act.* Many areas, especially urban fringe areas, need to maintain or improve the quality of surface and ground waters that are used as drinking water sources. This act requires states to develop Source Water Assessment Reports and implement Source Water Protection Programs. Low- or no-interest loans are available under the Drinking Water State Revolving Fund (SRF) Program.[10]

[7] Additional information about CWSRF is available at http://www.epa.gov/OWM/cwfinance/cwsrf/index.htm.
[8] More information on the TMDL program and 303(d) lists is provided at http://www.epa.gov/owow/tmdl.
[9] More information on the National Estuary Program is provided at http://www.epa.gov/nep.
[10] More information about the Safe Drinking Water Act and Source Water Protection Programs can be found at http://www.epa.gov/safewater/sdwa/index.html and http://www.epa.gov/safewater/protect.html.

- *Wildlife Habitat Incentives Program (WHIP)*. WHIP[11] is a voluntary program authorized by the Farm Security and Rural Investment Act of 2002 (Farm Bill)[12] that enables landowners to apply for technical and financial assistance to improve wildlife habitat. The program is administered by the Natural Resources Conservation Service (NRCS), which works with private landowners and operators, conservation districts, and federal, state, and tribal agencies to improve terrestrial and aquatic habitats. NRCS and participants work together to create a wildlife habitat development plan that includes a cost-share agreement. Continued assistance after habitat development includes monitoring, review of management guidelines, and technical advice. WHIP funds may also be used for dam removal. Additional information is available from an NRCS WHIP fact sheet.[13]

Two excellent resources for learning more about the CWA and the many programs established under it are *The Clean Water Act: An Owner's Manual* (Killam, 2005) and *The Clean Water Act Desk Reference* (WEF, 1997).

Introduction to Management Measures

Management measures may be implemented as part of state, tribal, or local programs to control nonpoint source pollution for a variety of purposes, including protection of water resources, aquatic wildlife habitat, and land downstream from increased pollution and flood risks. They can be used to guide in the development of a runoff management program. Management measures establish performance expectations and, in many cases, specify actions that can be taken to prevent or minimize nonpoint source pollution from hydromodification activities. Management measures might control the delivery of NPS pollutants to receiving water resources by:

- Minimizing pollutants available (source reduction)
- Retarding the transport and/or delivery of pollutants, either by reducing water transported, and thus the amount of the pollutant transported, or through deposition of the pollutant
- Remediating or intercepting the pollutant before or after it is delivered to the water resource through chemical or biological transformation

Management measures are generally designed to control a particular type of pollutant from specific activities and land uses. The intent of the six management measures in this guidance document is to provide information for addressing and considering the NPS pollution potential associated with hydromodification activities. Implementation of management measures can minimize and control hydromodification NPS pollution through erosion and sediment control, chemical and pollutant control, management of instream and riparian habitat restoration, and protection of surface water quality.

[11] http://www.nrcs.usda.gov/programs/whip
[12] http://www.nrcs.usda.gov/programs/farmbill/2002
[13] http://www.nrcs.usda.gov/programs/farmbill/2002/pdf/WHIPFct.pdf

Activities associated with these management measures may be regulated by federal, state, or local law (e.g., section 404 of the Clean Water Act). These measures do not supersede such requirements. Sometimes regulatory authorities may appear to conflict, as is sometimes the case of the CWA and water use and distribution. CWA sections 101(g) and 510 specifically allow for resolution of the conflict by placing water use and its distribution under the authority of the states, thus protecting any state agreements on "water rights." Users of this NPS guidance should recognize that the applicability of the guidance provided in this document will remain subject to state statutes, interstate compacts, and international treaties. As such, this guidance does not recommend or require any management measures or practices that hinder a state's ability to exercise existing water rights, which provide water for municipal, industrial, and agricultural needs. For further information regarding specific state policies on water rights and regulations of water use, contact the appropriate state water agency. Contact information is generally provided on state government Web sites.

This document also lists and describes management practices for each management measure. Management practices are specific actions taken to achieve, or aid in the achievement of, a management measure. A more familiar term might be best management practice (BMP). The word "best" has been dropped for the purposes of this guidance (as it was in the Coastal Management Measures Guidance (USEPA, 1993)) because the adjective is too subjective. The "best" practice in one area or situation might be entirely inappropriate in another area or situation. The practices listed in this document have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measures. EPA recognizes that there is often site-specific, regional, and national variability in the selection of appropriate practices, as well as in the design constraints and pollution control effectiveness of practices. The practices presented for each management measure are not all-inclusive. States or local agencies and communities might wish to apply other technically and environmentally sound practices to achieve the goals of the management measures.

Channelization and Channel Modification (Chapter 3)

Channelization can cause a variety of instream flow changes and may result in the faster delivery of pollutants to downstream areas. Channel modification might result in a combination of harmful effects (higher flows or increased risk of downstream flooding) and beneficial effects (local flood control or enhanced flushing in a stream channel). The management measures for channelization and channel modification are intended to protect waterbodies by ensuring proper planning before a proposed project is implemented. Planning and evaluation can help to identify and prevent local and downstream problems before a project is started. An added benefit of planning and evaluation is to correct or prevent detrimental changes to the instream and riparian habitat associated with the project. Implementation of the management measures can also ensure that operation and maintenance programs for existing projects improve physical and chemical characteristics of surface waters and restore or maintain instream and riparian habitat when possible.

Management Measure 1: Physical and Chemical Characteristics of Surface Water: Ensure that the planning process for new hydromodification projects addresses changes to physical and chemical characteristics of surface waters that may occur as a result of the proposed work. For existing projects, ensure that operation and maintenance programs use any opportunities available to improve the physical and chemical characteristics of surface waters.

Management Measure 2: Instream and Riparian Habitat Restoration: Correct or prevent detrimental changes to instream and riparian habitat from the impacts of channelization and channel modification projects, both proposed and existing.

Dams (Chapter 4)

Because of their instream locations, any construction activities associated with dams have the potential to introduce sediment and other pollutants into adjacent waterbodies. Construction activities, chemical spills during dams operation or maintenance, and changes in the quantity and quality of water held and released by a dam may alter the nature of the waterbody. The management measures for dams are intended to be applied to the construction of new dams, as well as any construction activities associated with the maintenance of existing dams. They can also be applied to dam operations that result in the loss of desirable surface water quality, and instream and riparian habitat.

Management Measure 3: Erosion and Sediment Control: Prevent sediment from entering surface waters during the construction or maintenance of dams.

Management Measure 4: Chemical and Pollutant Control: Prevent downstream contamination from pollutants associated with dam construction and operation and maintenance activities.

Management Measure 5: Protection of Surface Water Quality and Instream and Riparian Habitat: Protect the quality of surface waters and aquatic habitat in reservoirs and in the downstream portions of rivers and streams that are influenced by the quality of water contained in the releases (tailwaters) from reservoir impoundments.

Streambank and Shoreline Erosion (Chapter 5)

NPS pollution might result from the rapid increase in erosion of streambanks caused by increased flow rates associated with urbanization in a watershed. Not only is the land adjacent to these eroding streambanks unnaturally carried away, but these eroded soils are carried downstream and deposited in often undesirable locations. Shorelines erode more severely as the result of poorly planned and implemented shoreline protection projects located nearby. Habitats can be buried and wetlands can be filled. As runoff upstream increases, more erosion results on downstream streambanks. The streambank and shoreline erosion management measure promotes the necessary actions required to correct streambank and shoreline erosion where it must be controlled. Because erosion is a natural process, this management measure is not intended to be applied to all erosion occurring on streambanks and shorelines.

> **Management Measure 6: Eroding Streambanks and Shorelines:** Protect streambanks and shorelines from erosion and promote institutional measures that establish minimum setback requirements or measures that allow a buffer zone to reduce concentrated flows and promote infiltration of surface water runoff in areas adjacent to the shoreline.

Channelization and channel modification and dams represent forms of hydromodification that are direct results of human activities—someone performs a construction activity directly in or along a stream, river, or shoreline. For example, a town constructs concrete lined channels along a stream passing through the city limits to reduce stream meandering and prevent flooding. Another example is the construction (many years ago) of a dam in a stream for hydropower at a grist mill. Streambank and shoreline erosion are forms of hydromodification that result from direct and indirect human activities. For example, a streambank is eroding at a much faster rate because of recent development activities on shore that result in increased runoff, which is causing increased bank erosion. Another example is a concrete seawall that is protecting property at one location, but causing increased erosion on adjacent properties.

This distinction between forms of hydromodification and impacts from hydromodification is important when contrasting the relationship between Chapter 3 (Channelization and Channel Modification) and Chapter 5 (Streambank and Shoreline Erosion). Many of the operation and maintenance solutions presented in Chapter 3 are also practices that can be used to stabilize streambanks and shorelines as presented in Chapter 5. For example, a stream channel that has been hardened with vertical concrete walls to prevent local flooding and limit the stream to its existing channel (to protect property built along the stream channel), may benefit from operation and maintenance practices that use opportunities to replace the concrete walls with an appropriate vegetative or combined vegetative and non-vegetative structures along the streambank when possible. These same practices may be applicable to stabilize downstream streambanks that are eroding and creating a nonpoint source pollution problem because of the upstream development and hardened streambanks.

Chapter 2: Background

There are differing views on defining the stability of a stream channel and other waterbodies. From a navigation perspective, a stream channel is considered stable if shipping channels are maintained to enable safe movement of vessels. Landowners with property adjacent to a stream or shoreline might consider the waterbody to be stable if it does not flood and erosion is minimal. Ecologists might find some erosion of streambanks and meandering channels to be a part of natural evolution (i.e., changes that are not induced by humans) and consider long-term changes like these to be quite acceptable (Watson et al., 1999). In any case, new and existing channelization projects, construction and maintenance of dams, and streambank and shoreline erosion problems should be evaluated with these differing perspectives in mind and a balance of these perspectives should be taken into account when constructing or maintaining a project. Often, multiple priorities can be maintained with good up-front planning and communication among the different stakeholders involved.

Key Geomorphic Functions of Streams

Discharge, Slope, and Sinuosity

Figure 2.1 is a cross-section of a typical stream channel. The thalweg is the deepest part of the channel. The sloped bank is known as the scarp. The term discharge is used to describe the volume of water moving down the channel per unit time (usually described in the United States as cubic foot per second (cfs)). Discharge is the product of the area through which the water is flowing (in square feet) and the average velocity of the water (in feet per second). If discharge in a channel increases or decreases, there must be a corresponding change in streamflow velocity and/or flow area.

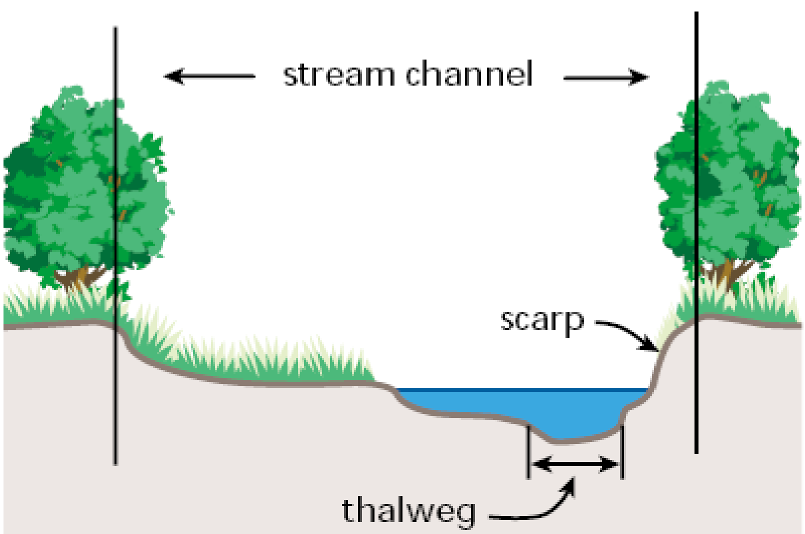

Figure 2.1 Cross-section of a Stream Channel (FISRWG, 1998)

Channel slope is an especially key concept when dealing with hydromodification projects. It is the difference in elevation between two points in the stream divided by the stream length between the two points. Stream sinuosity greatly affects stream slope. Sinuosity is the stream length between two points on a stream divided by the valley length between the two points. A meandering stream moving through a valley has a lower slope than a straight stream.

Erosion, Transport, and Deposition of Sediment

All streams accomplish three basic geomorphic tasks:

- *Erosion*—the detachment of soil particles along the stream bed and banks
- *Sediment transport*—the movement of eroded soil particles in streamflow
- *Sediment deposition*—the settling of eroded soil particles in the water or on land as water recedes

These processes largely determine the size and shape of the channel, both laterally and longitudinally. The ability to accomplish these geomorphic tasks is related to stream power, the product of slope and discharge. Slope directly affects flow velocity. Consequently, a shallow, meandering stream with low slope generates less stream power, and has lower erosion and sediment-transport capacity, than a deep, straight stream.

In addition to sinuosity, roughness along the boundaries of a stream area is also important in determining streamflow velocity and stream power. The rougher the channel bottom and banks, the more they are able to slow down the flow of water. The level of roughness is determined by many conditions including:

- Type and spacing of bank vegetation
- Size and distribution of sediment particles
- Bedforms
- Bank irregularities
- Other miscellaneous obstructions

Tractive stress, also known as shear stress, describes the lift and drag forces that work to create erosion along the stream bed and banks. In general, the larger the sediment particle, the more stream power is needed to dislodge it and transport it downstream. When stream power decreases in the channel, larger sediment particles are deposited back to the stream bed.

Dynamic Equilibrium

One of the primary functions of a stream is to move particles out of the watershed. Erosion, sediment transport, and deposition occur all the time at both large and small scales within a channel. A channel is considered stable when the average tractive stress maintains a stable streambed and streambanks. That is, sediment particles that erode and are transported downstream from one area are replaced by particles of the same size and shape that have originated in areas upstream. Lane (1955) qualitatively described this relationship as:

$$Qs * D \propto Qw * S$$

Where: Qs = Sediment discharge, D = Sediment particle size, Qw = Streamflow,
S = Stream slope

When all four variables are in balance, the channel is stable, or in dynamic equilibrium.

Lane's channel variable relationships can be visualized as a pan balance with sliding weights (Figure 2.2). Sediment discharge is placed on one pan and streamflow on the other. The hook holding the sediment load pan can slide back and forth based on changes in sediment size. Likewise, the hook holding the streamflow can slide according to changes in slope.

If a disturbance or stream modification occurs that causes a variable to change, one or more of the other variables must change in order to maintain the balance. During an imbalanced phase, the scale indicator will point to either degradation or aggradation. This indicates that the channel will try to adjust and regain equilibrium by either increasing sediment discharge by scouring the bottom or eroding its banks (degradation) or decreasing sediment discharge by depositing sediment on the bottom (aggradation), depending on the circumstance.

For example, if stream slope is decreased and streamflow remains the same (i.e., streamflow pan slides toward the center), the balance will tip and aggradation will occur (Figure 2.3). Alternatively, if streamflow increases and slope remains the same (i.e., more weight on the streamflow pan), degradation will occur. No matter the scenario, this basic relationship between the variables will hold true and aggradation or degradation will cease only when the system reaches equilibrium. This can occur naturally over time, or through management practices designed to deal with the "balancing" issue.

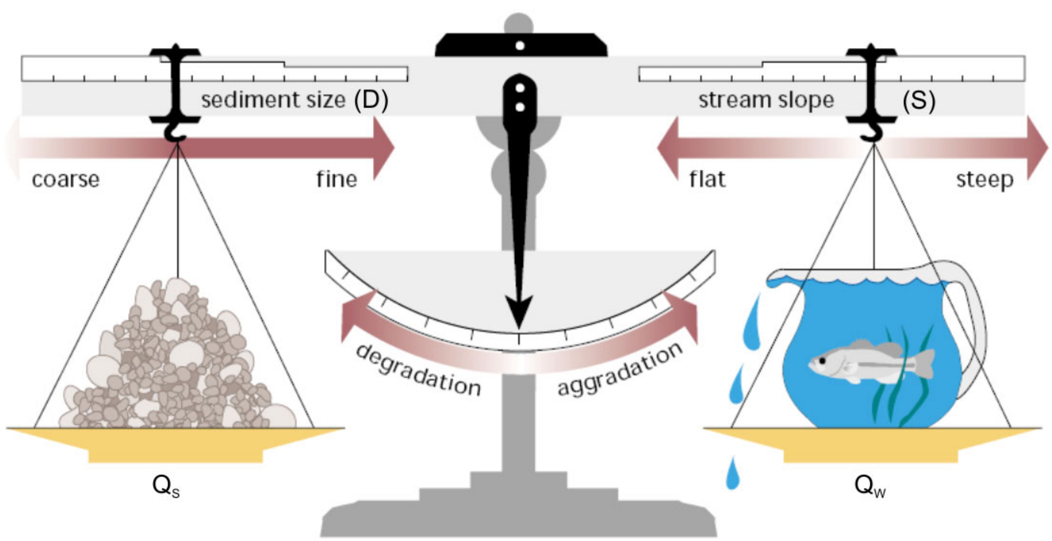

Figure 2.2 Factors Affecting Channel Degradation and Aggradation (FISRWG, 1998)

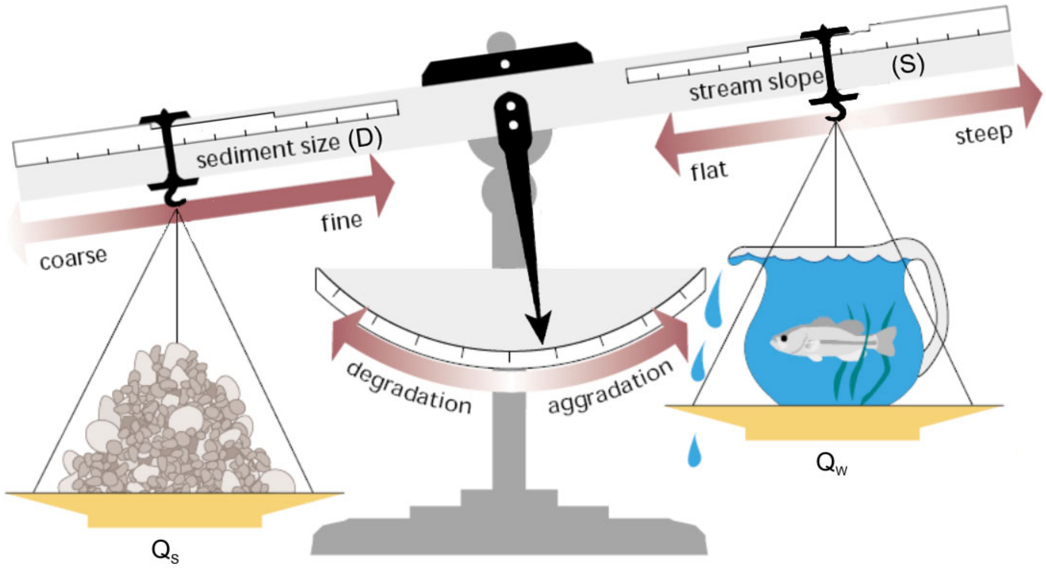

Figure 2.3 Example of Aggradation (Adapted from FISRWG, 1998)

Longitudinal View of Channels

The geomorphic processes that define the size and shape of channels can be observed in large and small scale longitudinal views. The overall longitudinal view of many streams can be divided into three general zones (Schumm, 1977):

- *Headwater zone*—characterized by steep slopes with sediment erosion as the most dominant geomorphic process.
- *Transfer zone*—characterized by more sinuous channel patterns and wider floodplains with sediment transfer as the most dominant geomorphic process.
- *Deposition zone*—characterized by lower slope and higher channel sinuosity than the other zone and is the primary deposition area for watershed sediment.

Key characteristics of each zone are summarized in Figure 2.4.

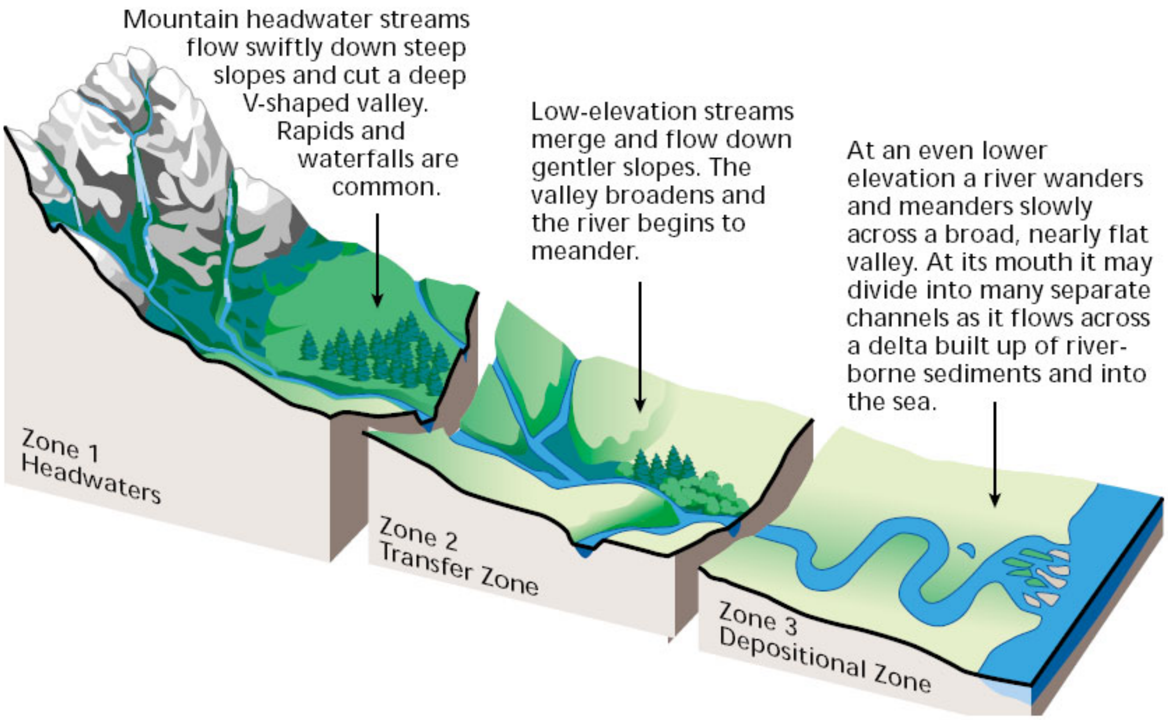

Figure 2.4 Three Longitudinal Profile Zones (FISRWG, 1998)

At a smaller scale, natural-forming channels are usually characterized by a series of riffles, pools, and runs. These structures are primarily associated with the thalweg, which meanders within the channel (Figure 2.5). Riffles are shallow, turbulent, and swiftly flowing stretches of water that flow over partially or totally submerged rocks. Deeper areas at stream bends are the pools and can be classified as large-shallow, large-deep, small-shallow, and small-deep. Runs are the sections of a stream with little or no surface turbulence that connect pools and riffles.

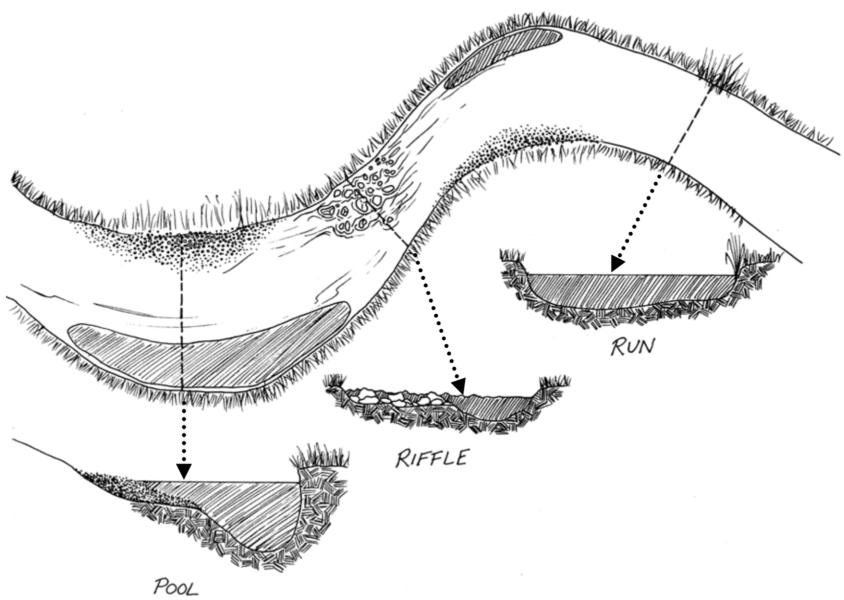

Figure 2.5 Overview of a Pool, Riffle, and Run (USEPA, 1997b)

The distribution in streamflow velocity and stream power throughout the riffle/pool/run sequence impact the geomorphic tasks. The stream bottom of a riffle is at a higher elevation than the stream areas surrounding it. Consequently, the water flowing in a run from riffle to pool has the highest velocity near the center of the channel just under the surface (i.e., away from the roughness associated with channel boundaries). On reaching a bend, angular momentum forces the highest velocity flow to the outside of the bend and, given enough tractive stress, causes erosion to the bank (cutbanks). Meanwhile on the inside of the bend deposition often occurs because of decreasing flow velocity. Importantly, these and other characteristics of the riffle/pool/run sequence create unique habitats which allow different species to live, reproduce, and feed.

Disruption of Dynamic Equilibrium

Changes caused by (or exacerbated by) hydromodification projects and other human activities can lead to a disruption of the dynamic equilibrium of the stream channel. If, for example, a modification occurs that causes a change in sediment discharge, channel slope, or streamflow, one or more of the other variables will be imbalanced and the channel will usually try to adjust and regain equilibrium by either increasing sediment discharge by scouring the bottom or eroding its banks (degradation) or decreasing sediment discharge by depositing sediment on the bottom (aggradation) (Biedenharn et al., 1997; Watson et al., 1999). In some cases, alterations to a stream channel can result in local or system-wide channel instability (FISRWG, 1998).

General Impacts of Channelization and Channel Modifications

Channelization and channel modifications are undertaken for many purposes including flood control, navigation, drainage improvement, and reduction of channel migration potential. Modifications also occur in association with the installation of culverts and bridges, urbanization of the watershed, and agricultural drainage. These changes may result in several physical and chemical impacts.

Physical Impacts

The most significant physical impact of channelization and channel modifications is the movement or deposition of sediment. Sediment erodes from stream banks and beds, is washed downstream in faster moving water, deposited in areas of slower flows, and transported into new areas of streams or other receiving waters. Critical habitat can be changed when channelization or channel modification projects alter the dynamic equilibrium of a stream and change sediment transport or deposition characteristics. Re-establishing equilibrium may take some time to occur and have long-lasting effects to habitat and water quality conditions.

Channel modification and channelization can lead to increased erosion in some areas of the stream, which produces sediment. Sediment can be dislodged and transported directly from the waterbody's shoreline, bank, or bottom. Sediment being transported by a stream is referred to as the sediment load, which is further classified as the bed load (those particles moving on or near the bed, or bottom of the channel) and the suspended load (those particles moving in the water column). Hydromodification typically results in more uniform channel cross-sections, steeper stream gradients, and reduced average pool depths.

An increase in the sediment load could lead to increased turbidity, which then may cause an increase in stream temperature because the darker sediment particles absorb heat (USEPA, 1997b). Changes in water temperature can influence several abiotic chemical processes, such as dissolved oxygen concentrations, sorption of chemicals onto particles, and volatilization rates. Water temperature influences reaeration rates of oxygen from the atmosphere. Dissolved oxygen concentrations in water are inversely related to temperature; solubility of oxygen decreases with increasing water temperature. In addition, sorption of chemicals to particulate matter and volatilization rates are influenced by changes in water temperature. Sorption often decreases with increasing temperature and volatilization increases with increasing temperature (University of Texas, 1998).

An increased sediment load that contains significant organic matter can increase the sediment oxygen demand (SOD). The SOD is the total of all biological and chemical processes in sediment that consume oxygen (USEPA, 2003a). These processes occur at or just below the sediment-water interface. Most of the SOD at the surface of the sediment is due to the biological decomposition of organic material and the bacterially facilitated nitrification of ammonia, while the SOD several centimeters into the sediment is often dominated by the chemical oxidation of species such as iron, manganese, and sulfide (Walker and Snodgrass, 1986 from USGS, 1997; Wang, 1980). Increases in SOD can lead to lower levels of dissolved oxygen, which can be harmful to aquatic life.

A channel that is deepened or widened can result in slower and/or shallower flow. Reduced stream velocities can result in more sediment deposits to a stream segment. When more sediment is deposited in an area of a stream, critical habitats can be buried, channels may become unstable, and flooding increases. In tidal areas, channel modification activities, such as deepening a channel to allow for larger ships to access a shoreline, may require frequent maintenance to remove accumulating sediment because of changes in flow patterns.

Chemical Impacts

A variety of chemicals can be introduced into surface waters when channelization and channel modification activities alter flow and sediment transport characteristics. Nutrients, metals, toxic organic compounds, pesticides, and organic materials can enter the water in eroding soils along banks and move throughout a stream as flow characteristics change. Changing temperatures and dissolved oxygen levels may lead to alterations in the bioavailability of metals and toxic organics. Complex chemical conditions can significantly change when stream flow and sedimentation characteristics change, resulting in new and/or potentially harmful forms of chemicals affecting instream or benthic organisms.

It is important to remember that many of the physical and chemical changes are interrelated. For a more detailed discussion of the impacts associated with chemical and physical changes to surface waters, see *Restoration of Aquatic Ecosystems* (NRC, 1992). The following discussion provides examples of impacts that may be present as a result of different kinds of channelization. For a more detailed discussion of types of channelization projects and potential impacts, see Watson et al. (1999).

Biological and Habitat Impacts

Pools, riffles, and runs create a mixture of flows and depths and provide a variety of habitats to support fish and invertebrate life (USEPA, 1997b). The shallow, turbulent, and swiftly flowing stretches of riffle water are well oxygenated and have a "patchy distribution of organisms," which means that different types of organisms are naturally found in different parts of the riffle. Pools can also be large or small and shallow or deep and support a wide variety of aquatic species. Sediments can deposit in pools, which can lead to the formation of islands, shoals, or point bars.

Changes in habitat and biological communities following hydromodification of a channel can be highly site-specific and complex. The physical and chemical alterations resulting from channelization impact various habitats and biological communities, including instream algae, fish, macroinvertebrate populations, and bank or floodplain vegetation. Mathias and Moyle (1992) compared unchannelized and channelized sections of the same stream and found a much higher diversity of many organisms, including aquatic invertebrates, fish, and riparian vegetation, in the unchannelized sections of the stream. Adams and Maughan (1986) compared the benthic community in a small headwater stream, prior to and after channelization. They found that the pathways of organic input shifted from materials associated with leaf fall and runoff to materials associated with periphyton production. Accompanying this change was a shift of the assemblage from shredder domination to grazer domination and a decrease in diversity. Biological and habitat impacts caused by channelization can result from increased stream velocity, decreases in pool and riffle habitat complex, decrease in canopy cover, increase in the solar radiation reaching the channel, channel incision, and increases in sediment.

Channelization of a stream may increase velocity due to increased channel slope and decreased friction with the bank and bed material. Changes in the velocity may cause an impact to organisms within the channel. For example, fish may have to expend more energy to stay in swifter currents and their source of food may be swept downstream. Studies have demonstrated that fisheries associated with channelized streams can be far less productive that those of non-channelized streams (Jackson, 1989). Increased rates of erosion as a result of increased velocities downstream of a channelization feature can also create unstable streambanks, which could lead to increased streambank erosion, higher risks of flooding, and ultimately negative impacts to aquatic organisms.

Channelization can result in a more uniform stream channel that is void of the pool and riffle habitat complex or obstructions, such as woody debris inputs. As repeatedly observed, this can result in changes to the biological community. Negishi et al. (2002) observed a decrease in the total density of macroinvertebrates in the middle of a channelized stream and a decrease in taxon richness in the middle and edge of a channelized stream. An overall reduction in habitat heterogeneity is likely responsible for the reduction in species diversity and the increased abundance of those species favored by the altered flows that is typically observed (Allan, 1995). On medium-sized, unregulated rivers, Benke (2001) found that habitat-specific invertebrate biomass was highest on snags, followed by the main channel and then the floodplain. It was concluded that invertebrate productivity from these habitats has likely been significantly diminished as a result of snag removal, channelization, and floodplain drainage (Benke, 2001).

The survival of the Gulf Coast walleye (*Stizostedion vitreum*) relies on the availability of appropriate spawning habitat, such as large woody debris, that locally reduce current velocity. Channelization and the removal of structures have been identified as activities of concern that could threaten the survival of the species (VanderKooy and Peterson, 1998). In one experiment, an assessment of water quality using environmental indices, such as macroinvertebrate communities, found that channelization and deforestation resulted in a completely different and less varied biocommunity (Bis et al., 2000). A lower persistence of the macroinvertebrate assemblage in the channelized stream was attributed to the lower availability of flow such as backwaters and inundated habitats (Negishi et al., 2002). In a study by Kubecka and Vostradovsky (1995), low fish populations were attributed to channelization of the riverbed.

The channelization of a river can also result in a decrease in canopy cover and an increase in the solar radiation reaching the channel. Bis et al. (2000) found that an increase in incident radiation on a river resulted in increased algal productivity and a significant decrease in scrapers, a macroinvertebrate that feeds on periphyton or algae growing on plant surfaces. Increased water temperatures can also lead to a shift in the algal community to predominately planktonic algal communities, which disrupts the aquatic food chain (Galli, 1991). The combination of increased water temperatures and loss of riparian vegetation falling into the stream (which provides both food and cover) may be responsible for the decrease in macroinvertebrates. Increased solar radiation on a channelized stream can act to decrease productivity by reaching the level of photoinhibition; a decrease in productivity due to excessive amounts of solar radiation. The temperature of the water can also be increased to the extent that it adversely impacts organisms. Elevated temperatures disrupt aquatic organisms that have narrow temperature limits, such as trout, salmon, and many aquatic insects.

Incision of a channel, a common impact of channelization, disconnects the channel from the floodplain by lowering the riverbed relative to the floodplain and decreasing the occurrence of overbank flow. Channel incision or downcutting has rarely been found to directly affect the biotic ecosystem, but indirect changes in habitat conditions are significant. Channel incision decreases habitat heterogeneity and, as a result, biodiversity (Tachet, 1997). An analysis of forest overstory, understory, and herbaceous strata along a channelized and unchannelized stream showed that there was a difference in terms of size-class structure and woody debris quantity (Franklin et al., 2001). Loss of woody vegetation along riparian zones on a channel that is incised because of upstream channelization was attributed to a decrease in over bank flooding and a lowering of the water table as the stream became incised (Steiger et al., 1998). A comparison of a regulated and an unregulated river in Colorado's Green River Basin found a difference in riparian vegetation composition. The regulated river supported banks with wetland species that survive in anaerobic soils and terraces with desert species adapted to xeric soil conditions. The unregulated river supported riparian vegetation that changed along a more gradual environmental continuum from a river channel to a high floodplain (Merritt and Cooper, 2000).

Sediment affects the use of water in many ways. When the rate of erosion changes, transport and deposition of sediment also changes. Excessive quantities of sediment can bury benthic organisms and the habitat of fish and waterfowl. Suspended solids in the water reduce the amount of sunlight available to aquatic plants, cover fish spawning areas and food supplies, fill rearing pools, reduce beneficial habitat structure in stream channels, smother coral reefs, clog the filtering capacity of filter feeders, and clog and harm the gills of fish. Those fish species that rely on visual means to get food may be restricted by increased turbidity. Sedimentation effects combine to reduce fish, shellfish, coral, and plant populations and decrease the overall productivity of lakes, streams, estuaries, and coastal waters.

Impacts Associated with Specific Hydromodification Actions

Channel Straightening and Deepening

Channels are straightened for a multitude of reasons, such as directing water away from a particular structure or area and reducing local flooding. Channelization that involves straightening of the stream channel increases the slope of the channel, which results in higher discharge velocities. Impacts associated with increased water velocities include more streambank and streambed erosion, higher sediment loads, changes in pools, riffle, and run structure, and increased transport of nutrients and other pollutants (FISRWG, 1998; Simons and Senturk, 1992).

Channelization can also result in alterations to the base level of the stream, including channel downcutting or incision of a section of the stream, which raise the height of the floodplain relative to the riverbed and decrease the frequency of overbank flow. When streams reach flood stage and flow into the floodplain, velocities decrease. The reduction in overbank flow reduces sediment deposition and the sediment storage potential of the floodplain (Wyzga, 2001). A change in the downstream base level of a stream can create an unstable stream system (Biedenharn et al., 1997).

Headcutting is the deepening of a waterway caused by channelization or localized stream-bed mining. Headcutting severely impacts the physical integrity of a stream, as streambanks become unstable and are more prone to eroding and sloughing. Bank failures may result, removing streamside vegetation and introducing significant amounts of sediment into the waterway. As sediments build on the stream bottom, natural substrate is covered and stream depth decreases. Water quality often diminishes as temperatures rise due to less shading by riparian vegetation and increased water surface area with decreased depth. The rapid alteration to stream habitat caused by headcutting is usually detrimental to aquatic wildlife. Various organizations, such as the U.S. Army Corps of Engineers, the Natural Resources Conservation Service (NRCS), and the Missouri Department of Conservation, are involved in projects to reduce headcutting (CSU, n.d.; MDC, 2007; USGS, 2000).

Channel Lining

The sides of channels can be lined with materials such as metal sheeting, concrete, wood, or stone to prevent erosion of a particular section of stream channel or stream bank. The artificially lined areas can reduce the friction between the channel and flowing water, leading to an increase in velocity. The increased velocity and thus the increased erosive potential of the flowing water are not able to erode the artificially lined channel area and can result in augmented erosion downstream as well as increased downstream flooding (Brookes, 1998). Lining the channel also removes aquatic habitat and important substrates that are essential to aquatic life.

Channel Narrowing

Narrowing of a stream channel often occurs when flood control measures such as levees and floodwalls are implemented. By narrowing a stream channel, the water is forced to flow through a more confined area and thus travels at an increased velocity (FISRWG, 1998). The increased velocity in turn increases the stream's erosive potential and ability to transport sediment. This can lead to increased erosion of the streambank and shoreline in downstream locations.

When a channel is made narrower, the water depth increases and the surface area exposed to the solar radiation and ambient temperature decreases, especially in the warmer months. This can cause a decrease in the water temperature. Increased depth may also reduce the surface area of the water in contact with the atmosphere and affect the transfer of oxygen into the water.

In a naturally flowing stream, floods are responsible for such processes as redistributing sediment from the river bottom to form sandbars and point bar deposits. Stream channel modifications to reduce flood damage, such as levees and floodwalls, often narrow the stream width, increasing the velocity of the water and thus its erosive potential. This can lead to increased erosion of the streambank and shoreline in downstream locations (FISRWG, 1998).

Channel Widening

Channel widening is often performed to increase a channel's ability to transport a larger volume of water. The design is often based on volumes of water that occur during flood events. The design of a channel modification project to increase the channel's ability to transport a large volume of water will determine the characteristic of the water flow. The widening of a channel can result in a channel with a capacity to transport water that far exceeds the typical daily discharge. This results in a typical flow that is shallow and wide. As a result of increased contact with the streambed and streambank, there is increased friction and a decreased water velocity. The decrease in velocity causes sediment to settle out of the water column and accumulate within the stream channel. This accumulation of sediment can decrease the capacity of the stream channel. The decreased depth and increased surface area of the water exposed to solar radiation and ambient air temperatures can lead to an increase in water temperature. A change in water temperature can influence dissolved oxygen concentrations as dissolved oxygen solubility decreases with increasing water temperature.

Where tidal flow restrictors cause impoundments, there may be a loss of streamside vegetation, disruption of riparian habitat, changes in the historic plant and animal communities, and decline in sediment quality. Restricted flows can impede the movement of fish or other aquatic life. Flow alteration can reduce the level of tidal flushing and the exchange rate for surface waters within coastal embayments, with resulting impacts on the quality of surface waters and on the rates and paths of sediment transport and deposition.

Culverts and Bridges

The presence of culverts and bridges along a channel can have an impact on the physical and chemical qualities of the water. A culvert can be in the form of an arch over a channel or a pipe that encircles a channel, and it functions to direct flow below a roadway or other land use. A culvert or the supports of a bridge can confine the width of a channel forcing the water to flow in a smaller area and thus at a higher velocity. Impacts associated with a higher flow velocity include increased erosion. An arch culvert maintains the natural integrity of the stream bottom. In addition, as compared with the natural substrate that can be found using an arch culvert without concrete inverts (floors), a pipe culvert may create less friction with the water flow and result in an increased flow velocity. The chemical and physical changes associated with increased erosion and sediment transport capacity would then result.

The culvert acts as a fixed point with a fixed elevation within the stream channel and as the stream attempts to adjust over time, the culvert remains stationary. Placement of this type of structure disturbs the natural equilibrium of a channel. A culvert sometimes may have beneficial attributes when it acts as a grade control structure, and as such, may serve to prevent upstream migrating incision (headcutting) from moving further up the channel. Depending on the watershed processes, the culvert may act to preserve the natural equilibrium of a channel.

Urbanization

As humans develop watersheds, the proportions of pervious and impervious land within the watershed change (most often increasing impervious areas and decreasing pervious areas). Development also results in reductions in vegetative cover in exchange for increases in houses, buildings, roads, and other non-vegetative cover. The result is a change in the fate of water from rainfall events. Generally, as imperviousness increases and vegetative cover is lost:

- Runoff increases
- Soil percolation decreases
- Evaporation decreases
- Transpiration decreases

Increased volumes of runoff resulting from some types of watershed development can result in hydraulic changes in downstream areas including bank scouring, channel modifications, and flow alterations (Anderson, 1992; Schueler, 1987). The resulting changes to the distribution, amount, and timing of flows caused by flow alterations can affect a wide variety of living resources. As urbanization occurs, changes to the natural hydrology of an area are inevitable. During urbanization, pervious spaces, including vegetated and open forested areas, are converted to land uses that usually have increased areas of impervious surface, resulting in increased runoff volumes and pollutant loadings. Hydrologic and hydraulic changes occur in response to site clearing, grading, and change in landscape. Water that previously infiltrated the ground and was slowly released runs off quickly into stream networks. Development, with corresponding increases in imperviousness, can lead to:

- Increased magnitude and frequency of bankfull and subbankfull floods
- Dimensions of the stream channel that are no longer in equilibrium with its hydrologic regime
- Enlargement of channels
- Highly modified stream channels (from human activity)
- Upstream channel erosion that contributes greater sediment load to the stream
- Reduced dry weather flow to the stream
- Decreased wetland perimeter of the stream
- Degraded in-stream habitat structure

- Reduced large woody debris
- Increased stream crossings and potential fish barriers
- Fragmented riparian forests that are narrower and less diverse
- Decline in water quality
- Increased summer stream temperatures
- Reduced aquatic diversity

The hydraulic changes associated with urbanization have often been addressed with channelization and channel modification as a solution. Evaluating impacts from urbanization on a watershed scale and planning solutions on the same watershed scale can often prevent the transference of upstream problems to downstream locations. There are a variety of management activities that can reduce the impacts associated with urban development. When these urban impacts are reduced, additional hydromodification impacts, such as channelization and channel modification or streambank and shoreline erosion effects, may be reduced. Changes in urban development practices that result in reduced sediment in runoff can enhance reservoir quality and lessen the need for management activities to reduce nonpoint source impacts associated with the operation of dams.[1]

Agricultural Drainage

Some activities, including channelization and channel modification, that take place within a watershed, can lead to unintended adverse effects on watershed hydrology. Even when the intended effect of the watershed activity is to reduce pollution or erosion for an area within a watershed, the impact of the project to the entire watershed's hydrology should be evaluated. Since hydrology is important to the detachment, transport, and delivery of pollutants, better understanding of these effects can lead to reduction of nonpoint source pollution problems (USEPA, 2003b).

One example of an activity that has been shown to provide localized nonpoint source benefits, but can negatively affect the hydrology of a watershed, is an agricultural drainage system. The main purpose of agricultural drainage is to provide a root environment suitable for plant growth, but it can also be used as a means of reducing erosion and improving water quality. Despite the localized positive effects of drainage, when drainage water is poor in quality or contains elevated levels of pollutants, adverse impacts may occur downstream within a watershed. Concentrations of salts, nutrients, and other crop-related chemicals, such as fertilizers and pesticides can damage downstream aquatic ecosystems. Many agricultural drainage systems include drain tiles placed strategically throughout a field to create a network of gravity fed drains. The drain tiles empty into a collection pipe that drains to a waterbody nearby. With the drain system in place and operating, water will leave the affected area quicker and at one or more focused points. Water from the drainage system may erode the banks of unlined surface drains, contribute to flashier runoff events in the receiving water or downstream, and increase the load of sediment in drainage water (USEPA, 2003b).

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[1] For additional information on hydrologic problems associated with urbanization and management practices that address urbanization issues, refer to *National Management Measures to Control Nonpoint Source Pollution from Urban Areas* (USEPA, 2005d): http://www.epa.gov/owow/nps/urbanmm/index.html.

Because of these adverse effects, drainage planners should analyze effluents from these systems for nutrients and pesticides to determine possible downstream impacts. Care should also be taken with drainage water so that it does not negatively alter the hydrology of a watershed (FAO, 1997). The degree to which management activities, such as agricultural drainage systems, affect watersheds beyond their intended purpose should be evaluated. In some cases, a thorough assessment and thoughtful discussion with key stakeholders is enough to evaluate the potential impacts of a project on hydrology. However, in many instances, some form of modeling is probably needed to integrate various small and large impacts of watershed activities. For more information on agricultural drainage and management practices related to agricultural drainage, refer to *National Management Measures for the Control of Nonpoint Pollution from Agriculture* (USEPA, 2003b).[2]

Shorelines

A shoreline is defined as the areas between low tide and the highest land affected by storm waves. The shape and position of shorelines are constantly being modified by the processes of erosion and deposition by waves and currents (Tarbuck and Lutgens, 2005). NOAA's Coastal Services Center defines shoreline as "the line of contact between the land and a body of water. On Coast and Geodetic Survey nautical charts and surveys the shoreline approximates the mean high water line" (NOAA, 2006).

The shoreline can be divided into three major areas:

1) *Coast*—the land inland from the base of the sea cliff (produced by the undercutting of bedrock at sea level by wave erosion).
2) *Beach (shore)*—the area between low tide level and dunes, sea cliff, or permanent vegetation. This can be separated into backshore and foreshore.
3) *Offshore*—the area continuously underwater, which can include a wave build platform.

Shoreline Processes

As mentioned above, the shape and position of shorelines are constantly modified by erosion and deposition by waves and currents. Waves are agents of erosion, transportation, and deposition of sediments. Waves can be formed by the following processes (Tulane University, n.d.; University of Alabama, 2006):

- *Wind-generated waves*—formed by shear stress between water and air when the wind speed is higher than about 3 km/hr. Factors that determine the size of waves are wind velocity, wind duration, and fetch (distance the wind blows over a continuous water surface).
- *Displacement of water*—can be caused by activities such as landslides.
- *Displacement of seafloor*—can be caused by faulting and volcanic eruptions.

[2] Available online at: http://www.epa.gov/owow/nps/agmm/index.html.

Wave refraction occurs where wave fronts approach the shore at an angle, but are bent to become more parallel to the shoreline by frictional drag on the bottom. The part of the wave in shallow water slows down because of bottom friction, while the part in the deep water keeps moving at regular speed. Wave refraction causes headland erosion and deposition in bays (Tulane University, n.d.; University of Alabama, 2006).

Nearshore currents occur in the area from the shoreline to beyond the surf zone and consist of (Tulane University, n.d.; University of Alabama, 2006):

- *Longshore currents* move parallel to shore in the same general direction as the approaching waves. They are produced by the movement of oblique waves in the surf zone, and can transport large amounts of sediment by longshore drift.
- *Rip currents* are strong, narrow currents of surface water that flow seaward through the surf into deeper water. The currents develop in areas with lower wave heights (deeper water depths).

Deposition and Erosion

Wave erosion and rivers that open into the ocean or lakes can deposit sediment, transported by longshore currents, developing the following depositional features (Tulane University, n.d.; University of Alabama, 2006):

1) *Beaches*—Any strip of sediment that extends from the low-water line inland to a cliff or zone of permanent vegetation, which is built of material eroded by waves from the headlands, and material brought down by rivers that carry the products of weathering and erosion from the land masses. Beaches are protected from the full force of water waves but are continually modified by wave and current erosion.
2) *Spits*—A narrow ridge or embankment of sediment forming a finger-like projection from the shore into the open ocean. Spits typically develop when the sediment being carried by long-shore drift is deposited where water becomes deeper, such as the mouth of a bay.
3) *Baymouth bars*—Sand bars that form as a result of longshore drift and completely cross a bay, sealing it off from the open ocean.
4) *Tombolo*—A ridge of sand that connects two islands or an island with the mainland, formed as the result of wave refraction around an island.
5) *Tidal inlet*—A break in a spit or baymouth bar, caused by storm erosion, through which tidal currents rush.
6) *Barrier islands*—Low offshore ridges of sediments that parallel the coast and are separated from the mainland by lagoons.

Wave erosion can also wear away land features, causing the following types of features to form (Tulane University, n.d.; University of Alabama, 2006):

1) *Sea cliffs*—formed by storm wave erosion which undercuts higher land, making it susceptible to mass wasting. Sea cliffs can erode very slowly or rapidly, depending on the rock type and wave energy.
2) *Wave-cut terrace or platform*—produced by the retreat of a sea cliff which slopes gently in a seaward direction.

3) *Headlands*—occur due to the seaward projections of shore eroded by wave refraction.

Common Natural and Anthropogenic Causes of Coastal Land Loss

Primary causes of coastal land loss, including both natural and anthropogenic causes, are summarized in Table 2.1 below (USGS, 2004).

Table 2.1 Common Causes of Coastal Land Loss

Agent	Examples
Natural Causes	
Erosion	Waves and currents, storms, landslides
Sediment reduction	Climate change, stream avulsion, source depletion
Submergence	Land subsidence, sea-level rise
Wetland deterioration	Herbivory, freezes, fires, saltwater intrusion
Anthropogenic Causes	
Transportation	Boat wakes, altered water circulation
Coastal construction	Sediment deprivation (bluff retention), coastal structures (jetties, groins, seawalls)
River modification	Control and diversion (dams, levees)
Fluid extraction	Water, oil, gas, sulfur
Climate alteration	Global warming and ocean expansion, increased frequency and intensity of storms
Excavation	Dredging (canals, pipelines, drainage), mineral extraction (sand, shell, heavy mines)
Wetland destruction	Pollutant discharge, traffic, failed reclamation, burning

Shorelines can also experience increased rates of erosion as a result of hydromodification activities. Alterations to the sediment sources for beaches can result in erosion. The sediment supplied to beaches or shorelines can come from a variety of sources including rivers, cliff and rocky foreshores, the seafloor, or windblown dune materials. Beaches and shorelines at the mouth of a river are often replenished by fluvial sediment. When changes within the river system decrease the sediment load carried to the mouth of the river, the result may be decreased sediment supplies to the shoreline or beach. While the design of each hydromodification system determines the impacts that will ensue, streambank and shoreline erosion is a common consequence.

Impacts Associated with Dams

The physical presence and operation of dams can result in changes in water quality and quantity. Some of the water quality impacts include changes in erosion, sedimentation, temperature, dissolved gases, and water chemistry. Examples of biological and habitat impacts, which may result from a combination of physical and chemical changes, include loss of habitat for existing or desirable fish, amphibian, and invertebrate species; changes from cold water to warm water species (or inversely, changes from warm water to cold water species); blockage of fish passage; or loss of spawning or necessary habitat.

The impacts associated with dams occur above (upstream) and below (downstream) the dam. Upstream impacts occur primarily in the impoundment/reservoir created by the presence and operation of the dam. The area and depth of the impoundment will determine the extent and complexity of the upstream and downstream impacts. For example, small, low-head dams with little impounded areas will exhibit different impacts than large storage dams. Sedimentation and fish passage issues at the smaller, low-head dam contrast with sedimentation, temperature, fish passage, flow regulation, and water quality issues that may be associated with the larger storage dam. The existence of the dam and associated impoundment results in much different water quality interactions than those associated with the preexisting naturally flowing streams or rivers.

Above dams, activities within the watershed can have significant impacts on water quality within impoundments and in releases from dams to downstream areas. Watershed activities, such as agricultural land use, unpaved rural roads, forestry harvesting, or urbanization can lead to changes in runoff water quantity and quality. Agricultural and forestry practices that lead to sediment-laden runoff may result in increased sediment accumulation within an impoundment. Chemicals (e.g., pesticides and nutrients) that are applied on agricultural crops can be carried with sediment in runoff. Increases in urbanization that result in more impervious areas within a watershed often result in dramatic changes in the quantity and timing of runoff flows. These external sources are integrated by the dam and may result in short- and long-term water quality changes within an impoundment and dam releases.

Water quality in reservoirs and releases from dams are closely linked and scrutinized to uses of the water. Often, there are multiple potential users who may have differing quality needs and perceptions. Management of dams includes balancing dam operations, watershed activities, reservoirs, and downstream water and uses. Dortch (1997) provides an excellent assessment on water quality considerations in *Reservoir Management*. Dortch (1997) notes the following about water quality:

- *Temperature* regulates biotic growth rates and life stages and defines fishery habitat (warm, cool, and cold water).
- *Oxygen* sustains aquatic life.
- *Turbidity* affects light transmission and clarity.
- *Nutrient enrichment* is linked to primary productivity (algal growth) and can cause oxygen depletion, poor taste, and odor problems.
- *Organic chemicals and metals* may be toxic and accumulate when bound to sediment that settles in the reservoir.
- *Total dissolved solids* may be problematic for water supplies and other users.
- *Total suspended solids* are a transport mechanism for nutrients and contaminants. Solids may settle in reservoirs and displace water storage volume.
- *pH* regulates many chemical reactions.
- *Dissolved iron, manganese, and sulfide* can accumulate in reservoir hypolimnions that are depleted of oxygen and can cause water quality problems in the reservoir and release water.
- *Pathogens* include bacteria, viruses, and protozoa that can cause public health problems.

Water uses include water supply, flood control, hydropower, navigation, fish and wildlife conservation, and recreation (Dortch, 1997). All of the uses have varying water quality requirements, ranging from almost none for flood control to high quality needs for water supply, fish and wildlife conservation, and recreation.

Dams act as a barrier to the flow of water, as well as to materials being transported by the water. This can impact water quality both in the impoundment/reservoir created by the dam and downstream of the dam. Alteration to the chemical and physical qualities of water held behind a dam is often a function of the retention time of a reservoir or the amount of time the water is retained and not able to flow downstream. Water held in a small basin behind a run-of-river dam may undergo minimal alteration. In contrast, water stored for months or even years behind a large storage dam can undergo drastic changes that impact the downstream environment when released (McCully, 2001). A storage dam that impounds a large reservoir of water for an extended time period will cause more extensive impacts to the physical and chemical characteristics of the water than a smaller dam with little storage capacity.

Several physical changes are possible when dams are introduced into a stream or river, including changes in:

- Instream water velocities
- Timing and duration of flows
- Flow rates
- Sediment transport capacities
- Turbidity
- Temperature
- Dissolved gasses

Similarly, changes to water chemistry are possible as a result of damming rivers and streams, including changes to:

- Nutrients
- Alkalinity and pH
- Metals and other toxic pollutants
- Organic matter

The nature and severity of impacts will depend on the location in the river or stream, in relation to the upstream or downstream side of the dam, the storage time of the impounded water, and the operational practices at the dam. Many of the above impacts are also interrelated. For example, changes in temperature may result in changes in dissolved oxygen levels or changes to pH may result in changes to nutrient dynamics and the solubility of metals.

Water Quality in the Impoundment/Reservoir

As water approaches a dam from upstream, the stream velocity slows down considerably, creating a lake-like environment. The water builds up behind the dam and forms a basin (i.e., impoundment, reservoir) that is deeper than the previous stream flow. The height of the dam and its operational characteristics will determine how much water is stored and the length of storage. The extent of impacted stream area above the dam is influenced by the size of the dam installed, how much water is released, and how often water is released. For example, a small run-of-the river dam constructed to divert water for a millrace will have minimal storage capacity and may only store water for several hours or less. In this case, instream water velocities may decrease, but with minimal upstream and downstream effects. Thus, the length of upstream channel that is impacted should be relatively small.

In contrast, a large flood control dam and reservoir may have many months of storage and severely alter instream velocities for long distances upstream. Topography surrounding the original stream channel and storage volume will be important parameters determining the length of stream channel affected by the large dam. The volume and frequency of discharges from the dam will also determine how much of the upstream channel is impacted with lower instream velocities as a result of the dam.

Dams act as a physical barrier to the movement of suspended sediments and nutrients downstream (McCully, 2001). When the stream flow behind a dam slows, the sediment carrying capacity of the water decreases and the suspended sediment settles onto the reservoir bottom. Any organic compounds, nutrients, and metals that are absorbed to the sediment also settle and can accumulate on the reservoir bottom.

Turbidity associated with sediment varies, depending on particle sizes of the sediment and the length of time water is held. Longer holding times in the reservoir could result in periodic episodes of high turbidity from upstream storm events that carry sediment rich stormwater, especially if the sediment is predominantly very fine clay particles. Turbidity may also increase as a result of planktonic algal growth in a reservoir.

The increased depth of the water in reservoirs reduces the volume of water exposed to solar radiation and ambient temperatures. Once the flow is controlled by the operation of the dam and the reservoir is mixed primarily by winds, temperature variations can become established within the reservoir. This can cause thermal stratification where, compared to the bottom, surface layers become warmer in the summer and cooler in the winter. In deeper reservoirs, the deepest layers may become nearly constant in temperature throughout the year. Changes in temperature can impact water quality and biological processes in the reservoir, including changes in predominant fish species. Since the density of water is a function of water temperature, thermal stratification creates density gradients within the impoundment. As density gradients become established, exchanges of gases and chemicals between gradients decrease. In a stratified impoundment well aerated surface waters often do not mix with hypolimnetic water and result in poorly oxygenated strata below the surface waters.

Nutrient transport is affected by dams, which can trap the nutrients in the impoundment/reservoir. When nutrients accumulate, the reservoir might become nutrient enriched (i.e., eutrophic). In warmer seasons, concentrated nutrients in waters exposed to light can promote growth of algae and other aquatic plants, which consume nutrients and release oxygen (during photosynthesis) and carbon dioxide (during respiration). When algae and other aquatic plants complete their growth cycles, they die and sink to the bottom of an impoundment. Microbial decomposition of the highly organic dead plant materials may release nutrients back into the water column. Microbial decomposition of the dead plant and algal cells in aerobic conditions consumes oxygen, which can rapidly deplete bottom waters of dissolved oxygen. Under anaerobic conditions, microbial decomposition can produce potentially toxic concentrations of gases, such as hydrogen sulfide.

The operational characteristics of a dam will influence nutrient levels in water releases. For example, water released from the surface of an impoundment may contain seasonally varying forms and levels of nutrients. During periods of algal growth, releases may contain lower levels of dissolved nutrients and higher levels of organic materials (algae) containing nutrients. When algal growth is not occurring, releases may contain higher levels of dissolved nutrients.

Anaerobic (oxygen-depleted) environments, which are typical of deeper waters in reservoirs, can result in several changes to the water chemistry. For example, as by-products of organic matter decomposition in an anaerobic environment, ammonia and hydrogen sulfide concentrations can become elevated (Freeman, 1977; Pozo et al., 1997). Highly acidic (or highly alkaline) waters tend to convert insoluble metal sulfides to soluble forms, which can increase the concentration of toxic metals in reservoir waters (FISRWG, 1998).

Changes in one water quality parameter in a reservoir/impoundment can impact other water quality parameters, causing a cycling of events to occur. For example, increased sedimentation (from internal or external sources) can lead to more organic matter remaining in the reservoir, resulting in more biochemical oxygen demand, potentially lower dissolved oxygen, and other changes to water chemistry, such as pH and metal solubility. Periodic growth and then die-off of aquatic plants and algae creates additional variable cycling of organic matter in the reservoir. The following references may provide additional detail on the complex water quality changes that can occur in impoundments and reservoirs:

- Holdren, C., W. Jones, and J. Taggart. 2001. *Managing Lakes and Reservoirs*. North American Lake Management Society and Terrene Institute, in cooperation with the Office of Water, Assessment and Watershed Protection Division, U.S. Environmental Protection Agency, Madison, WI.
- Thornton, K.W., B.L. Kimmel, and F.E. Payne. 1990. *Reservoir Limnology: Ecological Perspectives*. John Wiley & Sons, Inc., New York.
- U.S. Army Corps of Engineers. N.d. *The WES Handbook on Water Quality Enhancement Techniques for Reservoirs and Tailwaters*. U.S. Army Corps of Engineer Research and Development Center Waterways Experiment Station, Vicksburg, MS.

Water Quality Downstream of a Dam

The physical and chemical changes that occur to the water quality in an impoundment/reservoir have a large impact on the water released downstream of a dam. As previously stated, the presence of a dam can alter water velocities above and below the dam. In smaller dams with little storage capacity, velocities may slow locally and recover to an undisturbed state shortly downstream from the dam. When dams store large volumes of water in a reservoir, the operation of the dam will have a major impact on the downstream velocities and flows. Unless the dam is operated to consistently release water at flows near pre-dam levels, downstream areas will have flows and velocities that are directly related to the volume of water released in a given time period. The downstream flow characteristics will become a function of the operation of the dam, including the timing and duration of releases, the depth of reservoir intakes, and other physical characteristics of the release.

> *On the Columbia River, research found that prior to construction of dams, average water temperatures fluctuated more diurnally with cooler nighttime temperatures as compared with the existing average water temperatures. With the dams in place, cooler weather tends to cool the free flowing river but have little effect on the average temperature of the impounded river (USEPA, 2003c).*

When dams trap sediment upstream, water released from the dam may be starved of sediment and have an increase in erosive capacity. Along with trapping sediment, nutrients may also be trapped above the dam. When the nutrients are trapped and unavailable, sensitive downstream habitats and populations may be affected.

Whether the water is released from the surface or bottom of the reservoir can have a large impact on the characteristics of the water. The impacts of water outflows below a dam are an outcome of the seasonal temperature fluctuations and the outflow positioning. Seasonal temperature profiles in reservoirs are highly variable and dependent upon a complex set of factors including tributary inflow, basin morphometry, drawdown and discharge characteristics, and the degree of stratification (Wetzel, 2001). Compared to natural temperatures, in summer elevated temperatures in surface water releases can increase downstream river temperatures, whereas bottom water releases can be expected to decrease water temperatures. The opposite effect is generally observed in the winter due to changes in the water temperature gradient (USACE, 1999 in Fidler and Oliver, 2001).

Suspended Sediment and Reduced Discharge

Whether the release water originates from the surface or the bottom of the reservoir, the suspended sediment has typically settled out of the water column and thus the water released from behind the dam is usually relatively free from sediment (Simons and Senturk, 1992). This sediment-free water can easily pick up and carry a sediment load and have an increase in erosive capacity. Because of the rock lined channels of bank stabilization and navigation projects that usually occur below these reservoirs, the only place that the clear waters can find the sediments they need is in the streambed or navigation channel. This leads to channel deepening or bed degradation, which in turn lowers water tables and drains floodplain channels and backwaters (Rasmussen, 1999). Streambed and streambanks will continue to erode until an equilibrium suspended sediment load is established. Without sediment from upstream sources, downstream streambanks, streambeds, sandbars, and beaches can erode away more quickly (FISRWG, 1998).

A reduction in the discharge and sediment load generally results in degradation of the channel close to the dam and sedimentation downstream due to the increased supply from the erosion near the dam. Degradation may eventually migrate downstream, but is typically most dramatic the first few years following construction of the dam (Biedenharn et al., 1997). In addition, the physical impact of the discharge will depend, in part, on the channel substrate. A fine silt and sand channel bottom may experience more extensive erosion than a bed rock or cobble substrate.

Lower flow conditions below a dam within a tidally influenced basin can lead to changes in water chemistry. The impact of lower freshwater flow into estuaries was extensively studied in San Francisco Bay. Nichols et al. (1986) provide a detailed history of changes to freshwater inflows to San Francisco Bay. They also provide a summary of the impacts, which include the ecological and water quality effects. A study comparing an unregulated river and a dam regulated river found a significant difference in the water quality chemistry, including an analysis of levels of sodium, potassium, calcium, phosphorus, electrical conductivity, and pH in the middle and lower reaches of the rivers. These differences were attributed to increased tidal influence as a result of lower outflow volumes of fresh water from the dam (Colonnello, 2001). In addition, a decreased discharge from the dam and increased tidal influence can prolong the flushing time or the time it takes water to move through a system. This causes the nutrients and pollutants within the water to remain concentrated in areas below the dam near an estuary.

Biological and Habitat Impacts

The presence of a dam may cause physical and chemical changes to the water quality. These, in turn, can have an impact on the entire biological community including fish, macroinvertebrates, algae, and streamside vegetation. Impacts to the biological community differ upstream and downstream of a dam. Dams may disrupt spawning, increase mortalities from predation, change instream and riparian habitat, and alter plant and benthic communities. Resulting fish populations after dam construction may thrive and become well established, but could be very different than populations prior to installing the dam. For example, upstream of the dam, a fish population may change from a cold-water salmonid fishery to one that is dominated by cool- or warm-water species. A once thriving native trout population may become a largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*) dominated system. Similarly, downstream conditions may also change. In southern states, streams that once supported catfish and other tolerant warm-water species may now be able to support a trout fishery because of cold-water releases from bottom waters behind a dam. Although the trout fishery may be viewed as positive by some, the displaced native warmwater species may not be perceived as beneficial.

Dams prevent the movement of organisms throughout the river system (Morita and Yamamoto, 2002). Researchers found that fragmenting habitat by damming a river caused the disappearance of a fish species in several upstream locations and further disappearances were predicted (Morita and Yamamoto, 2002). Recently, some individual cases involving movement of invasive, non-native aquatic species note the presence of dams as a positive factor. In these cases, dams have blocked the movement of potentially harmful invasive species.

Flood control and hydropower projects influence a river's hydrograph. For example, in some regions normal river hydrographs featured a rise in water level elevation corresponding to spring rains. Other geographic areas had stream hydrographs corresponding to snowmelt in the mountains, or fall rainfall. Native species evolved under these scenarios and used such water level rises to trigger spawning movements onto floodplains and in the case of birds, for nesting on islands. Additionally, the stream water level fluctuations were important in providing feeding and resting areas for spring and fall waterfowl migrations. Under managed scenarios for commercial navigation, river water level elevations are raised in the spring and held stable throughout the navigation season, virtually eliminating the triggering mechanisms native species used to reproduce and complete their life cycles. Because of this, many native riverine species often fail to spawn or nest, and are becoming increasingly threatened (Rasmussen, 1999). Additionally, stabilization of periodic flooding has also lead to the loss of ephemeral wetlands and may lead to the accumulation of sediments in nearshore areas, thus negatively affecting fish spawning areas (NRC, 1992).

Dams may lead to increased predation of fish in several ways. A dam may cause populations of fish to concentrate on the upstream and downstream sides, which might lead to the likelihood of increased predation. Changes in the habitat adjacent to a dam can make conditions more suitable to predation. Dams may cause the migration process to be delayed, which also leads to increased predation (Larinier, 2000).

The physical and chemical changes to water released from a dam, including reduced streamflow variability and decreased sediment loads, may also impact benthic communities. Increased water clarity and reduced streamflow variability just below a dam may result in a greater abundance of periphyton or other plants as compared with other locations in the river (Stanford and Ward, 1996). A slowed stream flow velocity with decreased turbulence can also encourage the growth of phytoplankton blooms (Décamps et al., 1988). In contrast, the operation of some hydroelectric dams with large, sudden releases of water may scour the bottom of the downstream channel to the extent that there is a nearly complete removal of the plant communities (Allan, 1995).

Impacts Associated with Dam Removal

Removing a dam affects the flow of water, movement of sediment and chemical constituents, and the overall channel morphology (Academy of Natural Sciences, 2002) on the waterway where the dam was located. The impacts of removing a dam differ for the upstream and downstream sections of a waterway.

Changes in the biological community following the removal of a dam are difficult to generalize, as they are highly site specific and can vary in recovery time from a few months to

> The effects of river damming were evaluated in a study comparing a regulated river to an unregulated river in the Green River Basin in Colorado. Prior to installation of the dam in Green River in 1962, Green River and the Yampa River were similar in riparian vegetation and fluvial processes. Comparison of the now regulated Green River and the free-flowing Yampa River found distinctive vegetation differences between the parks that surround the rivers. The channel form of Green River has undergone three stages of morphologic change that have transformed the historically deep river into a shallow braided channel. The Yampa River has remained relatively unchanged. The land surrounding the Green River now consists of marshes with anaerobic soil that supports wetland species and terraces with desert species adapted to xeric soil conditions. The meandering Yampa River has maintained its original surroundings. Its frequently flooded bars and high floodplains provide a wide range of habitats for succession of riparian vegetation (Merritt and Cooper, 2000).

more than a decade. With the removal of a dam, there are changes in the vegetative community surrounding the stream channel and changes in the biological community within the stream itself.

Physical Changes: Upstream Impacts

The removal of a dam allows the water formerly held behind the dam to flow and will likely cause the extent of the impoundment area or reservoir area to decrease. As a dam is removed and the water recedes, sediment is scoured from the bottom and a stream channel returns sometimes to its pre-dam pathway and sometimes to a newly carved channel. As a channel is formed, areas that were formerly beneath the impoundment area become exposed. This can leave large areas of unvegetated and unstable land exposed, which makes these areas likely to undergo erosion and gully development, increasing the sediment load to the stream.

In time, vegetation will stabilize the newly formed stream banks, reducing erosion and allowing sediment transport levels to return to natural levels. The nutrient and metal constituents associated with the sediment will also return to natural levels. As the newly established channel-like flow develops and the stagnant and deep conditions are removed, the natural temperature and oxygen levels will be reestablished.

Physical Changes: Downstream Impacts

Once the physical barrier of the dam is removed, a river can flow unrestricted. As the channel is reformed, the water discharge volume and the stream channel can reach equilibrium. As a result, a more natural stream flow rate is maintained.

With the removal of a dam, the fate of the trapped sediments is of concern because flooding and downstream pollution problems can result. On a short-term time scale, the redistribution of the fine silt and sand sediments that accumulated behind the dam wall may cause an increase in turbidity and water quality problems. In addition, the impact can be greater if the sediments contain toxic pollutants, such as metals or bioaccumulative compounds such as mercury or PCBs. On a short-term time scale, the redistribution of the fine silt and sand sediments increases the turbidity and can damage spawning grounds, water quality, habitat, and food quality (American Rivers, 2002a). Suspended sediment loads can have a negative impact on a biological community and reach lethal levels during dam removal if preventive measures are not implemented (Doyle et al., 2000).

After a dam is removed and the sediment that has been trapped behind the dam is redistributed, natural sediment transport levels return. As a result, the constituents typically sorbed to sediment, including nutrients and metals, are no longer found localized in excess. Normal sediment transport levels typically result in a river bottom with a higher percentage of rocky substrate. Gravel and cobblestones located below the sediment may be exposed or may be transported from upstream locations as the flow rate of the river increases. This unrestricted flow and transport of sediment and gravel may also play a key role in restoring sediments to downstream locations and coastal beaches (USDOI, 1995). The removal of a dam and the return of natural flow rates should also help to restore a river's natural water temperature range and oxygen levels.

Short-term chemical changes to the water quality, including the possibility of supersaturation of nitrogen gas directly following the removal of a dam, can cause aquatic animals to experience adverse conditions. This can include gas bubble disease, in which nitrogen bubbles form in the blood and tissues and block capillaries by embolism (Colt, 1984; Soderberg, 1995). Adverse effects can be seen when the dissolved nitrogen level reaches 102% and at 105% widespread fish mortalities are possible (Dryden Aqua, 2002). Supersaturation was an issue in the 1992 removal of Little Goose Dam on the Snake River (American Rivers, 2002a). If a reservoir is drawn down slowly, the severity of the impact of supersaturation on aquatic organisms can be lessened (American Rivers, 2002a).

Biological Changes: Upstream Impacts

Following the removal of a dam, a return to the normal temperature range, flow rates, and oxygen levels supports the return of native aquatic vegetation species. Still water impoundments support aquatic vegetation that is free floating or that does not need to be strongly rooted, while free-flowing systems support plants that are rooted strongly enough to resist being uprooted by the water current (WRM, 2000).

As the water recedes and the formerly impounded area becomes exposed, vegetation can begin to colonize the area. Sometimes, the exposed area may be colonized by invasive plant species, which are able to remain for several years and prevent other vegetation from becoming established.

The removal of a dam and the subsequent drawdown of water from the impoundment area can affect the wetlands formerly bordering the impoundment area. As the dam is removed, the water table typically begins to drop. The elevation of the wetlands and the extent of the water table drawdown determine whether the wetland areas dry up and what changes will occur in the wetland species composition. Wetlands that develop alongside the newly carved channel are likely to be different than the wetlands formerly bordering the impoundment area in terms of plant and animal species composition.

The biological changes associated with the removal of a dam can be described in phases, as the waterbody makes the transition from reservoir to river. This includes a pattern of relatively rapid recovery for invertebrates or short-lived taxa, followed by a second phase of slower recovery for fish or longer-lived taxa if the dam removal is not an especially large or disruptive event. Overall, the initial impacts, such as colonization by invasive species, typically determine the ecological recovery that follows (Doyle et al., 2000).

Dam removal can allow for improved fish passage and unrestricted fish movement that provides access to spawning habitat upstream. For coastal rivers, the removal of a dam may enable tidal waters to reach upper portions of the stream that were formerly cut off by the dam, creating a spawning environment preferred by certain fish species. Access to upstream sections is particularly beneficial for some anadromous fish that live most of their lives in saltwater and swim upstream toward freshwater to spawn (Massachusetts River Restore Program, 2002).

A dam can also act as a barrier between upstream and downstream fish populations. If a downstream community of fish is an invasive fish species the dam serves as a physical barrier to separate the invasives from the upstream community (American Rivers, 2002a). Thus, the removal of the dam can negatively impact the ecosystem if it allows for the movement of a population of an invasive species that was previously prevented from traveling to a section of the stream because of the presence of a dam.

Biological Changes: Downstream Impacts

Downstream of the former dam, wetlands are likely to reappear along side the stream channel where they occurred prior to the construction of the dam (WRM, 2000). Revegetation of river beds and banks typically occurs within one growing season, following removal of a dam (Massachusetts River Restore Program, 2002).

Recolonization of the stream banks by vegetation affects the biological community within the stream by providing shade, reducing water temperatures, and supplying a source of woody debris and organic matter to the stream.

As streamside vegetation begins to recover and suitable habitat is restored, fish begin to return. Changes in flow as a result of dam removal lead to the development of side channels and ponds that provide habitat for fish and wildlife. Increased flow rates also allow for the transport of larger debris, including gravel and logs, which create spawning beds and pool and riffle habitat (River Recovery, 2001). In addition, the rocky substrate environment, which is typically exposed as a result of dam removal, provides habitat for aquatic insects and spawning fish. In the long term, the return to natural stream temperatures, oxygen levels, and flow rates all contribute to the reestablishment of a healthy aquatic and riparian ecosystem.

Chapter 3: Channelization and Channel Modification

Channelization and channel modification describe river and stream channel engineering undertaken for flood control, navigation, drainage improvement, and reduction of channel migration potential. Activities that fall into this category include straightening, widening, deepening, or relocating existing stream channels and clearing or snagging operations. These forms of hydromodification typically result in more uniform channel cross-sections, steeper stream gradients, and reduced average pool depths. Channelization and channel modification also refer to the excavation of borrow pits, canals, underwater mining, or other practices that change the depth, width, or location of waterways, or embayments within waterways.

Channelization and channel modification activities can play a critical role in nonpoint source pollution by increasing the downstream delivery of pollutants and sediment that enter the water. Some channelization and channel modification activities can also cause higher flows, which increase the risk of downstream flooding.

Channelization and channel modification can:

- Disturb stream equilibrium
- Disrupt riffle and pool habitats
- Create changes in stream velocities
- Eliminate the function of floods to control channel-forming properties
- Alter the base level of a stream (streambed elevation)
- Increase erosion and sediment load

Many of these impacts are related. For example, straightening a stream channel can increase stream velocities and destroy downstream pool and riffle habitats. As a result of less structure in the stream to retard velocities, downstream velocities may continue to increase and lead to more frequent and severe erosion.

Management Measure 1: Physical and Chemical Characteristics of Channelized or Modified Surface Waters

Management Measure 1
1) Evaluate the potential effects of proposed channelization and channel modification on the physical and chemical characteristics of surface waters. 2) Plan and design channelization and channel modification to reduce undesirable impacts. 3) Develop an operation and maintenance program for existing modified channels that includes identification and implementation of opportunities to improve physical and chemical characteristics of surface waters in those channels.

This management measure applies to proposed channelization or channel modification projects and is intended to occur concurrently with the implementation of Management Measure 2 (Instream and Riparian Habitat Restoration). The intent of the management measure is for project planners to consider potential changes in surface water characteristics when evaluating proposed channelization or channel modification projects. Also, for existing modified channels, the planning process can include consideration of opportunities to improve the surface water characteristics necessary to support desired fish and wildlife.

The purpose of the management measure is to ensure that the planning process for new hydromodification projects addresses changes to physical and chemical characteristics of surface waters that may occur as a result of proposed work. For existing projects, this management measure can be used to ensure the operation and maintenance program uses any opportunities available to improve the physical and chemical characteristics of the surface waters.

Changes created by channelization and channel modification activities are problematic if they unexpectedly alter environmental parameters to levels outside normal or desired ranges. The physical and chemical characteristics of surface waters that may be influenced by channelization and channel modification include sedimentation, turbidity, salinity, temperature, nutrients, dissolved oxygen, oxygen demand, and contaminants. Changes in natural sediment supplies, reduced freshwater availability, and accelerated delivery of pollutants are examples of the types of changes that can be associated with channelization and channel modification.

Published case studies of existing channelization and channel modification projects describe alterations to physical and chemical characteristics of surface waters (Burch et al., 1984; Petersen, 1990; Reiser et al., 1985; Roy and Messier, 1989; Sandheinrich and Atchison, 1986; Sherwood et al., 1990; Shields et al., 1995). Frequently, the post-project conditions are intolerable to desirable fish and wildlife. The literature also describes instream benefits for fish and wildlife that can result from careful planning of channelization and channel modification projects (Bowie, 1981; Los Angeles River Watershed, 1973; Sandheinrich and Atchison, 1986; Shields et al., 1990; Swanson et al., 1987; USACE, 1989).

Management Practices for Management Measure 1

Implementation of this management measure should begin during the planning process for new projects. For existing projects, implementation of this management measure can be included as part of a regular operation and maintenance program. The approach is two-pronged and should include:

1. Planning and evaluation, with numerical models for some situations, of the types of nonpoint source (NPS) pollution related to instream changes and watershed development.

2. Operation and maintenance programs that apply a combination of nonstructural and structural practices to address some types of NPS problems stemming from instream changes or watershed development.

Planning and Evaluation

> Use models/methodologies as one means to evaluate the effects of proposed channelization and channel modification projects on the physical and chemical characteristics of surface waters. Evaluate these effects as part of watershed plans, land use plans, and new development plans.

In planning-level evaluations of proposed hydromodification projects, it is critical to understand that the surface water quality and ecological impact of the proposed project will be driven primarily by the alteration of physical transport processes. In addition, it is critical to realize that the most important environmental consequences of many hydromodification projects will occur over a long-term time scale of years to decades.

The key element in the selection and application of models for the evaluation of the environmental consequences of hydromodification projects is the use of appropriate models to adequately characterize circulation and physical transport processes. Appropriate surface water quality and ecosystem models (e.g., salinity, sediment, cultural eutrophication, oxygen, bacteria, fisheries, etc.) are then selected for linkage with the transport model to evaluate the environmental impact of the proposed hydromodification project. There are several sophisticated two-dimensional (2D) and three-dimensional (3D) time-variable hydrodynamic models available for environmental assessments of hydromodification projects. Two-dimensional depth or laterally averaged hydrodynamic models can be routinely applied to assist with environmental assessments of beneficial and adverse effects on surface water quality by knowledgeable teams of physical scientists and engineers (Hamilton, 1990). Three-dimensional hydrodynamic models are also beginning to be more widely applied for large-scale environmental assessments of aquatic ecosystems (e.g., EPA/USACE-WES Chesapeake Bay 3D hydrodynamic and surface water quality model).

Refer to Chapter 8 for a list of some models available for studying the effects of channelization and channel modification activities (Table 8.1). Chapter 8 also provides examples of channelization and channel modification activities and associated models that can be used in the planning process.

Operation and Maintenance Programs

Several management practices can be implemented to avoid or mitigate the physical and chemical impacts generated by hydromodification projects. Many of these practices have been engineered and used for several decades, not only to mitigate human-induced impacts but also to rehabilitate hydrologic systems degraded by natural processes.

In cases where existing channelization or channel modification projects can be changed to enhance instream or streamside characteristics, several practices can be included as a part of regular operation and maintenance programs. New channelization and channel modification projects that are predicted to cause unavoidable physical or chemical changes in surface waters can also use one or more practices to mitigate the undesirable changes. Some of the types of practices include:

- Grade control structures
- Levees, setback levees, and floodwalls
- Noneroding roadways
- Streambank protection and instream sediment load controls
- Vegetative cover

Grade Control Structures

There are two basic types of grade control structures. The first type can be referred to as a bed control structure because it is designed to provide a hard point in the streambed that is capable of resisting the erosive forces of the degradational zone. The second type can be referred to as a hydraulic control structure because it is designed to function by reducing the energy slope along the degradational zone to the point where the stream is no longer capable of scouring the bed. The distinction between the operating processes of these two types is important whenever grade control structures are considered (Biedenharn and Hubbard, 2001).

Design considerations for siting of grade control structures include determining the type, location, and spacing of structures along the stream, along with the elevation and dimensions of structures. Siting grade control structures can be considered a simple optimization of hydraulics and economics. However, these factors alone are usually not sufficient to define optimum siting conditions. Hydraulic considerations must be integrated with a host of other factors that can vary from site to site to determine the final structure plan. Some of the more important factors to be considered when siting grade control structures are discussed more specifically in the U.S. Army Corps of Engineers' *Design Consideration for Siting Grade Control Structures* (Biedenharn and Hubbard, 2001).

When carefully applied, grade control structures can be highly versatile in establishing human and environmental benefits in stabilized channels. To be successful, application of grade control structures should be guided by analysis of the stream system both upstream and downstream from the area to be reclaimed (CASQA, 2003).

In some cases, grade control structures can be designed to allow fish passage. However, some grade control structures can obstruct fish passage. In many instances, fish passage is a primary consideration and may lead engineers to select several small fish passable structures in lieu of one or more high drops that would restrict fish passage. In some cases, particularly when drop heights are small, fish are able to migrate upstream past a structure during high flows. In situations where structures are impassable, and where the migration of fish is an important concern, openings, fish ladders, or other passageways must be incorporated into the structure's design (Biedenharn and Hubbard, 2001). Fish passage practices are described in Chapter 7.

A type of grade control structure is a check dam. Refer to Chapter 7 for more information about this practice.

Levees, Setback Levees, and Floodwalls

Levees are embankments or shaped mounds constructed for flood control or hurricane protection (USACE, 1981). Setback levees and floodwalls are longitudinal structures used to reduce flooding and minimize sedimentation problems associated with fluvial systems. These practices can be used to reduce the impacts of channelization and channel modification. A more detailed discussion of levees, setback levees, and floodwalls is available in Chapter 7.

Noneroding Roadways

Disturbances along the streambank that result from activities associated with operation and maintenance of channelization projects can lead to additional nonpoint source pollution impacts to the stream. An example of human-induced activities is erosion associated with roadways. Rural road construction, streamside vehicle operation, and stream crossings usually result in significant soil disturbance and create a high potential for increased erosion processes and sediment transport to adjacent streams and surface waters. Erosion during and after construction of roadways can contribute large amounts of sediment and silt to runoff waters, which can deteriorate water quality and lead to fish kills and other ecological problems (USEPA, 1995b).

Road construction involves activities such as clearing of existing native vegetation along the road right-of-way; excavating and filling the roadbed to the desired grade; installation of culverts and other drainage systems; and installation, compaction, and surfacing of the roadbed.

Although most erosion from roadways occurs during the first few years after construction, significant impacts may result from maintenance operations using heavy equipment, especially when the road is located adjacent to a waterbody. In addition, improper construction and lack of maintenance may increase erosion processes and the risk for road failure. To minimize erosion and prevent sedimentation impacts on nearby waterbodies during construction and operation periods, streamside roadway management needs to combine proper design for site-specific conditions with appropriate maintenance practices. A discussion of how roadways can impact fish habitat and passage is available from EPA's *National Management Measures to Control Nonpoint Source Pollution from Forestry* (USEPA, 2005a).

More information about suggested practices to consider during design, construction, operation and maintenance, and general maintenance of noneroding roadways, is available from EPA's *National Management Measures to Control Nonpoint Source Pollution from Forestry* (USEPA, 2005a). This EPA guidance document also provides some suggested permanent control BMPs that may be used to prevent erosion from roadways. Additional information about noneroding roadways is available in Chapter 7 and the Resources section of this document.

Streambank Protection and Instream Sediment Load Controls

Streambank erosion is a natural process that occurs in fluvial systems. Streambank erosion can also be induced or exaggerated as a result of human activities. There are several factors within a watershed that can contribute to human induced streambank erosion. Accelerated streambank erosion related to human activity can typically be attributed to three major causes including channel modifications, reservoir construction, and land use changes (Henderson, 1986). When possible, streambank erosion problems should be addressed in the context of the entire watershed, using a systems approach that considers and accommodates natural stream processes. Approaches to addressing streambank erosion problems associated with channelization and channel modification activities can involve efforts to identify and address all significant contributing factors in addition to treating the immediate symptom, bank erosion.

In general, the design of streambank protection may involve the use of several techniques and materials. Nonstructural or programmatic management practices for the prevention of streambank failures include:

- Protection of existing vegetation along streambanks
- Careful use or regulation of irrigation near streambanks, such as rerouting of overbank drainage
- Minimization of loads on top of streambanks (such as prevention of building within a defined distance from the streambed)

Several structural practices are used to protect or rehabilitate eroded banks. These practices are usually implemented in combination to provide stability of the stream system, and they can be grouped into direct and indirect methods. Direct methods place protecting material in contact with the bank to shield it from erosion. Indirect methods function by deflecting channel flows away from the bank or by reducing the flow velocities to nonerosive levels (Henderson, 1986; Henderson and Shields, 1984). Indirect bank protection requires less bank grading and tree and snag removal. However, some structural methods like stone toe protection, as discussed below, can be placed with minimal disturbance to existing slope, habitat, and vegetation.

Feasibility of the practices at a site depends on the engineering design of the structure, availability of the protecting material, extent of the bank erosion, and specific site conditions such as the flow velocity, channel depth, inundation characteristics, and geotechnical characteristics of the bank. The use of vegetation alone or in combination with other structural practices, when appropriate, could further reduce the engineering and maintenance efforts.

Vegetation can be considered with respect to site-specific characteristics. When vegetation is combined with low cost building materials or engineered structures, numerous techniques can be created for streambank erosion control. It is important to consider the assets and limitations when planning to use planted vegetation for streambank protection. Advantages of vegetation include the following (Allen and Leech, 1997):

- Reinforces soil (increases bank stability).
- Increases resistance to flow and reduces flow velocities (from exposed stalks), causing the flow to dissipate energy against the plant (rather than the soil).

- Intercepts water.
- Enhances water infiltration.
- Depletes soil water by uptake and transpiration.
- Acts as a buffer against the abrasive effect of transported materials.
- Induces sediment deposition (from close-growing vegetation).
- Reduces costs, in some cases, when compared to most structural methods.
- Improves conditions for fisheries and wildlife.
- Improves water quality.
- Protects cultural/archeological resources.

Limits of vegetation include failure to grow; being subject to undermining; being uprooted by wind, water, and the freezing and thawing of ice; ingestion by wildlife or livestock; and maintenance requirements. Chapter 3 of *Bioengineering for Streambank Erosion Control* discusses plant acquisition, handling, and timing of planting (Allen and Leech, 1997).

Streambanks can be protected or restored either by increasing resistance of the bank to erosion or by decreasing the energy of the water at the point of contact with the bank, for example by deflecting or interrupting flows (Henderson, 1986). Instream sediment can be controlled by using several structural, vegetative, or bioengineered practices, depending on the management objective and the source of sediment. Streambank protection and channel stabilization practices, including various types of revetments, grade control structures, and flow restrictors, have been effective in controlling sediment production caused by streambank erosion. Designs should match the protection capability of the treatment to the erosion potential of each stream zone. For example, riprap may be needed at the toe of a slope to protect it from undercutting combined with tree revetments to deflect flows and provide protection for live stakings that will develop permanent support. The growing body of research indicates management techniques that emulate nature and work with natural stream processes are more successful and economical.

Significant amounts of instream sediment deposition can be prevented by controlling bank erosion processes and streambed degradation. Channel stabilization structures can also be designed to trap sediment and decrease the sediment delivery to desired areas by altering the transport capacity of the stream and creating sediment storage areas. In regulated streams, alteration of the natural streamflow, particularly the damping of peak flows caused by surface water regulation and diversion projects, can increase streambed sediment deposits by impairing the stream's transport capacity and its natural flushing power. Sediment deposits and reduced flow alter the channel morphology and stability, the flow area, the channel alignment and sinuosity, and the riffle and pool sequence. Such alterations have direct impacts on the aquatic habitat and the fish populations in the altered streams (Reiser et al., 1985).

Vegetative Cover

Streambank protection using vegetation is a commonly used practice, particularly in areas of low water velocities. Vegetative cover, also used in combination with structural practices, is often relatively easy to establish and maintain, and is visually attractive (USACE, 1983). Emergent vegetation provides two levels of protection. First, the root system helps hold soil together and increases overall bank stability by forming a binding network. Second, the exposed stalks, stems, branches, and foliage provide resistance to streamflow, causing the flow to lose part of its energy by deforming the plants rather than by removing the soil particles. Above the waterline, vegetation protects against rainfall impact on the banks and reduces the velocity of the overland flow during storm events.

Vegetative controls are not suitable for all sites, especially those sites with severe erosion due to high flow rates or channel velocities. Refer to the Washington State Department of Transportation's (WSDOT's) *Hydraulics Manual*, Chapter 4[1] for information on calculating flow rates or channel velocities. Stabilization measures should only be implemented after a careful evaluation of the stream and the surrounding area. A knowledgeable fluvial geomorphologist may be helpful with this evaluation. In addition, plant species should be selected with care; native plant species should be used whenever possible. Appropriate species can be determined by consulting horticulturalists and botanists for plant selection assistance. The USDA-Forest Service guide, *A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization*[2] provides a list of plants for soil bioengineering associated systems. The International Erosion Control Association (IECA)[3] publishes a products and services directory listing sources of plant material and professional assistance.

In addition to bank stabilization, vegetation can also offer pollutant filtering capacity. Pollutants and sediment transported by overland flow may be partly removed as a result of a combination of processes including reduction in flow pattern and transport capacity, settling and deposition of particulates, and eventual nutrient uptake by plants.

Summary of Physical and Chemical Practices

All of the following practices can be used to address the effects of channelization and channel modification activities on the physical and chemical characteristics of a waterbody:

- Bank shaping and planting
- Branch packing
- Brush layering
- Brush mattressing
- Bulkheads and seawalls
- Check dams
- Coconut fiber roll
- Dormant post plantings
- Erosion and Sediment Control (ESC) Plans
- Joint plantings
- Levees, setback levees, and floodwalls
- Live cribwalls
- Live fascines
- Live staking
- Noneroding roadways
- Return walls

[1] http://www.wsdot.wa.gov/eesc/design/hydraulics/Manual/Rev3Publications/Chapter%204.pdf
[2] http://www.fs.fed.us/publications/soil-bio-guide
[3] http://ieca.org

- Revetments
- Riprap
- Root wad revetments
- Rosgen's Stream Classification Method
- Setbacks
- Toe protection
- Tree revetments
- Vegetated buffers
- Vegetated gabions
- Vegetated geogrids
- Vegetated reinforced soil slope (VRSS)
- Wing deflectors

Additional information about each of the above practices is available in Chapter 7. The Additional Resources section provides a number of sources for obtaining information about the effectiveness, limitations, and cost estimates for these practices.

Management Measure 2: Instream and Riparian Habitat Restoration

Management Measure 2
1) Evaluate the potential effects of proposed channelization and channel modification on instream and riparian habitat. 2) Plan and design channelization and channel modification to reduce undesirable impacts. 3) Develop an operation and maintenance program for existing modified channels that includes identification and implementation of opportunities to restore instream and riparian habitat in those channels.

Implementation of this management measure is intended to occur concurrently with the implementation of the Management Measure for Physical and Chemical Characteristics of Channelized or Modified Surface Waters (see previous management measure discussion). This management measure pertains to surface waters where channelization and channel modification have altered or have the potential to alter instream and riparian habitat, such that historically present plants, fish, or wildlife are adversely affected. This management measure is intended to apply to any proposed channelization or channel modification project to determine changes in instream and riparian habitat and to existing modified channels to evaluate possible improvements to instream and riparian habitat. The purpose of this management measure is to correct or prevent detrimental changes to instream and riparian habitat from the impacts of channelization and channel modification projects.

Management Practices for Management Measure 2

Implementation of this management measure should begin during the planning process for new projects. For existing projects, implementation of this management measure can be included as part of a regular operation and maintenance program. Ensuring the involvement and participation of all partners is a place to start on any restoration project. Determining the extent of the restoration activity can help identify potential partners and other interested stakeholders. Each stakeholder may bring a certain expertise, historical information and data, and possibly funding to a project. Development of a stream corridor restoration plan can help organize the group, set goals for implementation of management practices, secure funding or other types of support, and facilitate the sharing of ideas and accomplishments within the group and to others in the community. The approach is two-pronged and should include:

1. *Planning and evaluation*, with numerical models for some situations, of the types of NPS pollution related to instream and riparian habitat changes and watershed development.

2. *Operation and maintenance* activities that restore habitat through the application of a combination of nonstructural and structural practices to address some types of NPS problems stemming from instream and riparian habitat changes or watershed development.

Planning and Evaluation

Several tools can be used to evaluate the instream and riparian health of a stream system. These approaches include:

- Biological methods/models
- Temperature restoration practices
- Geomorphic assessment techniques
- Expert judgment and checklists

Biological Methods/Models

To assess the biological impacts of channelization, it is necessary to evaluate both physical and biological attributes of the stream system. Assessment studies should be performed before and after channel modification, with samples being collected upstream from, within, and downstream from the modified reach to allow characterization of baseline conditions. It also may be desirable to identify and sample a reference site within the same ecoregion as part of the rapid bioassessment procedures discussed below.

> Use models/methodologies to evaluate the effects of proposed channelization and channel modification projects on instream and riparian habitat and to determine the effects after such projects are implemented.

There are a number of different methods that can be used to assess the biological impacts of channelization. Rapid Bioassessment Protocols (RBPs) were developed as inexpensive screening tools for determining whether a stream is supporting a designated aquatic life use (Barbour et al., 1999; Plafkin et al., 1989). One component of these protocols is an instream habitat assessment procedure that measures physical characteristics of the stream reach (Barbour and Stribling, 1991). An assessment of instream habitat quality based on 12 instream habitat parameters is performed in comparison to conditions at a “reference” site, which represents the “best attainable” instream habitat in nearby streams similar to the one being studied. The RBP habitat assessment procedure has been used in a number of locations across the United States. A small field crew of one or two persons typically can perform the procedure in approximately 20 minutes per sampling site.

Rapid Bioassessment Protocols (Barbour et al., 1999; Plafkin et al., 1989) were designed to be scientifically valid and cost-effective and to offer rapid return of results and assessments. Protocol III (RBP III) focuses on quantitative sampling of benthic macroinvertebrates in riffle/run habitats or on other submerged, fixed structures (e.g., boulders, logs, bridge abutments, etc.) where such riffles may not be available. The data collected are used to calculate various metrics pertaining to benthic community structure, community balance, and functional feeding groups. The metrics are assigned scores and compared to biological conditions as described by either an ecoregional reference database or reference sites chosen to represent the “best attainable” biological community in similarly sized streams. In conjunction with the instream habitat quality assessment, an overall assessment of the biological and instream habitat quality at the site is derived. RBP III can be used to determine spatial and temporal differences in the modified stream reach. Application of RBP III requires a crew of two persons; field collections and lab processing require 4 to 7 hours per station and data analysis about 3 to 5 hours, totaling 7 to 12 hours per station. The RBP III has been extensively applied across the United States. More information about biological assessments is available from EPA's Biological Assessment Web site.[4]

Karr et al. (1986) describes an Index of Biological Integrity (IBI), which includes 12 metrics in three major categories of fish assemblage attributes: species composition, trophic composition, and fish abundance and condition. Data are collected at each site and compared to those collected at regional reference sites with relatively unimpacted biological conditions. A numerical rating is assigned to each metric based on its degree of agreement with expectations of biological condition provided by the reference sites. The sum of the metric ratings yields an overall score for the site. Application of the IBI requires a crew of two persons; field collections require 2 to 15 hours per station and data analysis about 1 to 2 hours, totaling 3 to 17 hours per station. The IBI, which was originally developed for Midwestern streams, can be readily adapted for use in other regions. It has been used in several states across the country to assess a wide range of impacts in streams and rivers.

Habitat Evaluation Procedures (HEPs) can be used to document the quality and quantity of available habitat, including aquatic habitat, for selected wildlife species. HEPs provide information for two general types of instream and riparian habitat comparisons:

- The relative value of different areas at the same point in time
- The relative value of the same area at future points in time

By combining the two types of comparisons, the impact of proposed or anticipated land and water use changes on instream and riparian habitat can be quantified (Ashley and Berger, 1997).

Additional information about the assessment methods discussed above, as well as other methods for assessing biological impacts is available in Table 8.2 of Chapter 8.

Temperature Restoration Practices

Channelization and channel modification activities can greatly impact stream temperature. All other factors remaining unchanged, when a channel is narrowed, the water depth increases and the surface area exposed to solar radiation and ambient temperature decreases. This can decrease water temperature. When a channel is widened, the opposite occurs; shallower depths and increased temperatures occur. Temperature may also be increased from increased turbidity because the sediment particles absorb heat. It is important to model how temperature will change in a stream, as a result of channelization and channel modification activities, to determine what other changes and impacts might occur in the stream.

[4] http://www.epa.gov/owow/monitoring/bioassess.html

Stream temperature has been widely studied, and heat transfer is one of the better-understood processes in natural watershed systems. Most available approaches use energy balance formulations based on the physical processes of heat transfer to describe and predict changes in stream temperature.

More information about temperature restoration models and practices is provided in Chapter 8 (Modeling).

Geomorphic Assessment Techniques

Fluvial geomorphology is the study of stream form and function. Geomorphic assessment focuses on qualitative and quantitative observations of stream form. It provides a "moment-in-time" characterization of the existing morphology of the stream. In addition, geomorphic assessment includes a stability component. Stability assessments place the stream in the context of past, present, and anticipated adjustment processes. Geomorphic assessments can be useful in predicting changes that could be created by channelization and channel modification activities.

Stream classification is a technique that is used to show the relationship between streams and their watersheds. There are several techniques for stream classification, all of which have advantages and limitations. Advantages of geomorphic assessment include (adapted from FISRWG, 1998):

- Promotes communication.
- Enables extrapolation of data collected on a few streams to a number of channels over a broader geographical area.
- Helps the restoration practitioner consider the landscape context and determine expected ranges of parameters.
- Enables practitioners to interpret the channel-forming or dominant processes active at the site.
- Uses reference reaches as the desired outcome of restoration.
- Provides an important cross-check to verify if the selected design values are within a reasonable range.

Limitations of geomorphic assessment include (adapted from FISRWG, 1998):

- Determination of bankfull or channel-forming flow depth may be difficult or inaccurate.
- The dynamic condition or the stream is not indicated in stream classification systems.
- River response to a perturbation or restoration action is normally not determined by classifying it alone.
- Biological health is not directly determined.
- Classifying a stream should not be used alone to determine the type, location, and purpose of restoration activities.

Schumm (1960) identified straight, meandering, and braided channels and related both channel pattern and stability to modes of sediment transport. Schumm recognized that stable straight and meandering channels have mostly suspended sediment loads and cohesive bank materials, as opposed to unstable braided streams characterized by mostly bedload sediment transport and wide sandy channels with noncohesive bank materials. Meandering mixed-load channels are found at an intermediate condition (FISRWG, 1998).

Montgomery and Buffington (1993) proposed a classification system similar to Schumm for alluvial, colluvial, and bedrock streams in the Pacific Northwest. This system addresses channel response to sediment inputs throughout the drainage network. Six classes of alluvial channels were identified—cascade, step-pool, plane-bed, riffle-pool, regime, and braided. The stream types are differentiated based on channel response to sediment inputs. For example, steeper channels maintain their morphology while transporting sediment. Streams with lower gradients make more morphological adjustments with increased sediment loads (FISRWG, 1998).

A conceptual model of channel evolution in response to channelization (CEM-channel evolution model) was developed by Simon and Hupp (1986, 1987), Hupp and Simon (1986, 1991), and Simon (1989a, 1989b). The model identifies six geomorphic stages of channel response and was developed and extensively applied to predict empirical stream channel changes following large-scale channelization projects in western Tennessee. Data required for model application include bed elevation and gradient, channel top-width, and channel length before, during, and after modification. Gauging station data can be used to evaluate changes through time of the stage-discharge relationship and bed-level trends. Riparian vegetation is dated to provide ages of various geomorphic surfaces and thereby to deduce the temporal stability of a reach.

A component of Simon and Hupp's (1986, 1987) channel response model is the identification of specific groups of woody plants associated with each of the six geomorphic channel response stages. Their findings for western Tennessee streams suggest that the site preference or avoidance patterns of selected tree species allow their use as indicators of specific bank conditions. This method might require calibration for specific regions of the United States to account for differences in riparian zone plant communities, but it would allow simple vegetative reconnaissance of an area to be used for a preliminary estimate of stream recovery stage (Simon and Hupp, 1987).

Restoring or maintaining streams to a stable form through natural channel design requires detailed information about surface water hydrology and the interactions between rainfall and overland flow or runoff. The Rosgen classification system, developed by David L. Rosgen, and presented in *Applied River Morphology*, is currently the most comprehensive and widely used quantitative assessment method for geomorphology. It represents a compilation of much of the early work in applied fluvial geomorphology and relies largely on the identification of bankfull field indicators. The bankfull discharge is the flow event that fills a stable alluvial channel up to the elevation of the active floodplain (Rosgen, 1996). Dunne and Leopold (1978) first developed hydraulic geometry relationships for the bankfull stage, also called regional curves. Most river engineers and hydrologists work under the assumption that the bankfull discharge is equivalent to the channel forming or dominant discharge in geomorphic classification and in analog and empirical design methods. The bankfull discharge is the only discharge that can be easily identified in the field using physical indicators; therefore it is one of the most commonly used in natural channel design. Additional information about Rosgen is available in Chapter 7.

Moment-in-time stream classifications provide insights into the existing form of the stream and can help to define design parameters and understand potential modifications in reference to existing conditions. Stream classification offers a way to categorize streams based on channel morphology. The older classification systems were largely qualitative descriptions of stream features and landforms and were difficult to apply universally. In 1994, Rosgen published *A Classification of Natural Rivers*. Because of its relative simplicity and usefulness in stream restoration, the Rosgen classification system has become popular among hydrologists, engineers, geomorphologists, and biologists working to restore the biological function and stability of degraded streams. The classification consists of 41 major stream types for which stream channel stability and stream bank erosion potential can be assessed. From the assessment, structures for in-stream and stream bank restoration or modification can be selected. When planning stream restoration projects, it is important for the planning team to use a multidisciplinary approach that includes consideration of hydraulics, hydrology, water quality, geomorphological processes, and biological interactions to develop and implement a successful restoration. Chapter 7 provides additional detailed information on stream classification practices.

In site selection, geomorphic assessments can determine if a site is unstable and in need of some form of restoration activity. During design, geomorphic assessments can be used in combination with hydrologic, hydraulic, and/or sediment transport analyses to define design elements such as channel slope and hydraulic geometry.

Sediment transport analysis in rivers and streams is used to approximate the amount of sediment being moved by flow event scenarios and to determine where it will be deposited. Modeling the sediment transport capacity of a channel and its predicted sediment deposition patterns are important for assessing existing and proposed channel design projects to estimate potential project impacts. Sediment transport analysis is also useful for determining restoration opportunities in existing channelization and channel modification projects. Sediment transport analysis is often coupled with stable channel analyses methods to refine channel geometries to estimate optimal scour and deposition characteristics (Schulte et al., 2000). A good source of technical information on sediment transport analysis can be found in *River Engineering for Highway Encroachments* (FHWA, 2001).

Sediment transport analysis has been used in many projects, including:

- Channel design projects (Schulte et al., 2000)
- Stream restoration design (Copeland et al., 2001; Shields et al., 2003)
- Flood control projects (USACE, 1994)
- Highway projects that include stream crossings (FHWA, 2001)

In the design of new channelization projects and analysis of existing projects, channels are typically evaluated using channel stability methods and then the analysis is refined using sediment transport models. Sediment transport analysis is used to refine geometry so that scour and deposition are minimized. It is also used to determine the optimum grade control structure elevation and placement and to find the excavation depths in depositional zones to minimize operational costs for maintaining the channel geometry (Schulte et al., 2000).

The methods and techniques used to accomplish a geomorphic assessment should be project-specific and conducted by personnel trained in applied fluvial geomorphology. Geomorphic assessment of streams has evolved rapidly over the past 10–15 years. Initial methodologies tended to be tailored for localized applications and required extensive data collection and validation. Rosgen's methodology provides a more universal approach to stream classification that represents trade-offs between data collection needs and ease of application for many different stream types. The challenge to this type of modeling and assessment has always been to balance the complexity and need for extensive data collection with ease of use and reliability of the results. The key is that the geomorphic assessment must provide a fundamental understanding of the linkage between river form and process. The assessment should provide insight into where the stream has been, is now, and in what direction it is moving. It should also place the project reach in the context of broader system wide adjustment processes. Geomorphic assessment can be used to select sites for restoration and develop designs.

Expert Judgment and Checklists

Approaches using expert judgment and checklists developed based on experience acquired in previous projects and case studies may be very helpful in integrating environmental goals into project development. The USACE used this concept of incorporating environmental goals into project design (Shields and Schaefer, 1990) in the development of a computer-based system for the environmental design of waterways (ENDOW). The ENDOW system is composed of three modules: a streambank protection module, a flood control channel module, and a streamside levee module. The three modules require the definition of the pertinent environmental goals to be considered in the identification of design features. Depending on the environmental goals selected for each module, ENDOW will display a list of comments or cautions about anticipated impacts and other precautions to be taken into account in the design.

Another example of using expert judgment is the Proper Functioning Condition (PFC) technique. PFC was developed by the Bureau of Land Management (BLM) to rapidly assess whether a stream riparian area is functioning properly in terms of hydrology, landform/soils, channel characteristics, and vegetation. The assessment is performed by an interdisciplinary team and involves completing a checklist evaluating 17 factors concerning hydrology, vegetation, and erosional/depositional characteristics. The PFC field technique is not quantitative, but with adequate training, results are reproducible to a high degree (FISRWG, 1998).

Operation and Maintenance Activities

Implementation practices for instream and riparian habitat restoration in planned or existing modified channels are consistent with those management practices for physical and chemical characteristics of channelized or modified surface waters. To prevent future impacts to instream or riparian habitat or to solve current problems caused by channelization or channel modification projects, include one or more of the following practices to mitigate the undesirable changes:

- Bank shaping and planting
- Branch packing
- Brush layering
- Brush mattressing
- Bulkheads and seawalls

- Check dams
- Coconut fiber roll
- Dormant post plantings
- Erosion and Sediment Control (ESC) Plans
- Establish and protect stream buffers
- Joint plantings
- Levees, setback levees, and floodwalls
- Live cribwalls
- Live fascines
- Live staking
- Marsh creation and restoration
- Noneroding roadways
- Return walls
- Revetments
- Riparian improvements
- Riprap
- Root wad revetments
- Rosgen's Stream Classification Method
- Setbacks
- Toe protection
- Tree revetments
- Vegetated buffers
- Vegetated gabions
- Vegetated geogrids
- Vegetated reinforced soil slope (VRSS)
- Wing deflectors

Additional information about each of the above practices is available in Chapter 7. The Additional Resources section provides a number of sources for obtaining information about the effectiveness, limitations, and cost estimates for these practices.

Operation and maintenance programs should weigh the benefits of including practices such as those for mitigating any current or future impairments to instream or riparian habitat. Additional information about these practices can be found in Chapter 7. Also, Fischenich and Allen (2000) provide a comprehensive summary of practices that can be evaluated for use in operation and maintenance programs.

Chapter 4: Dams

 

Dams are a common form of hydromodification. The National Research Council estimated that there were more than 2.5 million dams in the United States in 1992 (NRC, 1992). These dams range in size from berms across small streams that create farm ponds to large concrete structures across major rivers for hydropower and flood control. The USACE estimates (of these 2.5 million dams in the United States) about 79,000 are large enough to be included in the National Inventory of Dams (USACE, n.d.b.).[1]

Dams generally were built to store and provide water for mechanical power generation (e.g., waterwheels to mill grain), industrial cooling, hydroelectric power generation, agricultural irrigation, municipal water supplies for human consumption, and impoundment-based recreation (e.g., boating and sport fishing). Dams are also used for flood control and to maintain channel depths for barge transportation.

Dams can be associated with a number of effects, including changes to hydrology, water quality, habitat, and river morphology. Lakes and reservoirs integrate many processes that take place in their contributing watersheds, including processes that contribute energy (heat), sediment, nutrients, and toxic substances. Human activities, such as agricultural and urban land use, contribute to contaminant and sediment loads to reservoirs. The presence and operation of dams can determine the fate of these pollutants in a reservoir or impoundment and potentially downstream as water is released from the dam. For example, the presence of a dam may lead to sediment accumulation in a reservoir. However, there are management practices that can mitigate this integrative effect of a reservoir. One example is selective withdrawals, which are an operational technique that can be used by some dam operators to provide water quality and temperatures necessary to sustain downstream fish populations.

When dams are built, depending on size and design, they may alter the river system structure, causing it to change from a river (flowing) to lake (static) and back to a river (flowing) system.

[1] With the National Dam Inspection Act (P.L. 92-367) of 1972, Congress authorized the U.S. Army Corps of Engineers (USACE) to inventory U.S. dams. The Water Resources Development Act of 1986 (P.L 99-662) authorized USACE to maintain and periodically publish an updated National Inventory of Dams (NID).

Dams with large storage capacities will, by design, retain water longer than those with little storage. This can change system flow patterns, which can affect water quality and habitat upstream and downstream of the dam. Most effects from dams are observed downstream. Table 4.1 provides a description of several common types of dams.

Table 4.1 Types of Dams (FEMA, 2003)

Type of Dam	Description
Ambursen dam	A buttress dam in which the upstream part is a relatively thin, flat slab usually made of reinforced concrete
Arch dam	A concrete, masonry, or timber dam with the alignment curved upstream so as to transmit the major part of the water load to the abutments
Buttress dam	A dam consisting of a watertight part supported at intervals on the downstream side by a series of buttresses
Crib dam	A gravity dam built up of boxes, crossed timbers, or gabions, filled with earth or rock
Diversion dam	A dam built to divert water from a waterway or stream into a different watercourse
Double curvature arch dam	An arch dam that is curved both vertically and horizontally
Earth dam	An embankment dam in which more than 50% of the total volume is formed of compacted earth layers that are generally smaller than 3-inch size
Embankment dam	Any dam constructed of excavated natural materials, such as both earthfill and rockfill dams, or of industrial waste materials, such as a tailings dam
Gravity dam	A dam constructed of concrete and/or masonry, which relies on its weight and internal strength for stability
Hollow gravity dam	A dam constructed of concrete and/or masonry on the outside but having a hollow interior and relying on its weight for stability
Hydraulic fill dam	An earth dam constructed of materials, often dredged, which are conveyed and placed by suspension in flowing water
Industrial waste dam	An embankment dam, usually built in stages, to create storage for the disposal of waste products from an industrial process
Masonry dam	Any dam constructed mainly of stone, brick, or concrete blocks pointed with mortar
Mine tailings dam (or tailings dam)	An industrial waste dam in which the waste materials come from mining operations or mineral processing
Multiple arch dam	A buttress dam comprised of a series of arches for the upstream face
Overflow dam	A dam designed to be overtopped
Regulating dam (or afterbay dam)	A dam impounding a reservoir from which water is released to regulate the flow downstream
Rock-fill dam	An embankment dam in which more than 50% of the total volume is comprised of compacted or dumped cobbles, boulders, rock fragments, or quarried rock generally larger than 3-inch size
Roller compacted concrete dam	A concrete gravity dam constructed by the use of a dry mix concrete transported by conventional construction equipment and compacted by rolling, usually with vibratory rollers
Rubble dam	A stone masonry dam in which the stones are unshaped or uncoursed
Saddle dam (or dike)	A subsidiary dam of any type constructed across a saddle or low point on the perimeter of a reservoir

Siting, construction, operation, maintenance, and removal of dams can lead to nonpoint source (NPS) effects. For example, siting of dams can result in inundation of wetlands, riparian areas, and fastland in areas upstream of the dam. During construction or maintenance, erosion and soil loss occurs. Proper siting and design help prevent erosion prone areas from being developed. For dams actively controlled by human operators, dam operation and the amount of water released can affect downstream areas when flood waters necessary to deliver sediment are restricted, or when controlled releases from dams change the timing, quantity, or quality of downstream flow. While removal of dams can lead to physical and biological impacts, such as temporary increased turbidity from redistribution of sediment previously stored behind the dam or displacement of warm-water species that prefer lake-like conditions, dam removal has many biological and habitat benefits, such as allowing for easier fish movement and a return of natural stream temperatures and dissolved oxygen. Sometimes, however, dams limit passage of undesirable invasive species. Therefore, a comprehensive evaluation of the benefits and limitations resulting from the presence of a dam should be completed when evaluating operation and maintenance procedures, as well as options for removal. A more detailed discussion of water quality, biological, habitat, physical, and chemical changes from dam removal is provided in Chapter 2.

One opportunity to evaluate and address the NPS impacts of some larger dams that are used for hydropower occurs during the licensing/relicensing process. The Federal Power Act (FPA) requires all nonfederal hydropower projects located on navigable waters to be licensed. The FPA (16 U.S.C. 791-828c) was originally enacted as the Federal Water Power Act in 1920 and was made part of the FPA in 1935. The Federal Energy Regulatory Commission (FERC) is the independent regulatory agency within the Department of Energy that has exclusive authority, under the FPA, to license such projects. The hydropower dam relicensing process offers an opportunity to assess the balance between natural resources and the generation of electricity and to address some areas that are determined to be problematic. Stakeholders, including dam owners and operators, local governments, environmental groups, and the public, often have different interests to be balanced. Through the FPA and the relicensing process, these varied interests can be evaluated and a balanced outcome can be derived. In conjunction with FPA licensing requirements, states and authorized tribes certify that discharges (including those that originate from dams) meet water quality standards under section 401 of the Clean Water Act (CWA).

The FPA also requires relicensing to be conducted in light of recent laws and regulations that are in effect at the time of renewal. As regulations related to hydropower dams change, it is possible that many dams that were previously licensed and are up for relicensing may no longer be in compliance with current regulatory standards. For example, many dams were built prior to the CWA, which includes regulatory requirements for protecting and maintaining designated uses (such as protecting desired aquatic life or maintaining bacterial water quality that is protective of human health for all recreational activities). Other regulatory requirements that may be evaluated during relicensing include protections for wetlands, aquatic habitat, and endangered species.[2]

[2] Additional information about FERC and hydropower licensing/relicensing is available at http://www.ferc.gov.

Management Measure 3: Erosion and Sediment Control for the Construction of New Dams and Maintenance of Existing Dams

Management Measure 3
1) Reduce erosion and, to the extent practicable, retain sediment onsite during and after construction. 2) Prior to land disturbance, prepare and implement an approved erosion and sediment control plan or similar administrative document that contains erosion and sediment control provisions.

The purpose of this management measure is to prevent sediment from entering surface waters during the construction or maintenance of dams. This management measure emphasizes the importance of minimizing sediment loss to surface waters during both dam construction and maintenance. It is essential that proper erosion and sediment control practices be used to protect surface water quality because of the high potential for sediment loss directly to surface waters. Sediment and erosion control practices can be borrowed from other applications, such as urban development and construction activities.

Two broad performance goals constitute this management measure: minimizing erosion and maximizing the retention of sediment onsite. These performance goals allow for site-specific flexibility in specifying practices appropriate for local conditions. Regular inspections of a dam are valuable opportunities for dam owners to identify erosion problems and implement sediment controls to protect the integrity of the dam. Since the number of new dam construction projects is relatively small compared to the number of existing dams, operation and maintenance activities offer significantly more opportunities to prevent NPS problems associated with erosion and sediment control.

Dam owners are encouraged to establish a program of regular safety inspection of the dam's infrastructure and dam maintenance. Safety inspection of a dam is a program of regular visual inspection using simple equipment and techniques. These inspections are often an economical means of ensuring the long-term safety and survival of a dam structure. By regularly monitoring the condition and performance of the dam and its surroundings, adequate warning of potentially unsafe conditions will enable timely maintenance. Being able to recognize the signs of potential problems and failure, as well as what to do and whom to contact, is vital. Partial or total failure of a dam may cause extensive damage to downstream areas, including loss of life, property damage, and impacts to wetlands, riparian areas, stream channels, and other ecologically important lands, for which the owner may be held liable. There are also potentially expensive repair costs and lost income that may result from failures or poorly maintained dam structures.

The primary areas of dam structural failure are:

- Loss of clay soils used in berms and other earthen structures
- Seepage and leakage at the base or along pipes
- Erosion, including wave action, stock damage and spillways
- Cracking and movement of structural components
- Defects in associated structures
- Vegetation, including catchment protection and weed control

Operation and maintenance should be applied to small, as well as large dams. Many owners of small dams, like those on farm ponds, should regularly inspect their dams for maintenance needs. Local NRCS staff can provide technical assistance to small dam owners for operation and maintenance activities.[3]

Regular operation and maintenance efforts can lead to some dams being in need of repairs and/or upgrades. Designs for repairs and upgrades can involve replacing reinforced concrete risers and impact basins, replacing rusted out corrugated metal pipe principal spillways, raising the top of the dams, widening the auxiliary spillways, and removing sediment from the flood pools. Examples of project costs for these types of maintenance activities reported in Ohio have ranged from $175,000 on a small dam to $775,000 on the largest dam (Brate, 2004).

At the state and local levels, this measure can be incorporated into existing erosion and sediment control (ESC) programs. This measure can also be effectively implemented as part of safety inspection requirements. Erosion and sediment control is also intended to be part of a comprehensive land use or watershed management program.

Management Practices for Management Measure 3

The management measure can be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices described below can be applied successfully to implement the management measure for erosion and sediment control for construction of new dams and maintenance of existing dams.

Erosion Control Practices

Successful control of erosion and sedimentation from construction and maintenance activities can involve a system of management practices that targets each stage of the erosion process. The most efficient approach involves minimizing the potential sources of sediment from the onset. This means limiting the extent and duration of land disturbance to the minimum needed, and protecting surfaces once they are exposed. The second stage of the management practice system involves controlling the amount of runoff and its ability to carry sediment by diverting incoming flows and impeding internally generated flows. The third stage involves retaining sediment that is picked up on the project site through the use of sediment-capturing devices. On most sites

[3] Contact your local USDA Service Center (http://offices.sc.egov.usda.gov/locator/app) to access NRCS in your community.

successful erosion and sedimentation control requires a combination of structural and vegetative practices. All of these stages are better performed using advanced planning and good scheduling.

The timing of land disturbing activities and installation of erosion control measures must be coordinated to minimize water quality impacts. For large scale activities, the management practice system is typically installed in reverse order, starting with sediment capturing devices, followed by key runoff control measures and runoff conveyances, and then land clearing activities. Often, construction or maintenance activities that generate significant off-site sediment have failed to sequence activities in the proper order.

Erosion controls reduce the amount of sediment lost during dam construction and prevent sediment from entering surface waters. Erosion control is based on (1) minimizing the area and time of land disturbance and (2) quickly stabilizing disturbed soils to prevent erosion.

The effectiveness of erosion control practices can vary based on land slope, the size of the disturbed area, rainfall frequency and intensity, wind conditions, soil type, use of heavy machinery, length of time soils are exposed and unprotected, and other factors. In general, a system of erosion and sediment control practices can more effectively reduce offsite sediment transport than a single practice. Numerous nonstructural measures such as protecting natural or newly planted vegetation, minimizing the disturbance of vegetation on steep slopes and other highly erodible areas, maximizing the distance eroded material must travel before reaching the drainage system, and locating roads away from sensitive areas may be used to reduce erosion.

The following practices have proven to be useful in controlling erosion and can be incorporated into ESC plans and used during dam construction as appropriate. These practices can be used during and after construction and throughout ongoing maintenance activities.

- Bank shaping and planting
- Branch packing
- Brush layering
- Brush mattressing
- Bulkheads and seawalls
- Check dams
- Coconut fiber roll
- Construct runoff intercepts
- Construction management
- Dormant post plantings
- Erosion and sediment control (ESC) plans
- Erosion control blankets
- Joint planting
- Live cribwalls
- Live fascines
- Live staking
- Locate potential land disturbing activities away from critical areas
- Mulching

- Noneroding roadways
- Phase construction
- Preserve onsite vegetation
- Retaining walls
- Revegetate
- Revetment
- Riparian improvements
- Riprap
- Rootwad revetments
- Scheduling projects
- Sediment fences
- Seeding
- Site fingerprinting
- Sodding
- Soil protection
- Surface roughening
- Training—erosion and sediment control
- Tree armoring, fencing, and retaining walls or tree walls
- Tree revetments
- Vegetated buffers
- Vegetated filter strips
- Vegetated gabions
- Vegetated geogrids
- Vegetated reinforced soil slope (VRSS)
- Wildflower cover
- Wind erosions controls

A more detailed discussion of each of the above practices is provided in Chapter 7.

Runoff Control

To prevent the entry of sediment used during construction into surface waters, these precautionary steps should be followed:

- Identify areas with steep slopes, unstable soils, inadequate vegetation density, insufficient drainage, or other conditions that give rise to a high erosion potential.
- Identify measures to reduce runoff from such areas if disturbance of these areas cannot be avoided (Hynson et al., 1985).

Runoff diversions are structures that channel upslope runoff away from erosion source areas, divert sediment-laden runoff to appropriate traps or stable outlets, or capture runoff before it leaves the site, diverting it to locations where it can be used or released without erosion or flood damage. Diversions can be either temporary or permanent in nature.

Runoff control measures, mechanical sediment control measures, grassed filter strips, mulching, and/or sediment basins could be used to control runoff from the construction site. Scheduling

construction during drier seasons, exposing areas for only the time needed for completion of specific activities, and avoiding stream fording also help to reduce the amount of runoff created during construction.
The largest surface water pollution problem during construction is suspended sediment resulting from aggregate processing, excavation, and concrete work. Preventing the entry of these materials above and/or below a dam is always the preferable alternative because runoff due to these types of construction activities can add more sediment to a reservoir, harm aquatic life above and below the dam, or affect habitat in streams below a dam. Filtration and gravitational settling during detention are the main processes used to remove sediment from construction site runoff. Methods used to control runoff and associated sedimentation from construction sites include:

- Check dams
- Constructing runoff intercepts
- Locate potential land disturbing activities away from critical areas
- Preserve onsite vegetation
- Retaining walls
- Sediment basins/rock dams
- Sediment fences
- Sediment traps
- Vegetated buffers
- Vegetated filter strips

A more detailed discussion of each of the above practices is provided in Chapter 7.

Erosion and Sediment Control (ESC) Plans

ESC plans can be used to control erosion and sediment and incorporate such control in planning. Some states call for specific requirements to be included in state ESC plans. Table 4.2 provides examples of several state ESC plan requirements. Additional detail about ESC plans, including general objectives, and management techniques for ensure proper administration of plans, is available in Chapter 7.

Table 4.2 Examples of Erosion and Sediment Control Plan Requirements for Select States

Location	General Requirements for ESC Plan
Delaware	ESC plans required for sites over 5,000 ft^2. Temporary or permanent stabilization must occur within 14 days of disturbance.
Florida	ESC plans required on all sites that need a runoff management permit.
Georgia	ESC plan required for all land-disturbing activities.
Indiana	ESC plan required for sites over 5 acres.
Maine	ESC plans required for sites adjacent to a wetland or waterbody. Stabilization must occur at completion or if no construction activity is to occur for 7 days. If temporary stabilization is used, permanent stabilization must be implemented within 30 days.
Maryland	ESC plans required for sites over 5,000 ft^2 or 100 yd^3.
Michigan	ESC plans required for sites over 1 acre or within 500 ft of a waterbody. Permanent stabilization must occur within 15 days of final grading. Temporary stabilization is required within 30 days if construction ceases.

Location	General Requirements for ESC Plan
Minnesota	ESC plans required for land development over 1 acre.
New Jersey	ESC plans required for sites over 5,000 ft^2.
North Carolina	ESC plans required for sites over 1 acre. Controls must retain sediment on-site. Stabilization must occur within 30 days of completion of any phase of development.
Ohio	ESC plans required for sites over 5 acres. Permanent stabilization must occur within 7 days of final grading or when there is no construction activity for 45 days.
Oklahoma	ESC plans required for sites over 5 acres.
Pennsylvania	ESC plans required for all sites, but the state reviews only plans for sites over 25 acres. Permanent stabilization must occur as soon as possible after final grading. Temporary stabilization is required within 70 days if construction ceases for more than 30 days. Permanent stabilization is required if the site will be inactive for more than 1 year.
South Carolina	ESC plans required for all sites unless specifically exempted. Perimeter controls must be installed. Temporary or permanent stabilization is required for topsoil stockpiles and all other areas within 7 days of disturbance.
Virginia	For areas within the jurisdiction of the Chesapeake Bay Preservation Act, no more land is to be disturbed than necessary for the project. Indigenous vegetation must be preserved to the greatest extent possible.
Washington	ESC provisions are incorporated into the state runoff management plan.
Wisconsin	ESC plans required for all sites over 4,000 ft^3. Temporary or permanent stabilization is required within 7 days.

(Adapted from Environmental Law Institute, 1998; USEPA, 1993)

Management Measure 4: Chemical and Pollutant Control at Dams

Management Measure 4
1) Limit application, generation, and migration of toxic substances. 2) Ensure the proper storage and disposal of toxic materials. 3) Apply nutrients at rates necessary to establish and maintain vegetation without causing significant nutrient runoff to surface waters.

This management measure is intended to be applied to the construction of new dams, as well as to construction activities associated with the maintenance of dams. This management measure addresses fuel and chemical spills associated with dam construction and operation and maintenance activities, as well as concrete washout and related construction activities. The purpose of this management measure is to prevent downstream contamination from pollutants associated with dam construction and maintenance activities.

Although suspended sediment is the major pollutant generated at a construction site, other pollutants that may be present around dams (especially during construction and operation and maintenance activities) include:

- Petroleum products—fuels and lubricants, specifically gasoline, diesel oil, kerosene, lubricating oils, grease, and asphalt
- Pesticides—insecticides, herbicides, fungicides, and rodenticides
- Fertilizers
- Construction chemicals—acids, soil additives, and concrete-curing compounds
- Wastewater—aggregate wash water, herbicide wash water, concrete-curing water, core-drilling wastewater, or clean-up water from concrete mixers
- Solid wastes—paper, wood, metal, rubber, plastic, and roofing materials
- Garbage
- Sanitary wastes
- Cement
- Lime

This management measure is important because most erosion and sediment control practices are ineffective at retaining soluble NPS pollutants on a construction site. Many of the NPS pollutants, other than suspended sediment, generated at a construction site are carried offsite in solution or attached to clay particles in runoff. Some metals (e.g., manganese, iron, and nickel) attach to larger sediment particles and usually can be retained onsite. Other metals (e.g., copper, cobalt, and chromium) attach to fine clay particles and have greater potential to be carried offsite. Insoluble pollutants (e.g., oils, petrochemicals, and asphalt) form a surface film on runoff water and can be easily washed away (USEPA, 1973; USEPA, 2002b; USEPA, 2005d).
Factors that influence the pollution potential of construction chemicals include:

- The nature of the construction and maintenance activity
- The physical characteristics of the construction site
- The characteristics of the receiving water

Dam construction sites are particularly sensitive areas and have the potential to severely impact surface waters with runoff containing construction chemical pollutants. Because dams are located on rivers or streams, pollutants generated at these construction sites have a much shorter distance to travel before entering surface waters. Therefore, chemicals and other NPS pollutants generated at a dam construction site should be controlled.

Management Practices for Management Measure 4

The management measure generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices described below can be applied successfully to implement the control of chemicals and pollutants at dams. This includes dam construction as well as routine maintenance. Practices for controlling chemicals and pollutants include the following:

- Equipment runoff control
- Fuel and maintenance staging areas
- Locate potential land disturbing activities away from critical areas
- Pesticide and fertilizer management
- Pollutant runoff control
- Spill prevention and control program

A more detailed discussion of each of the above practices is provided in Chapter 7.

Management Measure 5: Protection of Surface Water Quality and Instream and Riparian Habitat

Management Measure 5
Develop and implement a program to manage the operation of dams that includes an assessment of: 1) Surface water quality and instream and riparian habitat and potential for improvement. 2) Significant nonpoint source pollution problems that result from excessive surface water withdrawals.

This management measure is intended to be applied to dam operation, maintenance, and removal activities that result in the loss of desirable surface water quality, and of desirable instream and riparian habitat.

The purpose of the management measure is to protect the quality of surface waters and aquatic habitat (including riparian habitat) in the portion of rivers and streams that are impacted by dams. Operation, maintenance, and dam removal activities can be assessed to determine opportunities for potential improvements in water quality and aquatic habitat. These activities, as well as actions within the watershed, that contribute NPS pollutants to an impoundment should be collectively and periodically evaluated to help identify opportunities for cost-effective change.

The recommended overall programmatic approach is to evaluate a set of practices that can be applied individually or in combination to protect and improve surface water quality and aquatic habitat in reservoirs, as well as in areas downstream of dams. Then, a program can be implemented using the most cost-effective operation, maintenance, and removal activities to protect and improve surface water quality and aquatic and riparian habitat.

The individual application of any particular technique, such as aeration, change in operational procedure, restoration of an aquatic or riparian habitat, or implementation of a watershed protection best management practice (BMP), will, by itself, probably not improve water quality to an acceptable level within the reservoir impoundment or in tailwaters flowing through downstream areas. The individual practices discussed in this portion of the guidance may have to be implemented in some combination in order to improve water quality in the impoundment or in tailwaters to acceptable levels.

Selection of the management measure for the protection of surface water and instream and riparian habitat was based on:

- The availability and demonstrated effectiveness of practices to improve water quality in impoundments and in tailwaters of dams.

- The level of improvement in water quality of impoundments and tailwaters that can be measured from implementation of engineering practices, operational procedures, watershed protection approaches, or aquatic or riparian habitat improvements.

Successful implementation of the management measure should generally involve the following categories of practices undertaken individually or in combination to improve water quality and aquatic and riparian habitat in reservoir impoundments and in tailwaters:

- Artificial destratification and hypolimnetic aeration of reservoirs with deep withdrawal points that do not have multilevel outlets to improve dissolved oxygen (DO) levels in the impoundment and to decrease levels of other types of NPS pollutants, such as manganese, iron, hydrogen sulfide, methane, ammonia, and phosphorus in reservoir releases.

- Aeration of reservoir releases, through turbine venting, injection of air into turbine releases, installation of reregulation weirs, use of selective withdrawal structures, or modification of other turbine start-up or pulsing procedures.

- Providing both minimum flows to enhance the establishment of desirable instream habitat and scouring flows as necessary to maintain instream habitat.

- Establishing adequate fish passage or alternative spawning ground and instream habitat for fish species.

- Improving watershed protection by installing and maintaining BMPs in the drainage area above the dam to remove phosphorus, suspended sediment, and organic matter and otherwise improve the quality of surface waters flowing into the impoundment.

- Removing dams, which are unsafe, unwanted, or obsolete, after careful consideration of alternatives.

Since the presence and operation of a dam have the potential to cause impacts, periodic assessments of reservoir water quality, watershed activities, and operational practices may provide valuable information for evaluating management strategies. The types and severity of the impacts can serve as an indicator of the frequency and magnitude of the assessments. There are a variety of assessment tools that are available to assist decision-makers in the evaluation of impacts associated with dams. Watershed-related impacts and management activities can be evaluated with a variety of models. EPA supports several models that may be useful for watershed assessments, such as BASINS.[4]

[4] More information about EPA-supported watershed assessment tools can be found at http://www.epa.gov/waterscience/wqm.

Reservoir water quality can also be assessed with various models. Table 8-1 in this document provides a list of models that may be used to assess reservoir water quality. Also presented in Table 8-1 are models that could be used to evaluate downstream impacts of dams.[5]

Management Practices for Management Measure 5

The management measure generally can be implemented by applying one or more management practices appropriate to the source, location, and climate. Management practices that can be used to achieve the management measure include practices to improve water quality, restore or maintain aquatic and riparian habitat, and maintain fish passage, as well as possible removal of dams. The subsection on dam removal includes planning and evaluation considerations, descriptions of the removal process, permitting requests, sediment removal techniques, descriptions of changes associated with dam removal, and a discussion of potential biological impacts.

Practices for Improving Water Quality

Management practices for improving water quality associated with the operation and maintenance of dams can be categorized as:

- Watershed Protection Practices—activities to reduce NPS pollution that take place within the watershed surrounding a dam. Reduced NPS pollutant inputs, such as sediment or nutrients, can have a significant, positive effect on water quality within a reservoir and often in reservoir releases, as well.

- Practices for Aeration of Reservoir Water—aeration activities within the reservoir. The primary goal for aerating a large portion of reservoir water is to increase oxygen levels throughout the reservoir. Other water quality factors may also improve, including levels of dissolved metals and nutrients, destratification of the water column, and improved oxygen levels in releases.

- Practices for Aeration of Reservoir Releases — a variety of aeration techniques for improving water quality, specifically dissolved oxygen levels, are presented.

> Management practices to protect surface water quality and instream and riparian habitat are discussed in the following subsections:
>
> - Improving Water Quality
>   - Watershed Protection
>   - Aeration of Reservoir Water
>   - Aeration of Reservoir Releases
> - Improving Aquatic Habitat
> - Maintaining Fish Passage
> - Dam Removal

Improving water quality in impoundments and tailwaters often requires consideration of the interaction of several different factors. For example, achievement of desired DO levels at specific projects may require evaluation of several different technologies and management activities. The U.S. Army Corps of Engineers created a computer-modeling program, AERATE, that performs calculations to

[5] The USACE Environmental Laboratory develops and supports several models, such as QUAL2E, Bathtub, and CE-QUAL-RI that can be found at http://el.erdc.usace.army.mil/products.cfm?Topic=none.

evaluate several direct (e.g., active aeration technologies) and indirect (e.g., activities such as watershed management to reduce nitrogen and phosphorous runoff, which result in improved DO) reservoir aeration techniques. The program considers the following aeration techniques: improving water quality in the reservoir, modifying the withdrawal outlet location (and thereby changing which water is withdrawn and released from the reservoir), treating the release water to eliminate the poor quality as the flow passes through the outlet structure, and treating the release water in the tail water area (Wilhelms and Yates, 1995).

Watershed Protection Practices

Many NPS pollution problems in reservoirs and dam tailwaters frequently result from sources in the contributing watershed (e.g., sediment, nutrients, metals, and toxics). Management of pollution sources from a watershed has been found to be a cost-effective solution for improving reservoir and dam tailwater water quality (TVA, 1988). Watershed protection practices can be effective in producing long-term water quality benefits and lack the high operation and maintenance costs associated with structural controls.

> Additional information about watershed protection, specifically developing and implementing watershed plans, is available from EPA's draft *Handbook for Developing Watershed Plans to Restore and Protect Our Waters*. The handbook is available at http://www.epa.gov/nps.

Watershed protection is a technique that provides long-term water quality benefits, and many states and local communities have adopted this practice. Numerous state and local governments have already legislated and implemented detailed watershed planning programs that are consistent with this management measure. For example, Oregon, New Jersey, Delaware, and Florida have passed legislation that requires county and municipal governments to adopt comprehensive plans, including requirements to direct future development away from sensitive areas. Many municipalities and regions have adopted land use and growth controls, including the towns of Amherst and Norwood and the Cape Cod region of Massachusetts; Narragansett, Rhode Island; King County, Washington; and many others.

Watershed protection management practices fall under the following four categories:

- Encourage drainage protection—includes descriptions and applications of zoning techniques that can be used to limit development density or redirect density to less environmentally sensitive areas.
- Establish and protect stream buffers—describes important steps for protecting or establishing riparian buffer zones to enhance water quality and pollutant removal.
- Identify and address NPS contributions—involves identifying potential upstream sources of nonpoint source pollution, as well as providing solutions to minimize those impacts.
- Identify and preserve critical areas—entails identifying properties that if preserved or enhanced could maintain or improve water quality and reduce the impacts of urban runoff, as well as, preserving environmentally significant areas (includes land acquisition, easements, and development restrictions of various types).

Refer to Chapter 7 for additional information about each of the above practices.

Reservoir Aeration Practices

Systems that have been developed and tested for reservoir aeration rely on atmospheric air, compressed air, or liquid oxygen to increase DO concentrations in reservoir waters. Mixing of reservoir water to destratify warmer, oxygen rich, epilimnion and cooler, oxygen poor, hypolimnion waters can be used. However, this practice has not been used at large hydropower reservoirs because of the associated cost in deep, large volume reservoirs. Refer to Chapter 7 for additional information about reservoir aeration practices.

Practices to Improve Oxygen Levels in Tailwaters

Aeration of water as it passes through the dam or through the portion of the waterway immediately downstream from the dam is another approach to improving DO in water releases from dams. The systems in this category rely on agitation and turbulence to mix the reservoir releases with atmospheric air. One approach involves the increased use of spillways, which release surface water to prevent it from overtopping the dam. An alternative approach is to install barriers called weirs in the downstream areas. Weirs are designed to allow water to overtop them, which can increase DO through surface agitation and increased surface area contact. Some of these downstream systems create supersaturation of dissolved gases and may require additional modifications to prevent supersaturation, which may be harmful to aquatic organisms.

The quality of reservoir releases can be improved through adjustments in the operational procedures at dams. These include scheduling of releases or of the duration of shutoff periods, instituting procedures for the maintenance of minimum flows, making seasonal adjustments in the pool levels or in the timing and variation of the rate of drawdown, selecting the turbine unit that most increases DO (often increasing the DO levels by 1 mg/L), and operating more units simultaneously (often increasing DO levels by about 2 mg/L). The magnitude and duration of reservoir releases also should be evaluated to determine impacts to the salinity regime in coastal waters, which could be substantially altered from historical patterns.

Two factors should be considered when evaluating the suitability of hydraulic structures such as spillways and weirs for their application in raising the DO concentration in waterways:

- Most of the measurements of DO increases associated with hydraulic structures have been collected at low-head facilities. The effectiveness of these devices may be limited as the level of discharge increases (Wilhelms, 1988).

- The hydraulic functioning of these types of structures should be carefully considered since undesirable flow conditions may occur in some instances (Wilhelms, 1988).

Practices that improve oxygen levels in tailwaters include:

- Gated conduits
- Labyrinth weirs
- Modifying operational procedures
- Reregulation weirs
- Selective withdrawal

- Spillway modifications
- Turbine operation
- Turbine venting
- Water conveyances

Additional information about each of these practices is available in Chapter 7.

Practices to Restore or Maintain Aquatic and Riparian Habitat

Several options are available for the restoration or maintenance of aquatic and riparian habitat in the area of a reservoir impoundment or in portions of the waterway downstream from a dam. One set of practices is designed to augment existing flows that result from normal operation of the dam. These include operation of the facility to produce flushing flows, minimum flows, or turbine pulsing. Another approach to producing minimum flows is to install small turbines that operate continuously. Installation of reregulation weirs in the waterway downstream from the dam can also achieve minimum flows. Finally, riparian improvements are discussed for their importance and effectiveness in restoring or maintaining aquatic and riparian habitat in portions of the waterway affected by the location and operation of a dam.

A 2004 report from the National Academies' National Research Council (NRC, 2004) illustrates the importance of maintaining instream flows and critical wildlife habitat in streams where dams are present and notes that areas along Nebraska's Platte River are properly designated as "critical habitats" for the river's endangered whooping crane and threatened piping plover. A series of dams and reservoirs have been constructed in the river basin for flood control and to provide water for farm irrigation, power generation, recreation, and municipal use. The alterations to the river and surrounding land caused by this extensive water-control system, however, resulted in habitat changes that were at odds with the protection of the listed species.

Conflicts over the protection of federally listed species and water management in the Platte River Basin have existed for more than 25 years. In recent years, the Fish and Wildlife Service of the U.S. Department of the Interior issued a series of biological opinions indicating that new water depletions would have to be balanced by mitigation measures, and a lawsuit forced the designation of "critical habitat" for the piping plover. These and other controversies prompted the Department of the Interior and the Governance Committee of the Platte River Endangered Species Partnership to request that the National Research Council examine whether the current designations of "critical habitat" for the whooping crane and piping plover are supported by existing science. The National Research Council was also asked to assess whether current habitat conditions are affecting the survival of listed species or limiting their chances of recovery, and to examine the scientific basis for the department's instream-flow recommendations, habitat-suitability guidelines, and other decisions. The report concludes that in most instances habitat conditions are indeed affecting the likelihood of species survival and recovery.

Additional information about the following practices to restore or maintain aquatic and riparian habitat are available in Chapter 7:

- Constructed spawning beds
- Flow augmentation

- Riparian improvements
- Spillway modifications

Practices to Maintain Fish Passage

Migrating fish populations may be unable to travel up or downstream because of the presence of a dam or suffer losses when passing through the turbines of hydroelectric dams at facilities that have not been equipped with special design features to accommodate fish passage. The effect of dams and hydraulic structures on migrating fish has been studied since the early 1950s in an effort to develop systems or identify operating conditions that would minimize mortality rates. Selecting a device or management strategy for optimal fish passage in a stream or river with a dam requires careful analysis of a variety of factors, such as species, type and operational strategy of the dam, and the physical characteristics of the river system.

Larinier (2000) reports that devices such as fish ladders and bypass channels can help fish travel past dams, but may result in increased mortality due to the hardship and stress involved with passing through these structures. In addition, the fish passage structures have to be placed in a suitable entrance location, have a flow that is attractive to the species of concern, be continually maintained, and possess the hydraulic conditions necessary for the target species (Larinier, 2000). With all of these requirements, the success of a fish ladder or similar device is often uncertain. Passage through the hydraulic turbines of a hydropower dam can cause increased stress as a result of changes in velocity or pressure and the possibility of electric shocks from the turbines and can lead to increased mortality (Larinier, 2000).

The safe passage of fish either upstream or downstream through a dam requires a balance between operation of the facility for its intended uses and implementation of practices that will ensure safe passage of fish. The United States Congress' Office of Technology Assessment (OTA) report on fish passage technologies at hydropower facilities provides an excellent overview of fish passage technologies and discusses some of the economic considerations associated with the safe passage of fish (OTA, 1995).

The U.S. Fish and Wildlife Service and its partners have created a database that makes information about barriers to fish passage in the United States available to policy makers and the public. The database, known as the Fish Passage Decision Support System (FPDSS),[6] is part of the U.S. Fish and Wildlife Service's National Fish Passage Program.[7]

Available fish-protection systems for hydropower facilities fall into one of four categories based on their mode of action (Stone and Webster, 1986): behavioral barriers, physical barriers, collection systems, and diversion systems. These are discussed in separate sections below, along with additional practices that have been successfully used to maintain fish passage: spill and water budgets, fish ladders, fish lifts, advanced hydroelectric turbines, transference of fish runs, and constructed spawning beds.

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[6] https://ecos.fws.gov/fpdss/index.do
[7] http://www.fws.gov/fisheries/fwma/fishpassage

Upstream fish passage systems have been constructed at approximately 10 percent of the FERC licensed hydropower plants. Upstream fish passage systems such as fish ladders and lifts are considered adequately developed for anadromous species such as salmon, American shad (*Alosa sapidissima*), alewives (*Alosa pseudoharengus*), and blueback herring (*Alosa aestivalis*). Fish passage systems for riverine fish have not been specifically designed, although some of these species will use fish passage systems designed for anadromous species (OTA, 1995).

Practices include:

- Advanced hydroelectric turbines
- Behavioral barriers
- Collection systems
- Fish ladders
- Fish lifts
- Physical barriers
- Spill and water budgets
- Transference of fish runs

Additional information about the above practices is available in Chapter 7.

Removal of Dams

The removal of dams has become an accepted practice for dam owners to deal with unsafe, unwanted, or obsolete dams. Dam removal may be necessary as dams deteriorate, sediments accumulate behind dams in reservoirs, human needs shift, and economics dictate (NRC, 1992). Dams serve a variety of important social and environmental purposes (e.g., water supply, flood control, power generation, wildlife habitat, and recreation). As a result, dam removal is often infrequent.

Dam Removal Resource

American Rivers is a nonprofit organization focusing on the health of U.S. river systems, fish, and wildlife. American Rivers' website hosts a variety of information related to hydromodification, including past and recent estimates of dam removals in the United States. http://www.americanrivers.org

Migratory fish passage throughout United States rivers and streams is obstructed by over 2 million dams and many other barriers such as blocked, collapsed, and perched culverts. The National Oceanic and Atmospheric Administration (NOAA) is expanding its community-based approach to restoring fish habitat through the recently developed Open Rivers Initiative (ORI).[8] Administered by NOAA Fisheries Service Office of Habitat Conservation, ORI is designed to help communities correct fish passage problems by focusing financial and technical resources on the removal of obsolete dams and other blockages. ORI strives to restore vital habitat for migrating fish like salmon, striped bass, sturgeon, and shad, as well as improve community safety and stimulate economic revitalization of riverfront communities. Through its more broadly focused Community-based Restoration Program (CRP), NOAA Fisheries Service has opened over 700 miles of stream habitat with financial and technical assistance provided to fish passage

[8] http://www.nmfs.noaa.gov/habitat/restoration/ORI

projects. Examples of successfully completed CRP projects that fit the Open Rivers Initiative model include:

- Culvert removal in the John Smith Creek (Mendocino County, CA)
- Mt. Scott Creek dam removal (Happy Valley, OR)
- Wyomissing Creek dam removal (Reading, PA)
- Town Brook dam removal and fish ladder (Plymouth, MA)
- Sennebec dam removal (Union, ME)

There are many things to consider when removing a dam, one of which is the function(s) of the dam and the status of that function (active vs. inactive). As discussed above, dams are used for various purposes, including water supply, hydroelectric power, recreation, and flood control benefits. When proposals are made to remove a dam with one or more of these active functions, the way in which these functions and benefits will be replaced or mitigated must be addressed (FOR, 1999). An example of this process can be seen with the Jackson Street Dam, located on Bear Creek in Medford, Oregon. The dam diverted water from the creek into the irrigation canals of Rogue River Valley Irrigation District (RRVID). Since the dam created a partial barrier to migratory fish, a loss of stream habitat, and an algae-filled impoundment near the city park, a consensus was reached that removing the dam was the most cost-efficient means of eliminating the problem. However, since the dam was currently providing irrigation diversion, another cost-efficient diversion had to be devised for RRVID. The decision was made to replace the old dam with a less damaging diversion structure. The new structure is approximately one-fourth the height of the Jackson Street Dam (about 3 feet) and is located 1,200 feet upstream. The new structure is also removed at the end of the irrigation season, which coincides with the time of the year when most upstream migration occurs. When the new structure is in place during the irrigation season, it allows fish to migrate (by well-designed fish ladders and screens), and it was designed so that little water will back up behind it. It is also equipped with fish screens to keep fish out of the irrigation canal (FOE et al., 1999).

It is also important to consider the cost of removing a dam, and who will pay for the removal. Removal costs can vary from tens of thousands of dollars to hundreds of millions of dollars, depending on the size and location of the dam. Who pays for dam removal can be a complex issue. Removal in the past has often been financed by the dam owner; local, state, and federal government; and in some cases agreements where multiple stakeholders cover the costs (American Rivers, n.d.a.). A guide to selected funding sources (*Paying for Dam Removal: A Guide to Selected Funding Sources)*[9] is available from American Rivers.

> Dam owners are responsible to keep the dam safe. When a dam begins to fail or breach, a decision must be made as to whether to keep or repair the structure. When a dam generates no revenue, the long-term costs of liability insurance, dam and impoundment maintenance, and operation weigh heavily on the side of dam removal. On average, dam removal costs 3–5 times less than repair.
>
> Source: Delaware Riverkeeper, n.d.

[9] http://www.americanrivers.org/site/DocServer/pdr-color.pdf?docID=727

In the case of the Jackson Street Dam, the most cost-effective alternative to solving the problems associated with the dam was to remove it. However, since it was currently functioning, an alternative means to provide that function was needed. In some instances, it is not more beneficial to remove the dam if it is functioning. For example, USACE expressed concern over the costs of air pollution created by fuel-burning power plants needed to replace the lost power from dams in the debate over the removal of the Snake River dams (Lee, 1999). There was much controversy over whether it was more cost-efficient to remove the dams, especially due to the functions the dams provided. USACE found that replacing the dams would be costly, both monetarily and ecologically. The estimated costs to replace the lower Snake hydropower were between $180 million to $380 million a year for 100 years (Lee, 1999). In addition, the cost of the resulting increase in pollution due to natural gas or coal replacement plants was very high, yet an actual amount was not determined.

Evaluations made by the USACE found that the costs associated with removing the Snake River dams greatly exceeded the costs of maintaining, improving, and keeping them (Associated Press, 2002). Therefore, the dams along the Snake River remain and have been repaired. USACE plans to pursue technical and operational changes at the Snake River dams to improve fish survival, in addition to barging or trucking juvenile salmon around the dams (Associated Press and the Herald Staff, 2002).

The entire decision-making process is a delicate balance that involves many stakeholders. One important step in this process is to decide if the ecological benefits of removing the dam outweigh the benefits of maintaining the dam.

When deciding whether to remove a dam, interested parties should collect as much information as possible about the potential removal project. American Rivers has published a fact sheet (*Data Collection: Researching Dams and Rivers Prior to Removal*),[10] which contains a variety of sources to help begin researching the particular dam that might be removed and the river on which it is located (American Rivers, n.d.b.).

American Rivers and Trout Unlimited have published a guide to help decide whether to remove a dam or not, *Exploring Dam Removal: A Decision-Making Guide* (American Rivers and Trout Unlimited, 2002).[11]

Repercussions of Unsafe Dams (American Rivers, 1999)

Unsafe dams may result in:

1. Loss of life from surging flows if a dam fails
2. Destruction of property
3. Harm to the downstream river environment (e.g., erosion)
4. Release of toxic sediments (e.g., dioxins, PCBs)
5. Risk to users of the river (i.e., users may not be able to avoid life threatening hazards if in close approximation to a failing dam)
6. Jeopardizing delivery of critical services to communities (e.g., power generation, flood control)

The decision-making process related to dam removal is often complex with inputs from stakeholders with opposing desired outcomes. Additional resources related to dam removal are available in the Resources chapter.

[10] http://www.americanrivers.org/site/DocServer/Reseaching_a_Dam_Data_Collection.pdf?docID=981
[11] http://www.americanrivers.org/site/DocServer/Exploring_Dam_Removal-A_Decision-Making_Guide.pdf?docID=3641

Chapter 5: Streambank and Shoreline Erosion

Figure 5.1 Shoreline Erosion: Before and After Photos (SEAS, 2007)

Streambanks and shorelines naturally erode. Water flowing along (parallel to) streambanks dislodges sediment and other materials that constitute the streambank. Similarly, water flowing perpendicular to shorelines, due to waves or tides, transports sediment and other materials away from the shoreline. Anthropogenic influences change the natural erosion processes, often increasing erosion locally and sedimentation downstream, along adjacent shorelines, or offshore. Many human activities change the hydraulic characteristics of stream flows or transfer energy to adjacent shorelines and contribute to increased streambank and shoreline erosion, for example:

- *Urbanization* that leads to changes in imperviousness creates changes in the hydraulics of water during wet weather events. Increased imperviousness can result in flashier runoff events that are shorter in duration with greater flow rates and more erosive force.
- *Agricultural practices*, such as drainage ditches, can change the characteristics of subsurface water flows into receiving streams. These changes result in less subsurface water storage and often increase stream flows during and after storms.
- *Livestock grazing* may reduce vegetative cover, which can result in more erosion on uplands and increased sediment and other pollutant loads in streams. Livestock that are allowed direct access to streams can significantly increase streambank erosion and destroy important riparian habitat.
- *Roads* built in rural areas, such as forest and recreational roads, alter the natural landscape and can destroy riparian habitat. If not properly installed and maintained, these types of roads erode and supply increased sediment and pollutants to adjacent streams. Additionally, roads may increase imperviousness, which leads to flashier runoff events. Stream crossings associated with rural roads can block fish passage, trap debris during storms, and lead to increased streambank erosion in nearby areas.
- *Marinas* can alter local wave and tidal flow patterns, resulting in transference of wave and tidal energy to adjacent shorelines.
- *Channelization or channel straightening* sometimes results in an increase in the slope of a channel, which causes an increase in stream flow velocities. Channel modifications to reduce flood damage, such as levees and floodwalls, often narrow the stream width, increasing the velocity of the water and thus its erosive potential. In addition, newly

constructed banks are generally more prone to erosion than “seasoned” banks and are more likely to require bank stabilization.

- *Dams* alter the flow of water, sediment, organic matter, and nutrients, resulting in both direct physical and indirect biological effects. The impact of a dam on a stream corridor can vary, depending on the purposes of the dam and its size in relation to stream flow. Varying discharges released from a hydropower dam can be a significant factor increasing streambank erosion. When dams are a barrier to the flow of sediment and organic materials, the decreased suspended sediment load in release waters may lead to scouring of downstream streambeds and streambanks.

In summary, these anthropogenic factors can affect the state of equilibrium in streams or along shorelines. The typical chain of events that follows the disturbance to a stream corridor or shoreline can be described as changes in:

- Hydrology
- Stream hydraulics
- Morphology
- Factors such as sediment transport and storage
- Alterations to the biological community
- Impervious cover

Management Measure 6: Eroding Streambanks and Shorelines

Management Measure 6
1) Where streambank or shoreline erosion is a nonpoint source (NPS) pollution problem, streambanks and shorelines should be stabilized. Vegetative methods are strongly preferred unless structural methods are more effective, considering the severity of stream flow discharge, wave and wind erosion, and offshore bathymetry, and the potential adverse impact on other streambanks, shorelines, and offshore areas. 2) Protect streambank and shoreline features with the potential to reduce NPS pollution. 3) Protect streambanks and shorelines from erosion due to uses of either the shorelands or adjacent surface waters.

Typically, several streambank and shoreline stabilization techniques may be used to effectively control erosion wherever it is a source of nonpoint pollution. Often a combination of techniques may be necessary to effectively control conditions that are causing the increased erosion. Techniques involving marsh creation and vegetative bank stabilization ("soil bioengineering") will usually be effective at sites with limited exposure to strong currents or wind-generated waves. In cases with increased erosional forces, an integrated approach that employs the use of structural systems in combination with soil bioengineering techniques can be utilized. The use of harder, more structural approaches, including beach nourishment and coastal or riparian structures, may need to be considered in areas facing severe water velocities or wave energy. In addition to controlling the sources of sediment contributed to surface waters, which are causing nonpoint source (NPS) pollution, these techniques can halt the destruction of wetlands and riparian areas located along the shoreline. Once affected streambanks and shorelines are protected, they can serve as a filter for surface water runoff from upland areas, or as a temporary sink for nutrients, contaminants, or sediment already present as NPS pollution in surface waters.

Stabilization practices involving vegetation or engineering structures should be properly designed and installed. These techniques should be applied only when there will be no adverse effects to aquatic or riparian habitat, or to the stability of adjacent shorelines. In addition to activities that are applied directly to an eroding streambank or shoreline, there may be opportunities to promote institutional measures that establish minimum setback requirements or a buffer zone to reduce concentrated flows and promote infiltration of surface water runoff in areas adjacent to the shoreline.

Stream-friendly Project Tips

Before Construction
Involve your neighbors to increase project success
Get the necessary permits
Flag and avoid disturbing wetlands
Preserve existing native trees and shrubs
Cut trees and shrubs rather than ripping them out of the ground (many may resprout)
Make a plan to replant disturbed areas and use native plants
Install sediment-control practices (e.g., coffer dams)

During Construction
Stockpile fertile topsoil for later use for plants
Use hand equipment rather than heavy equipment
If using heavy equipment, use wide-tracks or rubberized tires
Work from the streambank, preferably on the higher, non-wetland side
Avoid instream work except as authorized by your local fishery and wildlife authority
Stay 100 feet away from water when refueling or adding oil
Avoid using wood treated with creosote or copper compounds

After Construction
Keep out people and livestock during plant establishment
Check project after high flows
Water plants during *droughts*
Control grass until trees and shrubs overtop grass, usually two to three years

Source: SWCD. No date. *Protecting Streambanks from Erosion: Tips for Small Acreages in Oregon*. Washington County Soil and Water Conservation District and the Small Acreage Steering Committee, Oregon Association of Conservation Districts. http://www.or.nrcs.usda.gov/news/factsheets/fs4.pdf. Accessed June 2003.

Initially project planners can consider whether a complete removal or reversal of the causative effects is possible. For example, when evaluating restoration sites affected by upstream armoring and urbanization, rather than adding armoring to the downstream site that is eroding, the planning team may consider whether changes to operations up stream can be made. Next, activities to improve existing erosion damage may be examined. The alteration of operation approaches in combination with management and restoration efforts can reduce future impacts. Similarly, removal of channelization structures may allow for a greater recovery of the integrity of a stream corridor. If feasible, the objective of a restoration design should be to eliminate or moderate disruptive influences to allow for equilibrium (NRC, 1992). If this is not possible, restoration may have limited effectiveness in the long term or may require a closer look at an entire watershed to determine alternate restoration activities. See Chapter 6 for additional information on watershed planning and restoration information.

A glossary of stream restoration terms is available from U.S. Army Corps of Engineers' Ecosystem Management and Restoration Research Program at http://el.erdc.usace.army.mil/elpubs/pdf/sr01.pdf.

This management measure was selected for the following reasons:

- Many anthropogenic activities can destabilize streambanks and shorelines, resulting in erosion that contributes significant amounts of NPS pollution in surface waters.
- The loss of coastal land and streambanks due to shoreline and streambank erosion results in reduction of riparian areas and wetlands that have NPS pollution abatement potential.
- A variety of activities related to use of shorelands or adjacent surface waters can result in erosion of land along coastal bays or estuaries and loss of land along rivers and streams.

Preservation and protection of shorelines and streambanks can be accomplished through many approaches, but preference in this guidance is for vegetative practices, such as soil bioengineering and marsh creation, where their use is appropriate.

Management Practices for Management Measure 6

The management measure generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. A variety of vegetative and structural practices are presented and are examples of activities that can be used as a single practice or in combination with other practices to achieve the desired project goals. An example of a source of information is the USACE publication *Stream Management* (Fischenich and Allen, 2000), which provides a good summary of vegetative and structural practices as well as a comprehensive review of processes related to stream and streambank erosion. The document also presents a thorough overview of planning activities for approaching streambank erosion issues.

The types of practices that can be used to accomplish the elements of Management Measure 6, including the following groups of practices:

- Vegetative practices
- Structural practices
- Integrated systems
- Planning and regulatory approaches

Vegetative Practices

Vegetative practices have a long history of use in Europe for streambank and shoreline protection and for slope stabilization. Prior to the 1980s, they have been practiced in the United States only to a limited extent, primarily because other engineering options, such as the use of riprap, have been more commonly accepted practices (Allen and Klimas, 1986). The use of vegetative streambank and shoreline stabilization practices have become more common in the United States over the past several decades as their implementation has shown to be physically and ecologically successful. Economically, less costly alternatives of stabilization, such as vegetative practices, are being pursued as alternatives to engineering structures for controlling erosion of streambanks and shorelines.

Vegetative practices, sometimes referred to as soil bioengineering, refer to the installation of plant materials as a main structural component in controlling problems of land instability where erosion and sedimentation are occurring (USDA-NRCS, 1992). Vegetative practices can be defined as, “the use of live and dead plant materials, in combination with natural and synthetic support materials, for slope stabilization, erosion reduction, and vegetative establishment” (FISRWG, 1998).

Basic principles of soil bioengineering include the following (USDA-NRCS, 1992):

- Fit the soil bioengineering system to the site
  - Topography and exposure (e.g., note the degree of slope, presence of moisture)
  - Geology and soils (e.g., determine soil depth and type)
  - Hydrology (e.g., calculate peak flows in the project area)
- Retain existing vegetation whenever possible
- Limit removal of vegetation
- Stockpile and protect topsoil
- Protect areas exposed during construction
- Divert, drain, or store excess water

Additionally, vegetative approaches have the advantage of providing food, cover, and instream and riparian habitat for fish and wildlife and result in a more aesthetically appealing environment than traditional engineering approaches (Allen and Klimas, 1986). Many planners of vegetative practices try to utilize native plants and materials that can be obtained from local stands of species. These plants are already well adapted to the climate and soil conditions of the area and thus have an increased chance of becoming established and surviving. The use of locally available plants also cuts the costs of a restoration project (Gray and Sotir, 1996). Vegetative systems that use locally available plants have the added advantage of blending in with natural vegetation over time.

Additional benefits of using bioengineering methods include (USEPA, 2003c):

- Designed to be low maintenance or maintenance-free in the long run
- Enhance habitat not only by providing food and cover sources, but by serving as a temperature control for aquatic and terrestrial animals
- If successful, can stabilize slopes effectively in a short period of time (e.g., one growing season)
- Self-repairing after establishment
- Filter overland runoff, increase infiltration, and attenuate flood peaks

The limitations of vegetative practices include the need for skilled laborers and the difficulty of locating plant materials, particularly during the dormant season, which is the optimal time for installation. To properly establish a soil bioengineering planting, orientation, on-site training, and careful supervision of the labor crews are required. Another limitation, which is avoidable, is that projects that promote the growth of thick vegetation may increase roughness values or increase friction and raise floodwater elevations. This should be taken into consideration during the planning stages of a project and prevented.

Additional information about soil bioengineering principles is available from the *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992).[1] Local agencies, such as the USDA Natural Resources Conservation Service (NRCS) and the Cooperative Extension Service, can be useful sources of information on appropriate native plant species to consider in bioengineering projects.

The USDA Forest Service has published *A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization*,[2] which provides information on how to successfully plan and implement a soil bioengineering project, including the application of soil bioengineering techniques. The guide also provides specific tips for using soil bioengineering techniques successfully.

Specific vegetative practices include (USDA-NRCS, 1992):

- Branch packing
- Brush layering
- Brush mattressing
- Coconut fiber roll
- Dormant post plantings
- Live fascines
- Live staking
- Marsh creation and restoration
- Tree revetments
- Vegetated buffers

Refer to Chapter 7 for additional information about the above practices. The Additional Resources section provides a number of sources for obtaining information about the effectiveness, limitations, and cost estimates for these practices.

Structural Approaches

Soil bioengineering alone is not suitable in all instances. When considering an approach to streambank or shoreline stabilization, it is important to take several factors into account. For example, it is inappropriate to stabilize slopes with vegetative systems in areas that would not support plant growth, such as those areas with soils that are toxic to plants, areas of high water velocity, or where there is significant wave action (Gray and Sotir, 1996). Shores subject to wave erosion will usually require structures or beach nourishment to dampen wave or stream flow energy.

Properly designed and constructed shoreline and streambank erosion control structures are used in areas where higher water velocity or wave energy make vegetative stabilization and marsh creation ineffective. In addition to careful consideration of the engineering design, the proper planning for a shoreline or streambank protection project will include a thorough evaluation of

[1] The soil bioengineering chapter of the handbook is available at http://www.info.usda.gov/CED/ftp/CED/EFH-Ch18.pdf.
[2] Available at http://www.fs.fed.us/publications/soil-bio-guide.

the physical processes causing the erosion. To complete the analysis of physical factors, the following steps are suggested (Hobbs et al., 1981):

- Determine the limits of the shoreline reach
- Determine the rates and patterns of erosion and accretion and the active processes of erosion within the reach
- Determine, within the reach of the sites of erosion-induced sediment supply, the volumes of that sediment supply available for redistribution within the reach, as well as the volumes of that sediment supply lost from the reach
- Determine the direction of sediment transport and, if possible, estimation of the magnitude of the gross and net sediment transport rates
- Estimate factors such as ground-water seepage or surface water runoff that contribute to erosion

Some of the most widely accepted alternative engineering practices for streambank or shoreline erosion control are described below. These practices will have varying levels of effectiveness depending on the strength of waves, tides, streamflow, or currents at the project site. They will also have varying degrees of suitability at different sites and may have varying types of secondary impacts. One important impact that must always be considered is secondary effects, such as the transfer of wave or streamflow energy, which can cause erosion elsewhere, either offshore or alongshore. Finding a satisfactory balance between these three factors (effectiveness, suitability, and secondary impacts) is often the key to a successful streambank or shoreline erosion control project.

Examples of structural approaches include:

- Beach nourishment
- Breakwaters
- Bulkheads and seawalls
- Check dams
- Groins
- Levees, setback levees, and floodwalls
- Return walls
- Revetment
- Riprap
- Toe protection
- Wing deflectors

Refer to Chapter 7 for additional information about the above practices. The Additional Resources section provides a number of sources for obtaining information about the effectiveness, limitations, and cost estimates for these practices.

Integrated Systems

The use of structural systems alone may raise concern because these systems lack vegetation, which can be effective at stabilizing soils in most conditions. Additionally, vegetated systems can help to restore damaged habitat along shorelines and streambanks. Integrated systems, which combine structural systems and vegetation, can be very effective in many settings where vegetation adds support and habitat to structural systems. An example of an integrated system is the use of stones for toe protection (structural) and soil bioengineering techniques (vegetative) for the upper banks of a waterway. Integrated slope protection designs that employ the traditional structural methods and the soil bioengineering techniques have proven to be more cost effective than either method independently. Where construction methods are labor-intensive and labor costs are reasonable, the combination of methods may be especially cost effective (Gray and Sotir, 1996).

Integrated systems include:

- Bank shaping and planting
- Joint planting
- Live cribwalls
- Riparian improvements
- Root wad revetments
- Vegetated gabions
- Vegetated geogrids
- Vegetated reinforced soil slope (VRSS)

Refer to Chapter 7 for additional information regarding the above practices. The Additional Resources section provides a number of sources for obtaining information about the effectiveness, limitations, and cost estimates for these practices.

Planning and Regulatory Approaches

In addition to the vegetative, structural, and integrated practices discussed above, another group of practices that can be used to protect streambanks and shorelines includes planning and regulatory approaches. The variety of planning activities include practices in waters adjacent to eroding streambanks and shorelines (e.g., evaluating the erosion potential) and on land areas adjacent to eroding streambanks and shorelines (e.g., watershed planning processes). There are also a variety of local policy and regulatory activities that can be used to protect sensitive or eroding streambanks and shorelines ranging from setback requirements and vegetated buffer minimum widths to requirements for erosion and sediment control plans for various types of construction activities. The following are examples (with complete descriptions located in Chapter 7) of planning and regulatory protection activities that could be used to protect vulnerable streambanks or shorelines:

- Erosion and sediment control plans
- Establishment and protection of stream buffers
- Rosgen's stream classification method
- Setbacks
- Shoreline sensitivity assessment

Chapter 6: Guiding Principles

Many of the management measures and practices recommended by EPA to reduce the nonpoint source (NPS) pollutant impacts associated with hydromodification activities stress the need to incorporate planning as a tool. States, local governments, or community groups should begin the planning process early when trying to determine how to address a particular NPS issue associated with a new or existing hydromodification project. The planning process should bring key stakeholders together so that a variety of options can be explored to adequately define the problem and potential solutions. Once the issues are identified according to the various perspectives, project goals can be established to solve one or more environmental problems.

One important part of the planning process is the identification of the goals of the different stakeholders. Once these goals, which are sometimes different for the different groups of stakeholders, are identified and defined, the planning team can strive to achieve a balance among the needs of the various stakeholders. Often restoration compromises can be made to meet differing goals of the stakeholders to achieve a balance of the needs of the different groups. For example, changes in hydroelectric dam operation may be possible to produce minimum base flows downstream from the dam to support a variety of aquatic habitats, while still providing energy in a profitable manner. In addition, solutions that only allow for complete removal of the dam and restoration to preexisting stream conditions may not be possible because of other changes in the watershed (e.g., urbanization, other hydromodification projects, or the need for affordable and environmentally friendly electricity). A compromise solution that enables the dam to continue to operate while minimizing environmental impacts and to enhance critical downstream habitats that support a desirable fish population may be the best solution.

Part of the planning process and achievement of balance when evaluating techniques for restoring areas impacted by NPS pollution associated with hydromodification activities can be termed "creating opportunities." For example, an opportunity may be found by working with stakeholders such as local homeowners who are concerned about the unsightly algae present in a community reservoir. Reducing runoff containing an abundant supply of nitrogen and phosphorous pollutants from lawns surrounding the reservoir may lead to reductions in the algal bloom. Changes in land use that result in increasing the permeability of land adjacent to a channelized stream can reduce the overall volume and velocity of water in the stream. As flooding conditions are reduced, "hard" structures like bulkheads can be replaced with softer, vegetative solutions along the stream channel. The combination of reduced scouring flows associated with the greater stream velocities and vegetated channel banks can lead to improved instream ecological conditions. There are many other possible opportunities waiting to be found and implemented when projects are evaluated at the watershed level.

Project planning and analysis are essential parts of success when trying to reduce the impact of NPS pollution from new or existing hydromodification activities. One example of a planning process is explained in the EPA document *Ecological Restoration: A Tool to Manage Stream Quality* (USEPA, 1995a). This document outlines the key steps in the ecological restoration decision framework as:

- Identification of impaired or threatened watersheds

- Inventory of the watershed
- Identification of the restoration goals
- Selection of candidate restoration techniques
- Implementation of selected restoration techniques
- Monitoring

Other EPA guidance documents offer similar approaches to the restoration planning process, including *Community-Based Environmental Protection: A Resource Book for Protecting Ecosystems and Communities* (USEPA, 1997a). Both guidance documents offer a variety of case studies to provide readers with examples of the frameworks as they are applied to real-world situations. EPA's *Draft Handbook for Developing Watershed Plans to Restore and Protect Our Waters* (USEPA, 2005c) also provides useful planning information related to watershed plans.

The Natural Resources Conservation Service (NRCS) is also a source of information for planning. NRCS provides assistance through their Watershed Protection and Flood Prevention Program, whose purpose is to assist federal, state, local agencies, local government sponsors, tribal governments, and program participants to protect and restore watersheds from damage caused by erosion, floodwater, and sediment; to conserve and develop water and land resources; and to solve natural resource and related economic problems on a watershed basis. The program provides technical and financial assistance to local people or project sponsors, builds partnerships, and requires local and state funding contribution.[1]

NRCS uses locally-led conservation programs, which are an extension of the agency's traditional assistance to individual farmers and ranchers, for planning and installing conservation practices for soil erosion control, water management, and other purposes. Through this effort, local people, generally with the leadership of conservation districts along with NRCS technical assistance, will assess their natural resource conditions and needs, set goals, identify ways to solve resource problems, utilize a broad array of programs to implement solutions, and measure their success.

When planning any new development activities or restoration of already developed or impacted activities, it is important to account for the guiding principles:

- Using a watershed approach
- Smart growth principles
- Project design principles
- Monitoring and maintenance of structures

Each of these principles is discussed in more detail below.

[1] Additional information about this program, as well as contact information is available at http://www.nrcs.usda.gov/programs/watershed.

Using a Watershed Approach

EPA recommends the use of a watershed approach as the key framework for dealing with problems caused by runoff and other sources that impair surface waters (USEPA, 1998). The watershed protection approach is a comprehensive planning process that considers all natural resources in the watershed, as well as social, cultural, and economic factors. Using a watershed approach, multiple stakeholders integrate regional and locally-led activities with local, state, tribal, and federal environmental management programs. EPA works with federal agencies, states, tribes, local communities, and non-governmental sectors to make a watershed approach the key coordinating framework of planning, restoration, and protection efforts to achieve "clean and safe" water and healthy aquatic habitat.

The watershed approach framework can be applied to address impacts caused by hydromodification activities throughout a watershed. Additionally, the watershed approach can help to identify and address problems within a watershed that increase NPS pollution associated with hydromodification activities.

Major elements of successful watershed approaches include:

- Focusing on hydrologically-defined areas—watersheds and aquifers have hydrologic features that converge to a common point of flow; watersheds range in size from very large (e.g., the Mississippi River Basin) to a drainage basin for a small creek.

- Using an integrated set of tools and programs (regulatory and voluntary, federal/state/tribal/local and non-governmental sectors) to address the myriad problems facing the Nation's water resources, including NPS and point source pollution, habitat degradation, invasive species, and air deposition of pollutants (e.g., mercury and nutrients).

- Involving all parties that have a stake or interest in developing collaborative solutions to a watershed's water resource problems.

- Using an iterative planning or adaptive management process of assessment and setting environmental, water quality, and habitat goals (e.g., water quality standards).

- Planning, implementation, and monitoring to ensure that plans and implementation actions are revised to reflect new data.

- Breaking down barriers between plan development and implementation to enhance prospects for success.

A key attribute of the watershed approach is that it can be applied with equal success to large- and small-scale watersheds. Federal agencies, states, interstate commissions, and tribes usually apply the approach on larger scales, such as in watersheds greater than 100 square miles in size.

However, local agencies and urban communities can apply the approach to watersheds as small as several acres in size.

Although specifics may vary from large scale to small scale, the basic goals of the watershed approach remain the same—protecting, maintaining, and restoring water resources, based on the geomorphology, ecology, and other natural characteristics of the waterbody. Local runoff management program officials must be especially conscious of watershed scale when planning and implementing specific management practices. For example, programmatic practices, such as stream protection ordinances and public education campaigns, are usually applied community wide. Consequently, the results benefit many small watersheds. In contrast, structural practices, such as vegetative approaches, usually provide direct benefits to a single stream. Regional structural management practices such as headland breakwater systems for larger watersheds can be used, but they do not protect smaller contributing streams. Given limited resources, program officials must often analyze cost and benefits and choose between large- and small-scale practices. Often, a combination of nonstructural and structural practices implemented across the watershed and at regional and local levels is the most cost effective approach.

An example of the watershed approach being used for hydromodification activities is the South Myrtle Creek Ditch Project. South Myrtle Creek, which flows into the South Umpqua River in Oregon, was historically populated with cutthroat trout (*Oncorhynchus clarki*) and coho salmon (*Oncorhynchus kisutch*). However, since the early 20th century, diversion structures, used primarily to provide water for irrigating agricultural crops, have blocked the passage of fish through creek waters (USEPA, 2002c). One example of the diversion structures was a diversion dam with a concrete apron, which was installed in a portion of South Myrtle Creek to raise the water level in an impoundment to provide irrigation water for adjacent and downstream landowners. During the summer, water levels in the creek would elevate 14 feet above natural levels and were diverted into a 2.5 mile irrigation ditch. Ultimately, hydromodification of this stream caused flow modifications and high stream temperatures, which degraded water quality for the native trout and salmon populations.

9 Elements of Watershed Planning

EPA has identified a minimum of nine elements that are critical for achieving improvements in water quality. EPA requires that these nine elements be addressed for section 319-funded watershed plans and strongly recommends that they be included in all other watershed plans that are intended to remediate water quality impairments. Additional information is available from FY 2004 Guidelines for the Award of Section 319 Nonpoint Source Grants to States and Territories *at http://www.epa.gov/owow/nps/cwact.html. The nine elements are listed below:*

a. Identification of causes of impairment and pollutant sources or groups of similar sources that need to be controlled to achieve needed load reductions, and any other goals identified in the watershed plan. Sources that need to be controlled should be identified at the significant subcategory level along with estimates of the extent to which they are present in the watershed (e.g., X linear miles of eroded streambank needing remediation).

b. An estimate of the load reductions expected from management measures.

c. A description of the nonpoint source management measures that will need to be implemented to achieve load reductions and a description of the critical areas in which those measures will be needed to implement this plan.

d. Estimate of the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement this plan.

e. An information and education component used to enhance public understanding of the project and encourage their early and continued participation in selecting, designing, and implementing the nonpoint source management measures that will be implemented.

f. Schedule for implementing the nonpoint source management measures identified in this plan that is reasonably expeditious.

g. A description of interim measurable milestones for determining whether nonpoint source management measures or other control actions are being implemented.

h. A set of criteria that can be used to determine whether loading reductions are being achieved over time and substantial progress is being made toward attaining water quality standards.

i. A monitoring component to evaluate the effectiveness of the implementation efforts over time, measured against the criteria established under item h immediately above.

In 1998 one of the landowners initiated a project to restore flow and improve water quality in South Myrtle Creek. The project used the guiding principles of the watershed approach to restore the health of the creek.

- *Partnership*. The project was a collaborative effort of landowners, who donated services and supplies. The project received funding and support from government agencies, such as the U.S. Fish and Wildlife Service, the Oregon Water Resources Department, the Oregon Watershed Enhancement Board, the Bureau of Land Management, the Natural Resources Conservation Service, and the Douglas County Watermaster.

- *Geographic focus*. Resource management activities were directed specifically to the creek and the drainage ditch, where flow restoration and improved water quality were desired.

- *Sound management techniques based on strong science and data*. An assessment of South Myrtle Creek identified water quality problems from flow modification and high stream temperatures as the priority problems in the creek. The diversion dam and concrete apron were found to be causing the problems. Landowners, the Water Resources Department, and the Watershed Enhancement Board developed a plan, the goal of which was to restore flow and improve water quality in the creek. The plan was implemented by removing the diversion dam and concrete apron. The irrigation system was switched to a sprinkler type system, which is more efficient than the original ditch irrigation. In addition, the denuded riparian area was revegetated to help lower stream temperatures and new seedlings were protected with fencing to keep away livestock.

With the cooperation of the landowners, the county and state governments, and other interested parties, the South Myrtle Creek Ditch Project was a success. Water temperatures have improved and flows have increased by 2.5 cubic feet per second during the summer. Restoration of the streambed to its historical level has allowed passage of salmon and trout to the 10 miles of stream above the dam (USEPA, 2002c).[2]

Smart Growth

Smart growth practices cover a range of development and conservation strategies that are environmentally sensitive, economically viable, community-oriented, and sustainable. Environmental impacts of development can be reduced with techniques that include compact development, reduced impervious surfaces and improved water detention, safeguarding of environmentally sensitive areas, mixing of land uses (e.g., homes, offices, and shops), transit accessibility, and better pedestrian and bicycle amenities.

Through smart growth approaches that enhance neighborhoods and involve local residents in development decisions, these communities are creating vibrant places to live, work, and play. The high quality of life in these communities makes them economically competitive, creates business opportunities, and improves the local tax base. Smart growth practices have also been shown to help protect water quality by reducing the amount of paved surfaces and allowing natural lands to filter rainwater and runoff before it reaches downstream areas.

Based on the experience of communities around the nation that have used smart growth approaches to create and maintain great neighborhoods, the Smart Growth Network[3] developed a set of ten basic principles:

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[2] Additional information about the project is available at http://www.epa.gov/owow/nps/Section319III/OR.htm.
[3] Smart Growth Network (SGN) is a partnership of government, business, and civic organizations that support smart growth. The SGN Web site, Smart Growth Online (http://www.smartgrowth.org/Default.asp?res=1024), features an extensive array of smart growth-related news, events, information, research, presentations, and publications.

1. Mix land uses
2. Take advantage of compact building design
3. Create a range of housing opportunities and choices
4. Create walkable neighborhoods
5. Foster distinctive, attractive communities with a strong sense of place
6. Preserve open space, farmland, natural beauty, and critical environmental areas
7. Strengthen and direct development towards existing communities
8. Provide a variety of transportation choices
9. Make development decisions predictable, fair, and cost effective
10. Encourage community and stakeholder collaboration in development decisions

EPA offers help to communities through the EPA smart growth program to improve development practices and get the type of development they want. They work with local, state, and national experts to discover and encourage successful, environmentally sensitive development strategies. EPA is engaged in conducting research, publishing reports and other publications,[4] showcasing outstanding communities, working with communities through grants[5] and technical assistance (Smart Growth Implementation Assistance Program),[6] and bringing together diverse interests to encourage better growth and development.[7]

Low Impact Development

Low Impact Development (LID) is an innovative stormwater management approach. The goal of LID is to mimic a site's predevelopment hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source (Low Impact Development Center, Inc., n.d.).

LID is based on the paradigm that stormwater management should not be viewed as stormwater disposal and that numerous opportunities exist within the developed landscape to control stormwater runoff close to the source. These principles include (NRDC, n.d.):

- Integrate stormwater management early in site planning activities
- Use natural hydrologic functions as the integrating framework
- Focus on prevention rather than mitigation
- Emphasize simple, low-tech, and low cost methods
- Manage as close to the source as possible
- Distribute small-scale practices throughout the landscape
- Rely on natural features and processes
- Create a multifunctional landscape

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[4] http://www.epa.gov/piedpage/publications.htm
[5] http://www.epa.gov/piedpage/grants/index.htm
[6] http://www.epa.gov/piedpage/sgia.htm
[7] Links to technical assistance, tools, partnerships and grants and other funding are at "Making Smart Growth Happen" at http://www.epa.gov/piedpage/sg_implementation.htm.

The use of LID practices offers both economic and environmental benefits. LID measures result in less disturbance of the development area and conservation of natural features, and they can be less cost intensive than traditional stormwater control mechanisms. Cost savings for control mechanisms are not only for construction, but also for long-term maintenance and life cycle cost considerations (USEPA, 2000).

Ten common LID practices are the following (NRDC, n.d.):

- Impervious surface reduction and disconnection
- Permeable pavers
- Pollution prevention and good housekeeping
- Rain barrels and cisterns
- Rain gardens and bioretention
- Roof leader disconnection
- Rooftop gardens
- Sidewalk storage
- Soil amendments
- Tree preservation
- Vegetated swales, buffers, and strips

Project Design Considerations

General Design Factors

When designing any type of restoration project, it is important to consider the watershed as a whole as well as the specific site where restoration will occur. A watershed survey, or visual assessment, evaluates an entire watershed and can be used to help identify and verify pollutants, sources, and causes of impairments that lead to changes in streambank erosion. Additional monitoring of chemical, physical, and biological conditions may be necessary to determine if water quality is actually being affected by observed pollutants and sources. Watershed surveys can provide an accurate picture of what is occurring in the watershed. EPA's *Volunteer Stream Monitoring: A Methods Manual*[8] provides a watershed survey visual assessment form that may be used. In addition to EPA's method, a variety of visual assessment protocols have been developed by states and agencies. Designers of watershed restoration plans should look for assessment protocols that are already being used in their state or local area (USEPA, 2005c). Another general resource for planning and implementing restoration projects associated with hydromodification activities is EPA's *National Management Measures to Protect and Restore Wetlands* (USEPA, 2005b).

Photographs may also be a powerful tool that can be incorporated into watershed surveys. Photos serve as a visual reference for the site and provide before and after pictures that may be used to analyze restoration or remediation activities. In addition to taking individual photographs, aerial photographs may also provide important before and after information and can be obtained from

[8] http://www.epa.gov/owow/monitoring/volunteer/stream/vms32.html

USGS (Earth Science Information Center), USDA (Consolidated Farm Service Agencies, Aerial Photography Field Office), and other agencies (USEPA, 2005c). Refer to EPA's draft *Handbook for Developing Watershed Plans to Restore and Protect Our Waters* (USEPA, 2005c) for more information about watershed assessments.

Assessment

Tools to analyze channels on a site-by-site basis may include geomorphic assessments such as the methodology developed by Rosgen. Geomorphic assessments help to determine river and stream characteristics such as channel dimensions, reach slope, and channel enlargement and stability. This information about stream physical characteristics might help the restoration team to understand current stream conditions and may be evaluated over time to describe degradation or improvements in the stream. Geomorphic assessment may also be useful for predicting future stream conditions, which can help in selecting suitable restoration or protection approaches (USEPA, 2005c).

The Rosgen geomorphic assessment approach groups streams into different geomorphic classes, based on a set of criteria that include entrenchment ratio, width/depth ratio, sinuosity, channel slope, and channel materials. Assessment methodologies, such as Rosgen's Stream Classification System, can help identify streams at different levels of impairment, determine the types of hydrologic and physical factors affecting stream morphologic conditions, and choose appropriate management measures to implement if needed.[9] Another common geomorphic assessment method is the Modified Wolman Pebble Count (Harrelson et al., 1994), which characterizes the texture (particle size) in the stream or riverbeds of flowing surface waters. It can be used alone or with Rosgen-type assessments. The composition of the streambed can provide information about the characteristics of the stream, including effects of flooding, sedimentation, and other physical impacts on a stream (USEPA, 2005c). Other assessment methods may be available from state agencies or environmental organizations.

The physical conditions of a site can provide important information about factors affecting overall stream integrity, such as agricultural activities and urban development. Runoff from cropland and feedlots can carry sediment into streams, clog existing habitat, and change geomorphological characteristics. An understanding of stream physical conditions can facilitate identification of sources and pollutants and allow for designing and implementing more effective restoration and protection strategies. Physical characterization should also extend beyond the streambanks or shore and include a look at conditions in riparian areas (USEPA, 2005c).

Before choosing a practice to restore an area impacted by hydromodification activities, it is also important to determine what biological endpoints are desired and to consider other environmental or water quality goals. Biological endpoints may include metrics such as the number of fish surviving, number of offspring produced, impairment of reproductive capability, or morbidity. Biological endpoints can be used to evaluate the effectiveness of treatment schemes and can serve as a design parameter during restoration planning. Water quality goals, such as increasing low dissolved oxygen levels, reducing nitrogen or phosphorous pollutant

[9] More information about the Rosgen Stream Classification System is available at http://www.epa.gov/watertrain/stream_class/index.htm.

levels, or decreasing turbidity, are also important to consider when planning restoration. For example, if turbidity is a major problem in the waterbody, planners will want to choose a method of restoration that prevents erosion, is efficient at trapping sediment before it enters the waterbody, or one that will help sediment to settle in desired locations of the stream or river. Looking at endpoints and goals before designing the method of restoration can help planners and stakeholders achieve the desired results.

Engineering Considerations

When choosing from the various alternatives of engineering practices for addressing impacts associated with hydromodification, such as protecting and restoring eroding streambanks and shorelines, the following factors should be taken into consideration:

- Foundation conditions
- Level of exposure to erosive forces
- Availability of materials
- Initial and annual costs
- Past performance

Foundation conditions may have a significant influence on the selection of the specific practice or combination of practices to be used for restoring areas impacted by hydromodification, including shoreline or streambank stabilization. Foundation characteristics at the site must be compatible with the structure that is to be installed for erosion control. A structure such as a bulkhead, which must penetrate through the existing substrate for stability, will generally not be suitable for shorelines with a rocky bottom. Where foundation conditions are poor or where little penetration is possible, a gravity-type structure such as a stone revetment may be preferable. However, all vertical protective structures (revetments, seawalls, and bulkheads) built on sites with soft or unconsolidated bottom materials can experience scouring as incoming waves are reflected off the structures. In the absence of additional toe protection in these circumstances, the level of scouring and erosion of bottom sediments at the base of the structure may be severe enough to contribute to structural failure at some point in the lifetime of the installation.

Along streambanks, the erosive force of the current during periods of high streamflow will influence the selection of bank stabilization techniques and details of the design. For shorelines, the levels of wave exposure at the site will also generally influence the selection of shoreline stabilization techniques and details of the design. In areas of severe levels of exposure to erosive forces, such as strong wave action or currents, light structures such as vegetative techniques, timber cribbing, or light riprap revetment may not provide adequate protection. The effects of winter ice along the shoreline or streambank may also need to be considered in the selection and design of erosion control projects.

The availability of materials is another key factor influencing the selection of suitable techniques for protecting and restoring areas affected by hydromodification activities. For a vegetative approach, availability of plant materials of sufficient quantity and quality is an important design consideration. A particular type of bulkhead, seawall, or revetment may not be economically feasible if materials are not readily available near the construction site. Installation methods may also preclude the use of specific structures in certain situations. For instance, the installation of bulkhead pilings in coastal areas near wetlands may not always be permissible due to disruptive impacts in locating pile-driving equipment at the project site.

Costs should also be included in the decision making process for implementing hydromodification practices. The total cost of a project should be viewed as including both the initial costs (materials, labor, and planning) and the annual costs of operation and maintenance. To the extent possible, practices should be compared by their total costs. Although a particular practice may be cheaper initially, it could have operation and maintenance costs that make it more expensive in the long run. For example, in some parts of the country, the initial costs of timber bulkheads may be less than the cost of stone revetments. However, stone structures typically require less maintenance and have a longer life than timber structures. Other types of structures whose installation costs are similar may actually have a wide difference in overall cost when annual maintenance and the anticipated lifetime of the structure are considered (USACE, 1984). Environmental benefits, such as creation of habitat, should also be factored into cost evaluations.

An example of a valuable resource that provides specific cost information for practices to protect or reduce streambank and shoreline erosion is your local USDA Service Center, which makes available services provided by the NRCS.[10]

The engineering designers should also evaluate similar existing projects and practice designs to determine how well they performed compared to design specifications. An important consideration for determining past performance is to compare the physical, water quality, and biological endpoints specified in the design with the corresponding endpoints that were observed in the monitoring results. For example, if an operation and maintenance program for an urban channelization project incorporates establishment of vegetative cover along many of the low energy areas of an urban stream, the long-term performance of the vegetative cover can be evaluated with metrics such as:

- Percent of riparian area with erosion problems
- Number of recreationally important fish species present
- Annual operation and maintenance costs
- Changes in important water quality parameter values (e.g., dissolved oxygen, turbidity)

Incorporating Monitoring and Maintenance of Structures

Generally, the monitoring program will help to determine how well the project is performing with respect to the design goals and the extent of any maintenance activities needed (NRC, 1992). The project monitoring plan should be an integral part of the overall design and will be an important consideration for developing long-term project costs and resource needs. Once the project's goals are established, performance indicators are then matched to the goals to create the

[10] A list of USDA Service Centers is available at http://offices.sc.egov.usda.gov/locator/app. A list of regional and state NRCS offices is available at http://www.nrcs.usda.gov/about/organization/regions.html#state.

monitoring program (NRC, 1992). The monitoring program should also be appropriate to the scope of the project (NRC, 1992) by including considerations such as:

- The area covered by the monitoring compared to the area of the overall project—both should be similar.
- The frequency and intensity of sampling to provide reliable assessments of the performance indicators.
- The cost and resources required for monitoring should reflect the overall cost and resources of the project.
- The performance indicators provide information to enable effective assessments of the project goals and decision-making for project maintenance activities.

Each project will have unique goals and corresponding monitoring needs. Chapter 3 of The National Research Council's document *Restoration of Aquatic Ecosystems* (NRC, 1992) provides detailed advice on considerations for planning a monitoring program for restoration activities such as those associated with hydromodification activities. Some additional monitoring considerations can be found in the USDA Forest Service document *A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization* (USDA-FS, 2002):

- Keeping track of where plants were harvested—is there a correlation between growth rate of certain cuttings and the "mother" plants?
- Is the installation functioning as designed?
- Which areas are maturing more rapidly than others?
- Are seeds sprouting in the newly formed beds?
- Which plants have invaded the site through natural succession?
- What has sprouted in the second season?
- Which areas are experiencing difficulty and why?
- Is the bank stabilizing or washing away and why?
- Is something occurring that is unexpected?
- Which techniques are succeeding?
- Are any of the structures failing?

USDA NRCS' *The Practical Streambank Bioengineering Guide*[11] (Bentrup and Hoag, 1998) provides an example monitoring form. The monitoring sheet is also available in Appendix C of *A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization* (USDA-FS, 2002).[12]

During the first few years after installation, maintenance is necessary until vegetation becomes established and the bank stabilizes. Structures may shift or you may notice something that was left undone. Once vegetation is established, projects should become self-sustaining and require little or no maintenance. Be sure the site is managed to give the treatment every chance to be effective over a long period of time (USDA-FS, 2002).

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[11] http://www.engr.colostate.edu/~bbledsoe/CE413/idpmcpustguid.pdf
[12] http://www.fs.fed.us/publications/soil-bio-guide/guide/appendices.pdf

Common maintenance tasks include (USDA-FS, 2002; Bentrup and Hoag, 1998):

- Remove debris and weeds that may shade and compete with cuttings
- Secure stakes, wire, twine, etc.
- Control weeds
- Repair weakened or damaged structures (including fences)
- Replant and reseed as necessary (it is not uncommon for a flood to occur days after installation)

Planting success varies from project to project. Bentrup and Hoag (1998) provide the following potential growth success rates:

Pole Plantings	*70-100%*
Live Fascines	*20-50%*
Brush Layering	*10-70%*
Post Plantings	*50-70%*

It is beneficial to inspect the project every other week for the first 2 months after installation, once a month for the next 6 months, and then every other month for 2 years, at least. One should also inspect the project after heavy precipitation, flooding, snowmelt, drought, or any extraordinary occurrence. Assess damage from flooding, wildlife, grazing, boat wakes, trampling, drought, and high precipitation (USDA-FS, 2002). Additional information about monitoring is available from USDA NRCS' *The Practical Streambank Bioengineering Guide* (Bentrup and Hoag, 1998).

Plan and design all streambank, shoreline, and navigation structures so that they do not transfer erosion energy or otherwise cause visible loss of surrounding streambanks or shorelines.

Maintenance varies with the structural type. For stone revetments, the replacement of stones that have been dislodged is necessary; timber bulkheads need to be backfilled if there has been a loss of upland material, and broken sheet pile should be replaced as necessary. Gabion baskets should be inspected for corrosion failure of the wire, usually caused either by improper handling during construction or by abrasion from the stones inside the baskets. Baskets should be replaced as necessary since waves will rapidly empty failed baskets.

Steel, timber, and aluminum bulkheads should be inspected for sheet pile failure due to active earth pressure or debris impact and for loss of backfill. For all structural types not contiguous to other structures, lengthening of flanking walls may be necessary every few years. Through periodic monitoring and required maintenance, a substantially greater percentage of coastal structures will perform effectively over their design life. Since streambank or shoreline protection projects can transfer energy from one area to another, which causes increased erosion in the adjacent area, the possible effects of erosion control measures on adjacent properties should be routinely monitored.

Chapter 7: Practices for Implementing Management Measures

Many of the operation and maintenance solutions presented in Chapter 3 (Channelization and Channel Modification) are also practices that can be used to stabilize streambanks and shorelines as presented in Chapter 5 (Streambank and Shoreline Erosion). For example, a stream channel that has been hardened with vertical concrete walls to prevent local flooding and limit the stream to its existing channel (to protect property built along the stream channel), may benefit from operation and maintenance practices that use opportunities to replace the concrete walls with appropriate vegetative or combined vegetative and non-vegetative structures along the streambank when possible. These same practices may be applicable to stabilize downstream streambanks that are eroding and creating a nonpoint source (NPS) pollution problem because of the upstream development and hardened streambanks.

The following practices apply to one or more management measures. The descriptions and illustrations presented in this chapter are intended to provide a starting point for stakeholders and decision-makers for selecting possible practices to address NPS pollution problems associated with hydromodification activities. Table 7.1 provides a cross-reference of the practices with possible applications for the various hydromodification management measure components (e.g., instream and riparian restoration corresponds to the second component of Management Measures 1 and 2 described in detail in Chapter 3). Users of the information provided in the following table and descriptions evaluate the attributes of the possible practices with site-specific conditions in mind.

Table 7.1 Practices for Hydromodification Management Measures

	Channelization		Dams								Streambanks				Shorelines			
	Physical & chemical	Instream/riparian restoration	Erosion control	Runoff control	Chemical/pollutant control	Watershed protection	Aerate reservoir water	Improve tailwater oxygen	Restore/maintain habitat	Maintain fish passage	Vegetative	Structural	Integrated	Planning & regulatory	Vegetative	Structural	Integrated	Planning & regulatory
Practices	MM1	MM2	MM3		MM4	MM5					MM6							
Advanced Hydroelectric Turbines (7-7)										●								
Bank Shaping and Planting (7-9)	●	●	●										●				●	
Beach Nourishment (7-10)												●				●		
Behavioral Barriers (7-12)										●								
Branch Packing (7-14)	●	●	●								●							
Breakwaters (7-15)																●		
Brush Layering (7-17)	●	●	●								●							
Brush Mattressing (7-19)	●	●	●								●							
Bulkheads and Seawalls (7-21)	●	●	●									●				●		
Check Dams (7-22)	●	●	●	●								●						
Coconut Fiber Roll (7-23)	●	●	●								●							
Collection Systems (7-25)										●								
Construct Runoff Intercepts (7-26)			●	●														
Constructed Spawning Beds (7-27)									●									
Construction Management (7-28)			●															
Dormant Post Plantings (7-29)	●	●	●								●				●			

	Channelization		Dams								Streambanks				Shorelines			
	Physical & chemical	Instream/riparian restoration	Erosion control	Runoff control	Chemical/pollutant control	Watershed protection	Aerate reservoir water	Improve tailwater oxygen	Restore/maintain habitat	Maintain fish passage	Vegetative	Structural	Integrated	Planning & regulatory	Vegetative	Structural	Integrated	Planning & regulatory
Encourage Drainage Protection (7-30)						●												
Equipment Runoff Control (7-31)					●													
Erosion and Sediment Control (ESC) Plans (7-32)	●	●	●											●				●
Erosion Control Blankets (7-35)			●															
Establish and Protect Stream Buffers (7-37)		●				●								●				
Fish Ladders(7-38)										●								
Fish Lifts (7-40)										●								
Flow Augmentation (7-41)									●									
Fuel and Maintenance Staging Areas (7-43)					●													
Gated Conduits (7-44)								●										
Groins (7-45)																●		
Identify and Address NPS Contributions (7-46)						●												
Identify and Preserve Critical Areas (7-48)						●												
Joint Planting (7-50)	●	●	●										●					
Labyrinth Weir (7-51)								●										
Levees, Setback Levees, and Floodwalls (7-52)	●	●										●				●		

	Channelization		Dams								Streambanks				Shorelines			
	Physical & chemical	Instream/riparian restoration	Erosion control	Runoff control	Chemical/pollutant control	Watershed protection	Aerate reservoir water	Improve tailwater oxygen	Restore/maintain habitat	Maintain fish passage	Vegetative	Structural	Integrated	Planning & regulatory	Vegetative	Structural	Integrated	Planning & regulatory
Live Cribwalls (7-54)	●	●	●										●					
Live Fascines (7-56)	●	●	●								●							
Live Staking (7-58)	●	●	●								●							
Locate Potential Land Disturbing Activities Away from Critical Areas (7-60)			●	●	●													
Marsh Creation and Restoration (7-61)		●									●				●			
Modifying Operational Procedures (7-62)								●										
Mulching (7-63)			●															
Noneroding Roadways (7-64)	●	●	●															
Pesticide and Fertilizer Management (7-67)					●													
Phase Construction (7-69)			●															
Physical Barriers (7-70)										●								
Pollutant Runoff Control (7-72)					●													
Preserve Onsite Vegetation (7-73)			●	●														
Reregulation Weir (7-74)								●										
Reservoir Aeration (7-75)							●											
Retaining Walls (7-77)			●	●														
Return Walls (7-78)	●	●										●				●		
Revegetate (7-79)			●															

	Channelization		Dams								Streambanks				Shorelines			
	Physical & chemical	Instream/riparian restoration	Erosion control	Runoff control	Chemical/pollutant control	Watershed protection	Aerate reservoir water	Improve tailwater oxygen	Restore/maintain habitat	Maintain fish passage	Vegetative	Structural	Integrated	Planning & regulatory	Vegetative	Structural	Integrated	Planning & regulatory
Revetment (7-80)	●	●	●									●				●		
Riparian Improvements (7-82)		●	●						●				●				●	
Riprap (7-83)	●	●	●									●				●		
Root Wad Revetments (7-84)	●	●	●										●					
Rosgen's Stream Classification Method (7-86)	●	●												●				
Scheduling Projects (7-88)			●															
Sediment Basins/Rock Dams (7-89)				●														
Sediment Fences (7-91)			●	●														
Sediment Traps (7-92)				●														
Seeding (7-93)			●															
Selective Withdrawal (7-94)								●										
Setbacks (7-95)	●	●												●				●
Shoreline Sensitivity Assessment (7-97)																		●
Site Fingerprinting (7-99)			●															
Sodding (7-100)			●															
Soil Protection (7-101)			●															
Spill and Water Budgets (7-102)										●								
Spill Prevention and Control Program (7-103)					●													
Spillway Modifications (7-104)								●	●									
Surface Roughening (7-105)			●															

	Channelization		Dams								Streambanks				Shorelines			
	Physical & chemical	Instream/riparian restoration	Erosion control	Runoff control	Chemical/pollutant control	Watershed protection	Aerate reservoir water	Improve tailwater oxygen	Restore/maintain habitat	Maintain fish passage	Vegetative	Structural	Integrated	Planning & regulatory	Vegetative	Structural	Integrated	Planning & regulatory
Toe Protection (7-106)	●	●										●				●		
Training—ESC (7-107)			●															
Transference of Fish Runs (7-108)										●								
Tree Armoring, Fencing, and Retaining Walls or Tree Wells (7-109)			●															
Tree Revetments (7-110)	●	●	●								●				●			
Turbine Operation (7-112)								●										
Turbine Venting (7-113)								●										
Vegetated Buffers (7-114)	●	●	●	●							●				●			
Vegetated Filter Strips (7-115)			●	●														
Vegetated Gabions (7-116)	●	●	●										●				●	
Vegetated Geogrids (7-118)	●	●	●										●				●	
Vegetated Reinforced Soil Slope (VRSS) (7-120)	●	●	●										●				●	
Water Conveyances (7-121)								●										
Wildflower Cover (7-122)			●															
Wind Erosion Controls (7-123)			●															
Wing Deflectors (7-124)	●	●										●				●		

Advanced Hydroelectric Turbines

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☑ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Hydroelectric turbines can be designed to reduce impacts to juvenile fish passing through the turbine as it operates. Most research on advanced hydroelectric turbines is being carried out by power producers in the Columbia River basin (U.S. Army Corps of Engineers (USACE) and public utility districts) who are looking to improve the survival of hydroelectric turbine-passed juvenile fish by modifying the operation and design of turbines. Development of low impact turbines is also being pursued on a national scale by the U.S. Department of Energy (DOE) (Cada, 2001).

In the last few years, field studies have shown that improvements in the design of turbines have increased the survival of juvenile fish. Researchers continue to examine the causes and extent of injuries from turbine systems, as well as the significance of indirect mortality and the effects of turbine passage on adult fish. Overall, improvements in turbine design and operation, and new field, laboratory, and modeling techniques to assess turbine-passage survival, are contributing towards improving downstream fish passage at hydroelectric power plants (Cada, 2001).

The redesign of conventional turbines for fish passage has focused on strategies to reduce obstructions and to narrow the gaps between moveable elements of the turbine that are thought to injure fish. The effects of changes in the number, size, orientation, or shape of the blades that make up the runner (the rotating element of a turbine which converts hydraulic energy into mechanical energy) are being investigated (Cada, 2001).

The USACE has put considerable resources into improving turbine passage survival. The USACE Turbine Passage Survival Program (TSP) was developed to investigate means to improve the survival of juvenile salmon as they pass through turbines located at Columbia and Snake River dams. The TSP is organized along three functional elements that are integrated to achieve the objectives (Cada, 2001):[1]

- Biological studies of turbine passage at field sites
- Hydraulic model investigations
- Engineering studies of the biological studies, hydraulic components, and optimization of turbine operations

DOE supports development of low impact turbines under the Advanced Hydropower Turbine System (AHTS) Program. The AHTS program explores innovative concepts for turbine design that will have environmental benefits and maintain efficient electrical generation. The AHTS program awarded contracts for conceptual designs of advanced turbines to different firms/companies. Early in the development of conceptual designs, it became clear that there were

[1] Additional information about USACE efforts with advanced hydroelectric turbines is available at http://hydropower.inel.gov/turbines/pdfs/amfishsoc-fall2001.pdf.

significant gaps in the knowledge of fish responses to physical stresses (injury mechanisms) experienced during turbine passage. Consequently, the AHTS program expanded its activities to include studies to develop biological criteria for turbines (Cada, 2001).[2]

[2] Additional information about DOE efforts with advanced hydroelectric turbines is available at http://hydropower.inel.gov/turbines/pdfs/amfishsoc-fall2001.pdf.

Bank Shaping and Planting

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☑ Integrated
  - ☐ Planning & regulatory

Bank shaping and planting involve regrading a streambank to establish a stable slope angle, placing topsoil and other material needed for plant growth on the streambank, and selecting and installing appropriate plant species on the streambank. This design is most successful on streambanks where moderate erosion and channel migration are anticipated. Reinforcement at the toe of the bank is often required, particularly where flow velocities exceed the tolerance range for plantings and where erosion occurs below base flows. To determine the appropriate slope angle, slope stability analyses that take into account streambank materials, groundwater fluctuations, and bank loading conditions are recommended (FISRWG, 1998).

Additional Resources

- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.

- Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Bank Shaping and Vegetating.* Created for United States Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/bankshaping.pdf.

Beach Nourishment

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☑ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

The creation or nourishment of existing beaches provides protection to the eroding area and can also provide a riparian habitat function, particularly when portions of the finished project are planted with beach or dune grasses (Woodhouse, 1978). Beach nourishment (Figures 7.1 through 7.4) requires a readily available source of suitable fill material that can be effectively transported to the erosion site for reconstruction of the beach (Hobson, 1977). Dredging or pumping from offshore deposits is the method most frequently used to obtain fill material for beach nourishment. A second possibility is the mining of suitable sand from inland areas and overland hauling and dumping by trucks. To restore an eroded beach and stabilize it at the restored position, fill is placed directly along the eroded sector (USACE, 1984). In most cases, plans must be made to periodically obtain and place additional fill on the nourished beach to replace sand that is carried offshore into the zone of breaking waves or alongshore in littoral drift (Houston, 1991; Pilkey, 1992).

One important task that should not be overlooked in the planning process for beach nourishment projects is the proper identification and assessment of the ecological and hydrodynamic effects of obtaining fill material from nearby submerged coastal areas. Removal of substantial amounts of bottom sediments in coastal areas can disrupt populations of fish, shellfish, and benthic organisms (Atlantic States Marine Fisheries Commission, 2002). Grain size analysis should be performed on sand from both the borrow area and the beach area to be nourished. Analysis of grain size should include both size and size distribution, and fill material should match both of these parameters (Stauble, 2005). Fill materials should also be analyzed for the presence of contaminants, and contaminated sediment should not be used (CA Department of Boating and Waterways and State Coastal Conservancy, 2002). Turbidity levels in the overlying waters can also be raised to undesirable levels (EUCC, 1999). Certain

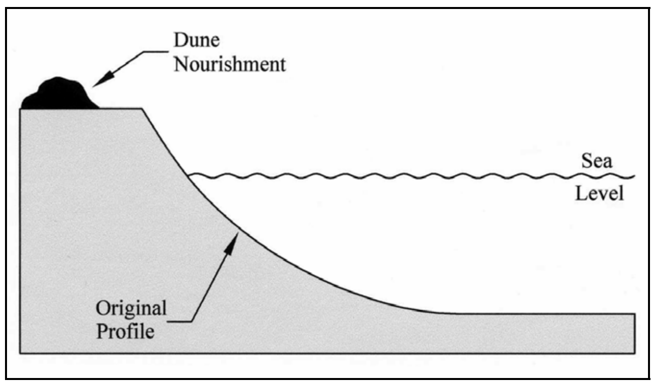

Figure 7.1 Dune Nourishment (CA Dept. of Boating and Waterways and State Coastal Conservancy, 2002)

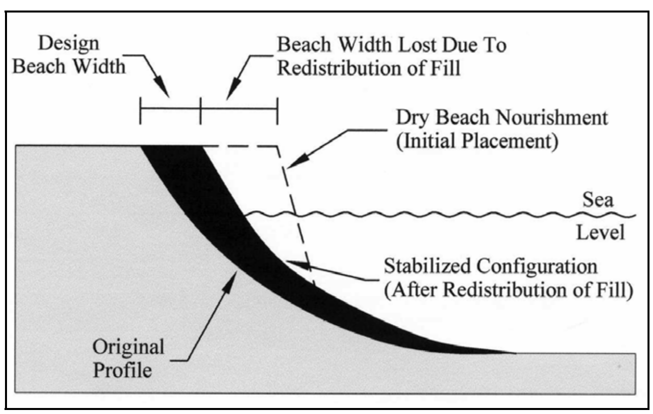

Figure 7.2 Dry Beach Nourishment (CA Dept. of Boating and Waterways and State Coastal Conservancy, 2002)

areas may have seasonal restrictions on obtaining fill from nearby submerged areas (TRB, 2001). Timing of nourishment activities is frequently a critical factor since the recreational demand for beach use frequently coincides with the best months for completing the beach nourishment. These may also be the worst months from the standpoint of impacts to aquatic life and the beach community such as turtles seeking nesting sites.

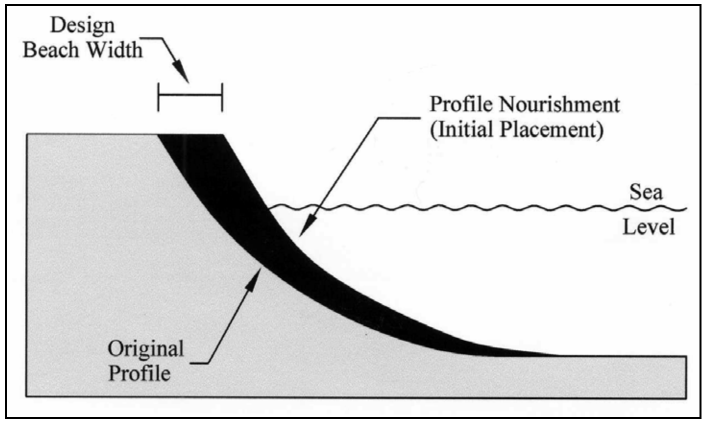

Figure 7.3 Profile Nourishment (CA Dept. of Boating and Waterways and State Coastal Conservancy, 2002)

Design criteria should include proper methods for stabilizing the newly created beach and provisions for long-term monitoring of the project to document the stability of the newly created beach and the recovery of the riparian habitat and wildlife in the area.

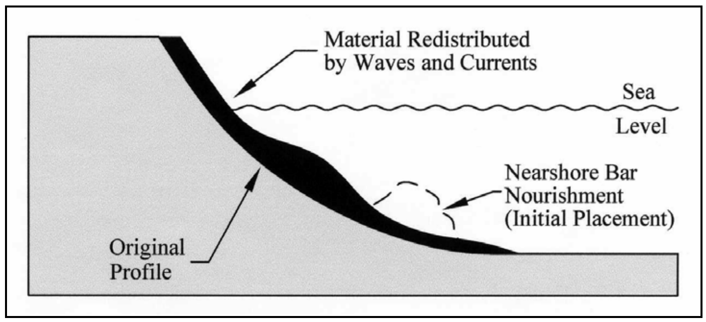

Figure 7.4 Nearshore Bar Nourishment (CA Dept. of Boating and Waterways and State Coastal Conservancy, 2002)

<u>Additional Resources</u>

- Barber, D. No date. *Beach Nourishment Basics.* http://www.brynmawr.edu/geology/geomorph/beachnourishmentinfo.html.
- NOAA. No date. *Beach Nourishment: A Guide for Local Government Officials.* U.S. Department of Commerce, NOAA Coastal Services Center. http://www.csc.noaa.gov/beachnourishment.
- Scottish National Heritage. No date. *A Guide to Managing Coastal Erosion in Beach/Dune Systems: Beach Nourishment.* http://www.snh.org.uk/publications/on-line/heritagemanagement/erosion/appendix_1.7.shtml.

Behavioral Barriers

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☑ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Behavioral barriers use fish responses to external stimuli to keep fish away from intakes or to attract them to a bypass. Since fish behavior is notably variable both within and among species, behavioral barriers cannot be expected to prevent all fish from entering hydropower intakes. Environmental conditions such as high turbidity levels can obscure some behavioral barriers, such as lighting systems and curtains. Competing behaviors such as feeding or predator avoidance can also be a factor influencing the effectiveness of behavioral barriers at a particular time.

Electric screens, bubble and chain curtains, light, sound, and water jets have been evaluated in laboratory or field studies and show mixed results. Despite numerous studies, very few permanent applications of behavioral barriers have been realized (EPRI, 1999). Some authors suggest using behavioral barriers in combination with physical barriers (Mueller et al., 1999).

Electrical screens keep fish away from structures and guide them into bypass areas for removal. Fish seem to respond to the electrical stimulus best when water velocities are low. Tests of an electrical guidance system at the Chandler Canal diversion (Yakima River, Washington) showed efficiency ranging from 70 to 84 percent for velocities of less than 1 ft/sec. Efficiencies decreased to less than 50 percent when water velocities were higher than 2 ft/sec (Pugh et al., 1971). Success of electrical screens may be specific to species and fish size. An electrical field strength suitable to deter small fish may result in injury or death to large fish, since total fish body voltage is directly proportional to fish body length (Stone and Webster, 1986). Electrical screens require constant maintenance of electrodes and associated underwater hardware to maintain effectiveness. Surface water quality can affect the life and performance of electrodes.

Bubble and chain curtains are created by pumping air through a diffuser to create a continuous, dense curtain of bubbles, which can cause an avoidance response. Many factors affect fish response to the curtains, including temperature, turbidity, light, and water velocity. Bubbler systems should be constructed from corrosion-resistant materials and be installed with adequate positioning of the diffuser away from areas where siltation might clog the air ducts. Hanging chains provide a physical, visible obstacle that fish avoid. They are species-specific and lifestage-specific. Efficiency of hanging chains is affected by such variables as velocity, instream flow, turbidity, and illumination levels. Debris can limit their performance. In particular, buildup of debris can deflect chains into a nonuniform pattern and disrupt hydraulic flow patterns.

Strobe lights repel fish by producing an avoidance response. A strobe light system at Saunders Generating Station in Ontario, Canada was found to be 67 to 92 percent effective at repelling or diverting eels (EPRI, 1999). Turbidity levels can affect strobe light efficiency. The intensity and duration of the flash can also affect the response of the fish; for instance, an increase in flash duration has been associated with less avoidance. Strobe lights have the potential for far-field fish attraction, since they can appear to fish as a constant light source due to light attenuation over a long distance (Stone and Webster, 1986). Strobe lights at Hiram M. Chittenden Locks in Seattle, Washington were examined to determine how fish respond, depending on strobe light distance. Vertical avoidance was 90 to 100 percent when lights were 0.5 meters away, 45 percent when 2.5 meters away, and 19 percent when 4.5 to 6.5 meters away (EPRI, 1999).

Mercury lights have successfully attracted fish to passage systems and repelled them from dams. Studies suggest their effectiveness is species-specific; alewives (*Alosa pseudoharengus*) were attracted to mercury light, whereas coho salmon (*Oncorhynchus kisutch*) and rainbow trout (*Oncorhynchus mykiss*) displayed no attraction to the light (Stone and Webster, 1986). In a test on the Susquehanna River (Maryland, Pennsylvania, and New York), mercury lights attracted gizzard shad (OTA, 1995). Although results have been mixed, low overall cost of the systems has led to continued research on their effectiveness (Duke Engineering & Services, Inc., 2000).

Underwater sound, broadcast at different frequencies and amplitudes, has been effective in attracting fish away from dams or repelling fish from dangers around dams, although the results of field tests are not consistent. Fish have been attracted, repelled, or guided by the sound. A study prepared for DOE showed that low-frequency, high particle motion was effective at invoking flight and avoidance responses in salmonids (Mueller et al., 1998). These finding agree with Knudsen et al. (1994), who found that low frequencies are efficient for evoking awareness reactions and avoidance responses in juvenile Atlantic salmon. Not all fish possess the ability to perceive sound or localized acoustical sources (Harris and Van Bergeijk, 1962). Fish also frequently seem to become habituated to the sound source.

Poppers are pneumatic sound generators that create a high-energy acoustic output to repel fish. Poppers have effectively repelled warm-water fish from water intakes. Laboratory and field studies in California indicate avoidance by several freshwater species such as alewives (*Alosa pseudoharengus*), perch, and smelt. Salmonids do not seem to be effectively repelled (Stone and Webster, 1986). Operation and maintenance considerations include frequent replacement of “O” rings, air entrainment in water inlets, and vibration of structures associated with the inlets.

Water jet curtains create hydraulic conditions that repel fish. Effectiveness is influenced by the angle at which water is jetted. Although effectiveness averages 75 percent (Stone and Webster, 1986), not enough is known to determine what variables affect performance of water jet curtains. Important operation and maintenance concerns would be clogging of the jet nozzles by debris or rust and the acceptable range of stream flow conditions, which contribute to effective results.

Hybrid barriers or combinations of different barriers can enhance the effectiveness of individual behavioral barriers. Laboratory studies showed a chain net barrier combined with strobe lights to be up to 90 percent effective at repelling some species and sizes of fish. Tests of combining rope-net and chain-rope barriers have shown good results. Barriers with horizontal and vertical components in the water column are more effective than those with vertical components alone. Barriers with a large diameter are more effective than those with a small diameter, and thicker barriers are more effective than thinner barriers. Effectiveness of hanging chains was increased when used in combination with strobe lights. Effectiveness also increased when strobe lights were added to air bubble curtains and poppers (Stone and Webster, 1986).

Branch Packing

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☐ Shorelines
  - ☑ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Branch packing consists of alternating layers of live branch cuttings and compacted backfill to repair small, localized slumps and holes in slopes (Figure 7.5). Live branch cuttings may range from 0.5 to 2 inches in diameter. They should be long enough to touch undisturbed soil at the back of the trench and extend slightly outward from the rebuilt slope face. Wooden stakes should be 5 to 8 feet long, depending on the depth of the slump or hole being repaired. Stakes should also be made from poles that are 3 to 4 inches in diameter or 2 by 4 feet lumber. Live posts can be substituted. As plant tops begin to grow, the branch packing system becomes more effective in retarding runoff and reducing surface erosion. Trapped sediment refills the localized slumps or holes, while roots spread throughout the backfill and surrounding earth to form a unified mass. Branch packing is not effective in slump areas greater than 4 feet deep or 5 feet wide (USDA-NRCS, 1992). Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002) and the USDA Natural Resources Conservation Service's (NRCS's) *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992).

<u>Additional Resources</u>

- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.

- ISU. 2006. *How to Control Streambank Erosion: Branchpacking*. Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/streambank/branchpacking.pdf.

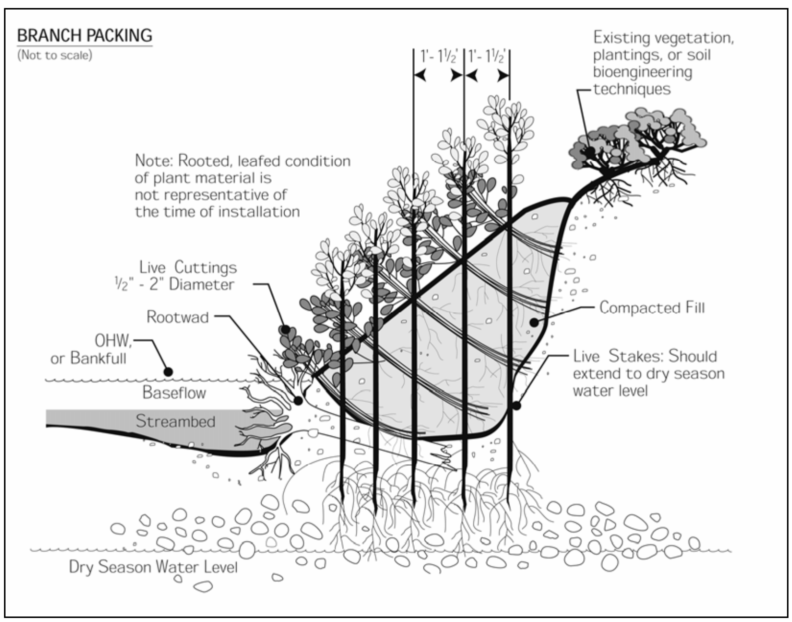

Figure 7.5 Branch Packing (USDA-FS, 2002)

Breakwaters

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☑ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Breakwaters are wave energy barriers designed to protect the land or nearshore area behind them from the direct assault of waves. Breakwaters have traditionally been used only for harbor protection and navigational purposes; in recent years, however, designs of shore-parallel segmented breakwaters have been used for shore protection purposes (Fulford, 1985; Hardaway and Gunn, 1989; Hardaway and Gunn, 1991; USACE, 1990). Segmented breakwaters can be used to provide protection over longer sections of shoreline than is generally affordable through the use of bulkheads or revetments. Wave energy is able to pass through the breakwater gaps, allowing for the maintenance of some level of longshore sediment transport, as well as mixing and flushing of the sheltered waters behind the structures. The cost per foot of shore for the installation of segmented offshore breakwaters is generally competitive with the costs of stone revetments and bulkheads (Hardaway et al., 1991).

Figure 7.6 provides a view of breakwaters off the coast of Pennsylvania and Figure 7.7 illustrates single and multiple breakwaters.

Figure 7.6 Breakwaters – View of Presque Isle, Pennsylvania (USACE, 2003)

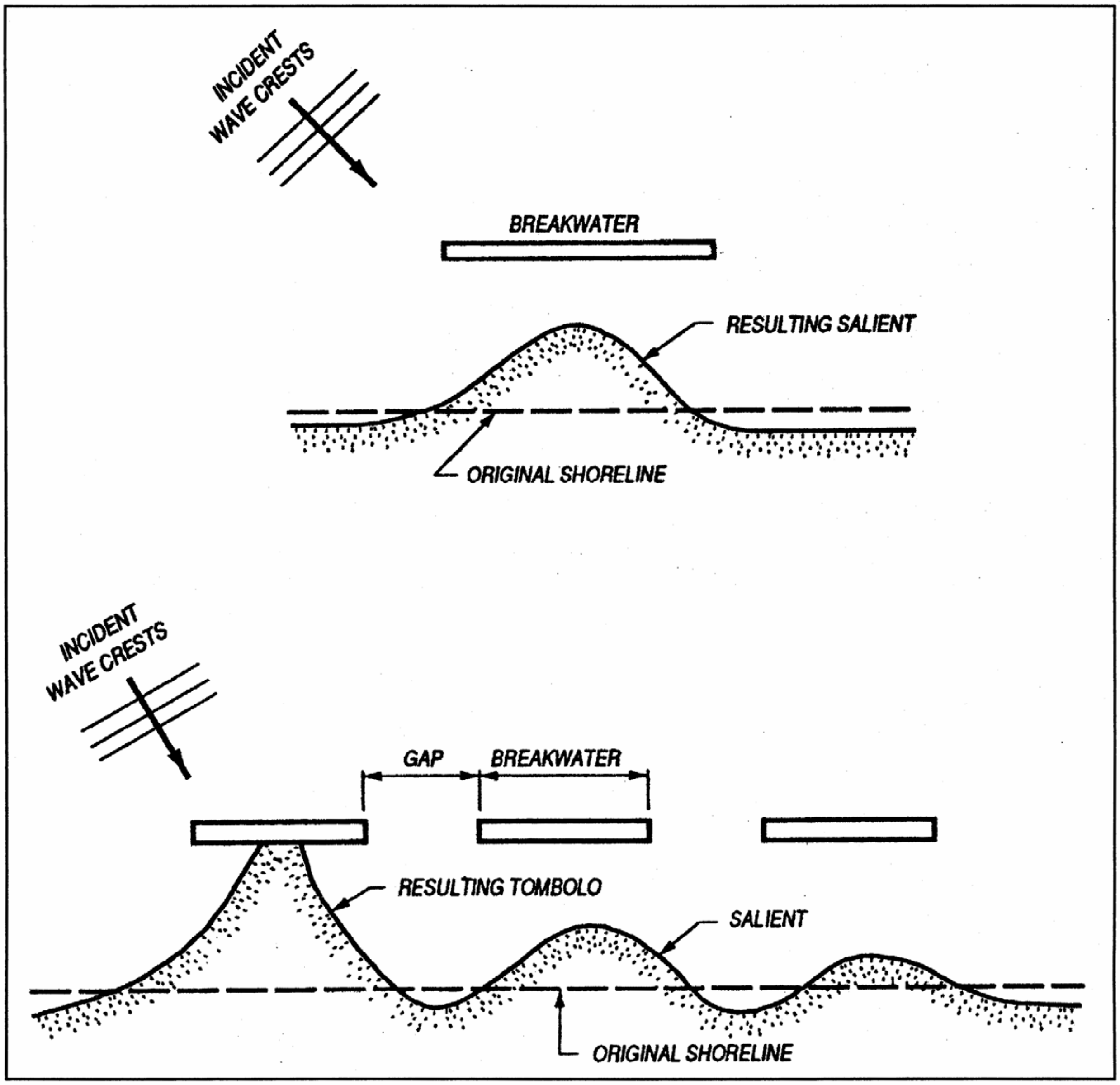

Figure 7.7 Single and Multiple Breakwaters (USACE, 2003)

Additional Resource

- USACE. No date. *Breakwaters.* http://www.usna.edu/NAOE/courses/en420/bonnette/breakwater_design.html.

Brush Layering

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☐ Shorelines
  - ☑ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Brush layering consists of placing live branch cuttings interspersed between layers of soil on cut slopes or fill slopes (Figures 7.8 and 7.9). These systems are recommended on slopes up to 2:1 in steepness and not to exceed 15 feet in vertical height. Branch cuttings, which are placed in a crisscross or overlapping pattern, should be long enough to reach the back of the bench and still protrude from the bank (growing tips facing the outside of the slope). The portions of the brush that protrude from the slope face assist in retarding runoff and reducing surface erosion. Backfill is then placed on the branches and compacted.

Brush layering can be used to stabilize a slope against shallow sliding or mass wasting, as well as to provide erosion protection. Brush layers can stabilize and reinforce the outside edge or face of drained earthen buttresses placed against cut slopes or embankment fills. Brush layering works better on fill slopes than cut slopes, because much longer stems can be used in fill (Mississippi State University, 1999). It is most applicable for areas subjected to cut or fill operations or areas that are highly disturbed and/or eroded (ECY, 2007)

Brush layering is somewhat similar to live fascine systems because both involve the cutting and placement of live branch cuttings on slopes. The two techniques differ principally in the orientation of the branches and the depth to which they are placed in the slope. In brush layering, the cuttings are oriented more or less perpendicular to the slope contour. In live fascine systems, the cuttings are oriented more or less parallel to the slope contour. The perpendicular orientation is more effective from the point of view of earth reinforcement and mass stability of the slope (USDA-NRCS, 1992). Thus, brush layering is more effective than live fascines in terms of earth reinforcement and mass stability (Mississippi State University, 1999). When used on a fill slope, brush layering is similar to vegetated geogrids, except the technique does not use geotextile fabric (USDA-FS, 2002).

Brush layering can disrupt native soils. Therefore, installation should be completed in phases and no more area should be excavated than is necessary (ECY, 2007).

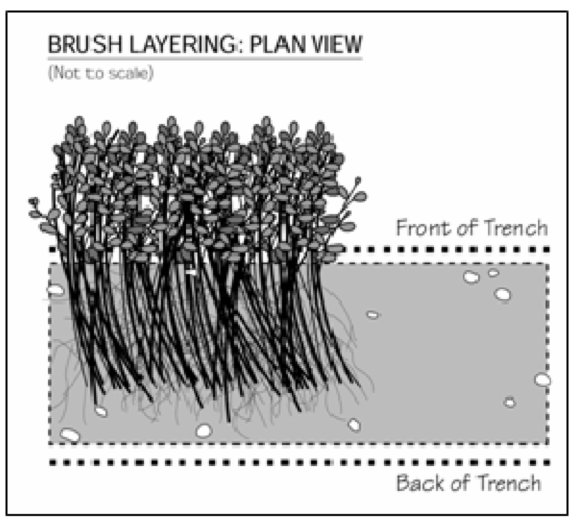

Figure 7.8 Brush Layering: Plan View (USDA-FS, 2002)

Additional Resources

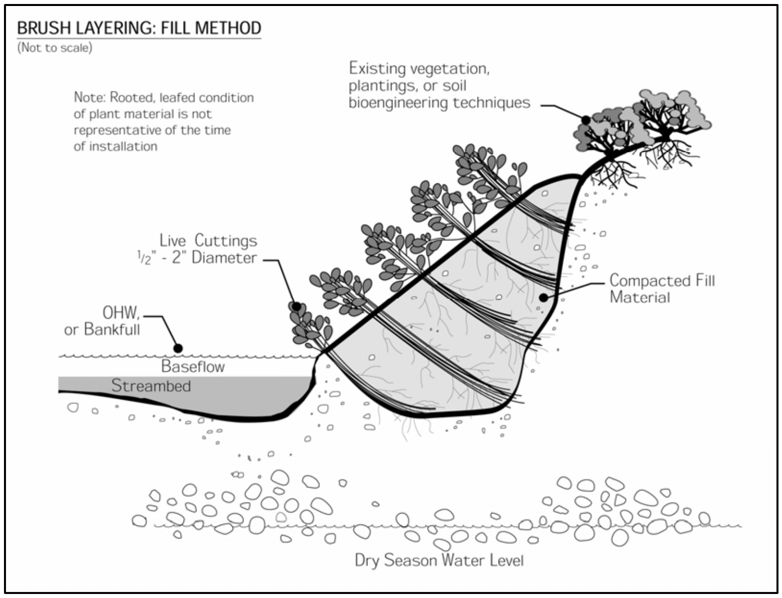

Figure 7.9 Brush Layering: Fill Method (USDA-FS, 2002)

- Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Brush Layering.* Created for United States Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/brushlayer.pdf.

- Myers, R.D. 1993. *Slope Stabilization and Erosion Control Using Vegetation: A Manual of Practice for Coastal Property Owners: Brush Layering.* Shorelands and Coastal Zone Management Program, Washington Department of Ecology. Olympia, WA. Publication 93-30. http://www.ecy.wa.gov/programs/sea/pubs/93-30/brush.html.

- Walter, J., D. Hughes, and N.J. Moore. 2005. *Streambank Revegetation and Protection: A Guide for Alaska. Revegetation Techniques: Brush/Hedge – Brush Layering.* Revised Edition. Alaska Department of Fish and Game, Division of Sport Fish. http://www.sf.adfg.state.ak.us/SARR/restoration/techniques/hedgebrush.cfm.

Brush Mattressing

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☐ Shorelines
  - ☑ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Brush mattressing is commonly used in Europe for streambank protection (Figure 7.10). It involves digging a slight depression on the bank and creating a mat or mattress from woven wire or single strands of wire and live, freshly cut branches from sprouting trees or shrubs. Branches approximately 1 inch in diameter are normally cut 6 to 9 feet long (the height of the bank to be covered) and laid in criss-cross layers with the butts in alternating directions to create a uniform mattress with few voids. The mattress is then covered with wire secured with wooden stakes 2.5 to 4 feet long. It is then covered with soil and watered repeatedly to fill voids with soil and facilitate sprouting; however, some branches should be left partially exposed on the surface. The structure may require protection from undercutting by placement of stones or burial of the lower edge. Brush mattresses are generally resistant to waves and currents and provide protection from the digging out of plants by animals. Disadvantages include possible burial with sediment in some situations and difficulty in making later plantings through the mattress.

Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002). Under the Ecosystem Management and Restoration Research Program (EMRRP), the USACE has presented research on brush mattresses in a technical note (*Brush Mattresses for Streambank Erosion Control*).[3]

Additional Resources

- Allen, H.H. and C. Fischenich. 2001. *Brush Mattresses for Streambank Erosion Control.* U.S. Army Corps of Engineers, Ecosystem Management and Restoration Research Program. http://el.erdc.usace.army.mil/elpubs/pdf/sr23.pdf.

- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.

- ISU. 2006. *How to Control Streambank Erosion*: *Brushmattress.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/streambank/brushmattress.pdf.

- Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Brush Mattress.* Created for United States Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/brushmattress.pdf.

[3] http://el.erdc.usace.army.mil/elpubs/pdf/sr23.pdf

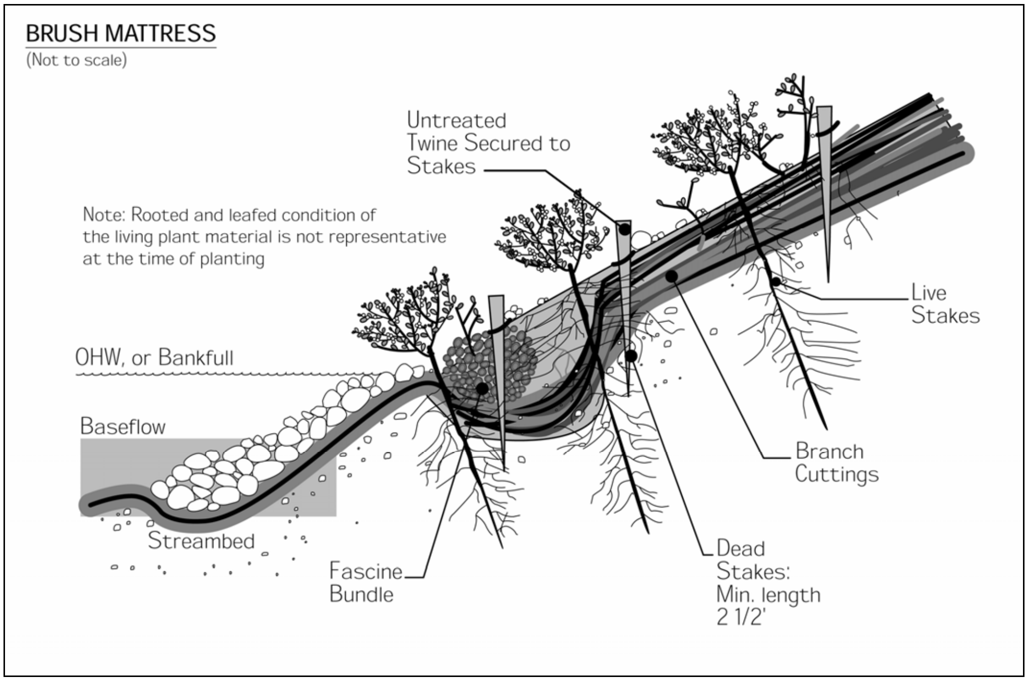

Figure 7.10 Brush Mattress (USDA-FS, 2002)

Bulkheads and Seawalls

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☑ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Bulkheads (Figure 7.11) are primarily soil-retaining structures designed to also resist wave attack. Seawalls are principally structures designed to resist wave attack, but they also may retain some soil (USACE, 1984). Both bulkheads and seawalls may be built of many materials, including steel, timber, or aluminum sheet pile, gabions, or rubble-mound structures. Although bulkheads and seawalls protect the upland area against further erosion and land loss, they often create a local problem. Downward forces of water, produced by waves striking the wall, can produce a transfer of wave energy and rapidly remove sand from the wall (Pilkey and Wright, 1988). A stone apron is often necessary to prevent scouring and undermining. With vertical protective structures built from treated wood, there are also concerns about the leaching of chemicals used in the wood preservatives. Chromated copper arsenate (CCA), the most popular chemical used for treating the wood used in docks, pilings, and bulkheads, contains elements of chromium, copper, and arsenic that are toxic above trace levels (CSWRCB, 2005; Kahler et al., 2000).

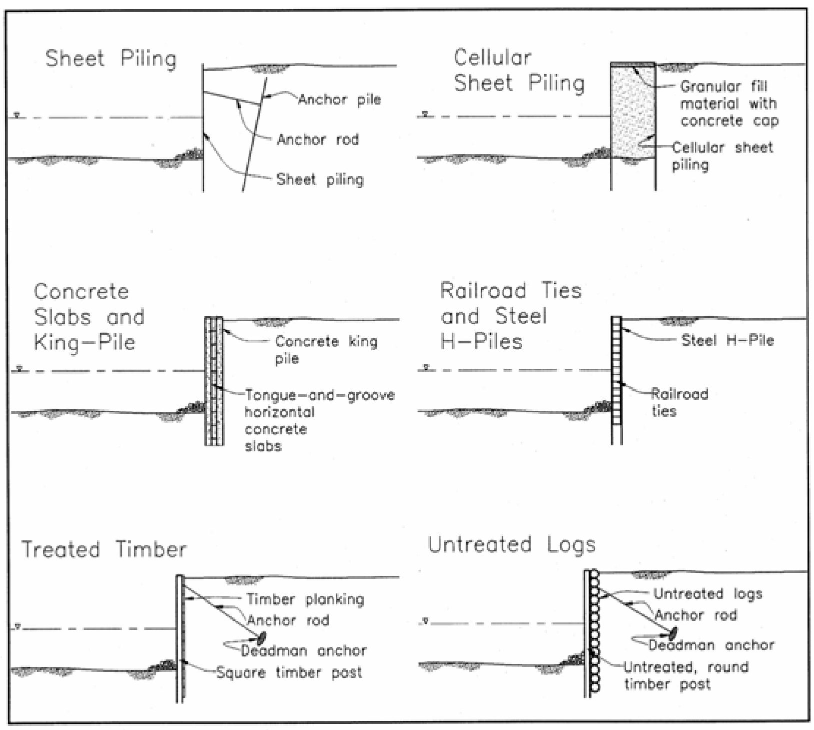

Figure 7.11 Typical Bulkhead Types (USACE, 2003)

Additional Resources

- Scottish National Heritage. No date. *A Guide to Managing Coastal Erosion in Beach/Dune Systems: Seawalls.* http://www.snh.org.uk/publications/on-line/heritagemanagement/erosion/appendix_1.12.shtml.

- USACE. No date. *Bulkheads and Seawalls.* http://www.usna.edu/NAOE/courses/en420/bonnette/Seawall_Design.html.

Check Dams

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☑ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☑ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Check dams, a type of grade control structure, are small dams constructed across an influent, intermittent stream, or drainageway to reduce channel erosion by restricting flow velocity. They can serve as emergency or temporary measures in small eroding channels that will be filled or permanently stabilized at a later date. Check dams can be installed in eroding gullies as permanent measures that fill up with sediment over time. In permanent usage, when the impounded area is filled, a relatively level surface or delta is formed over which water flows at a noneroding gradient. The water then cascades over the dam through a spillway onto a hardened apron. A series of check dams may be constructed along a stream channel of comparatively steep slope or gradient to create a channel consisting of a succession of gentle slopes with cascades in between.

Check dams can be nonporous (constructed from concrete, sheet steel, or wet masonry) or porous (using available materials such as straw bales, rock, brush, wire netting, boards, and posts). Porous dams release part of the flow through the structure, decreasing the head of flow over the spillway and the dynamic and hydrostatic forces against the dam. Nonporous dams are durable, permanent, and more expensive, while porous dams are simpler, more economical to construct, and temporary. Maintenance of check dams is important, especially the areas to the sides of the dam. Regular inspections, particularly after high flow events, should be performed to observe and repair erosion at the sides of the check dams. Excessive erosion could dislodge the check dam, create additional channel erosion, and add more sediment to the streambed.

<u>Additional Resources</u>

- CASQA. 2003. *California Stormwater BMP Construction Handbook*: *Check Dams.* California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Construction/SE-4.pdf.
- ISU. 2006. *Iowa Construction Site Erosion Control Manual: Check Dam.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/construction/3.3_check_dam.pdf.
- Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Check Dam.* Created for United States Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/water/erosion/checkdam.pdf.
- SMRC. No date. *Stream Restoration: Grade Control Practices.* The Stormwater Manager's Resource Center. http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Restoration/grade_control.htm.
- Tennessee Department of Environment and Conservation. 2002. *Erosion and Sediment Control Handbook: Check Dams*. Tennessee Department of Environment and Conservation, Nashville, TN. http://state.tn.us/environment/wpc/sed_ero_controlhandbook/cd.pdf.

Coconut Fiber Roll

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☐ Shorelines
  - ☑ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

The coconut fiber roll technique consists of cylindrical structures composed of coconut husk fibers held together with twine woven from coconut material (Figures 7.12 and 7.13). The fiber rolls are typically manufactured in 12-inch diameters and lengths of 20 feet, which serves to protect slopes from erosion, trap sediment, and as a result, encourage plant growth within the fiber roll. The system is typically installed near the toe of the streambank with dormant cuttings and rooted plants inserted into holes cut into the fiber rolls. Once installed, the system provides a good substrate for promoting plant growth and is appropriate where short-term moderate toe stabilization is needed. Installation of this design requires minimal site disturbance and is ideal for sites that are especially sensitive to disturbance. A limitation of this system is that it cannot withstand high velocities or large ice buildup, and it can be fairly expensive to construct. Coconut fiber rolls have an effective life of 6 to 10 years. In some locations, similar and abundant locally available materials, such as corn stalks, are being used instead of coconut materials (FISRWG, 1998).

Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002). Under EMRRP, the USACE has presented research on coconut rolls in a technical note (*Coir Geotextile Roll and Wetland Plants for Streambank Erosion Control*), which is available at http://el.erdc.usace.army.mil/elpubs/pdf/sr04.pdf.

Figure 7.12 Coconut Fiber Roll (Montgomery Watson, 2001)

Additional Resources

- CASQA. 2003. *California Stormwater BMP Construction Handbook: Fiber Rolls.* California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Construction/SE-5.pdf.
- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.
- ISU. 2006. *How to Control Streambank Erosion: Coconut Fiber Rolls.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/streambank/coconut_fiber.pdf.

- Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Coconut Fiber Roll.* Created for United States Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/coconutfiberroll.pdf.

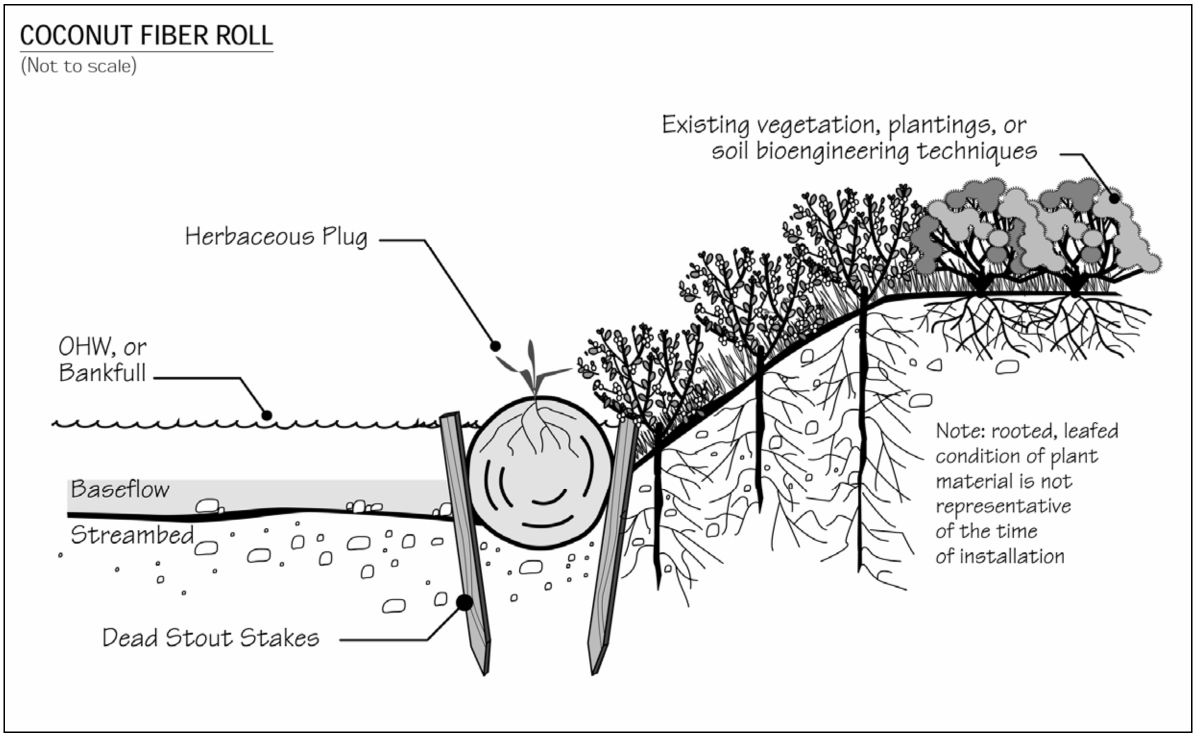

Figure 7.13 Coconut Fiber Roll (USDA-FS, 2002)

Collection Systems

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☑ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Collection systems involve capture of fish by screening and/or netting followed with transport by truck or barge to a downstream location. Since the late 1970s, the USACE has successfully implemented a program that takes juvenile salmon from the uppermost dams in the Columbia River system (Pacific Northwest) and transports them by barge or truck to below the last dam. The program improves the travel time of fish through the river system, reduces most of the exposure to reservoir predators, and eliminates the mortality associated with passing through a series of turbines (van der Borg and Ferguson, 1989). Survivability rates for the collected fish are in excess of 95 percent, as opposed to survival rates of about 60 percent when the fish remain in the river system and pass through the dams (Dodge, 1989). However, the collection efficiency can range from 70 percent to as low as 30 percent. At the McNary Dam on the Columbia River, spill budgets are also implemented to improve overall passage (discussed in greater detail below) when the collection rate achieves less than 70 percent efficiency (Dodge, 1989).

Additional Resource

- Chelan County Public Utility District. No date. *Juvenile Fish Bypass*. http://www.chelanpud.org/juvenile-fish-passage.html.

Construct Runoff Intercepts

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☑ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Benches, terraces, or ditches break up a slope by providing areas of low slope in the reverse direction. This keeps water from proceeding down the slope at increasing volume and velocity. Instead, the flow is directed to a suitable outlet or protected drainage system. The frequency of benches, terraces, or ditches will depend on the erodibility of the soils, steepness and length of the slope, and rock outcrops. This practice can be used if there is a potential for erosion along the slope.

Earth dikes, perimeter dikes or swales, or diversions can intercept and convey runoff from above disturbed areas to undisturbed areas or drainage systems. An earth dike is a temporary berm or ridge of compacted soil that channels water to a desired location. A perimeter dike/swale or diversion is a swale with a supporting ridge on the lower side that is constructed from the soil excavated from the adjoining swale (Delaware DNREC, 2003). These practices can intercept flow from denuded areas or newly seeded areas and keep clean runoff away from disturbed areas. The structures can be stabilized within 14 days of installation. A pipe slope drain, also known as a pipe drop structure, is a temporary pipe placed from the top of a slope to the bottom of the slope to convey concentrated runoff down the slope without causing erosion (Delaware DNREC, 2003).

Additional Resources

- CASQA. 2003. *California Stormwater BMP Construction Handbook*: *Earth Dikes and Drainage Swales.* California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Construction/EC-9.pdf.

- Fifield, J. 2000. *Design and Implementation of Runoff Control Structures: Diversion Dikes and Swales.* http://www.forester.net/ec_0001_design.html#diversion.

- Lake Superior/Duluth Streams. 2005. *Grassed Swales.* http://www.duluthstreams.org/stormwater/toolkit/swales.html.

Constructed Spawning Beds

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☑ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

When a dam adversely affects the aquatic habitat of an anadromous fish species, one option may be to construct replacement spawning beds. Additional facilities such as electric barriers, fish ladders, or bypass channels would be required to channel the fish to these spawning beds.

Merz et al., (2004) tested whether spawning bed enhancement increases survival and growth of Chinook salmon (*Oncorhynchus tshawytscha*) embryos in a regulated stream with a gravel deficit. The authors also examined a dozen physical parameters correlated with spawning sites (e.g., stream velocity, average turbidity, distance from the dam) and how they predicted survival and growth of Chinook salmon and steelhead (*Oncorhynchus mykiss*). The results suggest that spawning bed enhancement can improve embryo survival in degraded habitat. Measuring observed physical parameters before and after spawning bed manipulation can also accurately predict benefits. The National Oceanic and Atmospheric Administration's (NOAA's) S*tatus Review of Chinook Salmon from Washington, Idaho, Oregon, and California* (1998) states that artificial spawning beds for ocean-type Chinook salmon operated near three different dams was discontinued because of high pre-spawning mortality in adult fish and poor egg survival in the spawning beds. Success of constructed spawning beds in increasing survival and development of fish varies and often depends on the site.

Construction Management

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Construction areas can be managed properly to control erosion by stabilizing entrances and proper traffic routing. A construction entrance is a pad of gravel or rock over filter cloth located where traffic enters and leaves a construction site. As construction vehicles drive over the gravel, mud and sediment are collected from the vehicles' wheels. To maximize effectiveness, the rock pad should be at least 50 feet long and 10 to 12 feet wide. The gravel should be 1- to 2-inch aggregate 6 inches deep laid over a layer of filter fabric. Maintenance might include pressure washing the gravel to remove accumulated sediment and adding more rock to maintain thickness. Runoff from this entrance should be treated before exiting the site. This practice can be combined with a designated truck wash-down station to ensure sediment is not transported off-site.

Where possible, construction traffic should be directed to avoid existing or newly planted vegetation. Instead, it should be directed over areas that must be disturbed for other construction activity. This practice reduces the net total area that is cleared and susceptible to erosion.

Additional Resources

- CASQA. 2003. *California Stormwater BMP Construction Handbook*: *Stabilized Construction Entrance/Exit.* California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Construction/TR-1.pdf.

- ISU. 2006. *Iowa Construction Site Erosion Control Manual: Stabilized Construction Entrance.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/construction/3.14_stabilized_entrance.pdf.

Dormant Post Plantings

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☑ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Dormant post plantings include planting of either cottonwood, willow, poplar, or other sprouting species embedded vertically into streambanks to increase channel roughness, reduce flow velocities near the slope face, and trap sediment (Figure 7.14). Dormant posts are made up of large cuttings installed in streambanks in square or triangular patterns. Live posts should be 7 to 20 feet long and 3 to 5 inches in diameter. This method is effective for quickly establishing riparian vegetation particularly in arid regions. By decreasing near bank flow velocities, this design causes sediment deposition and reduces streambank erosion. This design is more resistant to erosion than live staking or similar designs that use smaller cuttings. Success of this design is most likely on streambanks that are not gravel dominated and where ice build up is not common. The exclusion of certain herbivores aids in the success of this design. This method should be combined with other soil bioengineering techniques to achieve a comprehensive streambank restoration design (FISRWG, 1998). Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002).

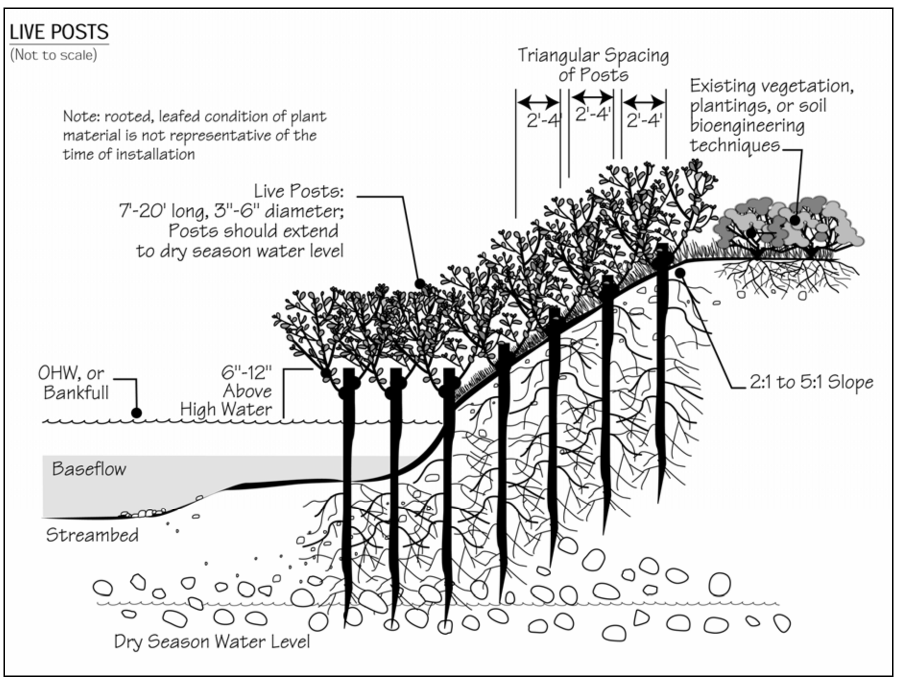

Figure 7.14 Live Posts (USDA-FS, 2002)

Additional Resources

- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.
- ISU. 2006. *How to Control Streambank Erosion: Dormant Post Plantings.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/streambank/dormant_post.pdf.

Encourage Drainage Protection

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☑ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

A complete understanding of watershed protection should include the implementation of practices that guide future development and land use activities. This will not only help to identify existing sources of NPS pollution but also to prevent future impairments that may impact dam construction or operations and reservoir management. Watershed protection practices can include zoning for natural resource protection. Several zoning techniques are:

- Use cluster zoning and planned unit development
- Consider resource protection zones
- Practice performance-based zoning
- Establish overlay zones
- Establish bonus or incentive zoning
- Consider large lot zoning
- Practice agricultural protection zoning
- Use watershed-based zoning
- Delineate urban growth boundaries

More details about these techniques and case studies can be found in *Protecting Wetlands: Tools for Local Governments in the Chesapeake Bay Region* (Chesapeake Bay Program, 1997).

Equipment Runoff Control

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☑ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

During construction and maintenance activities at dams, equipment and machinery can be a potential source of pollution to the surface and ground water. Thinners or solvents should not be discharged into sanitary or storm sewer systems or into surface water systems, when cleaning machinery. Use alternative methods for cleaning larger equipment parts, such as high-pressure, high-temperature water washes or steam cleaning. Equipment-washing detergents can be used and wash water appropriately discharged. Small parts should be cleaned with degreasing solvents that can be reused or recycled. Washout from concrete trucks should never be dumped directly into surface waters or into a drainage leading to surface waters but can be disposed of into:

- A designated area that will later be backfilled
- An area where the concrete wash can harden, can be broken up, and can then be appropriately disposed
- A location not subject to surface water runoff and more than 50 feet away from a receiving water

Erosion and Sediment Control (ESC) Plans

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☑ Planning & regulatory

ESC plans are important for controlling the adverse impacts of dam construction. ESC plans ensure that provisions for control measures are incorporated into the site planning stage of development. ESC plans also provide for prevention of erosion and sediment problems and accountability if a problem occurs (MDEP, 1990). In many municipalities, ESC plans are required under ordinances enacted to protect water resources. These plans describe the activities construction and maintenance personnel will use to reduce soil erosion and contain and treat runoff that is carrying eroded sediments. ESC plans typically include descriptions and locations of soil stabilization practices, perimeter controls, and runoff treatment facilities that will be installed and maintained before and during construction activities. In addition to special area considerations, the full ESC plan review inventory should include:

- Topographic and vicinity maps
- Site development plan
- Construction schedule
- Erosion and sedimentation control plan drawings
- Detailed drawings and specifications for practices
- Design calculations
- Vegetation plan
- Detailed drawings and specifications for control or management practices

Some erosion and soil loss is unavoidable during land-disturbing activities. Although proper siting and design help prevent areas prone to erosion from being developed, construction activities invariably produce conditions where erosion can occur. To reduce the adverse impacts associated with construction activities at dams, the construction management measure suggests a system of nonstructural and structural ESCs for incorporation into an ESC plan.

Nonstructural controls address erosion control by decreasing erosion potential, whereas structural controls are both preventive and mitigative because they control erosion and sediment movement. Brown and Caraco (1997) identified several general objectives that should be addressed in an effective ESC plan:

- *Minimize clearing and grading* – clearing and grading should occur only where absolutely necessary to build and provide access to structures and infrastructure. Clearing should be done immediately before construction, rather than leaving soils exposed for months or years (SQI, 2000).
- *Protect waterways and stabilize drainage ways* – all natural waterways within a development site should be clearly identified before construction activities begin. Clearing should generally be prohibited in or adjacent to waterways. Sediment control

practices such as check dams might be needed to stabilize drainage ways and retain sediment on-site.

- *Phase construction to limit soil exposure* – construction phasing is a process where only a portion of the site is disturbed at any one time to complete the required building in that phase. Other portions of the site are not cleared and graded until exposed soils from the earlier phase have been stabilized and the construction nearly completed.
- *Stabilize exposed soils immediately* – seeding or other stabilization practices should occur as soon as possible after grading. In colder climates, a mulch cover is needed to stabilize the soil during the winter months when grass does not grow or grows poorly.
- *Protect steep slopes and cuts* - wherever possible, clearing and grading of existing steep slopes should be completely avoided. If clearing cannot be avoided, practices should be implemented to prevent runoff from flowing down slopes.
- *Install perimeter controls to filter sediments* – perimeter controls are used to retain sediment-laden runoff or filter it before it exits the site. The two most common perimeter control options are silt fences and earthen dikes or diversions.
- *Employ advanced sediment-settling controls* – traditional sediment basins are limited in their ability to trap sediments because fine-grained particles tend to remain suspended and the design of the basin themselves is often simplistic. Sediment basins can be designed to improve trapping efficiency through the use of perforated risers; better internal geometry; the installation of baffles, skimmers, and other outlet devices; gentler side slopes; and multiple-cell construction.

ESC plans ensure that provisions for control measures that are incorporated into the site planning stage of development help to reduce the incidence of erosion and sediment problems, and improve accountability if a problem occurs. An effective plan for runoff management on construction sites controls erosion, retains sediments on-site to the extent practicable, and reduces the adverse effects of runoff. Climate, topography, soils, drainage patterns, and vegetation affect how erosion and sediment should be controlled on a site (Washington State Department of Ecology, 1989).

ESC plans should be flexible to account for unexpected events that occur after the plans have been approved, including:

- Discrepancies between planned and as-built grades
- Weather conditions
- Altered drainage
- Unforeseen construction requirements

Changes to an ESC plan should be made based on regular inspections that identify whether the ESC practices were appropriate or properly installed or maintained. Inspecting an ESC practice after storm events shows whether the practice was installed or maintained properly. Such inspections also show whether a practice requires cleanout, repair, reinforcement, or replacement with a more appropriate practice. Inspecting after storms is the best way to ensure that ESC practices remain in place and effective at all times during construction activities.

Because funding for ESC programs is not always dedicated, budgetary and staffing constraints may thwart effective program implementation. Brown and Caraco (1997) recommend several management techniques to ensure that ESC programs are properly administered:

- Local leadership committed to the ESC program
- Redeployment of existing staff from the office to the field or training room
- Cross-training of local review and inspection staff
- Submission of erosion prevention elements for early planning reviews.
- Prioritization of inspections based on erosion risk
- Requirement of designers to certify the initial installation of ESC practices
- Investment in contractor certification and private inspector programs
- Use of public-sector construction projects to demonstrate effective ESC controls
- Enlistment of the talents of developers and engineering consultants in the ESC program
- Revision and update of the local ESC manual

An allowance item that acts as an additional "insurance policy" for complying with the erosion and sediment control plan can be added to bid or contract documents (Deering, 2000a). This allowance covers costs to repair storm damage to ESC measures as specified in the ESC plan. This allowance does not cover storm damage to property that is not related to the ESC plan, because this would be covered under traditional liability insurance. Damage caused by severe and continuous rain events, windblown objects, fallen trees or limbs, or high-velocity, short-term rain events on steep slopes and existing grades would be covered by the allowance, as would deterioration from exposure to the elements or excessive maintenance for silt removal. The contractor is responsible for being in compliance with the ESC plan by properly implementing and maintaining all specified measures and structures. The allowance does not cover damage to practices caused by improper installation or maintenance.

Additional Resources

- ISU. 2006. *Iowa Construction Site Erosion Control Manual: Infiltration Basin and Trench.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/construction/4.1_infiltration.pdf.

- Milwaukee River Basin Partnership. 2003. *Detention & Infiltration Basins.* http://clean-water.uwex.edu/plan/drbasins.htm.

- Tennessee Department of Environment and Conservation. 2002. *Erosion and Sediment Control Handbook: Vegetative Practices*. Tennessee Department of Environment and Conservation, Nashville, TN. http://state.tn.us/environment/wpc/sed_ero_controlhandbook/2.%20Vegetative%20Practices.pdf.

Erosion Control Blankets

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Turf reinforcement mats (TRMs) combine vegetative growth and synthetic materials to form a high-strength mat that helps prevent soil erosion in drainage areas and on steep slopes (Figure 7.15) (USEPA, 1999). TRMs enhance vegetation's natural ability to protect soil from erosion. They are composed of interwoven layers of nondegradable geosynthetic materials (e.g., nylon, polypropylene) stitched together to form a three-dimensional matrix. They are thick and porous enough to allow for soil filling and retention. In addition to providing scour protection, the mesh netting of TRMs is designed to enhance vegetative root and stem development. By protecting the soil from scouring forces and enhancing vegetative growth, TRMs can raise the threshold of natural vegetation to withstand higher hydraulic forces on stabilization slopes, streambanks, and channels. In addition to reducing flow velocities, natural vegetation removes particulates through sedimentation and soil infiltration and improves site aesthetics. In general, TRMs should not be used for the following:

- To prevent deep-seated slope failure due to causes other than surficial erosion
- If anticipated hydraulic conditions are beyond the limits of TRMs and natural vegetation
- Directly beneath drop outlets to dissipate impact force (can be used beyond impact zone)
- Where wave height might exceed 1 foot (can protect areas upslope of wave impact zone)

The performance of a TRM-lined conveyance system depends on the duration of the runoff event. For short-term events, TRMs are typically effective at flow velocities of up to 15 feet per second and shear stresses of up to 8 lb/ft^2. However, specific high-performance TRMs may be effective under more severe hydraulic conditions. Practitioners should check with manufacturers for specifications and performance limits of different products. Factors influencing the cost of TRMs include the type of material required, site conditions (e.g., underlying soils, slope steepness), and installation-specific factors (e.g., local construction costs). TRMs typically cost considerably less than concrete and riprap solutions.

Figure 7.15 Erosion Control Blanket (Conwed Fibers, n.d.)

Additional Resources

- Barr Engineering Company. 2001. *Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates. Soil Erosion Control: Mulches, Blankets and Mats.* Prepared for the Metropolitan Council by Barr Engineering Company, St. Paul, MN. http://www.metrocouncil.org/Environment/Watershed/BMP/CH3_RPPSoilMulch.pdf.

- CASQA. 2003. *California Stormwater BMP Construction Handbook: Geotextiles and Mats.* California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Construction/EC-7.pdf.

- California Department of Transportation. 1999. *Soil Stabilization Using Erosion Control Blankets.* Construction Storm Water Pollution Prevention Bulletin. Vol. 3, No. 8. California Department of Transportation, Division of Environmental Analysis, Sacramento, CA. http://www.dot.ca.gov/hq/env/stormwater/publicat/const/Aug_1999.pdf.

- Matthews, M. 1998. *What are RECPs? Soil Stabilization Using Erosion Control Blankets*. Erosion Control Technology Council, St. Paul, MN. http://www.ectc.org/what.html.

- North American Green. 2004. *Green Views: Turn Reinforcement Mats as an Alternative to Rock Riprap*. North American Green, Evansville, IN. http://www.nagreen.com/resources/literature/GV_AltToRockRiprap.pdf.

- Tennessee Department of Environment and Conservation. 2002. *Erosion and Sediment Control Handbook: Vegetative Practices: Erosion Control Blanket/Matting*. Tennessee Department of Environment and Conservation, Nashville, TN. http://state.tn.us/environment/wpc/sed_ero_controlhandbook/2.%20Vegetative%20Practices.pdf.

Establish and Protect Stream Buffers

Channelization
- ☐ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☑ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☑ Planning & regulatory

Riparian buffers and wetlands can provide long-term pollutant removal capabilities without the comparatively high costs usually associated with constructing and maintaining structural controls. Conservation or preservation of these areas is important to water quality protection. Land acquisition programs help to preserve areas considered critical to maintaining surface water quality. Adequate buffer strips along streambanks provide protection for stream ecosystems, help stabilize the stream, and can prevent streambank erosion (Holler, 1989). Buffer strips can also protect and maintain near-stream vegetation that attenuates the release of sediment into stream channels. Levels of suspended solids have been shown to increase at a slower rate in stream channel sections with well-developed riparian vegetation (Holler, 1989).

Stream buffers should be protected and preserved as a conservation area because these areas provide many important functions and benefits, including:

- Providing a "right-of-way" for lateral movement
- Conveying floodwaters
- Protecting streambanks from erosion
- Treating runoff and reducing drainage problems from adjacent areas
- Providing nesting areas and other wildlife habitat functions
- Mitigating stream warming
- Protecting wetlands
- Providing recreational opportunities and aesthetic benefits
- Increasing adjacent property values

Specific stream buffer practices could include:

- Establishing a stream buffer ordinance
- Developing vegetative and use strategies within management zones
- Establishing provisions for stream buffer crossings
- Integration of structural runoff management practices where appropriate
- Developing stream buffer education and awareness programs

More information on establishing and protecting stream buffers is available from EPA's *National Management Measures to Control Nonpoint Source Pollution from Urban Areas*,[4] a document for use by state, local, and tribal managers in the implementation of nonpoint source pollution management programs. It contains a variety of practices and management activities for reducing pollution of surface and ground water from urban areas (USEPA, 2005d).

[4] http://www.epa.gov/owow/nps/urbanmm/index.html

Fish Ladders

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☑ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Fish ladders have been a commonly used structure to enable the safe upstream and downstream passage of mature fish (see Figure 7.16). There are four basic designs: pool-weir, Denil, vertical slot, and steeppass.

Pool-weir fish ladders are one of the oldest and most commonly designed fish passage structures, which consists of stepped pools and weirs that allow fish to pass from pool to pool over the weirs that separate each. Pool-weir fish ladders are normally used on slopes of about 10-degrees. Some pool-weir fish ladders can be modified to increase the possible number of fish that are passed by including submerged orifices that allow fish to pass the fish ladder without cresting the weirs.

Pool-weir fish ladders will pass many different species of fish if they are designed correctly for the environment in which they are employed. OTA (1995) provides details on design and operation of various forms of fish ladders.

Figure 7.16 Fish Ladder at Feather River Hatchery, Oroville Dam, CA (Feather River, n.d.)

Denil fish ladders are elongated rectangular channels that use internal baffles to dissipate flow energy and allow fish passage. They are widely used in the eastern United States due to their ability to pass a wide range of species (from salmonids to riverine) over a wider range of flows than pool-weir ladders. Denil ladders can be used on slopes from 10 to 25 degrees although 10 to 15 degrees is optimal. Most Denil fish ladders are 2–4 feet wide and 4–8 feet deep. This fish ladder design allows fish to pass at a preferred depth instead of through a jumping action. Denil ladders do not have resting areas and therefore fish must either be able to pass the ladder in one burst or resting pools must be provided between sections. Resting pools should be provided every 16 to 50 feet depending upon the species being passed. The high flow rates and turbulence associated with Denil fish ladders reduces the demand for attraction flow, which is commonly added to insure good attraction over varying flow rates.

Vertical slot fish ladders are elongated rectangular channels that use regularly spaced baffles to create steps and resting pools. The vertically oriented slots in the baffles allow fish to pass through the ladder at a preferred depth. Unlike Denil fishways, vertical slot fishways provide a resting area behind each baffle allowing fish to pass in a "burst-rest" manner instead of one sustained motion. The channel created by the baffles is off-center making the baffles on one side of the ladder wider than the opposing side. Eddies that form behind longer baffles allow fish to rest and end the need for resting areas. Although vertical slot ladders are usually operated at slopes of about 10 degrees, they can be operated over a larger variety of flows. The vertical slots create a water jet that is regulated by the pool on the downstream side of it. This creates a uniform, level flow throughout the ladder.

The steeppass fish ladder, often referred to as the "Alaska steeppass," is a modified Denil fish ladder most commonly used in remote areas for the passage of salmonids. Steeppass fish ladders are usually constructed of lightweight materials such as aluminum and can operate on slopes up to 33 percent. The construction materials and design allow this type of fish ladder to be deployed as a single unit to remote areas. The baffles used in steeppass ladders are more aggressively designed, which allow the ladder to more effectively control water flow. The steeppass ladder is not without its limitations. Due to their narrow design, steeppass ladders are more susceptible to clogging due to debris and changes in flow upstream or downstream of the ladder.

Although fish ladders can be extremely efficient at passing fish, small changes in design have been shown to significantly improve their functionality. A good example of this is the John Day Dam located on the Columbia River. The original design focused on the passage of salmonids and therefore only passed about 17 percent of the American shad (*Alosa sapidissima*) using the ladder. Research indicated that simple design changes could allow for the passage of riverine species such as American shad. By changing the placement of the weirs within the fish ladder, the fish ladder was able to pass 94 percent of the salmonids, and American shad passage increased to 74 percent (Monk et al., 1989).

According to the USACE, Portland District (1997), the success rate for adults negotiating fish ladders at dams in the Columbia River Basin is about 95 percent. The U.S. Fish and Wildlife Agency designs fishways assuming a 90 percent efficiency rate. Few studies document actual efficiency of fish ladders, but it is recognized that not all fishways are equally effective (for various reasons, such as predation or physical damage to passing fish). Some fishways installed in the last 20 years are less effective than newer ones (when federal licenses began to include fish passage requirements). Maine Department of Marine Resources (DMR) estimates efficiency between 75 and 90 percent (Presumpscot River Plan Steering Committee, 2002).

<u>Additional Resource</u>

- Michigan DNR. No date. *What is a fish ladder?* Michigan Department of Natural Resources, Lansing, MI. http://www.michigan.gov/dnr/0,1607,7-153-10364_19092-46291--,00.html.

Fish Lifts

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☑ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Fish lifts describe both fish elevators and locks, which are used to capture fish at the downstream side of a structure and then move them above the structure. Like fish ladders, these systems require sufficient attraction flow to move fish into the lift area. Lift systems can be advantageous because they are not species or flow specific. They can also be employed at structures too tall for fish ladders and to pass species with reduced swimming ability.

Lift systems have the potential to move large numbers of fish if they are operated efficiently. These systems can be automated to allow operation much like fish ladders. Fish lift systems do require additional operation and maintenance costs and are subject to mechanical failures not associated with fish ladders.

Most lift systems require either an active or passive bypass system to move fish far enough upstream to avoid entrainment in the flow through the dam. Passive bypass systems may include constructed waterways or pipes that discharge passed fish sufficiently up-steam of the structure. Active bypass systems include trucking and pumping operations that discharge the fish safely upstream of the structure. Active bypass systems, especially pumping systems, have come under scrutiny for fish behavior and health reasons. During the pumping process, fish may be subject to descaling and/or death due to overcrowding. After release, the fish may have orientation problems and therefore be subject to higher rates of predation mortality. Due to these concerns the United States Fish and Wildlife service has generally opposed the use of fish pumps (OTA, 1995).

Flow Augmentation

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☑ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Operational procedures such as flow regulation, flood releases, or fluctuating flow releases all have the potential for detrimental impacts on downstream aquatic and riparian habitat. When evaluating solutions associated with degraded aquatic and riparian habitat, stakeholders must balance operational procedures to address the needs of downstream aquatic and riparian habitat with the requirements of dam operation. There are often legal and jurisdictional requirements for an operational procedure at a particular dam that should also be considered (USDOI, 1988).

A flushing flow is a high-magnitude, short-duration release for the purpose of maintaining channel capacity and the quality of instream habitat by scouring the accumulation of fine-grained sediments from the streambed. Availability of suitable instream habitat is a key factor limiting spawning success. Flushing flows wash away the sediments without removing the gravel. Flushing flows also prevent the encroachment of riparian vegetation.

However, it is important to keep in mind that flushing flows are not recommended in all cases. Flushing flows of a large magnitude may cause flooding in the old floodplain or depletion of gravel below a dam. Flushing flows are more efficient and predictable for small, shallow, high-velocity mountain streams unaltered by dams, diversions, or intensive land use. Routine maintenance generally requires a combination of practices including high flows coupled with sediment dams or channel dredging, rather than simply relying on flushing or scouring flows (Nelson et al., 1988).

Several options exist for creating minimum flows in the tailwaters below dams. The selection of any particular technique as the most cost-effective is site-specific and depends on several factors including adequate performance to achieve the desired instream and riparian habitat characteristic, compatibility with other requirements for operation of the hydropower facility, availability of materials, and cost.

Sluicing is the practice of releasing water through the sluice gate rather than through the turbines. For portions of the waterway immediately below the dam, the steady release of water by sluicing provides minimum flows with the least amount of water expenditure. At some facilities, this practice may dictate that modifications be made to the existing sluice outlets to maintain continuous low releases. Continuous low-level sluice releases at Eufala Lake and Fort Gibson Lake (Oklahoma) provided minimum flows needed to sustain downstream fish populations. The sluicing also had the benefit of improving DO levels in tailwaters downstream of these two dams such that fish mortalities, which had been experienced in the tailwaters below these two dams prior to initiating this practice, no longer occurred (USDOE, 1991).

Turbine pulsing is a practice involving the release of water through the turbines at regular intervals to improve minimum flows. In the absence of turbine pulsing, water is released from large hydropower dams only when the turbines are operating, which is typically when the demand for power is high.

A study undertaken at the Douglas Dam (French Broad River, Tennessee) suggests some of the site-specific factors that should be considered when evaluating the advantages of practices such as turbine pulsing, sluicing, or other alternatives for providing minimum flows and improving dissolved oxygen (DO) levels in reservoir releases. Two options for maintaining minimum flows (turbine pulsing and sluicing), and two aeration alternatives (operation of surface water pumps and diffusers) were evaluated for their effectiveness, advantages, and disadvantages in providing minimum flows and aeration of reservoir releases. Computer modeling indicated that either turbine pulsing or sluicing could improve DO concentrations in releases by levels ranging from 0.7 to 1.5 mg/L. This is slightly below the level of improvement that might be expected from operation of a diffuser system for aeration. A trade-off can also be expected at this facility between water saved by frequent short-release pulses and the higher maintenance costs due to operating turbines on and off frequently (Hauser et al., 1989). Hauser et al. (1989) found that schemes of turbine pulsing ranging from 15-minute intervals to 60-minute intervals every 2 to 6 hours were found to provide fairly stable flow regimes after the first 3 to 8 miles downstream at several Tennessee Valley Authority (TVA) projects. However, at points farther downstream, less overall flow would be produced by sluicing than by pulsing. Turbine pulsing may also cause waters to rise rapidly, which could endanger people wading or swimming in the tailwaters downstream of the dam (TVA, 1990).

Fuel and Maintenance Staging Areas

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☑ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Proper maintenance of equipment and installation of proper stream crossings will further reduce pollution of water by these sources. Vehicles need to be inspected for leaks. To prevent runoff, fuel and maintain vehicles on site only in a bermed area or over a drip pan. Fuel tanks should be protected and have containment systems. Stream crossings can be minimized through proper planning of access roads. This will help to keep potential sources of pollution away from direct contact with surface waters.

Gated Conduits

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☑ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Gated conduits are hydraulic structures that divert the flow of water under the dam. They are designed to create turbulent mixing to enhance oxygen transfer. Gates are used to control the cross-sectional area of flow. Gated conduits have been extensively analyzed for their performance and effectiveness (Wilhelms and Smith, 1981), although the available data are mostly from high-head projects (Wilhelms, 1988). An example of the effectiveness found that gated conduit structures were able to achieve 90 percent aeration and a minimum DO standard of 5 mg/L (Wilhelms and Smith, 1981).

Groins

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☑ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Groins are structures that are built perpendicular to the shore and extend into the water. Examples of possible planform shapes for groins are illustrated in Figure 7.17. They are generally constructed in series, referred to as a groin field, along the entire length of shore to be protected. Groins trap sand in littoral drift and halt its longshore movement along beaches. The sand trapped by each groin acts as a protective barrier that waves can attack and erode without damaging previously unprotected upland areas. Unless the groin field is artificially filled with sand from other sources, sand is trapped in each groin by interrupting the natural supply of sand moving along the shore in the natural littoral drift. This frequently results in an inadequate natural supply of sand to replace the sand carried away from beaches located farther along the shore in the direction of the littoral drift. If "downdrift" beaches are kept starved of sand for long periods of time, severe beach erosion in unprotected areas can result. As with bulkheads and revetments, the most durable materials for construction of groins are timber and stone. Less expensive techniques for building groins use sand- or concrete-filled bags or tires. It must be recognized that the use of lower-cost materials in the construction of bulkheads, revetments, or groins frequently results in less durability and reduced project life. Figure 7.18 illustrates transition from a groin field to a natural shoreline.

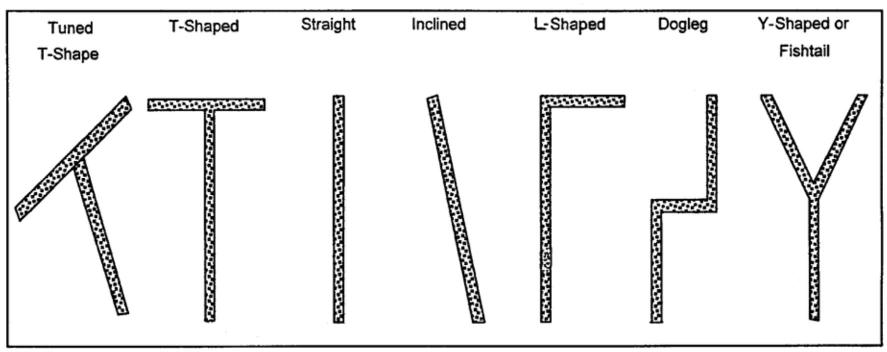

Figure 7.17 Possible Planform Shapes for Groins (USACE, 2003)

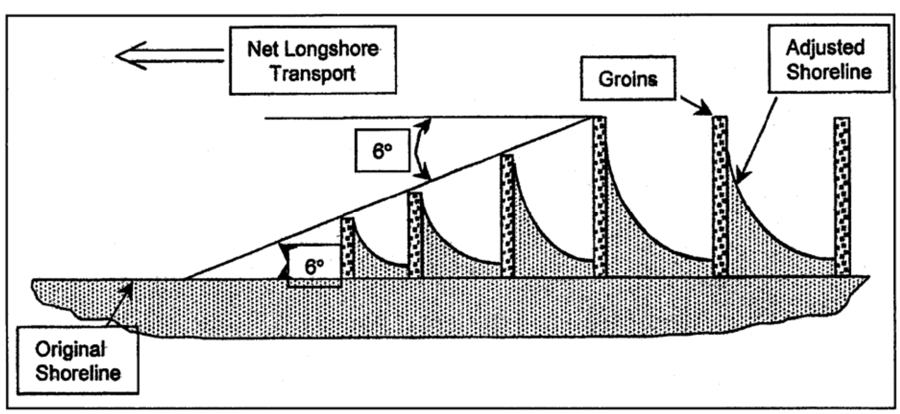

Figure 7.18 Transition from Groin Field to Natural Shoreline (USACE, 2003)

Additional Resource

- USACE. No date. *Groins*. U.S. Army Corps of Engineers, Coastal & Hydraulics Laboratory. http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=ARTICLES!188.

Identify and Address NPS Contributions

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☑ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Another watershed protection practice involves the evaluation of the total NPS pollution contributions in the watershed. NPS contributions can stem from different land use activities upstream from a dam. For example, the analysis and interpretation of stereoscopic color infrared aerial photographs can be used to find and map specific areas of concern where a high probability of NPS pollution exists from septic tank systems, animal wastes, soil erosion, and other similar types of NPS pollution (TVA, 1988). Other remote sensing techniques, such as analysis of satellite imagery, can be used to map areas of concern within a watershed. Historically, TVA has used analysis of aerial photography images to survey about 25 percent of the Tennessee Valley to identify sources of nonpoint pollution in a period of less than 5 years at a cost of a few cents per acre (TVA, 1988). Modern geographic information systems (GIS) enable watershed planners and modelers to rapidly assess large watersheds in a cost-effective manner.

The development of Total Maximum Daily Loads (TMDLs) in watersheds with impaired waterbodies is a way to identify all sources of pollution. TMDLs are planning documents that provide load allocations, for both point and nonpoint sources, and identify potential contributions of pollutants to an impaired waterbody. TMDLs often include the involvement of stakeholders throughout the watershed, in not only the development, but also with implementation of specific activities within the watershed. TMDL documents can provide a plan for addressing pollution sources throughout a watershed.

Different practices can be used to control NPS pollution once sources have been identified. These practices may include the following:

Soil Erosion Control

Soil erosion has been determined to be the major source of suspended solids, nutrients, organic wastes, pesticides, and sediment that combined form the most problematic form of NPS pollution (TVA, 1988). Soil erosion and runoff controls have been addressed throughout earlier management measures in this document.

Mine Reclamation

Abandoned mines may have the potential to contribute significant sediment, metals, acidified water, and other pollutants to reservoirs (TVA, 1988). Old mines need to be located and reclaimed to reduce NPS pollutants emanating from them. Revegetation is a cost-effective method of reclaiming denuded strip-mined lands, and agencies such as the Natural Resource Conservation Service (NRCS) can provide technical insight for revegetation practices.

Animal Waste Control

A major contributor to reservoir pollution in some watersheds is waste from animal confinement facilities. TVA (1988) estimated that in the Tennessee Valley, farms produced about six times the organic wastes of the population of the valley. EPA also has available the *National Management Measures to Control Nonpoint Source Pollution from Agriculture*,[5] which is a technical guidance and reference document for use by state, local, and tribal managers in the implementation of NPS pollution management programs. It contains information on a variety of practices and management strategies for reducing pollution of surface and ground water from agriculture (USEPA, 2003b).

Correcting Failing Septic Systems

The objective of this practice is to protect waterbodies from pollutants discharged by onsite sewage disposal systems (OSDS). They should be sited, designed, and installed so that impacts to waterbodies will be reduced to the extent practicable. Factors such as soil type, soil depth, depth to water table, rate of sea level rise, and topography should be considered. The installation of OSDS should be prevented in areas where soil absorption systems will not provide adequate treatment of effluents containing solids, phosphorus, pathogens, nitrogen, and nonconventional pollution prior to entry into surface waters and ground water. Setbacks, separation distances, and maintenance requirements should be established.

Failing septic tank or OSDS are another source of NPS pollution in reservoirs. TVA has found septic tank failures to be a problem in some of its reservoirs and has identified them through an aerial survey (TVA, 1988). Additional guidance on OSDS is available from EPA's *Onsite Wastewater Treatment Systems Manual* (EPA 625-R-00-008), which is available through EPA's National Service Center for Environmental Publications.[6]

Land Use Planning

Land use plans that establish guidelines for permissible uses of land within a watershed serve as a guide for reservoir management programs addressing NPS pollution (TVA, 1988). Watershed land use plans identify suitable uses for land surrounding a reservoir, establish sites for economic development and natural resource management activities, and facilitate improved land management (TVA, 1988). Land use plans must be flexible documents that account for the needs of the landowners, state and local land use goals, the characteristics of the land and its ability to support various uses, and the control of NPS pollution (TVA, 1988).

Comprehensive planning is an effective nonstructural tool to control NPS pollution. Where possible, growth should be directed toward areas where it can be sustained with minimal impact on the environment (Meeks, 1990). Poorly planned growth and development have the potential to degrade and destroy natural drainage systems and surface waters (Mantell et al., 1990). Proper planning and zoning decisions allow water quality managers to direct development and land disturbance away from areas that drain to sensitive waters. Land use designations and zoning laws can also be used to protect environmentally sensitive areas such as riparian corridors and wetlands.

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[5] http://www.epa.gov/owow/nps/pubs.html
[6] http://www.epa.gov/ncepihom

Identify and Preserve Critical Areas

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☑ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Protection of sensitive areas and areas that provide water quality benefits (e.g., natural wetlands and riparian areas) is integral to maintaining or minimizing the impacts of development on receiving waters and associated habitat. Without a comprehensive planning approach that includes the use of riparian buffers, open space, bioretention, and structural controls to maintain the predevelopment hydrologic characteristics of the site, significant water quality and habitat impacts are likely. The experience of various communities has shown that the use of structural controls in the absence of adequate local land use planning and zoning often does not adequately protect water quality and might even cause detrimental effects, such as increased temperature.

An initial step for incorporating targeted land conservation into a runoff management program is to identify critical conservation areas on a watershed map and superimpose this information on a tax map. Owners of potential conservation lands could include a mix of individuals, corporations or other business entities, homeowner associations, government agencies, and land trusts.

Land conservation includes more than simply preserving land in its current state. It also means that an individual or organization should take responsibility for restoration of areas of the property that are contributing to runoff problems or have been adversely affected by runoff. Stewardship activities for land conservation might include:

- Resource monitoring
- General maintenance
- Control of exotic species
- Installation of structural runoff management practices and maintenance

There are several options for landowners who would like to retain ownership of the parcel but relinquish stewardship and conservation management to another organization. These nonexclusive management options, discussed below, include establishing conservation easements, leases, deed restrictions, covenants, or transfer of development rights (TDRs).

Conservation Easements

A conservation easement is a legal agreement that transfers specific rights concerning the use of land by sale or donation to a government agency (municipal, county, or state), a qualified nonprofit organization (e.g., land trust or conservancy), or other legal entity without transferring title of the land (Cwikiel, 1996).

Leases

Even though government agencies, land trusts, and other nonprofit organizations would prefer that conservation lands be acquired by donation or that conservation easements be placed on the property, some lands hold so much value as conservation areas that leasing is worth the expense and effort. Leasing a property allows the agency, trust, or organization to actively manage the land for conservation.

Deed Restrictions

Restrictions can be included in deeds for the purpose of constraining use of the land. In theory, deed restrictions are designed to perform functions similar to those of conservation easements. In practice, however, deed restrictions have proven to be much weaker substitutes because unlike conservation easements, deed restrictions do not necessarily designate or convey oversight responsibilities to a particular agency or organization to enforce protection and maintenance provisions. Also, deed restrictions can be relatively easy to modify or vacate through litigation. Modifying or nullifying an easement is difficult, especially if tax benefits have already been realized. For these reasons, conservation easements are generally preferred over deed restrictions.

Covenants

A covenant is similar to a deed restriction in that it restricts activities on a property, but it is in the form of a contract between the landowner and another party. The term *mutual covenants* is used to describe a situation where one or more nearby or adjacent landowners are contracted and covered by the same restrictions.

Transfer of Development Rights (TDRs)

The concept of TDRs as a watershed protection tool is based on the premise that ownership of land includes a "bundle" of property rights. One of these rights is the right to develop the property to its "highest and best use." Although this right can be restricted by zoning building codes, environmental constraints, and other types of restrictions, the basic right to develop remains. A TDR system creates an opportunity for property owners to transfer development potential or density at one property, called a sending area to another property, called a receiving area. In the context of watershed planning objectives, TDR programs can be an effective way to transfer development potential from sensitive subwatersheds to subwatersheds that can better deal with increased imperviousness.

Joint Planting

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☑ Integrated
  - ☐ Planning & regulatory

Joint planting (or vegetated riprap) involves tamping live cuttings of rootable plant material into soil between the joints or open spaces in rocks that have previously been placed on a slope (Figure 7.19). Alternatively, the cuttings can be tamped into place at the same time that rock is being placed on the slope face. Joint planting is useful where rock riprap is required or already in place. It is successful 30 to 50 percent of the time, with first year irrigation improving survival rates. Live cuttings must have side branches removed and bark intact. They should range from 0.5 to 1.5 inches in diameter and be long enough to extend well into the soil, reaching into the dry season water level. Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002) and the USDA NRCS *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992).

<u>Additional Resources</u>

- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.

- ISU. 2006. *How to Control Streambank Erosion: Joint Planting.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/streambank/joint_planting.pdf.

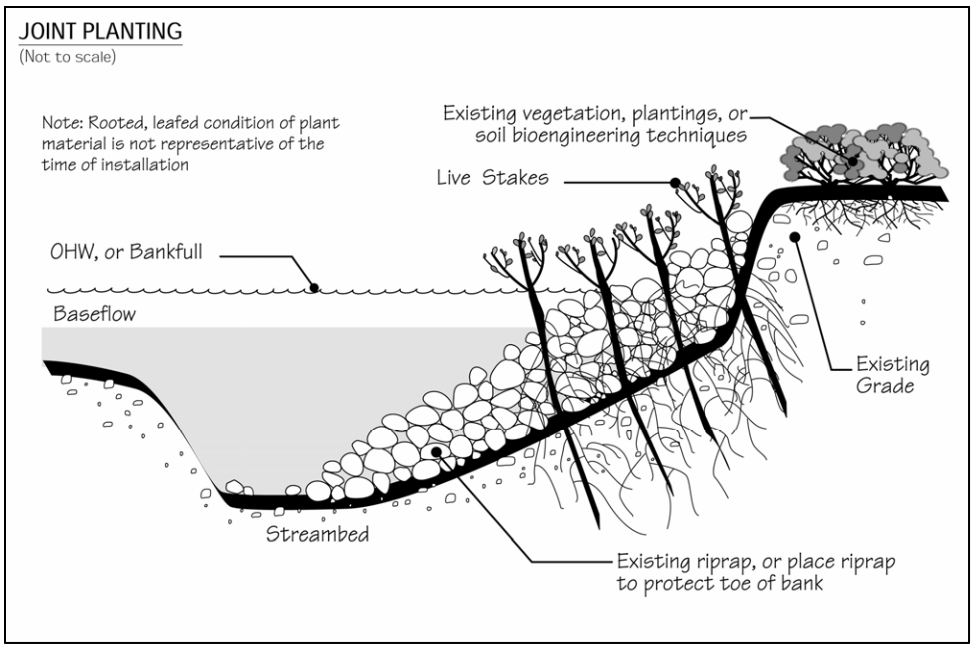


Figure 7.19 Joint Planting (USDA-FS, 2002)

Labyrinth Weir

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☑ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Labyrinth weirs have extended crest length and are usually W-shaped. These weirs spread the flow out to prevent dangerous undertows in the plunge pool. A labyrinth weir at South Holston Dam (Tennessee) was constructed for the dual purpose of providing minimum flows and improving DO in reservoir releases. The weir aerates to up to 60 percent of the oxygen deficit. For instance, projected performance at the end of the summer is an increase in the DO from 3 mg/L to 7 mg/L (or an increase of 4 mg/L) (Hauser, 1992). Actual increases in the DO will depend on the temperature and the level of DO in the incoming water.

Levees, Setback Levees, and Floodwalls

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☑ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Many valuable techniques can be used, when applied correctly, to protect, operate, and maintain levees (Hynson et al., 1985). Evaluation of site-specific conditions and the use of best professional judgment are the best methods for selecting the proper levee protection and operation and maintenance plan. According to Hynson and others (1985), maintenance activities generally consist of vegetation management, burrowing animal control, upkeep of recreational areas, and levee repairs.

Care must be taken during construction to prevent disturbing the natural channel vegetation, cross section, or bottom slope. No immediate instream effects from sedimentation are usually caused by implementing this type of modification. The potential for long-term channel adjustments can be evaluated using methods outlined in *Channel Stability Assessment for Flood Control Projects* (USACE, 1994).

Methods to control vegetation include mowing, grazing, burning, and using chemicals. Selection of a vegetation control method should consider the existing and surrounding vegetation, desired instream and riparian habitat types and values, timing of controls to avoid critical periods, selection of livestock grazing periods, and timing of prescribed burns to be consistent with historical fire patterns. Additionally, a balance between the vegetation management practices for instream and riparian habitat and engineering considerations should be maintained to avoid structural compromise. Animal control methods are most effective when used as a part of an integrated pest management program and might include instream and riparian habitat manipulation or biological controls. Recreational area management includes upkeep of planted areas, disposal of solid waste, and repairing of facilities (Hynson et al., 1985).

The prevention of floods by dams and levees can eliminate or diminish essential ecological functions. Dams, levees and channel training structures have dramatically altered or eliminated the frequency, duration, magnitude, and timing of periodic high flows. These projects significantly reduce the likelihood of floodplain inundation, block the transfer of organic matter and nutrients between river and floodplain, block plant succession, eliminate fish access to spawning areas, and rob rivers of the erosive power to restore and create a diversity of habitats (Environmental Defense, 2002). Levees have had several impacts on the Snake River in Wyoming. Anthony (1998) found habitat losses, including changes in vegetation (including losses of cottonwood and riparian habitats from 1956) and changes in channel and floodplain complexity from a braided to a single channel pattern.

Siting of levees and floodwalls should be addressed prior to design and implementation of these types of projects. Proper siting of such structures can avoid several types of problems. First, construction activities should not disturb the physical integrity of adjacent riparian areas and/or wetlands. Second, by setting back the structures (offsetting them from the streambank), the relationship between the channel and adjacent riparian areas can be preserved. Proper siting and alignment of proposed structures can be established based on hydraulic calculations, historical flood data, and geotechnical analysis of riverbank stability.

Additional Resource

- LSU AgCenter. 1999. *Floodwalls*. Louisiana State University Agricultural Center, Louisiana Cooperative Extension Service. http://www.louisianafloods.org/NR/rdonlyres/7A01F7C8-703B-47D1-BCCD-63CD0A57721F/2995/pub2745Floodwall6.pdf.

Live Cribwalls

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☑ Integrated
  - ☐ Planning & regulatory

A live cribwall is used to rebuild a bank in a nearly vertical setting. It consists of a hollow, box-like interlocking arrangement of untreated log or timber members (Figure 7.20). The structure is filled with suitable backfill material and layers of live branch cuttings, which root inside the crib structure and extend into the slope. Logs or untreated timbers should range from 4 to 6 inches in diameter. Lengths will vary with the size of the crib structure. Fill rock should be 6 inches in diameter. Live branch cuttings should be 0.5 to 2.5 inches in diameter and long enough to reach the back of the wooden crib structure. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members. Live cribwalls are appropriate where space is limited and at the base of a slope where a low wall may be required to stabilize the toe of the slope and to reduce its steepness. They are also appropriate above and below the water level where stable streambeds exist. They are not designed for or intended to resist large, lateral earth stress. Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002) and the USDA NRCS *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992).

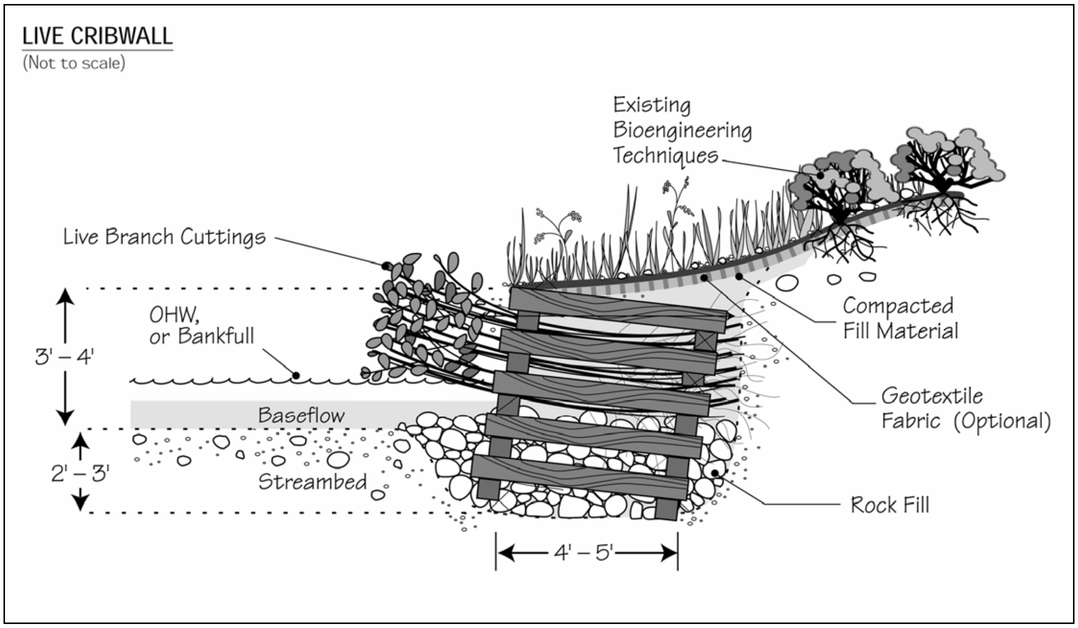


Figure 7.20 Live Cribwall (USDA-FS, 2002)

Additional Resources

- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.

- ISU. 2006. *How to Control Streambank Erosion: Live Cribwall.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/streambank/live_cribwall.pdf.

- Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Live Cribwall.* Created for United States Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/livecribwall.pdf.

- Ohio DNR. No date. *Ohio Stream Management Guide: Live Cribwalls.* Ohio Department of Natural Resources. http://www.ohiodnr.com/water/pubs/fs_st/stfs17.htm.

Live Fascines

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☐ Shorelines
  - ☑ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Live fascines are long bundles of branch cuttings bound together in a cylindrical structure (Figure 7.21). They are suited to steep, rocky slopes, where digging is difficult (USDA-NRCS, 1992). When cut from appropriate species (e.g., young willows or shrub dogwoods) that root easily and have long straight branches, and when properly installed, they immediately begin to stabilize slopes. The cuttings (0.5 to 1.5 inches in diameter) form live fascine bundles that vary in length from 5 to 10 feet or longer, depending on site conditions and handling limitations. Completed bundles should be 6 to 8 inches in diameter. The goal is for natural recruitment to follow once slopes are secured. Live fascines should be placed in shallow contour trenches on dry slopes and at an angle on wet slopes to reduce erosion and shallow face sliding. Live fascines should be applied above ordinary high-water mark or bankfull level except on very small drainage area sites. In arid climates, they should be used between the high and low water marks on the bank. This system, installed by a trained crew, does not cause much site disturbance.

Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002) and the USDA NRCS *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992). Under their Ecosystem Management and Restoration Research Program (EMRRP), the U.S. Army Corps of Engineers presents research on live fascines in a technical note (*Live and Inert Fascine Streambank Erosion Control*).[7]

Additional Resources

- Massachusetts DEP. 2006. *Massachusetts Nonpoint Source Pollution Management Manual: Live Fascines.* Massachusetts Department of Environmental Protection, Boston, MA. http://projects.geosyntec.com/NPSManual/Fact%20Sheets/Live%20Fascines.pdf.

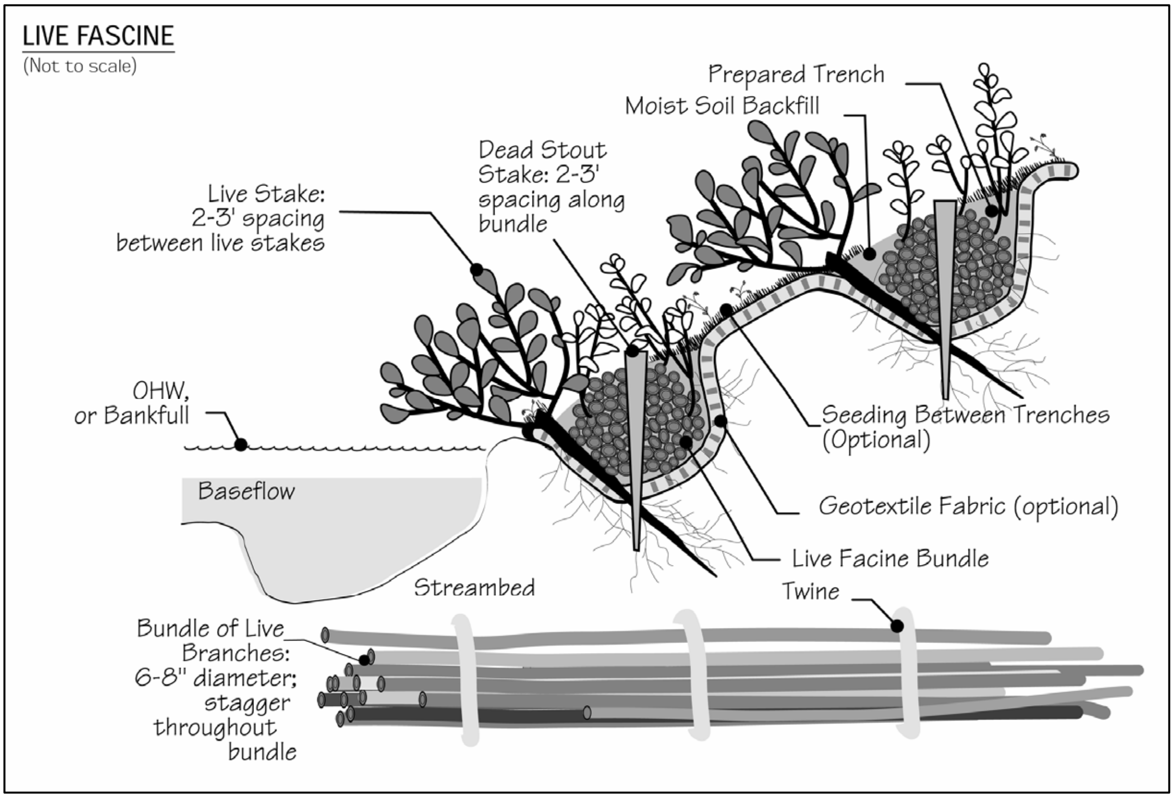
- Greene County Soil & Water Conservation District. No date. *Construction Specification VS-01: Live Fascines.* http://www.gcswcd.com/stream/library/pdfdocs/vs-01.pdf.

- ISU. 2006. *How to Control Streambank Erosion: Live Fascine.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/streambank/live_fascine.pdf.

- Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Live Fascine.* Created for United States Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/livefacine.pdf.

[7] http://el.erdc.usace.army.mil/elpubs/pdf/sr31.pdf

- Ohio DNR. No date. *Ohio Stream Management Guide: Live Fascines.* Ohio Department of Natural Resources. http://www.ohiodnr.com/water/pubs/fs_st/stfs14.pdf.



Note: OHW (Ordinary High Water) is the mark along a streambank where the waters are common and usual. This mark is generally recognized by the difference in the character of the vegetation above and below the mark or the absence of vegetation below the mark (USDA-FS, 2002).

Figure 7.21 Live Fascine (USDA-FS, 2002)

Live Staking

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☐ Shorelines
  - ☑ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Live staking (Figure 7.22) is appropriate for relatively uncomplicated site conditions when construction time is limited. It can also be used to stabilize intervening areas between other soil bioengineering techniques (USDA-NRCS, 1992). Live staking involves the insertion and tamping of live, rootable vegetative cuttings into the ground. If correctly prepared and placed, the live stake will root and grow. A system of stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture. Stakes are generally 1 to 2 inches in diameter and 2 to 3 feet long. Specific site requirements and available cutting source will determine size. Vegetation selected should be able to withstand the degree of anticipated inundation, provide year round protection, have the capacity to become well established under sometimes adverse soil conditions, and have root, stem, and branch systems capable of resisting erosive flows. Most willow species are ideal for live staking because they root rapidly and begin to dry out a slope soon after installation. Sycamore and cottonwood are also species commonly used for live staking. This is an appropriate technique for repair of small earth slips and slumps that are frequently wet. Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002) and the USDA NRCS *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992).

<u>Additional Resources</u>

- ISU. 2006. *How to Control Streambank Erosion: Live Stakes.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/streambank/live_stakes.pdf.

- Myers, R.D. 1993. *Slope Stabilization and Erosion Control Using Vegetation: A Manual of Practice for Coastal Property Owners. Live Staking.* Shorelands and Coastal Zone Management Program, Washington Department of Ecology. Olympia. Publication 93-30. http://www.ecy.wa.gov/programs/sea/pubs/93-30/livestaking.html.

- Walter, J., D. Hughes, and N.J. Moore. 2005. *Streambank Revegetation and Protection: A Guide for Alaska. Revegetation Techniques: Live Staking.* Revised Edition. Alaska Department of Fish and Game, Division of Sport Fish. http://www.sf.adfg.state.ak.us/SARR/restoration/techniques/livestake.cfm.

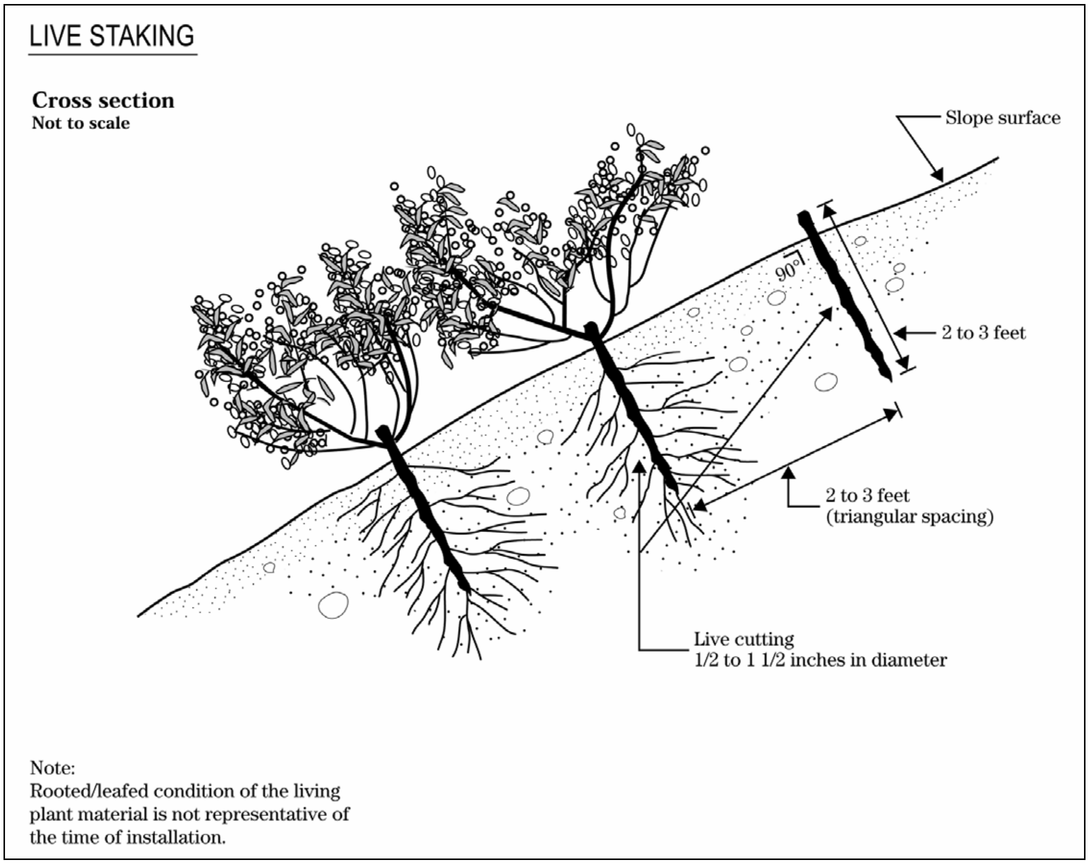


Figure 7.22 Live Staking (USDA-NRCS, 1992)

Locate Potential Land Disturbing Activities Away from Critical Areas

Material stockpiles, borrow areas, access roads, and other land-disturbing activities can often be located away from critical areas such as steep slopes, highly erodible soils, and areas that drain directly into sensitive waterbodies.

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☑ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Marsh Creation and Restoration

Channelization
- ☐ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☑ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Marsh creation and restoration is a useful vegetative technique that can address problems with erosion of shorelines. Marsh plants perform two functions in controlling shore erosion (Knutson, 1988). First, their exposed stems form a flexible mass that dissipates wave energy. As wave energy is diminished, the offshore transport and longshore transport of sediment are reduced. Ideally, dense stands of marsh vegetation can create a depositional environment, causing accretion of sediments along the intertidal zone rather than continued shore erosion. Second, marsh plants form a dense mat of roots, which can add stability to the shoreline sediments. The basic approach for marsh creation is to plant a shoreline area in the vicinity of the tide line with appropriate marsh grass species. Suitable fill material may be placed in the intertidal zone to create a wetlands planting terrace of sufficient width (at least 18 to 25 feet) if such a terrace does not already exist at the project site. For shoreline sites that are highly sheltered from the effects of wind, waves, or boat wakes, the fill material is usually stabilized with small structures, similar to groins, which extend out into the water from the land. For shorelines with higher levels of wave energy, the newly planted marsh can be protected with an offshore installation of stone that is built either in a continuous configuration or in a series of breakwaters.

<u>Additional Resource</u>

- Maryland Department of the Environment. 2006. *Shore Erosion Control Guidelines: Marsh Creation*. http://www.mde.state.md.us/assets/document/wetlandswaterways/Shoreerosion.pdf.

Modifying Operational Procedures

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☑ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

A useful tool for evaluating the effects of operational procedures on the quality of tailwaters is computer modeling. For instance, computer models can describe the vertical withdrawal zone that would be expected under different scenarios of turbine operation (Smith et al., 1987). Zimmerman and Dortch (1989) modeled release operations for a series of dams on a Georgia river and found that procedures that were maintaining cool temperatures in summer were causing undesirable decreases in DO and increases in dissolved iron in autumn. The suggested solution was a seasonal release plan that is flexible, depending on variations in the in-pool water quality and predicted local weather conditions. Care should be taken with this sort of approach to accommodate the needs of both the fishery resource and reservoir recreationalists, particularly in late summer.

Modeling has also been undertaken for a variety of TVA and USACE facilities to evaluate the downstream impacts on DO and temperature that would result from changes in several operational procedures, including (Hauser et al., 1990a; Hauser et al., 1990b; Higgins and Kim, 1982; Nestler et al., 1986):

- Maintenance of minimum flows
- Timing and duration of shutoff periods
- Seasonal adjustments to the pool levels
- Timing and variation of the rate of drawdown

Mulching

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Newly established vegetation does not have as extensive a root system as existing vegetation and therefore is more prone to erosion, especially on steep slopes. Additional stabilization should be considered during the early stages of seeding. This extra stabilization can be accomplished using mulches or mulch mats, which are applied to disturbed soil surfaces and can protect the area while vegetation becomes established.

Mulches and mulch mats include tacked straw, wood chips, and jute netting and are often covered by blankets or netting. Mulching alone should be used only for temporary protection of the soil surface or when permanent seeding is not feasible. The useful life of mulch varies with the material used and the amount of precipitation, but, generally, is approximately 2 to 6 months. Mulching and/or sodding may be necessary as slopes become moderate to steep, as soils become more erosive, and as areas become more sensitive. During the times of the year when vegetation cannot be established, mulch can be applied to moderate slopes and soils that are not highly erodible. On steep slopes or highly erodible soils, mulching may need to be reapplied if washed away.

<u>Additional Resources</u>

- Barr Engineering Company. 2001. *Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates. Soil Erosion Control: Mulches, Blankets and Mats.* Prepared for the Metropolitan Council by Barr Engineering Company, St. Paul, MN. http://www.metrocouncil.org/Environment/Watershed/BMP/CH3_RPPSoilMulch.pdf.

- CASQA. 2004. *California Stormwater BMP Construction Handbook*: *Hydraulic Mulch.* California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Construction/EC-3.pdf.

- ISU. 2006. *Iowa Construction Site Erosion Control Manual: Mulching.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/construction/2.3_mulching.pdf.

Noneroding Roadways

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

General Road Construction Considerations

Road design and construction activities that are tailored to topography and soils and take into consideration the overall drainage pattern in the watershed where the road is being constructed can prevent road-related water quality problems. Lack of adequate consideration of watershed and site characteristics, road system design, and construction techniques appropriate to the site can result in mass soil movements, extensive surface erosion, and severe sedimentation in nearby waterbodies. The effect that a road network has on stream networks largely depends on the extent to which the networks are interconnected. Road networks can be hydrologically connected to stream networks where road surface runoff is delivered directly to stream channels (at stream crossings or via ditches or gullies that direct flow off the road into a stream) and where road cuts transform subsurface flow into surface flow (in road ditches or on road surfaces that deliver sediment and water to streams much more quickly than without a road present). The combined effects of these drainage network connections are increased sedimentation and peak flows that are higher and arrive more quickly after storms. This can lead to increased instream erosion and stream channel changes, especially in small watersheds (USEPA, 2005a).

Site characteristics should be considered during construction planning. On-site verification of information from topographic maps, soil maps, and aerial photos can ensure that locations where roads are to be cut into slopes or built on steep slopes or where skid trails, landings, and equipment maintenance areas are to be located are appropriate to the use. If an on-site visit indicates that construction changes can reduce the risk of erosion, the project manager can make these changes prior to construction, and in some cases as the project progresses (USEPA, 2005a).

Road drainage features tailored to the site prevent water from pooling or collecting on road surfaces. This prevents saturation of the road surface, which can lead to rutting, road slumping, and channel washout. Many roads associated with channelization projects are temporary or seasonal-use roads, and their construction should not involve the high level of disturbance generated by construction of permanent, high-standard roads. However, these types of roads still need to be constructed and maintained to prevent erosion and sedimentation (USEPA, 2005a).

Erosion control practices need to be applied while a road is being constructed, when soils are most susceptible to erosion, to minimize soil loss to waterbodies. Since sedimentation from roads often does not occur incrementally and continuously, but in pulses during large rainstorms, it is important that road, drainage structure, and stream crossing design take into consideration a sufficiently large design storm that has a good chance of occurring during the life of the project. Such a storm might be the 10-year, 25-year, 50-year, or even 100-year, 12- to 24-hour return period storm. Sedimentation cannot be completely prevented during or after road construction, but the process is exacerbated if the road construction and design are inappropriate for the site conditions or if the road drainage or stream crossing structures are insufficient (USEPA, 2005a).

When constructing a new road, it is useful to consider road surface shape and composition, slope stabilization, and wetlands. A more detailed discussion of these topics is provided below. More information about potential impacts to fish habitat and passage are provided in EPA's *National Management Measures to Control Nonpoint Source Pollution from Forestry*.[8]

Road Shape and Composition

The shape of a road is an important runoff control component. Road drainage and runoff control are obtained by shaping the road surface to be insloping, outsloping, or crowned. Insloping roads can be effective where soils are highly erodible and directing runoff directly to the fill slope would be detrimental. Outsloped roads tend to dissipate runoff more than insloped roads, which concentrate runoff at cross drain locations, and are useful where erosion of backfill or ditch soil might be a problem. Crowned roads are suited to two lane roads and to steep single-lane roads that have frequent cross drains or ditches and ditch relief culverts (USEPA, 2005a). These road surface shapes are illustrated in Figure 7.23. Maintain one of these shapes to ensure good drainage. Crowns, inslopes, and outslopes will quickly lose effectiveness if not maintained frequently, due to ruts created by traffic when the road surface is damp or wet (USEPA, 2005a).

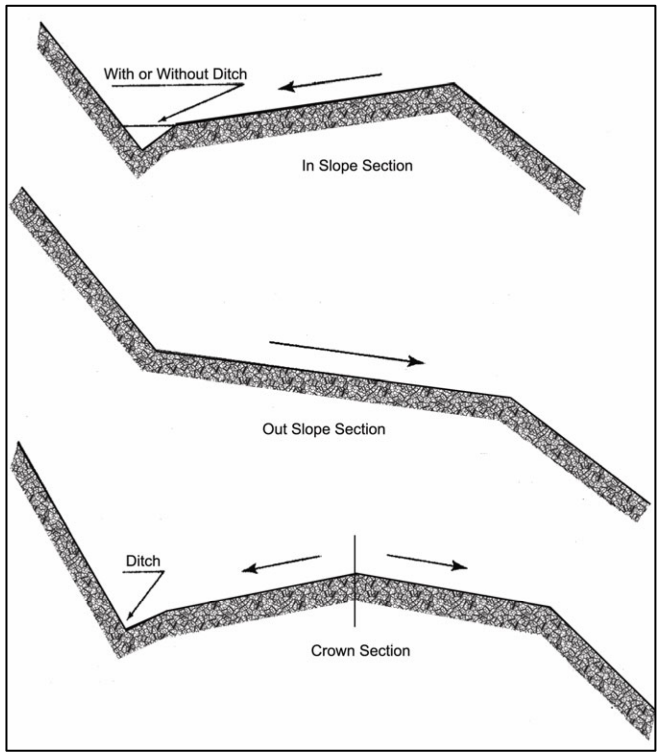


Figure 7.23 Types of Road Surface Shapes (USEPA, 2005a)

Road surface composition can effectively control erosion from road surfaces and slopes. It is important to choose a surface that is suitable to the topography, soils, and intended use. Surface protection of the roadbed and cut-and-fill slopes with a suitable material can minimize soil losses during storms, reduce frost heave erosion production, restrain downslope movement of soil slumps, and minimize erosion from softened roadbeds (USEPA, 2005a).

Slope Stabilization

Road cuts and fills can be a large source of sediment when constructing a rural road. Stabilizing back slopes and fill slopes as they are constructed is important in minimizing erosion from these areas. Combined with gravel or other surfacing, establishing grass or another form of slope stabilization can significantly reduce soil loss from road construction. If constructing on an unstable slope is necessary, consider consulting with an engineering geologist or geotechnical

[8] Available online at http://www.epa.gov/owow/nps/forestrymgmt.

engineer for recommended construction methods and to develop plans for the road segment. Unstable slopes that threaten water quality should be considered unsuitable for road building.

Planting grass on cut-and-fill slopes of new roads can effectively reduce erosion, and placing forest floor litter or brush barriers on downslopes in combination with establishing grass is also effective for reducing downslope sediment transport. Grass-covered fill is generally more effective than mulched fill in reducing soil erosion from newly constructed roads because of the roots that hold the soil in place, which are lacking with other cover. Because grass needs some time to establish itself, a combination of straw mulch with netting to hold it in place can be used to cover a seeded area and effectively reduce erosion while grass is growing. The mulch and netting provide immediate erosion control and promote grass growth (USEPA, 2005a).

Wetland Road Considerations

Sedimentation is a concern when considering road construction through wetlands. It is better to avoid putting a road through a wetland when an alternative route exists. If no alternative exists, make sure to implement best management practices (BMPs) suggested by the state. Road construction or maintenance for certain farming, forestry, or mining activities might be exempt under Clean Water Act (CWA) section 404. However, to qualify for the exemption, the roads must be constructed and maintained following application of specific BMPs designed to protect the aquatic environment (USEPA, 2005a).

Pesticide and Fertilizer Management

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☑ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Chemicals used in dam management include pesticides (insecticides, herbicides, and fungicides) and fertilizers. Since pesticides can be toxic, they have to be mixed, transported, loaded, and applied correctly and their containers disposed properly to prevent potential nonpoint source pollution. Since fertilizers can also be toxic or can damage the ecosystem, it is important that they be handled and applied properly, according to label instructions.

Even though a limited number of applications might be made at a specific dam site, consider that throughout a watershed many sites could receive applications of fertilizers and pesticides, which can accumulate in soils and in waterbodies. Application techniques also partly determine the potential risk to the aquatic environment from infrequent applications of pesticides and fertilizers. These chemicals can directly enter surface waters through five major pathways—direct application, drift, mobilization in ephemeral streams, overland flow, and leaching. Direct application is the most important source of increased chemical concentrations and is also one of the most easily controlled.

Some more specific implementation practices for pesticide maintenance include:

- Apply pesticides during favorable atmospheric conditions. Do not apply pesticides when wind conditions increase the likelihood of significant drift. It is also best to avoid pesticide application when temperatures are high or relative humidity is low because these conditions influence the rate of evaporation and enhance losses of volatile pesticides.
- Ensure that pesticide users abide by the current pesticide label, which might specify whether users be trained and certified in the proper use of the pesticide; allowable use rates; safe handling, storage, and disposal requirements; and whether the pesticide may be used under the provisions of an approved State Pesticide Management Plan.
- Locate mixing and loading areas, and clean all mixing and loading equipment thoroughly after each use, where pesticide residues will not enter streams or other waterbodies.
- Dispose of pesticide wastes and containers according to state and federal laws.
- Consider the use of pesticides as only one part of an overall program to control pest problems. Integrated Pest Management (IPM) strategies have been developed to control pests without total reliance on chemical pesticides.
- Base selection of pesticide on site factors and pesticide characteristics. These factors include vegetation height, target pest, adsorption (attachment) to soil organic matter, persistence or half-life, toxicity, and type of formulation.
- Check all equipment carefully, particularly for leaking hoses and connections and plugged or worn nozzles. Calibrate spray equipment periodically to achieve uniform pesticide distribution and rate.

- Always use pesticides in accordance with label instructions, and adhere to all federal and state policies and regulations governing pesticide use.

Specific implementation practices for fertilizer maintenance include:

- Apply slow-release fertilizers when possible. This practice reduces potential nutrient leaching to ground water, and it increase the availability of nutrients for plant uptake.
- Apply fertilizer during favorable atmospheric conditions. Do not apply fertilizer when wind conditions increase the likelihood of significant drift.
- Apply fertilizers during maximum plant uptake periods to minimize leaching.
- Base fertilizer type and application rate on soil and/or foliar analysis.

Phase Construction

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Construction site phasing involves disturbing only small portions of a site at a time to prevent erosion from dormant parts (CWP, 1997c). Grading activities and construction are completed and soils are effectively stabilized on one part of the site before grading and construction commence at another. This is different from the more traditional practice of construction site sequencing, in which construction occurs at only one part of the site at a time but site grading and other site-disturbing activities typically occur all at once, leaving portions of the disturbed site vulnerable to erosion. To be effective, construction site phasing must be incorporated into the overall site plan early. Elements to consider when phasing construction activities include (CWP, 1997c):

- Managing runoff separately in each phase
- Determining whether water and sewer connections and extensions can be accommodated
- Determining the fate of already completed downhill phases
- Providing separate construction and residential accesses to prevent conflicts between residents living in completed stages of the site and construction equipment working on later stages

A comparison of sediment loss from a typical development and from a comparable phased project showed a 42 percent reduction in sediment export in the phased project (CWP, 1997c). Phasing can also provide protection from complete enforcement and shutdown of the entire project. If a contractor is in noncompliance in one phase or zone of a site, that will be the only zone affected by enforcement. This approach can help to minimize liability exposure and protect the contractor financially (Deering, 2000b).

Physical Barriers

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☑ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Physical barriers are diversion systems that lead or force fish to bypasses that transport them above or below the dam (FAO, 2001). Physical diversion structures deployed at dams include angled screens, drum screens, inclined plane screens, louvers, and traveling screens. The success and effectiveness of physical barriers has been found to be specific to individual hydropower facilities (Mattice, 1990).

Angled screens are used to guide fish to a bypass by guiding them through the channel at some angle to the flow. Coarse-mesh angled screens have been shown to be highly effective with numerous warm- and cold-water species at adult life stages. Fine-mesh angled screens have been shown in laboratory studies to be highly effective in diverting larval and juvenile fish to a bypass with resultant high survival. Performance of angled screens can vary by species, stream velocity, fish length, screen mesh size, screen type, and temperature (Stone and Webster, 1986). Clogging from debris and fouling organisms is a maintenance problem associated with angled screens.

Angled rotary drum screens oriented perpendicular to the flow direction have been used extensively to lead fish to a bypass. Angled rotary drum screens tend not to experience the major operational and maintenance clogging problems of stationary screens, such as angled vertical screens. Maintenance of angled rotary drum screens typically consists of routine inspection, cleaning, lubrication, and periodic replacement of the screen mesh (Stone and Webster, 1986).

An inclined plane screen is used to divert fish upward in the water column into a bypass. Once concentrated, the fish are transported to a release point below the dam. An inclined plane pressure screen at the T.W. Sullivan Hydroelectric Project (Willamette Falls, Oregon) is located in the penstock of one unit. The design is effective in diverting fish, with a high survival rate. However, this device has been linked to injuries in some species of migrating fish, and it has not been accepted for routine use (Stone and Webster, 1986).

Louvers consist of an array of evenly spaced, vertical slats aligned across a channel at an angle leading to a bypass. The turbulence they create is sensed and avoided by the fish (Stone and Webster, 1986). Louver systems rely on a fish’s instincts to use senses other than sight to move around obstacles. Once the louver is sensed, the fish tend to reverse their head first downstream orientation (to head upstream, tail to the louver) and move laterally along it until they reach the bypass (OTA, 1995).

Submerged traveling screens are used to divert downstream migrating fish out of turbine intakes to adjoining gatewell structures, where the fish are concentrated for release downstream. This device has been tested extensively at hydropower facilities on the Snake and Columbia Rivers. Because of their complexity, submerged traveling screens must be continually maintained. The screens must be serviced seasonally, depending on the debris load, and trash racks and bypass orifices must be kept free of debris (Stone and Webster, 1986).

Physical barrier fish diversion systems have been found to work best when specifically designed to the structure and fish being passed. Small differences in design, such as the spacing or depth of the louvers, can mean the difference in success and failure. A successful louver system has been installed at the Holyoke Hydroelectric Power Station, on the Connecticut River. This partial depth louver system was installed in the intake channel at the power plant and successfully passed 86 percent of the juvenile clupeids and 97 percent of the Atlantic salmon (*Salmo salar*) smolts (Marmulla, 2001). Another partial depth louver system on the same river has experienced less successful results. The system installed at the Vernon Dam on the Connecticut River is successfully passing about 50 percent of the Atlantic salmon smolts (OTA, 1995).

Pollutant Runoff Control

Store, cover, and isolate construction materials, refuse, garbage, sewage, debris, oil and other petroleum products, mineral salts, industrial chemicals, and topsoil to prevent runoff of pollutants and contamination of ground water.

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☑ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Preserve Onsite Vegetation

Channelization

- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams

- ☑ Erosion control
- ☑ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion

- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Preserving onsite vegetation retains soil and limits runoff of water, sediment, and pollutants. The destruction of existing onsite vegetation can be minimized by initially surveying the site to plan access routes, locations of equipment storage areas, and the location and alignment of the dam. Construction workers can be encouraged to limit activities to designated areas only. Reducing the disturbance of vegetation also reduces the need for revegetation after construction is completed, including the required fertilization, replanting, and grading that are associated with revegetation. Additionally, as much natural vegetation as possible should be left next to the waterbody where construction is occurring. This vegetation provides a buffer to reduce the NPS pollution effects of runoff originating from areas associated with the construction activities.

<u>Additional Resource</u>

- CASQA. 2004. *California Stormwater BMP Construction Handbook*: *Preservation of Existing Vegetation.* California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Construction/EC-2.pdf.

Reregulation Weir

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☑ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Reregulation weirs have been constructed from stone, wood, and aggregate. In addition to increasing the levels of DO in the tailwaters, reregulation weirs result in a more constant rate of flow farther downstream during periods when turbines are not in operation. A reregulation weir constructed downstream of the Canyon Dam (Guadalupe River, Texas) increased DO levels in waters leaving the turbine from 3.3 mg/L to 6.7 mg/L (EPRI, 1990).

The USACE Waterways Experiment Station (Wilhelms, 1988) has compared the effectiveness with which various hydraulic structures accomplished the reaeration of reservoir releases. The study concluded that, whenever operationally feasible, more discharge should be passed over weirs to improve DO concentrations in releases. Results indicated that overflow weirs aerate releases more effectively than low-sill spillways (Wilhelms, 1988).

Reservoir Aeration

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☑ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Some techniques for reservoir aeration include:

- Air injection systems
- Diffused air systems
- Oxygen injection systems
- U-tube design

Air injection systems mix water from different strata in the impoundment by using air or pure oxygen injected into a pumping system. Air injection systems are categorized as partial air lift systems and full air lift systems. In the partial air lift system, compressed air is injected at the bottom of the unit; then the air and water are separated at depth and the air is vented to the surface. In the full air lift system, compressed air is injected at the bottom of the unit (as in the partial air lift system), but the air-water mixture rises to the surface. The full air lift design has a higher efficiency than the partial-air lift and has a lesser tendency to elevate dissolved nitrogen levels (Thornton et al., 1990).

Diffused air systems provide effective transfer of oxygen to water by forcing compressed air through small pores in diffuser systems to form bubbles. One diffuser system test in the Delaware River near Philadelphia, Pennsylvania in 1969–1970 demonstrated the efficiency of this practice. Coarse-bubble diffusers were deployed at depths ranging from 13 to 38 feet. Depending on the depth of deployment, the oxygen transfer efficiency varied from 1 to 12 percent. When compared with other systems discussed below, this efficiency rate is rather low. But the results of this test determined that river aeration was more economical than advanced wastewater treatment as a strategy for improving the levels of DO in the river (EPRI, 1990). Another type of oxygen injection system, which pumps gaseous oxygen into the hypolimnion through diffusers, has effectively improved DO levels in the reservoir behind the Richard B. Russell Dam (Savannah River, on the Georgia-South Carolina border). The system is operated 1 mile upstream of the dam, with occasional supplemental injection of oxygen at the dam face when DO levels are especially low. The system has successfully maintained DO levels above 6 mg/L in the releases, with an average oxygen transfer efficiency of 75 percent (EPRI, 1990; Gallagher and Mauldin, 1987).

The diffused air system has been found to be a cost-effective method to raise low DO levels within a reservoir (Henderson and Shields, 1984). However, the costs of air diffuser operation may be high for deep reservoirs because of hydraulic pressures that must be overcome. Destratification that results from deployment of an air diffuser system may also mix nutrient-rich waters located deep in the impoundment into layers located closer to the surface, increasing the potential for stimulation of algal populations. Barbiero et al. (1996), in a study on the effects of artificial circulation on a small northeastern impoundment, found that artificial circulation ultimately had no effect on the magnitude of summer phytoplankton populations. However, the authors note that intermittent mixing events tend to promote increased transport of phosphorus into the epilimnion. While this had no effect on phytoplankton populations in the studied lake, it demonstrates the potential of artificial circulation to impact water quality and the need for careful evaluation of potential impacts.

Oxygen injection systems use pure oxygen to increase levels of dissolved oxygen in reservoirs. One type of design, termed side stream pumping, carries water from the impoundment onto the shore and through a piping system into which pure oxygen is injected. After passing through this system, the water is returned to the impoundment (EPRI, 1990).

The U-tube design, in which water from deep in the impoundment is pumped to the surface layer, provides a means to aerate reservoir waters. Oxygen transfer is increased as a mixture of water and oxygen gas is subjected to greater hydrostatic pressure. Water moves down the U-tube and pressure increases as a function of depth, dissolving the oxygen gas into the water. The oxygenated water then travels back up through the system and is released to the waterway (Jones and Stokes, 2004). The inducement of artificial circulation through aeration of the impoundment may also provide the opportunity for a "two-story" fishery, reduce internal phosphorus loading, and eliminate problems with iron and manganese in drinking water (Thornton et al., 1990).

If the principal objective is to improve DO levels only in the reservoir releases and not throughout the entire impoundment, then aeration can be applied selectively to discrete layers of water immediately surrounding the intakes or as water passes through release structures such as hydroelectric turbines. Localized mixing is a practice to improve releases from thermally stratified reservoirs by destratifying the reservoir in the immediate vicinity of the outlet structure. This practice differs from the practice of artificial destratification, where mixing is designed to destratify all or most of the reservoir volume (Holland, 1984). Localized mixing is provided by forcing a jet of high-quality surface water downward into the hypolimnion. Pumps used to create the jet generally fall into two categories, axial flow propellers and direct drive mixers (Price, 1989). Axial flow pumps usually have a large-diameter propeller (6 to 15 feet) that produces a high-discharge, low-velocity jet. Direct drive mixers have small propellers (1 to 2 feet) that rotate at high speeds and produce a high-velocity jet. The axial flow pumps are suitable for shallow reservoirs because they can force large quantities of water down to shallow depths. The high-momentum jets produced by direct drive mixers are necessary to penetrate deeper reservoirs (Price, 1989).

Additional Resource

- Thornton, K.W., B.L. Kimmel, and F.E. Payne. 1990. *Reservoir Limnology: Ecological Perspectives*. John Wiley & Sons, Inc., New York.

Retaining Walls

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☑ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Retaining walls are used in areas where soils are unstable, where slopes are steeper than the angle of repose, and where the horizontal distance is limited. They help stabilize slopes and can decrease the steepness of a slope. If the steepness of a slope is reduced, the runoff velocity is decreased and, therefore, the erosion potential is decreased.

According to the *Iowa Construction Site Erosion Control Manual*, a variety of materials can be used for construction of retaining walls, including concrete masonry, concrete cribbing, steel piling, gabions, precast stone, rock riprap, reinforced earth, stone drywall, and treated wood timbers. Costs vary by the material selected for construction. When designing a retaining wall, the following factors should be taken into account: drainage, bearing value of the soil, wall thickness, stress, foundation design, and wall height.

Additional Resources

- ISU. 2006. *Iowa Construction Site Erosion Control Manual: Retaining Wall.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/construction/3.13_retaining_wall.pdf.
- Leposky, R.E. 2004. *Retaining Walls: What You See and What You Don't.* http://www.forester.net/ecm_0401_retaining.html.

Return Walls

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☑ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Whenever shorelines or streambanks are "hardened" through the installation of bulkheads, seawalls, or revetments, the design process must include consideration that waves and currents can continue to dislodge the substrate at both ends of the structure, resulting in very concentrated erosion and rapid loss of fastland. This process is called flanking. To prevent flanking, return walls should be provided at either end of a vertical protective structure and should extend landward for a horizontal distance consistent with the local erosion rate and the design life of the structure.

Additional Resource

- USACE. 1985. *Coastal Engineering Technical Note: Determining Lengths of Return Walls*. U.S. Army Engineer Waterways Experiment Station. http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/cetn-iii-25.pdf.

Revegetate

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Revegetation of construction sites during and after construction is the most effective way to permanently control erosion (Hynson et al., 1985). To select the right plants for your bioengineering project, note what native plant communities grow in the area. Avoid planting noxious or invasive grasses, such as reed canary grass or ryegrass. Remove invasive plants such as yellow starthistle, English ivy, deadly nightshade, field morning glory, scotch broom, cheatgrass, and purple loosestrife. Use more of the same native plants in the bioengineering design, as these plants are most likely adapted to conditions to the area.

Plants like willow, red osier dogwood, alder, ash, and cottonwood can be well suited for bioengineering. They establish easily, grow quickly, and have thick root systems. Cuttings are available from native plant nurseries. They may also be collected next to the project site, if the area is well vegetated (Oregon Association of Conservation Districts, 2004).

Ecological and vegetational areas vary throughout the country. Therefore, other plant materials may be more suitable for a project. Contact local cooperative extension services for more plant information.[9]

Additional Resources

- Barr Engineering Company. 2001. *Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates. Soil Erosion Control: Vegetative Methods.* Prepared for the Metropolitan Council by Barr Engineering Company, St. Paul, MN. http://www.metrocouncil.org/environment/Watershed/BMP/CH3_RPPSoilVeget.pdf.

- Ohio DNR. No date. *Ohio Stream Management Guide: Restoring Streambanks with Vegetation.* Ohio Department of Natural Resources. http://www.ohiodnr.com/water/pubs/fs_st/stfs07.htm.

[9] http://www.csrees.usda.gov/qlinks/partners/state_partners.html

Revetment

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☑ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

A revetment (Figure 7.24) is a type of vertical protective structure used for shoreline protection. One revetment design contains several layers of randomly shaped and randomly placed stones, protected with several layers of selected armor units or quarry stone. The armor units in the cover layer should be placed in an orderly manner to obtain good wedging and interlocking between individual stones. The cover layer may also be constructed of specially shaped concrete units (USACE, 1984). Sometimes gabions (stone-filled wire baskets) or interlocking blocks of precast concrete are used in the construction of revetments. In addition to the surface layer of armor stone, gabions, or rigid blocks, successful revetment designs also include an underlying layer composed of either geotextile filter fabric and gravel or a crushed stone filter and bedding layer. This lower layer functions to redistribute hydrostatic uplift pressure caused by wave action in the foundation substrate. Precast cellular blocks, with openings to provide drainage and to allow vegetation to grow through the blocks, can be used in the construction of revetments to stabilize banks. Vegetation roots add additional strength to the bank. In situations where erosion can occur under the blocks, fabric filters can be used to prevent the erosion. Technical assistance should be obtained to properly match the filter and soil characteristics. Typically blocks are hand placed when mechanical access to the bank is limited or costs need to be minimized. Cellular block revetments have the additional benefit of being flexible to conform to minor changes in the bank shape (USACE, 1983).

<u>Additional Resource</u>

- Ohio DNR. No date. *Ohio Stream Management Guide: Riprap Revetments.* Ohio Department of Natural Resources. http://www.ohiodnr.com/water/pubs/fs_st/stfs16.pdf.

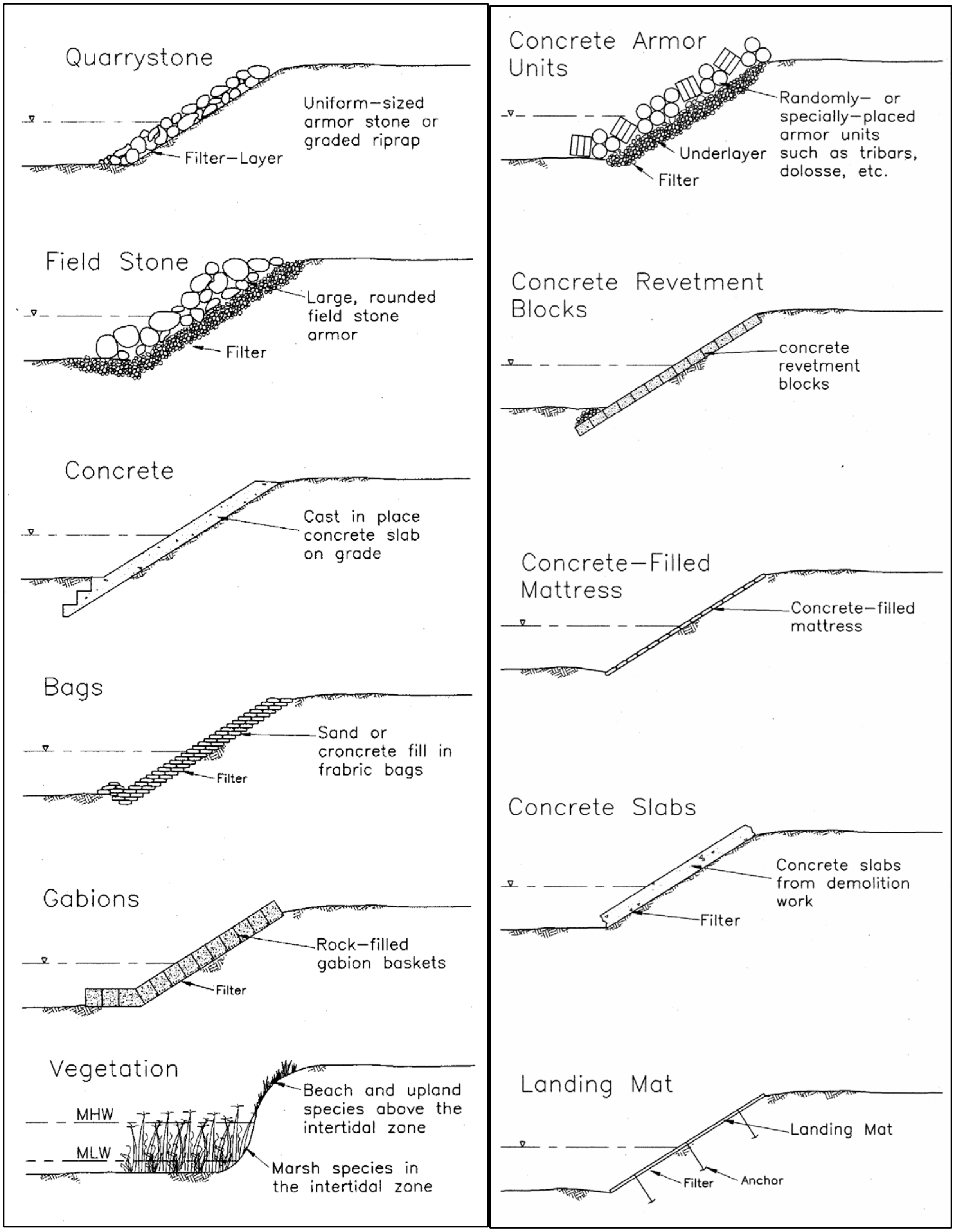


Figure 7.24 Revetment Alternatives (USACE, 2003)

Riparian Improvements

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☑ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☑ Integrated
  - ☐ Planning & regulatory

Riparian improvements are another strategy that can be used to restore or maintain aquatic and riparian habitat around reservoir impoundments or along the waterways downstream from dams. In fact, Johnson and LaBounty (1988) found that riparian improvements were more effective, in some cases, than flow augmentation for protection of instream habitat. In the Salmon River (Idaho), a variety of instream and riparian habitat improvements have been recommended to improve the indigenous stocks of Chinook salmon (*Oncorhynchus tshawytscha*). These improvements include reducing sediment loading in the watershed, improving riparian vegetation, eliminating barriers to fish migration (see sections discussing this practice below), and providing greater instream and riparian habitat diversity (Andrews, 1988).

Maintaining and improving riparian areas upstream of a dam may also be an important consideration for reducing flow-related impacts to dams. Riparian areas along brooks and smaller streams are sometimes altered in a manner that impairs their ability to detain and absorb floodwater and stormwater (e.g., removal of forest cover or increased imperviousness). The cumulative impact of the riparian changes results in the smaller streams discharging increased volumes and velocities of water, which then result in more severe downstream flooding and increased storm damage and/or maintenance to existing structures (such as dams). These downstream impacts may occur even though main stem floodplains and riparian areas are safeguarded and remain close to their natural condition (Cohen, 1997).

Riprap

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☑ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Riprap is a layer of appropriately sized stones designed to protect and stabilize areas subject to erosion, slopes subject to seepage, or areas with poor soil structure. Riprap extends from the toe of the slope to a height needed for long term durability (Figure 7.25).

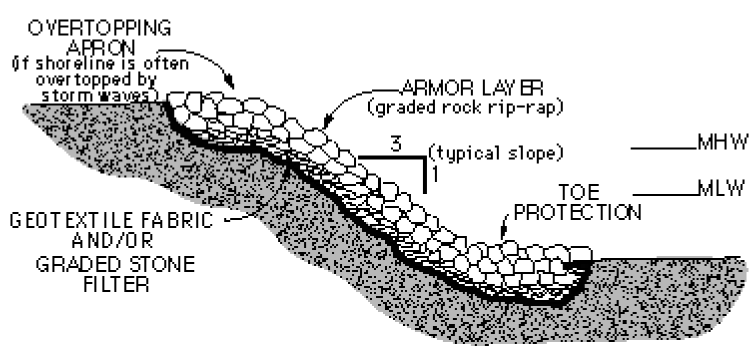
Riprap can be used where vegetation cannot be established or in combination with vegetative approaches. This method is suitable where stream flow velocity is high or where there is a threat to life or property. This method can be expensive, particularly if materials are not locally available. This method should be combined with soil bioengineering techniques, particularly revegetation efforts, to achieve a comprehensive streambank restoration design (FISRWG, 1998).

Additional Resources

- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.

- ISU. 2006. *Iowa Construction Site Erosion Control Manual: Riprap.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/construction/3.15_riprap.pdf.

- Tennessee Department of Environment and Conservation. 2002. *Erosion and Sediment Control Handbook: Riprap*. Tennessee Department of Environment and Conservation, Nashville, TN. http://state.tn.us/environment/wpc/sed_ero_controlhandbook/rr.pdf.



Proper riprap placement (MHW=mean high water, MLW=mean low water).

Figure 7.25 Riprap Diagram
(http://www.extension.umn.edu/distribution/naturalresources/components/DD6946g.html)

Root Wad Revetments

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☑ Integrated
  - ☐ Planning & regulatory

Root wads armor a bank by keeping faster moving currents away from the bank (Figures 7.26 and 7.27). They are most useful for low energy streams that meander and have out-of-bank flow conditions. Root wads should be used in combination with other soil bioengineering techniques to stabilize a bank and ensure plant establishment on the upper portions of the streambank. Stabilizing the bank will reduce streambank erosion, trap sediment, and improve habitat diversity. There are a number of ways to install root wads. The trunk can be driven into the bank, laid in a deep trench, or installed as part of a log and boulder revetment. Use tree wads that have brushy top and durable wood, such as Douglas fir, oak, hard maple, juniper, spruce, cedar, red pine, white pine, larch, or beech. Ponderosa pine and aspen are too inflexible, and alder decomposes rapidly.

With the added support of a log and boulder revetment, root wads can stabilize banks of high-energy streams. Root wad span should be approximately 5 feet with numerous root protrusions. The trunk should be at least 8 to 12 feet long. Boulders should be as large as possible, but at least one and a half times the log's diameter. They should also have an irregular surface. Logs are to be used as footers or revetments and should be over 16 inches in diameter.

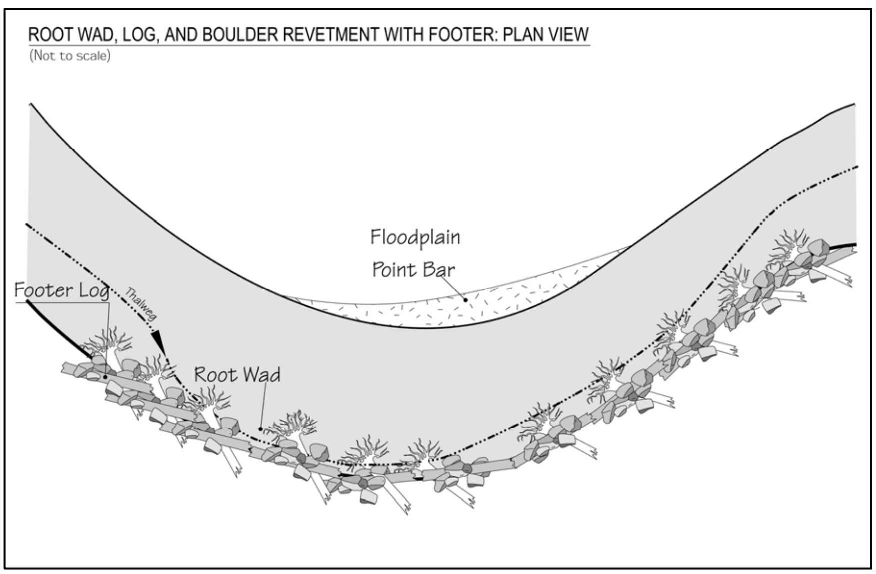


Figure 7.26 Root Wad, Log, and Boulder Revetment with Footer: Plan View (USDA-FS, 2002)

When logs and root wads are well anchored, this design will tolerate high boundary shear stress. However, local scour and erosion is possible. Varying with climate and tree species used, the decomposition of the logs and rootwads will limit the life span of this design. If colonization of streambank vegetation does not take place, replacement may be required. The project site must be accessible to heavy equipment. Locating materials may be difficult in some locations and this method can be expensive (FISRWG, 1998).

Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002). Under EMRRP, the USACE has presented research on rootwad composites in a technical note (*Rootwad Composites for Streambank Erosion Control and Fish Habitat Enhancement*).[10]

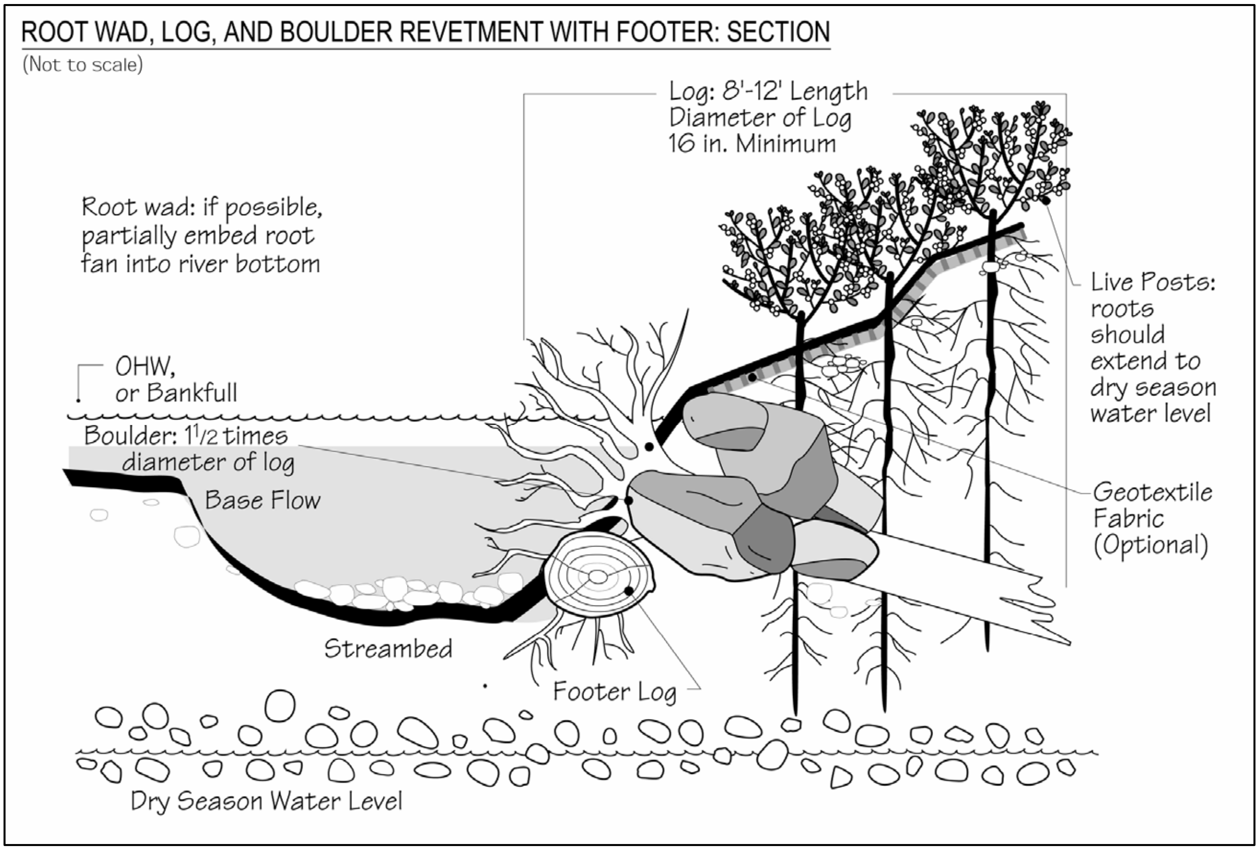


Figure 7.27 Rootwad, Log, and Boulder Revetment with Footer: Section (USDA-FS, 2002)

Additional Resources

- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.

- Harmon, W.A. and R. Smith. 2000. *Using Root Wads and Rock Vanes for Streambank Stabilization.* River Course Fact Sheet Number 4. North Carolina Cooperative Extension Service. http://www.bae.ncsu.edu/programs/extension/wqg/sri/rv-crs-4.pdf.

- Walter, J., D. Hughes, and N.J. Moore. 2005. *Streambank Revegetation and Protection: A Guide for Alaska. Revegetation Techniques: Root Wads.* Revised Edition. Alaska Department of Fish and Game, Division of Sport Fish. http://www.sf.adfg.state.ak.us/SARR/restoration/techniques/rootwad.cfm.

10 http://el.erdc.usace.army.mil/elpubs/pdf/sr21.pdf

Rosgen's Stream Classification Method

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☑ Planning & regulatory

Rosgen's stream channel stability method provides a sequence of steps for the field practitioner to use in reaching final conclusions and making recommendations for management, stream design, or restoration. The field practitioner uses field-measured variables to assess:

- Stream state or channel condition variables
- Vertical stability (degradation/aggradation)
- Lateral stability
- Channel patterns
- Stream profile and bed features
- Channel dimension factor
- Channel scour/deposition (with competence calculations of field verified critical dimensionless shear stress and change in bed and bar material size distribution)
- Stability ratings adjusted by stream type
- Dimensionless ratio sediment rating curves by stream type and stability ratings
- Selection of position in stream type evolutionary scenario as quantified by morphological variables by stream type to determine state and potential of stream reach.

The stability assessment is conducted on a reference reach and a departure analysis is performed when compared to an unstable reach of the same stream type. Changes in the variables controlling river channel form, primarily streamflow, sediment regime, riparian vegetation, and direct physical modifications can cause stream channel instability. Separating the differences between anthropogenic versus geologic processes in channel adjustment is a key to prevention, mitigation, and restoration of disturbed systems.

Rosgen (1996) has also created a river inventory hierarchy involving four levels that would allow a stream assessment to be conducted at various levels, ranging from broad qualitative descriptions to detailed quantitative descriptions. The idea is to provide documented measurements, coupled with consistent, quantitative indices of stability, to make the approach to stream assessments less subjective and more consistent and reproducible. Level I and Level II are used to do the initial stratification of a reach by valley and stream type. Level III is used to predict stability. Level IV is used for validation, and requires the greatest amount of detail over a longer time period. For example, vertical stability and bank erosion can be estimated at Level III. But, in a Level IV assessment, permanent cross-sections are revisited over time to verify shifts in bed elevation and measure actual erosion that occurred.

The four hierarchal levels, and the measurements and determinations they include, are shown below along with their objectives.

Level I—Geomorphic characterization: Used to describe generalized fluvial features using remote sensing and existing inventories of geology, landform evolution, valley morphology, depositional history and associated river slopes, relief and patterns utilized for generalized categories of major stream types, and associated interpretations.

Level II—Morphological description: To delineate homogeneous stream types that describe specific slopes, channel materials, dimensions and patterns from reference reach measurements and provide a more detailed level of interpretation than Level I. Includes measurements such as sinuosity, width/depth ration, slope, entrenchment ratio, and channel patterns and material.

Level III—Stream "state" or condition: The "state" of streams further describes existing conditions that influence the response of channels to imposed change and provide specific information for prediction methodologies (such as stream bank erosion calculations). Provides for very detailed descriptions and associated interpretation and predictions. Includes such measurements and/or characterizations of vegetation, deposition, debris, meander patterns, channel stability index, and flow regime.

Level IV—Reach specific studies (validation level): Provides reach-specific information on channel processes. Used to evaluate prediction methodologies; to provide sediment, hydraulic and biological information related to specific stream types; and to evaluate effectiveness of mitigation and impact assessments for activities by stream type. Involves direct measurements of sediment transport, bank erosion rates, aggradation/degradation, hydraulics, and biological data.

Rosgen's stream classification methodologies can assist in stream restoration design by:

- Enabling more precise estimates of quantitative hydraulic relationships associated with specific stream and valley morphologies.
- Establishing guidelines for selecting stable stream types for a range of dimensions, patterns, and profiles that are in balance with the river's valley slope, valley confinement, depositional materials, streamflow, and sediment regime of the watershed.
- Providing a method for extrapolating hydraulic parameters and developing empirical relationships for use in the resistance equations and hydraulic geometry equations needed for restoration design.
- Developing a series of meander geometry relationships that are uniquely related to stream types and their bankfull dimensions.
- Identifying the stable characteristics for a given stream type by comparing the stable form to its unstable or disequilibrium condition.

Refer to *Applied River Morphology* (Rosgen, 1996) for more information on this stream classification system and potential applications.

Scheduling Projects

Often clearing and grading for a project can be scheduled during the time of year that the erosion potential of the site is relatively low. In many parts of the country, there is a certain period of the year when erosion potential is relatively low and construction scheduling could be very effective. For example, in the Pacific region if construction can be completed during the 6-month dry season (e.g., May 1 to October 31), temporary erosion and sediment controls might not be needed. In some parts of the country erosion potential is very high during certain parts of the year, such as the spring thaw in northern and high-elevation areas. During that time of year, snowmelt generates a constant runoff that can erode soil. In addition, construction vehicles can easily turn the soft, wet ground into mud, which is more easily washed off-site. Therefore, in the north, limitations could be placed on clearing and grading during the spring thaw (Goldman et al., 1986).

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Additional Resource

- CASQA. 2004. *California Stormwater BMP Construction Handbook: Scheduling.* California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Construction/EC-1.pdf.

Sediment Basins/Rock Dams

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☑ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

An earthen or rock embankment that is located to capture sediment from runoff and retain it on the construction site.

Sediment basins, also known as silt basins, are engineered impoundment structures that allow sediment to settle out of the urban runoff. They are installed prior to full-scale grading and remain in place until the disturbed portions of the drainage area are fully stabilized. They are generally located at the low point of sites, away from construction traffic, where they will be able to trap sediment-laden runoff. Basin dewatering is achieved either through a single riser and drainage hole leading to a suitable outlet on the downstream side of the embankment or through the gravel of the rock dam. In both cases, water is released at a substantially slower rate than would be possible without the control structure.

The following are general specifications for sediment basin design criteria as presented in Schueler (1997):

- Provide 1,800 to 3,600 ft^3 of storage per contributing acre (a number of states, including Maryland, Pennsylvania, Georgia, and Delaware, recently increased the storage requirement to 3,600 ft^3 or more [CWP, 1997b]).
- Surface area equivalent to 1 percent of drainage area (optional, seldom required).
- Riser with spillway capacity of 0.2 ft^3/s/ac of drainage area (peak discharge for 2-year storm with 1-foot freeboard).
- Length-to-width ratio of 2 or greater.
- Basin side slopes no steeper than 2:1 (h:v).
- Safety fencing, perforated riser, dewatering (optional, seldom required).

Sediment basins can be classified as either temporary or permanent structures, depending on the length of service of the structure. If they are designed to function for less than 36 months, they are classified as temporary; otherwise, they are considered permanent. Temporary sediment basins can also be converted into permanent runoff management ponds. When sediment basins are designed as permanent structures, they must meet all standards for wet ponds. It is important to note that even the best-designed sediment basin seldom exceeds 60 to 75 percent total suspended solids (TSS) removal, which should be considered when selecting a sediment control practice.

Basins are most commonly used at the outlets of diversions, channels, slope drains, or other runoff conveyances that discharge sediment-laden water.

Additional Resources

- CASQA. 2003. *California Stormwater BMP Construction Handbook*: *Sediment Basin.* California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Construction/SE-2.pdf.

- ISU. 2006. *Iowa Construction Site Erosion Control Manual: Sediment Basin.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/construction/3.17_sediment_basin.pdf.

- Michigan Department of Environmental Quality. 1992. *SESC Training Manual*: *Sedimentation Basin*. Michigan Department of Environmental Quality, Lansing, MI. http://www.deq.state.mi.us/documents/deq-swq-nps-sb.pdf.

- Tennessee Department of Environment and Conservation. 2002. *Erosion and Sediment Control Handbook: Sediment Basin*. Tennessee Department of Environment and Conservation, Nashville, TN. http://state.tn.us/environment/wpc/sed_ero_controlhandbook/sb.pdf.

Sediment Fences

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☑ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Silt fence, also known as filter fabric fence, is available in several mesh sizes from many manufacturers. Sediment is filtered out as runoff flows through the fabric. Such fences should be used only where there is sheet flow (no concentrated flow), and the maximum drainage area to the fence should be 0.5 acre or less per 100 feet of fence. To ensure sheet flow, a gravel collar or level spreader can be used upslope of the fence. Many types of fabrics are available commercially. The characteristics that determine a fence's effectiveness include filtration efficiency, permeability, tensile strength, tear strength, ultraviolet resistance, pH effects, and creep resistance. The longevity of silt fences depends heavily on proper installation and maintenance, however they typically last 6 to 12 months. CWP (1997d) identified several conditions that increase the effectiveness of silt fences:

- The length of the slope does not exceed 50 feet for slopes of 5 to 10 percent, 25 feet for slopes of 10 to 20 percent, or 15 feet for slopes greater than 20 percent.
- The silt fence is aligned parallel to the slope contours.
- Edges of the silt fence are curved uphill, which does not allow flow to bypass the fence.
- The contributing length to the fence is less than 100 feet.
- The fence has reinforcement if receiving concentrated flow.
- The fence was installed above an outlet pipe or weir.
- The fence is down slope of the exposed area and alignment considers construction traffic.
- Sediment is not allowed to accumulate behind the fence (increases capacity and decreases breach potential).
- Alignment of the silt fence mirrors the property line or limits of disturbance.

<u>Additional Resources</u>

- ➢ CASQA. 2003. *California Stormwater BMP Construction Handbook: Straw Bale Barrier.* California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Construction/SE-9.pdf.

- ➢ ISU. 2006. *Iowa Construction Site Erosion Control Manual: Sediment Barrier.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/construction/3.16_sediment_barrier.pdf.

- ➢ Missouri Department of Natural Resources. 2006. *Protecting Water Quality, A Construction Site Water Quality Field Guide: Sediment Fence*. Missouri Department of Natural Resources. http://www.dnr.mo.gov/env/wpp/field-guide/fg05_06_sedimentcontrol.pdf.

- ➢ Tennessee Department of Environment and Conservation. 2002. *Erosion and Sediment Control Handbook: Silt Fence*. Tennessee Department of Environment and Conservation, Nashville, TN. http://state.tn.us/environment/wpc/sed_ero_controlhandbook/sf.pdf.

Sediment Traps

Channelization
☐ Physical & chemical
☐ Instream/riparian restoration
Dams
☐ Erosion control
☑ Runoff control
☐ Chemical/pollutant control
☐ Watershed protection
☐ Aerate reservoir water
☐ Improve tailwater oxygen
☐ Restore/maintain habitat
☐ Maintain fish passage
Erosion
☐ Streambanks ☐ Shorelines
☐ Vegetative
☐ Structural
☐ Integrated
☐ Planning & regulatory

Sediment traps are small impoundments that allow sediment to settle out of runoff water. They are typically installed in a drainage way or other point of discharge from a disturbed area. Temporary diversions can be used to direct runoff to the sediment trap. Sediment traps are ideal for sites 1 acre and smaller and should not be used for areas greater than 5 acres. They typically have a useful life of approximately 18 to 24 months. A sediment trap should be designed to maximize surface area for infiltration and sediment settling. This design increases the effectiveness of the trap and decreases the likeliness of backup during and after periods of high runoff intensity. The approximate storage capacity of each trap should be at least 1,800 ft^3/acre of disturbed land draining into the trap (Smolen et al., 1988).

<u>Additional Resources</u>

- British Columbia Ministry of Agriculture, Food and Fisheries. 2004. *Constructed Ditch Fact Sheet: Sediment Traps*. No. 9. http://www.agf.gov.bc.ca/resmgmt/publist/600Series/641310-1.pdf.

- CASQA. 2003. *California Stormwater BMP Construction Handbook*: *Sediment Traps*. California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Construction/SE-3.pdf.

- Tennessee Department of Environment and Conservation. 2002. *Erosion and Sediment Control Handbook: Sediment Trap*. Tennessee Department of Environment and Conservation, Nashville, TN. http://www.state.tn.us/environment/wpc/sed_ero_controlhandbook/st.pdf.

Seeding

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Seeding establishes a vegetative cover on disturbed areas and is very effective in controlling soil erosion once a dense vegetative cover has been established. Seeding establishes permanent erosion control in a relatively short amount of time and has been shown to decrease solids load by 99 percent (CWP, 1997a). The three most common seeding methods are (1) broadcast seeding, in which seeds are scattered on the soil surface; (2) hydroseeding, in which seeds are sprayed on the surface of the soil with a slurry of water; and (3) drill seeding, in which a tractordrawn implement injects seeds into the soil surface. Broadcast seeding is most appropriate for small areas and for augmenting sparse and patchy grass covers. Hydroseeding is often used for large areas (in excess of 5,000 square feet) and is typically combined with tackifiers, fertilizers, and fiber mulch. Drill seeding is expensive and is cost-effective only on sites greater than 2 acres. For best results, bare soils should be seeded or otherwise stabilized within 15 calendar days after final grading. Denuded areas that are inactive and will be exposed to rain for 15 days or more can also be temporarily stabilized, usually by planting seeds and establishing vegetation during favorable seasons in areas where vegetation can be established. In very flat, nonsensitive areas with favorable soils, stabilization may involve simply seeding and fertilizing. The Soil Quality Institute (SQI, 2000) recommends that soils that have been compacted by grading should be broken up or tilled before vegetating.

To establish a vegetative cover, it is important to use seeds from adapted plant species and varieties that have a high germination capacity. Supplying essential plant nutrients, testing the soil for toxic materials, and applying an adequate amount of lime and fertilizer can overcome many unfavorable soil conditions and establish adequate vegetative cover. Specific information about seeds, various species, establishment techniques, and maintenance can be obtained from *Erosion Control & Conservation Plantings on Noncropland* (Landschoot, 1997) or a local Cooperative State Research, Education, and Extension Service[11] or Natural Resources Conservation Service[12] office.

Additional Resources

- CASQA. 2003. *California Stormwater BMP Construction Handbook: Hydroseeding.* California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Construction/EC-4.pdf.

- Wisconsin Department of Natural Resources. 2003. *Seeding for Construction Site Erosion Control.* Wisconsin Department of Natural Resources, Madison, WI. http://dnr.wi.gov/org/water/wm/nps/pdf/stormwater/techstds/erosion/Seeding%20For%20Construction%20Site%20Erosion%20Control%20_1059.pdf.

[11] http://www.csrees.usda.gov
[12] http://www.nrcs.usda.gov

Selective Withdrawal

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☑ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Temperature control in reservoir releases depends on the volume of water storage in the reservoir, the timing of the release relative to storage time, and the level from which the water is withdrawn. Dams capable of selectively releasing waters of different temperatures can provide cooler or warmer water temperatures downstream at times that are critical for other instream resources, such as during periods of fish spawning and development of fry (Fontane et al., 1981; Hansen and Crumrine, 1991). Stratified reservoirs are operated to meet downstream temperature objectives such as to enhance a cold-water or warm-water fishery or to maintain preproject stream temperature conditions. Release temperature may also be important for irrigation (Fontane et al., 1981).

Multilevel intake devices in storage reservoirs allow selective withdrawal of water based on temperature and DO levels. These devices minimize the withdrawal of surface water high in blue-green algae, or of deep water enriched in iron and manganese. Care should be taken in the design of these systems not to position the multilevel intakes too far apart because this will increase the difficulty with which withdrawals can be controlled, making the discharge of poor-quality hypolimnetic water more likely (Howington, 1990; Johnson and LaBounty, 1988; Smith et al., 1987).

Setbacks

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☑ Planning & regulatory

Where setbacks have been implemented to reduce the hazard of coastal land loss, they have also included requirements for the relocation of existing structures located within the designated setback area. Setbacks can also include restrictions on uses of waterfront areas that are not related to the construction of new buildings (Davis, 1987). Upland drainage from development should be directed away from bluffs and banks so as to avoid accelerating slope erosion.

In most cases, states have used the local unit of government to administer the program on either a mandatory or voluntary basis. This allows local government to retain control of its land use activities and to exceed the minimum state requirements if this is deemed desirable (NRC, 1990).

Technical standards for defining and delineating setbacks also vary from state to state. One approach is to establish setback requirements for any “high hazard area” eroding at greater than 1 foot per year. Another approach is to establish setback requirements along all erodible shores because even a small amount of erosion can threaten homes constructed too close to the streambank or shoreline. Several states have general setback requirements that, while not based on erosion hazards, have the effect of limiting construction near the streambank or shoreline.

The basis for variations in setback regulations between states seems to be based on several factors, including (NRC, 1990):

- The language of the law being enacted
- The geomorphology of the coast
- The result of discretionary decisions
- The years of protection afforded by the setback
- Other variables decided at the local level of government

From the perspective of controlling NPS pollution resulting from erosion of shorelines and streambanks, the use of setbacks has the immediate benefit of discouraging concentrated flows and other impacts of storm water runoff from new development in areas close to the streambank or shoreline. In particular, the concentration of storm water runoff can aggravate the erosion of shorelines and streambanks, leading to the formation of gullies, which are not easily repaired. Therefore, drainage of storm water from developed areas and development activities located along the shoreline should be directed inland to avoid accelerating slope erosion.

The most significant NPS benefits are provided by setbacks that not only include restrictions on new construction along the shore but also contain additional provisions aimed at preserving and protecting coastal features such as beaches, wetlands, and riparian forests. This approach promotes the natural infiltration of surface water runoff before it passes over the edge of the bank or bluff and flows directly into the coastal waterbody. Setbacks also help protect zones of naturally occurring vegetation growing along the shore. As discussed in the section on “bioengineering practices,” the presence of undisturbed shoreline vegetation itself can help to control erosion by removing excess water from the bank and by anchoring the individual soil particles of the substrate.

Almost all states and territories with setback regulations have modified their original programs to improve effectiveness or correct unforeseen problems (NRC, 1990). Experiences have shown that procedures for updating or modifying the setback width need to be included in the regulations. For instance, application of a typical 30-year setback standard in an area whose rate of erosion is 2 feet per year results in the designation of a setback width of 60 feet. This width may not be sufficient to protect the beaches, wetlands, or riparian forests whose presence improves the ability of the streambank or shoreline to respond to severe wave and flood conditions, or to high levels of surface water runoff during extreme precipitation events. A setback standard based on the landward edge of streambank or shoreline vegetation is one alternative that has been considered (NRC, 1990; Davis, 1987).

From the standpoint of NPS pollution control, an approach that designates streambanks, shorelines, wetlands, beaches, or riparian forests as a special protective feature, allows no development on the feature, and measures the setback from the landward side of the feature is recommended (NRC, 1990). In some cases, provisions for soil bioengineering, marsh creation, beach nourishment, or engineering structures may also be appropriate since the special protective features within the designated setbacks can continue to be threatened by uncontrolled erosion of the shoreline or streambank. Finally, setback regulations should recognize that some special features of the streambank or shoreline will change position. For instance, beaches and wetlands can be expected to migrate landward if water levels continue to rise. Alternatives for managing these situations include flexible criteria for designating setbacks, vigorous maintenance of beaches and other special features within the setback area, and frequent monitoring of the rate of streambank or shoreline erosion and corresponding adjustment of the setback area.

Shoreline Sensitivity Assessment

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☑ Planning & regulatory

Currently there are no complete, universal assessment methodologies that apply to all shorelines and assess erosion vulnerabilities in various types of lakes, reservoirs, estuaries, and coasts. The methods presented by NOAA and the U.S. Geological Survey (USGS) were originally developed for other purposes and are being applied for other shoreline assessments:

- Environmental Sensitivity Mapping
- USGS Coastal Classification (Coastal & Marine Geology Program)
- Coastal Vulnerability Index (CVI) (focus is on SLR—the "erosion" factor may be the only relevant factor in CVI)

Environmental Sensitivity Mapping

The Environmental Sensitivity Index (ESI) was originally created for NOAA to prioritize areas for environmental cleanup (mainly oil-spills), to assist spill-response coordinators in evaluating the potential impact of oil along a shoreline, and to facilitate the allocation of resources during and after a spill.

ESI maps are comprised of three general types of information (NOAA, 1997):

- Shoreline Classification—ranked according to a scale relating to sensitivity, natural persistence of oil, and ease of cleanup.
- Biological Resources—including oil-sensitive animals and rare plants as well as habitats that are used by oil-sensitive species or are themselves sensitive to oil spills, such as submersed aquatic vegetation and coral reefs.
- Human-Use Resources—specific areas that have added sensitivity and value because of their use, such as beaches, parks and marine sanctuaries, water intakes, and archaeological sites.

The standardized ESI shoreline guideline rankings include estuarine, lacustrine, riverine, and palustrine habitats (NOAA, 1997). The classification scheme is based on an understanding of the physical and biological character of the shoreline environment, not just the substrate type and grain size. Relationships among physical processes, substrate type, and associated biota produce specific geomorphic/ecologic shoreline types, sediment transport patterns, and predictable patterns in oil behavior and biological impact. The concepts relating natural factors to the relative sensitivity of coastline, mostly developed in the estuarine setting, were slightly modified for lakes and rivers. The sensitivity ranking is controlled by the following factors:

- Relative exposure to wave and tidal energy
- Shoreline slope

- Substrate type (grain size, mobility, penetration and/or burial, and trafficability)
- Biological productivity and sensitivity

ESI maps have proven to have a long-term use, and they are excellent tools for studying shoreline change and its effects on the distribution and concentration of plants and animals living near the coast. Environmental sensitivity mapping is still evolving, and NOAA researchers are working with federal, state, and private industry partners to improve the ESI mapping system to extend beyond spill response.

USGS Coastal Classification (Coastal & Marine Geology Program)

The objective of the Coastal Classification Map is to determine the hazard vulnerability of an area. The coastal geomorphic classification scheme utilizes morphology and human modifications of the coast as the primary basis for hazard assessment. It emphasizes physical factors that influence erosion, overwash of sandy beaches and barrier islands, and landward sediment transport during storms along and across those features (USGS, 2004).

USGS National Assessment of Coastal Vulnerability to Sea-Level Rise

The USGS Coastal and Marine Geology Program's National Assessment, seeks to determine the relative risks due to future sea-level rise for the U.S. Atlantic, Pacific, and Gulf of Mexico coasts USGS, 2002). Through the use of a CVI, the relative risk that physical changes will occur as sea-level rises is quantified based on the following criteria: tidal range, wave height, coastal slope, shoreline change, geomorphology, and historical rate of relative sea-level rise. This approach combines a coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions, and yields a relative measure of the system's natural vulnerability to the effects of sea-level rise.

In 2001, USGS in partnership with the National Park Service (NPS) Geologic Resources Division, began conducting hazard assessments and creating map products to assist the NPS in managing vulnerable coastal resources. One of the most important and practical issues in coastal geology is determining the physical response of coastal environments to water-level changes.

Additional Resources

- NOAA. 1997. *Environmental Sensitivity Index Guidelines (Version 3)* Chapter 2. Seattle, WA. http://response.restoration.noaa.gov/book_shelf/876_chapter2.pdf.

- USGS. 2002. *Vulnerability of US National Parks to Sea-Level Rise and Coastal Change*. U.S. Geological Survey. http://pubs.usgs.gov/fs/fs095-02/fs095-02.html.

- USGS. 2004. *Coastal Classification Mapping Project*. U.S. Geological Survey, Coastal & Marine Geology Program. http://coastal.er.usgs.gov/coastal-classification/class.html.

Site Fingerprinting

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Often areas of a construction site are unnecessarily cleared. The total amount of disturbed area can be reduced with site fingerprinting, which involves placing development in the most environmentally sound locations on the site and minimizing the size of disturbed area. With site fingerprinting, only those areas essential for completing construction activities are cleared. The remaining area is left undisturbed.

Fingerprinting places development away from environmentally sensitive areas (wetlands, steep slopes, etc.), areas for future open space and restoration, areas where trees are to be saved, and temporary and permanent vegetative buffer zones.

The proposed limits of land disturbance can be physically marked off to ensure that only the land area required for buildings, roads, and other infrastructure is cleared. Existing vegetation, especially vegetation on steep slopes, can be avoided.

Sodding

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Sodding permanently stabilizes an area with a thick vegetative cover. Sodding provides immediate stabilization of an area and can be used in critical areas or where establishing permanent vegetation by seeding and mulching would be difficult. Sodding is also a preferred option when there is high erosion potential during the period of vegetative establishment from seeding. According to the Soil Quality Institute (SQI, 2000), soils that have been compacted by grading should be broken up or tilled before placing sod.

Additional Resources

- Barr Engineering Company. 2001. *Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates. Soil Erosion Control: Vegetative Methods.* Prepared for the Metropolitan Council by Barr Engineering Company, St. Paul, MN. http://www.metrocouncil.org/environment/Watershed/BMP/CH3_RPPSoilVeget.pdf.

- ISU. 2006. *Iowa Construction Site Erosion Control Manual: Sodding.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/construction/2.6_sodding.pdf.

Soil Protection

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Unprotected stockpiles are very prone to erosion, and they must be protected. Small stockpiles can be covered with a tarp to prevent erosion. Large stockpiles can be stabilized by erosion blankets, seeding, or mulching.

Because of the high organic content of topsoil, it is not recommended for use as fill material or under pavement. After a site is cleared, the topsoil is typically removed. Since topsoil is essential to establish new vegetation, it should be stockpiled and then reapplied to the site for revegetation, if appropriate. Although topsoil salvaged from the existing site can often be used, it must meet certain standards, and topsoil might need to be imported onto the site if the existing topsoil is not adequate for establishing new vegetation.

Spill and Water Budgets

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☑ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Although often used together, spill and water budgets are independent methods of facilitating downstream fish migration. Spill budgets provide alternative methods for fish passage that are less dangerous than passage through turbines. Spillways are used to allow fish to leave the reservoir by passing over the dam rather than through the turbines. The spillways must be designed to ensure that hydraulic conditions do not induce injury to the passing fish from scraping and abrasion, turbulence, rapid pressure changes, or supersaturation of dissolved gases in water passing through plunge pools (Stone and Webster, 1986).

In the Columbia River basin (Pacific Northwest), the USACE provides spill on a limited basis to pass fish around specific dams to improve survival rates. At key dams, spill is used in special operations to protect hatchery releases or provide better passage conditions until bypass systems are fully developed or, in some cases, improved (van der Borg and Ferguson, 1989). The cost of this alternative depends on the volume of water lost for power production (Mattice, 1990). Analyses of this practice, using a USACE model called FISHPASS, historically has shown that application of spill budgets in the Columbia River basin is consistently the most costly and least efficient method of improving overall downstream migration efficiency (Dodge, 1989).

In 1995 the National Marine Fisheries Service (NMFS) released a draft biological opinion to save Columbia River Basin salmon. The opinion was issued after concluding that current operations of the hydropower system were jeopardizing Columbia Basin salmon. The opinion addresses safer passage for young fish through the dams and modification to a number of hydropower operations and facilities. It calls for using as much water as possible during fish-passage season to improve flow for fish moving through the system. Specifically the draft called for spilling water over dams to increase passage of juvenile salmon via non-turbine routes to at least 80 percent. The USACE now runs the Juvenile Fish Transportation Program in cooperation with NMFS (NOAA, 1995; USACE, 2002b).

Water budgets increase flows through dams during the out-migration of anadromous fish species. They are used to speed smolt migration through reservoirs and dams. Water normally released from the impoundment during the winter period to generate power is instead released in May or June, when it can be sold only as secondary energy. This concept has been used in some regions of the United States, although quantification of the overall benefits is lacking (Dodge, 1989).

The volume of a typical water budget is generally not adequate to sustain minimum desirable flows for fish passage during the entire migration period. The Columbia Basin Fish and Wildlife Authority has proposed replacement of the water budget on the Columbia River system with a minimum flow requirement to prevent problems of inadequate water volume in discharge during low-flow years (Muckleston, 1990).

Spill Prevention and Control Program

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☑ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Spill procedure information can be posted, and persons trained in spill handling should be onsite or on call at all times. Materials for cleaning up spills can be kept onsite and easily available. Spills should be cleaned up immediately and the contaminated material properly disposed.

In general, a spill prevention, control, and countermeasure (SPCC) plan can include guidance to site personnel on:

- Proper notification when a spill occurs
- Site responsibility with respect to addressing the cleanup of a spill
- Stopping the source of a spill
- Cleaning up a spill
- Proper disposal of materials contaminated by the spill
- Location of spill response equipment programs
- Training program for designated on-site personnel

A periodic spill “fire drill” can be conducted to help train personnel on proper responses to spill events and to keep response actions fresh in the minds of personnel. It is important to maintain an adequate spill and cleaning kit, which could include the following:

- Detergent or soap, hand cleaner, and water
- Activated charcoal, adsorptive clay, vermiculite, kitty litter, sawdust, or other adsorptive materials
- Lime or bleach to neutralize pesticides or other spills in emergency situations
- Tools such as a shovel, broom, and dustpan and containers for disposal
- Proper protective clothing

Spillway Modifications

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☑ Improve tailwater oxygen
- ☑ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Spill at hydroelectric dams is routinely required during periods of high runoff when the river discharge exceeds what can be passed through the powerhouse turbines. In some cases, spill has been associated with gas supersaturation problems. The USACE has proposed several practices for solving the gas supersaturation problem. These include (1) passing more headwater storage through turbines, installing new fish bypass structures, and installing additional power units to reduce the need for spill; (2) incorporating "flip-lip" deflectors in spillway-stilling basins, transferring power generation to high-dissolved-gas-producing dams, and altering spill patterns at individual dams to minimize nitrogen mass entrainment; and (3) collecting and transporting juvenile salmonids around affected river reaches. Only a few of these practices have been implemented (Tanovan, 1987). As more attention is being paid to maintaining minimum flows in rivers for fish passage and spawning, mangers are balancing the need for spills with the potential impacts of gas supersaturation (Anderson, 2004; Anderson, 1995; DeHart, 2003; USFWS, 2001; Van Holmes and Anderson, 2004). For example, the U.S. Fish and Wildlife Service has routinely monitored gas supersaturation in reaches below Bonneville Dam (Columbia River, Oregon) to protect migrating salmon, many of which are endangered species (USFWS, 2001).

Surface Roughening

Roughening is the scarifying of a bare sloped soil surface with horizontal grooves or benches running across the slope. Roughening aids the establishment of vegetative cover, improves water infiltration, and decreases runoff velocity.

Additional Resource

- Tennessee Department of Environment and Conservation. 2002. *Erosion and Sediment Control Handbook: Surface Roughening*. Tennessee Department of Environment and Conservation, Nashville, TN. http://www.state.tn.us/environment/wpc/sed_ero_controlhandbook/sr.pdf.

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Toe Protection

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☑ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

A number of qualitative advantages are to be gained by providing toe protection for vertical bulkheads. Toe protection usually takes the form of a stone apron installed at the base of the vertical structure to reduce wave reflection and scour of bottom sediments during storms. The installation of rubble toe protection should include filter cloth and perhaps a bedding of small stone to reduce the possibility of rupture of the filter cloth. Ideally, the rubble should extend to an elevation such that waves will break on the rubble during storms.

Additional Resources

- Massachusetts DEP. 2006. *Massachusetts Nonpoint Source Pollution Management Manual: Stone Toe Protection.* Massachusetts Department of Environmental Protection, Boston, MA. http://projects.geosyntec.com/NPSManual/Fact%20Sheets/Stone%20Toe%20Protection.pdf.

- Wisconsin Department of Natural Resources. 2006. *Vegetated Armoring Erosion Control Methods*. http://dnr.wi.gov/org/water/fhp/waterway/erosioncontrol-vegetated.html.

Training—ESC

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Provide education and training opportunities for designers, developers, and contractors. One of the most important factors determining whether ESCs will be properly installed and maintained on a construction site is the knowledge and experience of the contractor and onsite personnel. Many communities require certification for key on-site employees who are responsible for implementing the ESC plan. Certification can be accomplished through municipally sponsored training courses; more informally, municipalities can hold mandatory preconstruction or prewintering meetings and conduct regular and final inspection visits to transfer information to contractors (Brown and Caraco, 1997). Information that can be covered in training courses and meetings includes the importance of ESC for water quality protection; developing and implementing ESC plans; the importance of proper installation, regular inspection, and diligent maintenance of ESC practices; and record keeping for inspections and maintenance activities.

Transference of Fish Runs

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☑ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Transference of fish runs involves inducing anadromous fish species to use different spawning grounds in the vicinity of an impoundment. To implement this practice, the nature and extent of the spawning grounds that were lost due to the blockage in the river need to be assessed, and suitable alternative spawning grounds need to be identified. The feasibility of successfully collecting the fish and transporting them to alternative tributaries also needs to be carefully determined.

One strategy for mitigating the impacts of diversions on fisheries is the use of ephemeral streams as conveyance channels for all or a portion of the diverted water. If flow releases are controlled and uninterrupted, a perennial stream is created, along with new instream and riparian habitat. However, the biota that had been adapted to preexisting conditions in the ephemeral stream will probably be eliminated.

Tree Armoring, Fencing, and Retaining Walls or Tree Wells

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Tree armoring protects tree trunks and natural vegetation from being damaged by construction equipment. Fencing can also protect tree trunks, but it should be placed at the tree's drip line so that construction equipment is kept away from the tree. A tree's drip line is the minimum area around the tree in which the tree's root system should not be disturbed by cut, fill, or soil compaction caused by heavy equipment. When cutting or filling must be done near a tree, a retaining wall or tree well can be used to minimize the cutting of the tree's roots or the quantity of fill placed over the tree's roots. It is recommended that cutting or filling be done only when absolutely necessary. Fill placement over the tree root flare or within the dripline will eventually kill the tree.

Tree Revetments

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☑ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Tree revetments consist of a row of interconnected trees anchored to the toe of the streambank or to the upper streambank (Figures 7.28 and 7.29). This serves to reduce flow velocities along eroding streambanks, trap sediment, and provide a substrate for plant establishment and erosion control. This design relies on the installation of an adequate anchoring system and is best suited for streambank heights under 12 feet and bankfull velocities under 6 feet per second. In addition, this structure should occupy no more than 15 percent of the channel at bankfull. Toe protection is needed to accompany this design if scour is anticipated and upper bank soil bioengineering techniques are recommended to ensure streamside regeneration. This design allows for the use of local materials if they are readily available. Decay resistant species are recommended for the logs to extend the life of the structure and thus the ability of vegetation to become established. Due to decomposition, these structures have a limited life and might require periodic replacement. It is considered beneficial that decomposition of the logs over time allows the streambank to return to a natural state with protection provided by mature streambank vegetation. There is a potential for the logs to dislodge, and these structures should not be located upstream of bridges or other structures sensitive to damage. Tree revetments are susceptible to damage by ice (FISRWG, 1998). Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002).

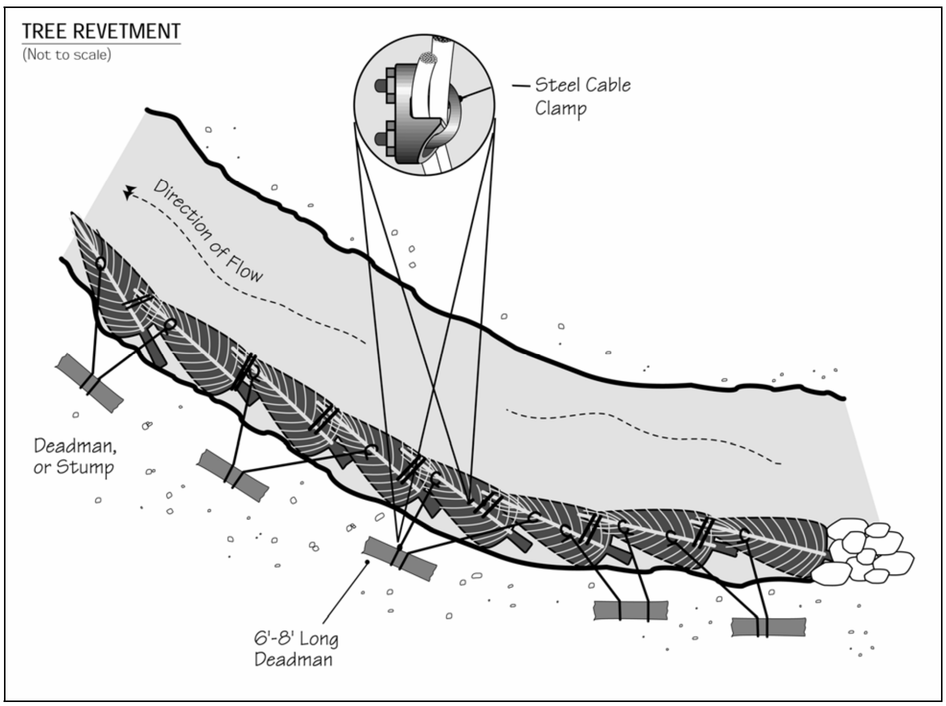


Figure 7.28 Tree Revetment (USDA-FS, 2002)

Additional Resources

- Alaska Department of Fish and Game. 2005. *Spruce Tree Revetment.* http://www.sf.adfg.state.ak.us/sarr/restoration/techniques/images/csbs_strevet.pdf.
- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.
- Goard, D. 2006. *Riparian Forest Best Management Practices: Tree Revetments.* Kansas State University, Manhattan, KS. http://www.oznet.ksu.edu/library/forst2/MF2750.pdf.
- Gough, S. 2004. *Tree Revetments for Streambank Revitalization.* Missouri Department of Conservation, Fisheries Division, Jefferson City, MO. http://mdc.mo.gov/fish/streams/revetmen/.

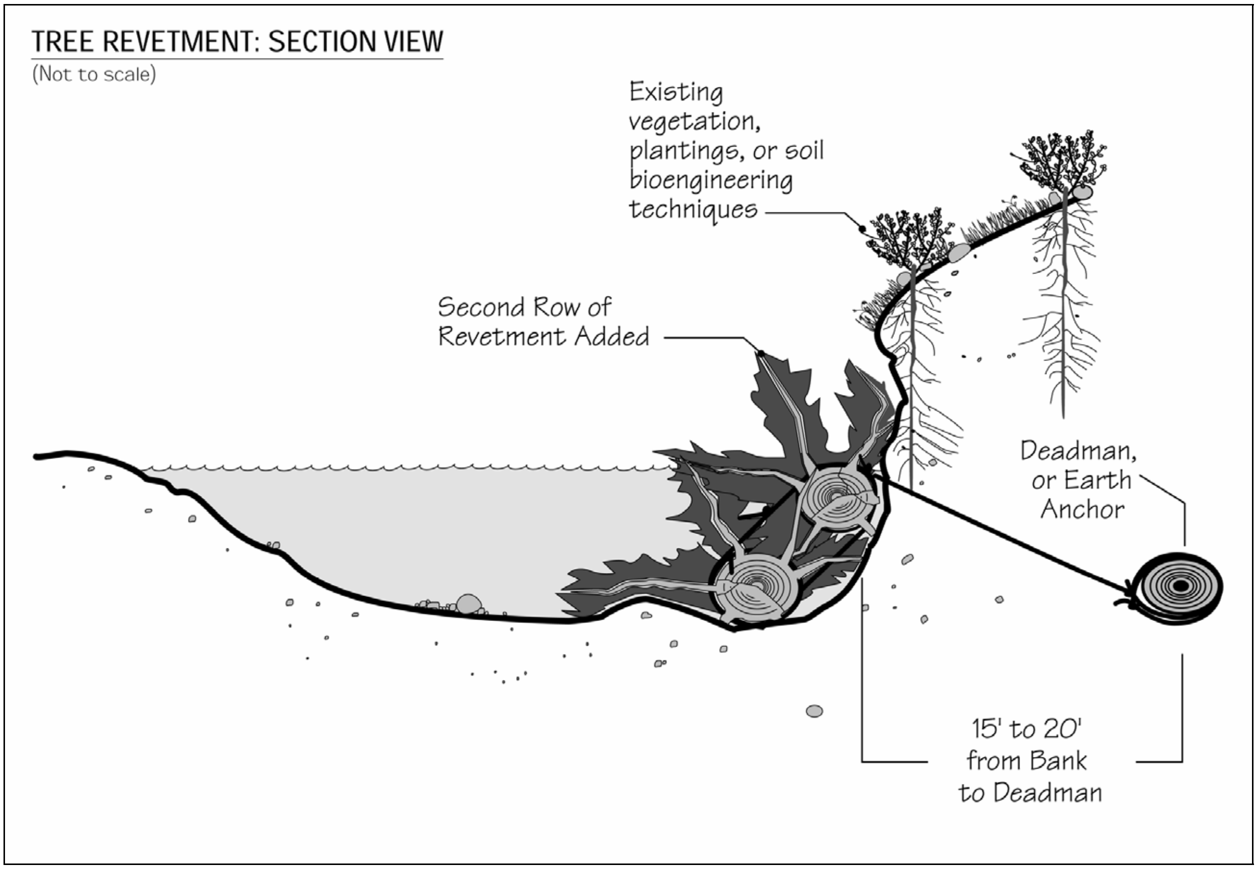


Figure 7.29 Tree Revetment: Section View (USDA-FS, 2002)

Turbine Operation

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☑ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Implementation of changes in the turbine start-up procedures can also enlarge the zone of withdrawal to include more of the epilimnetic waters in the downstream releases. Monitoring of the releases at the Walter F. George lock and dam (Chattahoochee River, Georgia), showed levels of DO declined sharply at the start-up of hydropower production. The severity and duration of the DO drop were found to be reduced by starting up all the generator units within a minute of each other (Findley and Day, 1987).

Turbine Venting

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☑ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Turbine venting is the practice of injecting air into water as it passes through a turbine. If vents are provided inside the turbine chamber, the turbine will aspirate air from the atmosphere and mix it with water passing through the turbine as part of its normal operation. In early designs, the turbine was vented through existing openings, such as the draft tube opening or the vacuum breaker valve in the turbine assembly. Air forced by compressors into the draft tube opening enriched reservoir waters with little detectable DO to concentrations of 3 to 4 mg/L. Overriding the automatic closure of the vacuum breaker valve (at high turbine discharges) increased DO by only 2 mg/L (Harshbarger, 1987).

Turbine venting uses the low-pressure region just below the turbine wheel to aspirate air into the discharges (Wilhelms, 1984). Autoventing turbines are constructed with hub baffles, or deflector plates placed on the turbine hub upstream of the vent holes to enhance the low-pressure zone in the vicinity of the vent and thereby increase the amount of air aspirated through the venting system. Turbine efficiency relates to the amount of energy output from a turbine per unit of water passing through the turbine. Efficiency decreases as less power is produced for the same volume of water. In systems where the water is aerated before passing through the turbine, part of the water volume is displaced by the air, thus leading to decreased efficiency. Hub baffles have also been added to autoventing turbines at the Norris Dam (Clinch River, Tennessee) to further improve the DO levels in the turbine releases (Jones and March, 1991).

Developments in autoventing turbine technology show that it may be possible to aspirate air with no resulting decrease in turbine efficiency. In one test of an autoventing turbine at the Norris Dam, the turbine efficiency increased by 1.8 percent (March et al., 1991; Waldrop, 1992). Technologies like autoventing turbines are very site-specific and outcomes will vary considerably.

Vegetated Buffers

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☑ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☑ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Like filter strips, vegetated buffers provide a physical separation between a construction site and a waterbody. The difference between a filter strip and a vegetated buffer area is that a filter strip is an engineered device, whereas a buffer is a naturally occurring filter system. Vegetated buffers remove nutrients and other pollutants from runoff, trap sediments, and shade the waterbody to optimize light and temperature conditions for aquatic plants and animals (Welsch, n.d.). Preservation of vegetation for a buffer can be planned before any site-disturbing activities begin so as to minimize the impact of construction activities on existing vegetation. Trees can be clearly marked at the dripline to preserve them and to protect them from ground disturbances around the base of the tree.

Proper maintenance of buffer vegetation is important. Maintenance requirements depend on the plant species chosen, soil types, and climatic conditions. Maintenance activities typically include fertilizing, liming, irrigating, pruning, controlling weeds and pests, and repairing protective markers (e.g., fluorescent fences and flags).

Additional Resources

- CASQA. 2003. *California Stormwater BMP Construction Handbook: Vegetated Buffer Strips.* California Stormwater Quality Association, Sacramento, CA. http://www.cabmphandbooks.com/Documents/Development/TC-31.pdf.

- Ohio DNR. No date. *Ohio Stream Management Guide: Forested Buffer Strips.* Ohio Department of Natural Resources. http://www.ohiodnr.com/water/pubs/fs_st/stfs13.htm.

- River Alliance of Wisconsin. No date. *Benefits of Vegetated Buffers.* River Alliance of Wisconsin, Madison, WI. http://www.wisconsinrivers.org/documents/policy/Fact%20Sheet%20-%20Benefits%20of%20Vegetated%20Buffers.pdf.

- Tennessee Department of Environment and Conservation. 2002. *Erosion and Sediment Control Handbook: Vegetative Practices*. Tennessee Department of Environment and Conservation, Nashville, TN. http://state.tn.us/environment/wpc/sed_ero_controlhandbook/2.%20Vegetative%20Practices.pdf.

Vegetated Filter Strips

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☑ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Vegetated filter strips are low-gradient vegetated areas that filter overland sheet flow. Runoff must be evenly distributed across the filter strip. Channelized flows decrease the effectiveness of filter strips. Level spreading devices are often used to distribute the runoff evenly across the strip (Dillaha et al., 1989).

Vegetated filter strips should have relatively low slopes and adequate length to provide optimal sediment control and should be planted with erosion-resistant plant species. The main factors that influence the removal efficiency are the vegetation type, soil infiltration rate, and flow depth and travel time. These factors are dependent on the contributing drainage area, slope of strip, degree and type of vegetative cover, and strip length. Maintenance requirements for vegetated filter strips include sediment removal and inspections to ensure that dense, vigorous vegetation is established and concentrated flows do not occur. For more information on vegetated filter strips, refer to EPA's *National Management Measures to Protect and Restore Wetlands and Riparian Areas for the Abatement of Nonpoint Source Pollution* (USEPA, 2005b).

Additional Resources

- ISU. 2006. *Iowa Construction Site Erosion Control Manual: Vegetative Filter Strip.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/construction/2.8_veg_filter_strip.pdf.

- Leeds, R., L.C. Brown, M.R. Sulc, and L. VanLieshout. No date. *Vegetative Filter Strips: Application, Installation and Maintenance*. The Ohio State University, Food, Agriculture and Biological Engineering, Columbus, OH. http://ohioline.osu.edu/aex-fact/0467.html.

- USDA. 2003. *Grass Filter Strips.* U.S. Department of Agriculture, Natural Resources Conservation Service. http://www.oh.nrcs.usda.gov/programs/Lake_Erie_Buffer/filter_strips.html.

Vegetated Gabions

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☑ Integrated
  - ☐ Planning & regulatory

Vegetated gabions (Figure 7.30) start with wire-mesh, rectangular baskets filled with small to medium rock and soil. The baskets are then laced together to form a structural toe or sidewall. Live branches (0.5 to 1 inch in diameter) are then placed on each consecutive layer between the rock filled baskets to take root, join together the structure, and bind it to the slope. This method is effective for protecting steep slopes where scouring or undercutting is occurring. However, this method is not appropriate in streams with heavy bed load or where severe ice damage occurs. This method provides moderate structural support and should be placed at the base of a slope to stabilize the slope and reduce slope steepness. A stable foundation is required for the installation of these structures. When the rock size needed is not locally available, this design is effective because smaller rocks can be used. A limiting factor of this method is that it is expensive to install and to replace. These structures are relatively expensive to construct and frequently require costly repairs. This method should be combined with other soil bioengineering techniques, particularly revegetation efforts, to achieve a comprehensive streambank restoration design (FISRWG, 1998). There is often opposition to these structures based on their inability to blend in with natural settings and their general lack of aesthetically pleasing qualities (Gore, 1985).

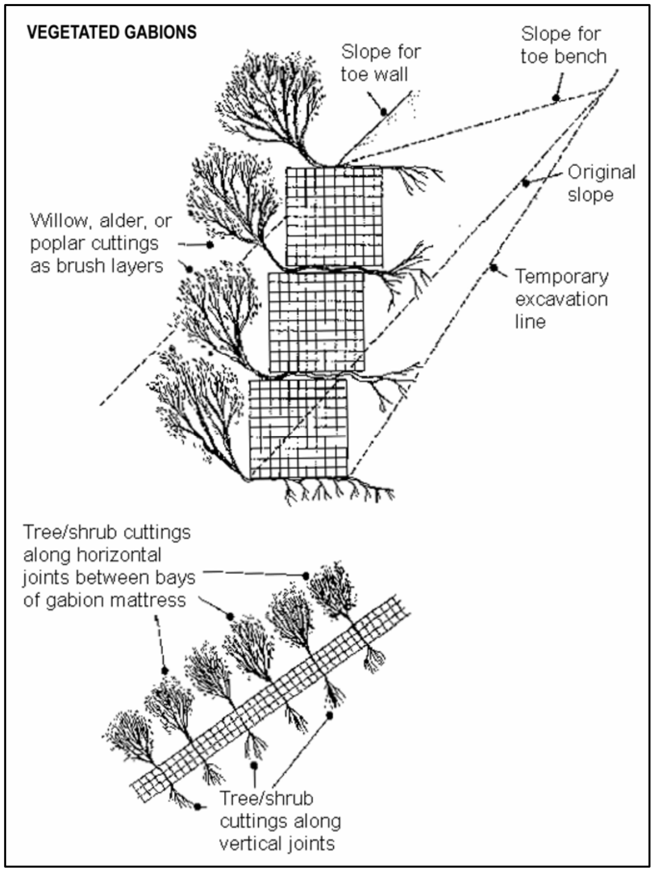


Figure 7.30 Vegetated Gabion (Allen and Leech, 1997)

Installation guidelines are available from the USDA NRCS *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992). Under EMRRP, the USACE has presented research on vegetated gabions in a technical note (*Gabions for Streambank Erosion Control*).[13]

[13] http://el.erdc.usace.army.mil/elpubs/pdf/sr22.pdf

Additional Resources

- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.

- ISU. 2006. *Iowa Construction Site Erosion Control Manual: Gabion.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/construction/3.8_gabion.pdf.

- Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Vegetated Rock Gabions/Gabions.* Created for United States Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/veg_rockgabions.pdf.

- MMG Civil Engineering Systems, Ltd. 2001. *Vegetated Gabions*. MMG Civil Engineering Systems, Ltd., St. Germans, Kings Lynn, Norfolk, England. http://www.verdantsolutions.ltd.uk/acrobat/vegsod.pdf.

- Ohio DNR. No date. *Ohio Stream Management Guide: Gabion Revetments.* Ohio Department of Natural Resources. http://www.ohiodnr.com/water/pubs/fs_st/stfs15.htm.

- Tennessee Department of Environment and Conservation. 2002. *Erosion and Sediment Control Handbook: Gabion*. Tennessee Department of Environment and Conservation, Nashville, TN. http://state.tn.us/environment/wpc/sed_ero_controlhandbook/ga.pdf.

Vegetated Geogrids

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☑ Integrated
  - ☐ Planning & regulatory

Vegetated geogrids consist of layers of live branch cuttings and compacted soil with natural or synthetic geotextile materials wrapped around each soil layer (Figure 7.31). This serves to rebuild and vegetate eroded streambanks, particularly on outside bends where erosion can be a problem. This system is designed to capture sediment providing a substrate for plant establishment and if properly designed and installed, these systems help to quickly establish riparian vegetation. Its benefits are similar to those of brush layering (e.g., dries excessively wet sites, reinforces soil as roots develop, which adds significant resistance to sliding or shear displacement). Due to the strength of this design and the higher initial tolerance to flow velocity, these systems can be installed on a 1:1 or steeper streambank or lakeshore. Limitations of this design include the complexity involved with constructing this system and the fairly high expense (FISRWG, 1998). When constructing this type of system, use live branch cuttings that are brushy and root readily. Also use cuttings that are 0.5 to 2 inches in diameter and 4 to 6 feet long. This type of system requires biodegradable erosion control fabric. Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002).

<u>Additional Resources</u>

- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.

- Massachusetts DEP. 2006. *Massachusetts Nonpoint Source Pollution Management Manual: Vegetated Geogrids.* Massachusetts Department of Environmental Protection, Boston, MA. http://projects.geosyntec.com/NPSManual/Fact%20Sheets/Vegetated%20Geogrids.pdf.

- ISU. 2006. *How to Control Streambank Erosion: Vegetated Geogrids.* Iowa State University. http://www.ctre.iastate.edu/erosion/manuals/streambank/vegetated_geogrids.pdf.

- Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Vegetated Geogrids.* Created for United States Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/vegegeogrids.pdf.

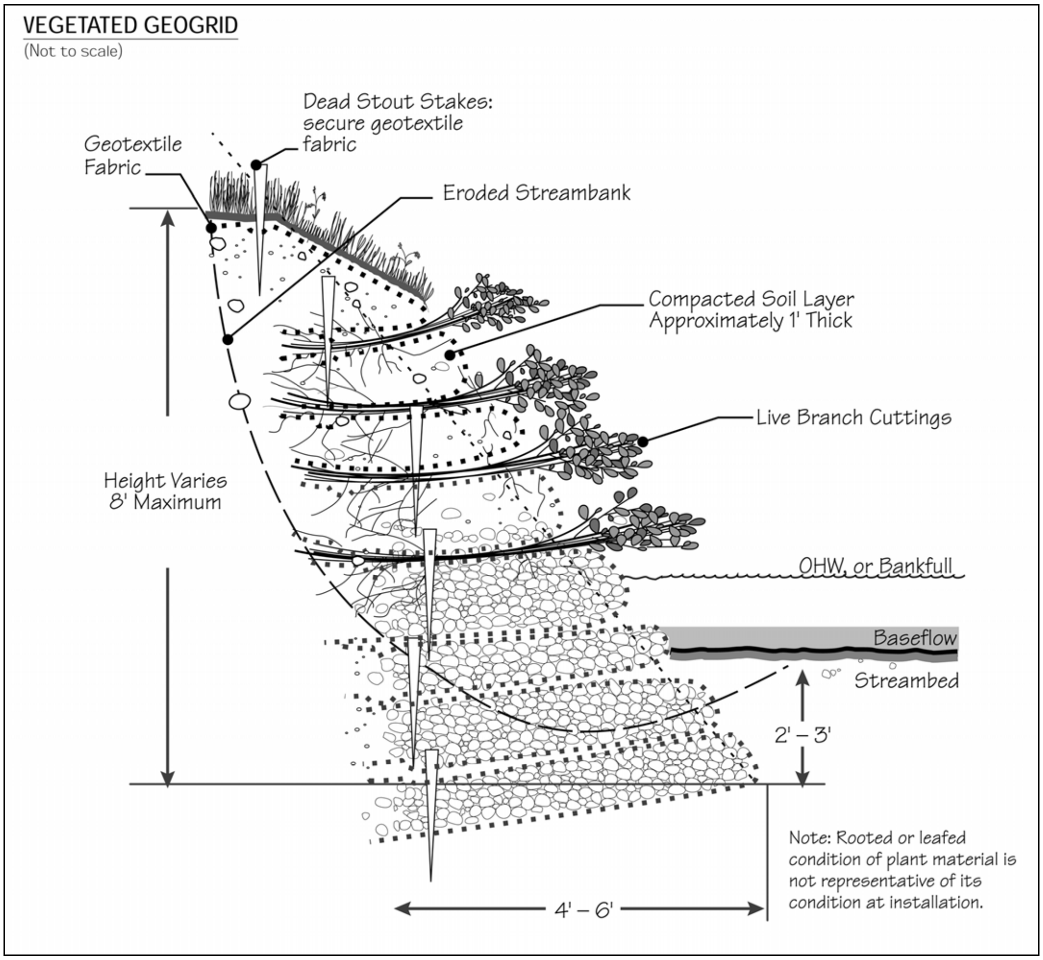


Figure 7.31 Vegetated Geogrid (USDA-FS, 2002)

Vegetated Reinforced Soil Slope (VRSS)

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☑ Integrated
  - ☐ Planning & regulatory

The vegetated reinforced soil slope (VRSS) soil system (Figures 7.32 and 7.33) is an earthen structure constructed from living, rootable, live-cut, woody plant material branches, bare root, tubling or container plant stock, along with rock, geosynthetics, geogrids, and/or geocomposites. The VRSS system is useful for immediately repairing or preventing deeper failures, providing a structurally sound system with soil reinforcement, drainage, and erosion control (typically on steepened slope sites with limited space). Living cut branches and plants grow and perform additional soil reinforcement via the roots and surface protection via the top growth (Sotir and Fischenich, 2003).

Live vegetation is typically installed from just above baseflow elevation and up the face of the reconstructed streambank, acting to protect the bank through immediate soil reinforcement and confinement, drainage, and, in the toe area, with rock. The system extends below the depth of scour, typically with rock, which improves infiltration and supports the riparian zone. Internal systems (e.g., rock, live cut branches) can be configured to act as drains that redirect or collect internal bank seepage and transport water to the stream via a rock toe (Sotir and Fischenich, 2003).

Figure 7.32 VRSS Structure After Construction
(Sotir and Fischenich, 2003)

Figure 7.33 Established VRSS Structure (Sotir and Fischenich, 2003)

Plants may be selected to provide color, texture, and other attributes to add a natural landscape appearance. Examples of plants include dogwood, willow, hybiscus, and *Viburnum* spp. Check with your local NRCS office to make sure these are appropriate for the location. If a compound channel cross section is desirable near or just below the baseflow elevation, a step-back terrace may be incorporated to offer an enhanced riparian zone where emergent aquatic plants may invade over time. Although the total mass uptake may be small, they assimilate contaminants within the water column. Aquatic wetland plants that may be installed adjacent to the stream include blueflag, monkey flower, and pickerelweed. Again, check with your local NRCS office to ensure these are appropriate. VRSS systems can be constructed on slopes ranging from 1V on 2H (1:2) to 1:0.5. When constructed in step or terrace fashion, they improve pollutant control by intercepting sediment and attached pollutants during overbank flows (Sotir and Fischenich, 2003). Additional information about VRSS systems is available from USACE's *Vegetated Reinforced Soil Slope Streambank Erosion Control.*[14]

[14] http://el.erdc.usace.army.mil/elpubs/pdf/sr30.pdf

Water Conveyances

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☑ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

These are the open or closed channel, conduit, or drop structure used to convey water from a reservoir. The USACE has studied the performance of spillways and overflow weirs at its facilities to determine the importance of these structures in improving DO levels. For example, data have been analyzed for the test spill done in 1999 at Canyon Ferry Dam in Montana, which found that allowing a portion of the releases to go over the spillways resulted in a significant increase in DO in the river downstream of the dam. Initially the use of spillways appeared to be a viable solution to the problem of low dissolved oxygen in the river below the dam. However, there was a problem with nitrogen supersaturation.

The operation of some types of hydraulic structures has been linked to problems of the supersaturation. An unexpected fish kill occurred in spring 1978 due to supersaturation of nitrogen gas in the Lake of the Ozarks (Missouri) within 5 miles of Truman Dam, caused by water plunging over the spillway and entraining air. The vertical drop between the spillway crest and the tailwaters was only 5 feet. The maximum total gas saturation was 143 percent, which is well above desired saturation levels. In this case, the spillway was modified by cutting a notch to prevent water from plunging directly into the stilling basin (ASCE, 1986).

Wildflower Cover

Channelization
- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams
- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Because of the hardy, drought-resistant nature of wildflowers, they may be more beneficial as an erosion control practice than turf grass. Though not as dense as turfgrass, wildflower thatches and associated grasses are expected to be as effective in erosion control and contaminant absorption. An additional benefit of wildflower thatches is that they provide habitat for wildlife, including insects and small mammals. Because thatches of wildflowers do not need fertilizers, pesticides, or herbicides and watering is minimal, implementation of this practice may result in cost savings.

A wildflower stand requires several years to become established, but maintenance requirements are minimal once established. Prices vary greatly, from less than $15 (Stock Seed Farms, n.d.) to $40 (Albright Seed Company, 2002) a pound, for wildflower seed mixes. The amount of wildflower seeds applied depends on the desired coverage of wildflowers. However, Stock Seed Farms recommends that one pound of seed can cover 3,500 ft^2 (Stock Seed Farms, n.d.). Keep in mind that species selection should focus on those wildflowers and grasses native to the given area or appropriate to the site.

Wind Erosion Controls

Wind erosion controls limit the movement of dust from disturbed soil surfaces and include many different practices. Wind barriers block air currents and are effective in controlling soil blowing. Many different materials can be used as wind barriers, including solid board fences, snow fences, and bales of hay. Sprinkling moistens the soil surface with water and must be repeated as needed to be effective for preventing wind erosion (Delaware DNREC, 2003); however, applications must be monitored to prevent excessive runoff and erosion.

Channelization

- ☐ Physical & chemical
- ☐ Instream/riparian restoration

Dams

- ☑ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion

- ☐ Streambanks ☐ Shorelines
  - ☐ Vegetative
  - ☐ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Wing Deflectors

Channelization
- ☑ Physical & chemical
- ☑ Instream/riparian restoration

Dams
- ☐ Erosion control
- ☐ Runoff control
- ☐ Chemical/pollutant control
- ☐ Watershed protection
- ☐ Aerate reservoir water
- ☐ Improve tailwater oxygen
- ☐ Restore/maintain habitat
- ☐ Maintain fish passage

Erosion
- ☑ Streambanks ☑ Shorelines
  - ☐ Vegetative
  - ☑ Structural
  - ☐ Integrated
  - ☐ Planning & regulatory

Wing deflectors are structures that protrude from either streambank but do not extend entirely across a channel. The structures are designed to deflect flows away from the bank, and create scour pools by constricting the channel and accelerating flow. The structures can be installed in series on alternative streambanks to produce a meandering thalweg and stream diversity. The most common design is a rock and rock-filled log crib deflector structure. The design bases the size of the structure on anticipated scour. These structures need to be installed far enough downstream from riffle areas to avoid backwater effects that could drown out or damage the riffle. This design should be employed in streams with low physical habitat diversity, particularly channels that lack pool habitats. Construction on a sand bed stream may be susceptible to failure and should be constructed with the use a filter layer or geotextile fabric beneath the wing deflector structure (FISRWG, 1998).

Additional Resources

- FISRWG. 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. Federal Interagency Stream Restoration Working Group. http://www.nrcs.usda.gov/technical/stream_restoration/PDFFILES/APPENDIX.pdf.

- Massachusetts DEP. 2006. *Massachusetts Nonpoint Source Pollution Management Manual: Wing Deflectors.* Massachusetts Department of Environmental Protection, Boston, MA. http://projects.geosyntec.com/NPSManual/Fact%20Sheets/Wing%20Deflectors.pdf.

- Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Single Wing Deflector.* Created for United States Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/singlewing.pdf.

- Mississippi State University, Center for Sustainable Design. 1999. *Water Related Best Management Practices in the Landscape: Double Wing Deflector.* Created for United States Department of Agriculture, Natural Resource Conservation Service, Watershed Science Institute. http://abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/doublewing.pdf.

- Ohio DNR. No date. *Ohio Stream Management Guide: Deflectors.* Ohio Department of Natural Resources. http://www.ohiodnr.com/water/pubs/fs_st/stfs19.pdf.

- SMRC. No date. *Stream Restoration: Flow Deflection/Concentration Practices.* The Stormwater Manager's Resource Center. http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Restoration/flow_deflection.htm.

Chapter 8: Modeling Information

Physical and chemical effects of hydraulic and hydrologic changes to streams, rivers, or other surface water systems can often be estimated with models and past experience (expert judgment). Several different models are available that can simulate many of the complex physical, chemical, and biological interactions that occur when hydraulic changes are imposed on surface water systems. Additionally, models can sometimes be used to determine a combination of practices to mitigate the unavoidable effects that occur even when a project is properly planned. Models, however, cannot be used independently of expert judgment gained through past experience. When properly applied models are used in conjunction with expert judgment, the effects of hydromodification activities (both potential and existing projects) can be evaluated and many undesirable effects prevented or eliminated. Models combined with expert judgment can also be used to evaluate existing hydromodification activities as part of operation and maintenance programs to identify possible opportunities to reduce or eliminate water quality impacts.

In the U.S. Army Corps of Engineers' (USACE's) report, *Review of Watershed Water Quality Models*[1] (Deliman et al., 1999), the authors compare and evaluate existing hydrologic and watershed water quality models, make recommendations for base model(s) for predicting nonpoint source (NPS) pollution, and identify areas for model improvement. The authors review commonly used and well validated models used in urban or nonurban settings. Users of the models can use the report to obtain basic model information and to review how well the models simulate NPS pollution and where the authors think improvements could be made. This information might be useful to readers who are trying to select the best model for analyzing how to reduce NPS pollution in their watersheds (Deliman et al., 1999).

Tables 8.1 and 8.2 below provided example of models and assessment approaches that could be used to determine the effects of hydromodification activities.

[1] http://el.erdc.usace.army.mil/elpubs/pdf/trw99-1.pdf

Available Models and Assessment Approaches

Table 8.1 lists some of the models available for studying the effects of channelization and channel modification activities, as well as models to analyze watershed runoff and to assess BMPs and low impact development to reduce impacts (of hydromodification activities.) The table also provides a quick description of each model and the dimension in which it models, as well as source and contact information.

Table 8.1 Models Applicable to Hydromodification Activities

Model	Dimension	Description	Model Resources
Channelization and Channel Modification Models			
BRANCH	1	The Branch-Network Dynamic Flow Model is used to simulate steady state flow in a single open channel reach or throughout a system of branches connected in a dendritic or looped pattern. The model is typically applied to assess flow and transport in upland rivers where flows are highly regulated or backwater effects are evident, or in coastal networks of open channels where flow and transport are governed by the interaction of freshwater inflows, tidal action, and meteorological conditions. (Last updated: 1997)	http://water.usgs.gov/cgi-bin/man_wrdapp?branch
CE-QUAL-RIV1	1	CE-QUAL-RIV1 is a one-dimensional (cross-sectionally averaged) hydrodynamic and water quality model, meaning that the model resolves longitudinal variations in hydraulic and quality characteristics and is applicable where lateral and vertical variations are small. CE-QUAL-RIV1 consists of two parts, a hydrodynamic code (RIV1H) and a water quality code (RIV1Q). The hydrodynamic code is applied first to predict water transport and its results are written to a file, which is then read by the quality model. It can be used to predict one-dimensional hydraulic and water quality variations in streams and rivers with highly unsteady flows, although it can also be used for prediction under steady flow conditions.	http://www.wes.army.mil/el/elmodels/riv1info.html

Model	Dimension	Description	Model Resources
CE-QUAL-W2	2	CE-QUAL-W2 is a two-dimensional, laterally averaged, finite difference hydrodynamic and water quality model for rivers, reservoirs, and estuaries. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow waterbodies exhibiting longitudinal and vertical water quality gradients. Branched networks can be modeled. The model accommodates variable grid spacing (segment lengths and layer thicknesses) so that greater resolution in the grid can be specified where needed.	http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home?selection=cequalw2 http://www.ce.pdx.edu/w2
CH3D-SED	1, 2, or 3	The CH3D numerical modeling system can be used to investigate sedimentation on bendways, crossings, and distributaries. Applications address dredging, channel evolution, and channel training structure evaluations.	http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Software;22
EFDC	1, 2, or 3	The Environmental Fluid Dynamics Code is a single source, three-dimensional, finite-difference modeling system having hydrodynamic, water quality-eutrophication, sediment transport and toxic contaminant transport components linked together.	John Hamrick developed this at the Virginia Institute of Marine Science 1990-1991. Dr. John Hamrick, Tetra Tech, Inc. 10306 Eaton Place, Suite 340 Fairfax, VA 22030
EFM	1	Ecosystem Functions Model (EFM) is a planning tool that analyzes ecosystem response to changes in flow regime. EFM allows environmental planners, biologists, and engineers to determine whether proposed alternatives (e.g., reservoir operations, levee alignments) would maintain, enhance, or diminish ecosystem health. Project teams can use EFM software to visualize existing ecologic conditions, highlight promising restoration sites, and assess and rank alternatives according to the relative enhancement (or decline) of ecosystem aspects. The hydraulic modeling portion of the EFM process is performed by existing independent software, such as HEC-RAS.	http://el.erdc.usace.army.mil/elpubs/pdf/smartnote04-4.pdf

Model	Dimension	Description	Model Resources
FESWMS-2DH	2	FESWMS-2DH is a finite element surface water modeling system for two-dimensional flow in a horizontal plane. The model can simulate steady and unsteady surface water flow and is useful for simulating two-dimensional flow where complicated hydraulic conditions exist (e.g., highway crossings of streams and flood rivers). It can also be applied to many types of steady or unsteady flow problems. (Last updated: 1995)	http://water.usgs.gov/cgi-bin/man_wrdapp?feswms-2dh
HEC-6	1	HEC-6 is a one-dimensional, moveable boundary, open channel flow numeric model designed to simulate and predict changes in river profiles resulting from scour and deposition over moderate time periods, typically years. Latest revision occurred in 1993.	http://www.hec.usace.army.mil/software/legacysoftware/hec6/hec6.htm
HEC-HMS	1	The HEC-HMS model is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is applicable in a wide range of geographic areas for solving the widest possible range of problems, including large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.	http://www.hec.usace.army.mil/software/hec-hms/index.html http://el.erdc.usace.army.mil/elpubs/pdf/smartnote04-3.pdf

Model	Dimension	Description	Model Resources
HEC-RAS	1	HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking, multi-user network environment. The system is comprised of a graphical interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The model performs one-dimensional steady flow, unsteady flow, and sediment transport calculations. The key element is that all three components will use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the three hydraulic analysis components, the system contains several hydraulic design features that can be invoked once basic water surface profiles are computed. The HEC-RAS modeling system was developed as a part of the Hydrologic Engineering Center's "Next Generation" (NexGen) of hydrologic engineering software. The NexGen project encompasses several aspects of hydrologic engineering, including: rainfall-runoff analysis; river hydraulics; reservoir system simulation; flood damage analysis; and real-time river forecasting for reservoir operations.	http://www.hec.usace.army.mil/software/hec-ras
HIVEL2D	1, 2	HIVEL2D is a free-surface, depth averaged model designed specifically to simulate flow in typical high-velocity channels.	http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Software;6
RiverWare™	1	RiverWare™ is a reservoir and river modeling software decision support tool. With RiverWare™, users can model the topology, physical processes and operating policies of river and reservoir systems, and make better decisions about how to operate these systems by understanding and evaluating the trade-offs among the various management objectives. Water management professionals can improve their management of river and reservoir systems by using the software. The Bureau of Reclamation, the Tennessee Valley Authority, and the USACE sponsor ongoing RiverWare™ research and development.	http://cadswes.colorado.edu/riverware

Model	Dimension	Description	Model Resources
SAM	1	The model calculates the width, depth, slope and n-values for stable channels in alluvial material. SAM can be used to evaluate erosion, entrainment, transportation, and deposition in alluvial streams. Channel stability can be evaluated, and the evaluation used to determine the cost of maintaining a constructed project. The model is currently being improved and enhanced at WES.	http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Software;2
SIAM	N/A	SIAM is a model designed to simulate the movement of sediment through a drainage network from source to outlet. It allows for evaluation of numerous sediment management alternatives relatively quickly. The model provides an intermediate level of analysis more quantitative than a conventional geomorphic evaluation, but less specific than a numerical, mobile-boundary simulation. SIAM is to be incorporated into a future release of HEC-RAS.	http://www.usbr.gov/pmts/sediment/model/srhsiam/index.html http://www.wes.army.mil/rsm/pubs/pdfs/RSM-2-WS04.pdf
SMS (RMA2 and RMA4)	1, 2	The Surface-Water Modeling System is a generalized numerical modeling system for open-channel flows, sedimentation, and constituent transport.	http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Software;4
TABS-MD (RMA2, RMA4, RMA10, SED2D)	1, 2, or 3	The multi-dimensional numerical modeling system is a collection of generalized computer programs and utility codes, designed for studying multidimensional hydrodynamics in rivers, reservoirs, bays, and estuaries. The models can be applied to study project impacts of flows, sedimentation, constituent transport, and salinity.	http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Software;10
WASP	1, 2, or 3	Water Quality Analysis Simulation Program. Framework for modeling contaminant fate and transport in surface waters. The WASP framework can be used to model biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and organic chemical and heavy metal contamination.	http://www.epa.gov/athens/wwqtsc/html/wasp.html

Model	Dimension	Description	Model Resources
Models to Analyze Watershed Runoff and Assess Practices to Reduce Impacts of Hydromodification			
BMP Decision Support System (BMP-DSS)	1	BMP-DSS is a decision-making tool for placement of BMPs/LID practices at strategic locations in urban watersheds based on integrated data collection and hydrologic/hydraulic/water quality modeling. The system uses GIS technology, integrates BMP processes simulation models, and applies system optimization techniques for BMP placement and selection. The system also provides interfaces for BMP placement, BMP attribute data input, and decision optimization management. The system includes a stand-alone BMP simulation and evaluation module, which complements both research and regulatory nonpoint source control assessment efforts and allows flexibility in examining various BMP design alternatives.	Developed by the EPA and Prince George's County Department of Environmental Resources. Contact Dr. Mow-Soung Cheng at 301-883-5836 for more information.
HSPF	1	Hydrological Simulation Program——FORTRAN (HSPF) is a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF incorporates watershed-scale ARM and NPS models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with In-stream hydraulic and sediment-chemical interactions. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at any point in a watershed. HSPF simulates three sediment types (sand, silt, and clay) in addition to a single organic chemical and transformation products of that chemical.	http://www.epa.gov/ceampubl/swater/hspf/index.htm

Model	Dimension	Description	Model Resources
LSPC	1	LSPC is the Loading Simulation Program in C++, a watershed modeling system that includes streamlined Hydrologic Simulation Program Fortran (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land as well as a simplified stream transport model. LSPC is derived from the Mining Data Analysis System (MDAS), which was developed by EPA Region 3 and has been widely used for mining applications and TMDLs. A key data management feature of this system is that it uses a Microsoft Access database to manage model data and weather text files for driving the simulation. The system also contains a module to assist in TMDL calculation and source allocations. For each model run, it automatically generates comprehensive text-file output by subwatershed for all land-layers, reaches, and simulated modules, which can be expressed on hourly or daily intervals. Output from LSPC has been linked to other model applications such as EFDC, WASP, and CE-QUAL-W2.	http://www.epa.gov/ATHENS/wwqtsc/html/lspc.html
Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds—Urban Catchment Model (P8–UCM)	1	P8–UCM is a model for predicting the generation and transport of stormwater pollutants in urban watersheds. Continuous water balance and mass balance calculations are performed on a user-defined system consisting of watersheds, devices (runoff storage/treatment areas, BMPs), particle classes, and water quality components. Simulations are driven by continuous hourly rainfall and daily air temperature time series data. The model simulates pollutant transport and removal in a variety of treatment devices (BMPs).	http://wwwalker.net/p8

Model	Dimension	Description	Model Resources
Storm Water Management Model (SWMM)	1	SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.	http://www.epa.gov/ednnrmrl/models/swmm/index.htm

Table 8.2 lists some of the available assessment models and approaches for assessing the biological impacts of channelization. The table also provides a quick description of the model or approach, as well as sources of additional information.

Table 8.2 Assessment Models and Approaches

Model or Assessment Approach	Description	Model Resources
Assessment Models		
AQUATOX	A freshwater ecosystem simulation model designed to predict the fate of various pollutants such as nutrients and organic toxicants and their effects on the ecosystem, including fish, invertebrates, and aquatic plants (including periphyton).	http://epa.gov/waterscience/models/aquatox
Cornell Mixing Zone Expert System (CORMIX)	A water quality modeling and decision support system designed for environmental impact assessment of mixing zones resulting from wastewater discharge from point sources. The system emphasizes the role of boundary interaction to predict plume geometry and dilution in relation to regulatory mixing zone requirements.	http://www.epa.gov/waterscience/models/cormix.html
HEC-HMS, Hydrologic Modeling System	A system designed to simulate the precipitation-runoff processes of dendritic watershed systems. In addition to unit hydrograph and hydrologic routing options, capabilities include a linear quasi-distributed runoff transform (ModClark) for use with gridded precipitation, continuous simulation with either a one-layer or more complex five-layer soil moisture method, and a versatile parameter estimation option.	http://www.hec.usace.army.mil/software/hec-hms/index.html
HEC-RAS, River Analysis System	The HEC-RAS system is used to calculate water surface profiles for both steady and unsteady gradually varied flow. The system can handle a full network of channels, a dendritic system, or a single river reach.	http://www.hec.usace.army.mil/software/hec-ras/hecras-hecras.html http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/Ras.html

Model or Assessment Approach	Description	Model Resources
Physical Habitat Simulation Model (PHABSIM)	A set of computer programs designed to predict the microhabitat (depth, velocities, channel indices) conditions in rivers at different flow levels and the relative suitability of those conditions for different life stages of aquatic life. (Serves as the key microhabitat simulation component of IFIM.)	http://www.fort.usgs.gov/Products/Software/PHABSIM
Riverine Community Habitat Assessment and Restoration Concept (RCHARC)	A simulation approach using computer models to compare hydraulic conditions and microhabitats of a reference reach to alternative study reach(es).	Nestler, J., T. Schneider, and D. Latka. 1993. RCHARC: A new method for physical habitat analysis. *Engineering Hydrology*, 294-99.
RiverWare™	RiverWare™ is a reservoir and river modeling software decision support tool. With RiverWare™, users can model the topology, physical processes, and operating policies of river and reservoir systems, and make better decisions about how to operate these systems by understanding and evaluating the trade-offs among the various management objectives. Water management professionals can improve their management of river and reservoir systems by using the software. The Bureau of Reclamation, the Tennessee Valley Authority, and the Army Corps of Engineers sponsor ongoing RiverWare™ research and development.	http://cadswes.colorado.edu/riverware
Salmonid Population Model (SALMOD)	A computer model that simulates the dynamics (spawning, growth, movement, and mortality) of freshwater salmonid populations, both anadromous and resident, under various habitat quality and capacities.	http://www.fort.usgs.gov/Products/Software/SALMOD
Assessment Approaches		
A Procedure to Estimate the Response of Aquatic Systems to Changes in Phosphorus and Nitrogen Inputs	A simple tool to estimate the responsiveness of a waterbody to changes in the loading of phosphorus and nitrogen using a dichotomous key that classifies it according to key characteristics.	ftp://ftp.wcc.nrcs.usda.gov/downloads/wqam/aqusens.pdf

Model or Assessment Approach	Description	Model Resources
EPA Volunteer Stream Monitoring Methods	A series of methods geared for volunteer monitoring programs offering simple to advanced techniques for monitoring macroinvertebrates, habitat, water quality, and physical conditions.	http://www.epa.gov/owow/monitoring/volunteer/stream
Habitat Evaluation Procedures/Habitat Suitability Index (HEP/HSI)	HEP is an evaluation method that determines the suitability of available habitat for select aquatic and terrestrial wildlife species and measures the impact of proposed land or water use changes on that habitat. HSI is a measure of habitat suitability.	http://policy.fws.gov/870fw1.html http://www.fort.usgs.gov/Products/Software/HEP http://www.fort.usgs.gov/Products/Software/HSI
Index of Biological Integrity (IBI)	An aquatic ecosystem health index using measures of total native fish species composition, indicator species composition, pollutant intolerant and tolerant species composition, and fish condition.	http://www.epa.gov/owow/wetlands/wqual/bio_fact/fact5.html
Indicators of Hydrologic Alteration (IHA)	A method for assessing the degree of hydrologic alteration attributable to human impacts within an ecosystem. The method takes daily stream flow values and calculates indices relating to the five components of flow regime critical for ecological processes: magnitude, frequency, duration, timing, and rate of change of hydrologic conditions.	http://www.nature.org/initiatives/freshwater/conservationtools/art17004.html
Instream Flow Incremental Methodology (IFIM)	A river network analysis that incorporates fish habitat, recreational opportunity, and woody vegetation responses to alternative water management schemes. Information is presented as a time series of flow and habitat at select points within the network.	http://www.fort.usgs.gov/Products/Software/IFIM
Invertebrate Community Index (ICI)	An invertebrate community health index using ten structural and compositional invertebrate community metrics including number of mayfly, caddisfly, and dipteran taxa.	http://www.epa.state.oh.us/dsw/bioassess/BioCriteriaProtAqLife.html

Model or Assessment Approach	Description	Model Resources
(Modified) Index of Well-Being (IWB)	The IWB is a fish community health index using measures of fish species abundance and diversity estimates. The *modified* index of well being factors out 13 pollutant tolerant species of fish from certain calculations to prevent false high readings on polluted streams which have large populations of pollutant tolerant fish.	http://www.epa.state.oh.us/dsw/bioassess/BioCriteriaProtAqLife.html
Rapid Bioassessment Protocols (RBP)	A set of protocols that offer cost-effective techniques of varying complexity to characterize the biological integrity of streams and rivers using the collection and analysis of biological, physical, and chemical data. It focuses on periphyton, benthic macroinvertebrates, and fish assemblages, and on assessing the quality of the physical habitat.	http://www.epa.gov/owow/monitoring/rbp
Rapid Channel Assessment (RCA)	A reference stream/integrated ranking approach to evaluate the physical condition of a stream channel based on channel geometry, percent channel-bank scour, sediment size distribution and embeddedness, large wood debris, and thalweg profiles.	CWP. 1998. *Rapid Watershed Planning Handbook: A Comprehensive Guide for Managing Urbanizing Watersheds*. Center for Watershed Protection, Ellicott City, MD. For a copy contact: The Center for Watershed Protection, 8391 Main Street Ellicott City, MD 21043, email: center@cwp.org.
Rapid Stream Assessment Technique (RSAT)	A reference stream/integrated ranking approach to evaluate steam health based on chemical stability, channel scouring/sediment deposition, physical instream habitat, water quality, riparian habitat, and biological indicators.	CWP. 1998. *Rapid Watershed Planning Handbook: A Comprehensive Guide for Managing Urbanizing Watersheds*. Center for Watershed Protection, Ellicott City, MD. For a copy contact: The Center for Watershed Protection, 8391 Main Street Ellicott City, MD 21043, email: center@cwp.org. http://www.stormwatercenter.net
Rosgen's Stream Classification Method	A classification method that uses morphological stream characteristics to organize streams into relatively homogeneous stream types to predict stream behavior and to apply interpretive information.	Reference: Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, CO. For a copy contact: Wildland Hydrology Books, 1481 Stevens Lake Road, Pagosa Springs, CO 81147.

Model or Assessment Approach	Description	Model Resources
Stream Network/Stream Segment Temperature Models (SNTEMP/SSTEMP)	Developed to help predict the consequences of stream manipulation on water temperatures, these computer models simulate mean daily water temperatures for streams and rivers from data describing the stream's geometry, meteorology, and hydrology. SNTEMP is for a stream network with multiple tributaries for multiple time periods. SSTEMP is a scaled down version suitable for single (to a few) reaches and single (to a few) time periods.	http://www.fort.usgs.gov/Products/Software/SNTEMP
Stream Visual Assessment Protocol (SVAP)	A simple procedure to evaluate the condition of a stream based on visual characteristics. It also identifies opportunities to enhance biological value and conveys information on how streams function.	ftp://ftp.wcc.nrcs.usda.gov/downloads/wqam/svapfnl.pdf
Systems Impact Assessment Model (SIAM)	An integrated set of models used to aid the evaluation of water management alternatives, it address significant interrelationships among selected physical (temperature, microhabitat), chemical (dissolved oxygen, water temperature), and biological variables (young-of-year Chinook salmon production), and stream flow. Developed for the Klamath River in northern California.	http://www.fort.usgs.gov/Products/Software/SIAM
Time-Series Library (TSLIB)	A set of DOS-based computer programs to create monthly or daily habitat time-series and habitat-duration curves using the habitat-discharge relationship produced by PHABSIM. (Can serve as the hydraulic component of IFIM).	http://www.fort.usgs.gov/Products/Software/TSLIB
TR-20, Computer Program for Project Formulation Hydrology	A physically based watershed scale runoff event model that computes direct runoff and develops hydrographs resulting from any synthetic or natural rainstorm. Developed hydrographs are routed through stream and valley reaches as well as through reservoirs.	http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/WinTR20.html
TR-55, Urban Hydrology for Small Watersheds	Simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs.	http://www.info.usda.gov/CED/ftp/CED/tr55.pdf

Examples of Channel Modification Activities and Associated Models/Practices

Modeling for Impoundments

A low-complexity option for modeling impoundments is to use simple models like the Bathtub model to simulate the waterbody. Compared to more complex multi-dimensional models, which use multiple computational cells to estimate volumetric and contaminant fluxes between the cells, Bathtub-type models typically use a single cell. This single cell, while a simplification of the system, may be appropriate if the system is fully mixed in both the horizontal and vertical dimensions. This approach can also be economically developed using spreadsheets (such as Excel) to calculate the results. However, a Bathtub-type model has limited utility if the water body is stratified or if results are required at more than one location in the system.

Another example of a modeling tool that has the ability to simulate impoundments is CE-QUAL-W2, a two-dimensional hydrodynamic water quality model. CE-QUAL-W2 provides results for either a horizontal or cross-sectional, two-dimensional plane. Because the model assumes a vertically or horizontally-mixed environment, it is best suited for relatively long and narrow water bodies (rivers, lakes, reservoirs, and estuaries) that exhibit longitudinal or vertical water quality stratification. The water quality portion of CE-QUAL-W2 includes the major processes of eutrophication kinetics and a single algal compartment. The bottom sediment compartment stores settled particles, releases nutrients to the water column, and exerts sediment oxygen demand based on user-supplied fluxes; a full sediment diagenesis (i.e., the process of chemical and physical change in deposited sediment during its conversion to rock) model is under development.

The Environmental Fluid Dynamics Code (EFDC) is a general-purpose modeling package for simulating one- or multi-dimensional flow, transport, and bio-geochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. The EFDC model was originally developed by Hamrick in 1992 at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software. This model is now EPA-supported as a component of EPA Region 2's PRVI BASINS software system and EPA's TMDL Toolbox,[2] and has been used extensively to support TMDL development throughout the country. In addition to hydrodynamic, salinity, and temperature transport simulation capabilities, EFDC is capable of simulating cohesive and non-cohesive sediment transport, near field and far field discharge dilution from multiple sources, eutrophication processes, the transport and fate of toxic contaminants in the water and sediment phases, and the transport and fate of various life stages of finfish and shellfish.

Modeling for Estuary Tidal Flow Restrictions

Artificial hydraulic structures have the ability to alter natural flow patterns (hydrodynamic) in an estuary, which may modify erosion patterns, salinity regimes, and the fate and transport of pollutants. Some examples of artificial hydraulic structures include culverts, bridges, tide gates,

[2] http://www.epa.gov/athens/wwqtsc/html/efdc.html

and weir structures. Installation or removal of these structures may cause a significant change in local hydrodynamics, and tools may be used to estimate the impacts prior to the modification.

The EFDC model, as described above, allows modelers to evaluate the impacts of hydraulic structures, such as culverts, bridges, tide gates, and weirs. Due to the flexibility of EFDC, each of these structures can also be conceptually represented in a variety of ways. For example, the weir equation can be applied to locations in the modeling grid to estimate water surface-dependent flow through one or more grid cells. This enables a modeler to evaluate the effect of placement of structures that modify surface flow patterns (such as a weir). Structures such as piers and impermeable barriers (e.g. jetties, breakwaters) can also be simulated using this code.

Another modeling tool that can address estuary tidal flow restrictions is the Finite Element Surface Water Modeling System (FESWMS) model. This modeling code was developed by the Federal Highway Administration (FHA) and is distributed by the U.S Geological Survey (USGS). FESWMS is a hydrodynamic modeling code that simulates two-dimensional, depth-integrated, steady or unsteady surface-water flows. It supports both super and subcritical flow analysis, and area wetting and drying. FESWMS is also suited for modeling regions involving flow control structures, such as are encountered at the intersection of roadways and waterways. Specifically, the FESWMS model allows the user to include weirs, culverts, drop inlets, and bridge piers into a standard two-dimensional finite element model. FESWMS does not have three-dimensional capabilities.

Modeling for Estuary Flow Regime Alterations

A number of structures or processes can alter the flow regime of a system. Flow contributions to an estuary can be altered by upstream rediversions or basin transfers, dams and dam releases, or other channel modifications. For example, when freshwater flows patterns are altered by the presence and operation of a dam, EFDC can be used to model the impact to downstream estuaries. EFDC can provide modelers with a time series representation of flow that is withdrawn from a simulated reservoir/dam system. Coupling the time series flow projections with hydrodynamic analysis of the receiving esturay enables modelers to determine potential impacts of altered flow patterms and to evaluate various spill options for the dam operation. Structures within the estuary that may alter the flow patterns include marinas, piers, jetties, and other similar type structures. Flow regime alterations due to these structures can be simulated using the same modeling tools described in the Flow Restrictions section above. Flow restrictions are the cause of most changes in the flow regime, so the simulation of the causes of restriction using a process-based modeling tool produces the desired flow alterations. Therefore, EFDC and FESWMS can be utilized in the same manner to obtain flow regime results.

Temperature Restoration Practices

Several computer models that predict instream water temperature are currently available. These models vary in the complexity of detail with which site characteristics, including meteorology, hydrology, stream geometry, and riparian vegetation, are described. The U.S. Fish and Wildlife Service developed an instream surface water temperature model (Theurer et al., 1984) to predict mean daily temperature and diurnal fluctuations in surface water temperatures throughout a stream system. The model, Stream Network Temperature Model (SNTEMP), can be applied to any size watershed or river system. This predictive model uses either historical or synthetic hydrological, meteorological, and stream geometry characteristics to describe the ambient conditions. The purpose of the model is to predict the longitudinal temperature and its temporal variations. The instream surface water temperature model has been used satisfactorily to evaluate the impacts of riparian vegetation, reservoir releases, and stream withdrawal and returns on surface water temperature. In the Upper Colorado River Basin, the model was used to study the impact of temperature on endangered species (Theurer et al., 1982). It also has been used in smaller ungauged watersheds to study the impacts of riparian vegetation on salmonid habitat.[3]

The Stream Segment Temperature Model (SSTEMP) is a much-scaled down version of the SNTEMP model developed by the USGS Biological Resource Division. Unlike the large network model (SNTEMP), this program only handles single stream segments for a single time period (e.g., month, week, day) for any given "run." Initially designed as a training tool, SSTEMP may be used satisfactorily for a variety of simple cases that one might face on a day-to-day basis. It is especially useful to perform sensitivity and uncertainty analysis. The model predicts minimum 24-hour temperatures, mean 24-hour temperatures, and maximum 24-hour stream temperatures for a given day, as well as a variety of intermediate values. The SSTEMP model identifies current stream and/or watershed characteristics that control stream temperatures. The model also quantifies the maximum loading capacity of the stream to meet water quality standards for temperature. This model is important for estimating the effect of changing controls or factors (such as riparian grazing, stream channel alteration, and reduced streamflow) on stream temperature. The model can also be used to help identify possible implementation activities to improve stream temperature by targeting those factors causing impairment to the stream. Good input data and an awareness of the model's assumptions are critical to obtaining reliable predictions. SSTEMP may be used to evaluate alternative reservoir release proposals, analyze the effects of changing riparian shade or the physical features of a stream, and examine the effects of different withdrawals and returns on instream temperature.[4]

Selecting Appropriate Models

Although a wide range of adequate hydrodynamic and surface water quality models are available, the central issue in selecting appropriate models for evaluating hydromodification projects is the appropriate match of the financial and geographical scale of the proposed project with the cost required to perform a credible technical evaluation of the projected environmental impact. It is highly unlikely, for example, that a proposal for a relatively small stream channel modification project, such as installing culverts in a stream segment, would be expected or required to contain a state-of-the-art hydrodynamic and surface water quality analysis that requires one or more person-years of effort. In such projects, a simplified, desktop approach (e.g., HEC-RAS Model) requiring less time and money would most likely be sufficient (USACE, 2002a). In contrast, substantial technical assessment of the long-term environmental impacts would be expected for channelization proposed as part of construction of a major harbor facility or as part of a system of navigation and flood control locks and dams. The assessment should

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[3] For more information or to download SNTEMP, see the U.S. Geological Survey Web site: http://www.fort.usgs.gov/Products/Software/SNTEMP.
[4] More information about the model is available on the U.S. Geological Survey Web site: http://www.mesc.usgs.gov/products/software/default.asp (navigate to Stream Network Temperature Model and Stream Segment Temperature Model).

incorporate the use of detailed 2D or 3D hydrodynamic models coupled with sediment transport and surface water quality models.

In general, six criteria can be used to review available models for potential application in a given hydromodification project:

1. Time and resources available for model application
2. Ease of application
3. Availability of documentation
4. Applicability of modeled processes and constituents to project objectives and concerns
5. Hydrodynamic modeling capabilities
6. Demonstrated applicability to size and type of project

The Center for Exposure Assessment Modeling (CEAM),[5] EPA Environmental Research Laboratory, Athens, Georgia, provides continual support for several hydrodynamic and surface water quality models, such as HSCTM2D, HSPF, PRZM3, and SED3D. Another source of information and technical support is the Waterways Experiment Station, USACE, Vicksburg, Mississippi.[6] Although a number of available models are in the public domain, costs associated with setting up and operating these models may exceed the project's available resources. For a simple to moderately difficult application, the approximate level of effort varies, but could range from 1 to 12 person-months.

Several factors need to be considered in the application of mathematical models to predict impacts from hydromodification projects including:

- Variations and uncertainties in the accuracy of these models when they are applied to the short- and long-term response of natural systems.
- Availability of relevant information (data collection) to derive the simulations and validate the modeling results.

The cost of a given modeling project depends on a number of factors. Questions need to be asked prior to the start of a modeling project to determine the purpose and future use of the model, and/or its results. For example, the modeler needs to know if the model results are to be used deterministically (the model assumes there is only one possible result that is known for each alternative course or action), or if the model is to be used for a heuristic (involving or serving as an aid to learning, discovery, or problem-solving by experimental and especially trial-and-error methods) scoping exercise to identify data gaps in a system. In a deterministic study, the results are traditionally compared to observed data in an effort regarded as calibration and validation. The model must therefore be rigorous enough to represent the system accurately. The complexity of the system under study is also a consideration that must be made prior to the project. The complexity of the system generally correlates well with the level of complexity of the model required to simulate it. Likewise, the more complex the model is, the more intensive it is to develop and run, and the more costly the modeling project is.

[5] http://www.epa.gov/ceampubl
[6] http://www.erdc.usace.army.mil

A number of approaches are available to model a given system, and the discussion above only highlights a few of the modeling tools currently available. The cost to set up a model for a given system varies tremendously, based not only on the modeling code selected, but also on what the modeler decides to simulate. For example, a modeler may aim to obtain flow results for an estuary using a given model. In reality, surface winds in that estuary may or may not be influencing the flow regime. If observed wind data is available from a weather station nearby, the modeler may choose to incorporate these data into the model to better represent that influence. The modeler may also choose not to incorporate these data, or the data may not be available. Although the modeler is utilizing the same modeling code, the decision regarding whether or not to simulate the wind conditions is not only a question regarding the model's purpose, but also what the development of this model will cost.

Modeling tools can range from simple spreadsheet tools using "back of the envelope" type calculations, to complex processed based models that must be run on high performance computing systems. As discussed previously, the tool selected for a given modeling project needs to be chosen with a number of questions in mind. As a result, each system can be modeled in a number of different ways with a number of different modeling codes. Therefore, the range in cost for even a single estuary or impoundment may range tenfold depending on the model's purpose. Typically, the cost of developing a model may range from a few thousand dollars for a simple spreadsheet model, to in excess of one million dollars for a more robust modeling system.

Chapter 9: Dam Removal Requirements, Process, and Techniques

Chapter 2 provided a discussion of specific impacts from dams, water quality above and below the dam, suspended sediment and recharge issues, and biological and habitat impacts. Chapter 4 then provided a discussion of types of dams, Federal Energy Regulatory Commission (FERC) requirements, management measures and practices that can be used to mitigate for some of the effects of dams, and information to consider when contemplating removing a dam. Chapter 9 focuses on what occurs after the decision has been made to remove a dam. This chapter provides a more detailed discussion on some permitting requirements for removing dams, the dam removal process, and sediment removal techniques to consider when removing a dam.

Requirements for Removing Dams

Removing a dam may require evaluations and permits from state, federal, and local authorities. These requirements are typically to ensure that the removal is done is a manner that is safe and minimizes short and long term impacts to the river and floodplain. States and local governments have different requirements. The following federal requirements may apply to dam removal:

- Rivers and Harbors Act Permit
- FERC License Surrender or Non-power License Approval
- National Environmental Policy Act (NEPA) Review
- Federal Consultations (Endangered Species Act Section 7 Consultation, Magnuson-Stevenson Act Consultation, National Historic Preservation Act Compliance)
- State Certifications (Water Quality Certification, Coastal Zone Management Act Certification)

The following state requirements might apply to dam removal:

- Clean Water Act (CWA) Section 404 Dredge and Fill Permit
- Waterway Development Permits
- Dam Safety Permits
- State Environmental Policy Act Review
- Historic Preservation Review
- Resetting the Floodplain
- State Certifications

Demolition and building permits may also be required for dam removal. Individual state and local governments may have additional requirements as well.

Tips for a Successful Permitting Process (American Rivers, 2002b)

Dam removal is relatively new and the permitting process can be difficult. Most state and federal agencies are not yet practiced at moving dam removal through the permitting process. The relevant permitting requirements were designed for more destructive activities, and dam removal does not easily fit into the requirements. Tips to help make the process smoother include:

Schedule Time
- *Expect dam removal projects to take longer than construction efforts.*
- *Schedule more lead-time into the permitting process to avoid delays and frustrations.*

Establish a Relationship with the Permitting Agencies
- *Hold a pre-application meeting with key agency staff once your project is well thought out.*
- *Do not attempt to circumvent the process and stick with the permitting timeline.*
- *Do not provide inconsistent information.*
- *A single point of contact for the group applying for the permit will help avoid confusion and maintain communication.*

Providing Information about the Proposed Project
- *Create clear and simple descriptions and drawings (to scale) of the proposed project.*
- *Be sure to identify complicating conditions, schedules, seasonal constraints, etc.*
- *Provide and discuss alternatives, but make it clear why the chosen approach should be used.*
- *Assume the reviewers know nothing about your project.*

Dam Removal Process

The complexity of the removal process of a dam is specific to each particular case of removal. There are two major components of the removal process: the stakeholders involved in the decision-making process of removing the dam and the actual physical removal of the dam itself. The authorities that govern dams are numerous, yet overlapping. These entities include: USACE, Bureau of Reclamation, FERC, and other federal agencies; interest groups; and state and local governments. There are also various state programs that have been created to keep dams safe and environmentally friendly, as well as to help owners finance dam removal. A study by the Aspen Institute (2002) provides a list of priority issues to consider when dam removal may be a possibility. Among the considerations listed are dam and public safety, economics, environmental concerns, risk, social values and community interests, scientific information, and stakeholder participation. This report suggests that success of dam removal is dependent upon a thorough analysis of these competing factors and input from all interested parties (Aspen Institute, 2002). Often, the dam owner makes the decision to remove a dam, deciding that the costs of continuing operation and maintenance are greater than the cost of removing the dam. However, state dam safety offices can order for a dam to be removed if there are safety concerns; FERC can order removal of dams under their jurisdiction for environmental and safety reasons (American Rivers, n.d.a.).

State governments have authority over the dams in their jurisdiction. Other state and local government agencies dealing with issues such as water quality, water rights, and fish and wildlife protection can also play a role in overseeing dams within their jurisdiction if they so choose

(FOE et al., 1999). Certain states have implemented stringent rules for dams that are and are not regulated by FERC or USACE. For example, the state of Wisconsin has a Dam Safety Inspection Program that requires dams to be inspected every 10 years by the Wisconsin Department of Natural Resources (WDNR) (Doyle et al., 2000). Any dam that fails to meet safety requirements set by WDNR must be repaired or removed. The state of Pennsylvania has implemented a law that was written under the order of the Pennsylvania Fish and Boat Commission that states that any newly constructed or existing dam that requires a state permit for construction or modification must also include provisions for fish passage (Doyle et al., 2000).

Some states have programs that aid dam owners in the process of removing their structures. The Pennsylvania Department of Environmental Protection (DEP) has adopted procedures to make it easier and less expensive for dam owners to remove unsafe, unused, or unwanted dams. In this process, owners of dams on third order or larger streams are contacted and asked if they are interested in removing their dams. If they are, then all the landowners affected by the removal are contacted, and a public meeting is held if interest warrants one. After public comments, an engineering design is created, followed by an environmental assessment, then sediment and erosion control (ESC) plans are established, and finally approval is sought by the USACE. This program was used in the removal of seven dams on Conestoga River and also in the removal of the Williamsburg Station Dam on the Juniata River. This approval process takes between 12 and 18 weeks (FOE et al., 1999). However, the physical decommissioning and removing of a dam can still be a lengthy and diversified process.

Sediment Removal Techniques

Large dams can trap thousands to millions of cubic yards of sediment over time, eliminating the flood control or storage capacity of the dam. Removal or control of sediment behind a dam can represent a large portion of the cost and planning effort of a dam removal project. There are several methods available to project planners and dam owners that target different pollution concerns and budgetary limitations (International Rivers Network, 2003). The options in terms of sediment removal range from complete removal and relocation of all accumulated material from the inundated regions; removing sediment only from the anticipated channel of the river, or allowing the river to erode a new channel through the sediment (Wunderlich et al., 1994).

If the sediment is basically clean and the main concern is turbidity and clogging downstream streambed spawning areas, gradual incremental drawdowns of the reservoir behind the dam allow the sediment to be transported downstream in smaller portions and avoids the release one large, lethal volume of sediment. If contaminated sediment is the main concern, dredging is an option that can be used. While the use of silt curtains can minimize turbidity during dredging, silt curtains do not contain dissolved substances such as metals, which can pose a threat to downstream ecosystems (EMC2, 2001). Another option for contaminated sediments is to stabilize the sediment in place within the stream. This can be accomplished by leaving a portion of the dam in place to hold back an area of sediment that is of concern. The strategic placement of boulders can also contain the sediment from moving downstream.

For more information on issues associated with dam removal, see the Additional Resources section of this document.

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Zimmerman, M.J., and M. S. Dortch. 1989. Modelling water quality of a reregulated stream below a hydropower dam. *Regulated Rivers: Research and Management* 4:235-247.

Additional Resources

The following are additional resources that may be used to obtain supplementary information for topics presented in this document.

Background on Streams, Restoration, and Hydrology

The following are basic references regarding stream ecology, restoration, and hydrology:

Allan, J.D. 1995. *Stream Ecology—Structure and Function of Running Waters*. Chapman and Hall, New York.

Brookes, A. and F.D. Shields, eds. 1999. *River Channel Restoration: Guiding Principles for Sustainable Projects*. John Wiley and Sons, Chichester, U.K.

Cooke, G.D., E.B. Welch, S.A. Peterson, and P.R. Newroth. 1993. *Restoration and Management of Lakes and Reservoirs*. 2nd ed. Lewis Publishers, Boca Raton, FL.

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Ponce, V.M. 1989. *Engineering Hydrology: Principles and Practices*. Prentice-Hall, Englewood Cliffs, New Jersey.

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Detailed Information for Practices to Achieve Management Measures

Additional information about practices, their effectiveness, limitations, and cost estimates are available from a number of sources, including:

Allen, H.H. and J.R. Leech. 1997. *Bioengineering for Streambank Erosion Control: Report 1 Guidelines*. U.S. Army Corps of Engineers, Environmental Impact Research Program, Technical Report EL-97-8. http://el.erdc.usace.army.mil/elpubs/pdf/trel97-8.pdf.

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Center for Watershed Protection (CWP). 2007. *The Stormwater Manager's Resource Center*. http://www.stormwatercenter.net.

Federal Interagency Stream Restoration Working Group (FISRWG). 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. http://www.nrcs.usda.gov/technical/stream_restoration.

Fischenich, J. C. and H. Allen. 2000. *Stream Management*. ERDC/EL SR-W-00-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://el.erdc.usace.army.mil/elpubs/pdf/srw00-1/srw00-1.pdf. Accessed October 2004.

Knutson, P.L., and M.R. Inskeep. 1982. *Shore Erosion Control with Salt Marsh Vegetation*. Coastal Engineering Technical Aid No. 82-3. U.S. Army Corps of Engineers Coastal Engineering Research Center, Vicksburg, MS.

National Association of Home Builders (NAHB). 1995. *Storm Water Runoff & Nonpoint Source Pollution Control Guide for Builders and Developers*. National Association of Home Builders, Washington, DC. http://www.nahbrc.org.

Oregon Association of Conservation Districts. 1999. *Protecting Streambanks from Erosion: Tips for Small Acreages in Oregon*. http://www.or.nrcs.usda.gov/news/factsheets/fs4.pdf.

Urban Drainage and Flood Control District. 1999. *Urban Storm Drainage Criteria Manual: Volume 3—Best Management Practices*. Urban Drainage and Flood Control District, Denver, CO. http://www.udfcd.org.

U.S. Army Corps of Engineers (USACE). 2007. *Engineer Research and Development Center (ERDC) Web site*. http://www.erdc.usace.army.mil.

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U.S. Environmental Protection Agency (USEPA). 2002. *Development Document for Proposed Effluent Guidelines and Standards for the Construction and Development Category*. EPA-821-R-02-007. http://www.epa.gov/waterscience/guide/construction/devdoc.htm.

U.S. Environmental Protection Agency (USEPA). 2007. *National Menu of Stormwater Best Management Practices*. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/menu.cfm.

Additional information about hydromodification, soil bioengineering, and restoration is available from the following:

- *Ann Riley, Urban Stream Restoration: A Video Tour of Ecological Restoration Techniques* (http://www.noltemedia.com/nm/urbanstream): This video, which can be ordered online, is a documentary tour of six urban stream restoration sites. It provides background information on funding, community involvement, and the history and principles of restoration. The demonstration includes examples of stream restoration in very urbanized areas, re-creating stream shapes and meanders, creek daylighting, soil bioengineering, and ecological flood control projects. Ann Riley, a nationally known hydrologist, stream restoration professional, and executive director of the Waterways Restoration Institute in Berkley, California, leads the tour.

- *California Forest Stewardship Program*. Bioengineering to Control Streambank Erosion (http://ceres.ca.gov/foreststeward/html/bioengineering.html): This fact sheet discusses various bioengineering techniques applicable to California streams.

- *Lower American River Corridor River Management Plan* (http://www.safca.com): The plan provides information on aquatic habitat management goals, including restoration to improve aquatic habitat impaired by low flows from channel modification of the Lower American River.

- *Natural Resources Conservation Service, Watershed Technology Electronic Catalog* (http://www.wcc.nrcs.usda.gov/wtec/wtec.html): This online catalog is a source of technical guidance on a variety of restoration techniques and management practices, to provide direction for watershed managers and restoration practitioners. The site is focused on providing images and conceptual diagrams.

- *North Delta Improvements Project* (http://ndelta.water.ca.gov/index.html): The North Delta Improvements Project (NDIP), which is under the California Department of Water Resources, presents unique opportunities for synergy in achieving flood control and ecosystem restoration goals.

- *Ohio Department of Natural Resources*. Stream Management Guide Fact Sheets (http://www.dnr.state.oh.us/water/pubs/fs_st/streamfs.htm): This is a compilation of fact sheets offering technical guidance for streambank and instream practices, general stream management, and stream processes.

- *Sacramento River Riparian Habitat Program* (http://www.sacramentoriver.ca.gov): The Sacramento River Riparian Habitat Program is working to ensure that riparian habitat management along the river addresses the dynamics of the riparian ecosystem and the reality of the local agricultural economy.

- Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments, Washington, DC.

- *South Delta Improvements Program* (http://baydeltaoffice.water.ca.gov/sdb/sdip/index_sdip.cfm): The purpose of the South Delta Improvements Program (SDIP) is to incrementally maximize diversion capability into Clifton Court Forebay, while providing an adequate water supply for diverters within the South Delta Water Agency and reducing the effects of State Water Project exports on both aquatic resources and direct losses of fish in the South Delta.

- *South Sacramento County Streams Project* (http://www.spk.usace.army.mil): South Sacramento County Streams Project provides flood damage reduction to the urban areas of the Morrison Creek and Beach Stone Lake drainage basins in the southern area of Sacramento, as well as around the Sacramento Regional Waste Water Treatment Plant. The project will fund stream restoration in southern Sacramento County.

- *USDA Natural Resources Conservation Service, Stream Visual Assessment Protocol* (http://www.nrcs.usda.gov/technical/ECS/aquatic/svapfnl.pdf): This document outlines methods for field conservationists and landowners to evaluate stream ecological conditions.

- *Washington State Department of Transportation, Soil Bioengineering Web site* (http://www.wsdot.wa.gov/eesc/design/roadside/sb.htm): This is a comprehensive Web site, with information on cost, specifications for project design, funding, and case studies.

- *WATERSHEDSS:Water, Soil and Hydro-Environmental Decision Support System* (http://www.water.ncsu.edu/watershedss): The "Educational Component" of this Web site contains fact sheets with information on a variety of techniques for management practices, including soil bioengineering and structural streambank stabilization.

Resources for Dams

Thornton, K.W., B.L. Kimmel, and F.E. Payne, eds. 1990. *Reservoir Limnology: Ecological Perspectives*. John Wiley and Sons, Inc., New York, NY.

U.S. Army Corps of Engineers. No date. *The WES Handbook on Water Quality Enhancement Techniques for Reservoirs and Tailwaters*. U.S. Army Engineer Research and Development Center Waterways Experiment Station, Vicksburg, MS.

Web sites for dam removal include the following:

- American Rivers' Rivers Unplugged Program: http://www.americanrivers.org/site/PageServer?pagename=AMR_content_1270
- Association of State Dam Safety Officials: http://www.damsafety.org
- Friends of the Earth's River Restoration: http://www.foe.org/camps/reg/nw/river/index.html
- International River Network's River Revival Program: http://www.irn.org/revival/decom
- Massachusetts Department of Fisheries, Wildlife, and Environmental Law Enforcement River Restore Program: http://www.mass.gov/dfwele/river/programs/riverrestore/riverrestore.htm
- National Performance of Dams Program Stanford University: http://www.stanford.edu/group/strgeo/researchcenters.html
- New Hampshire Department of Environmental Services: http://www.des.state.nh.us/dam.htm
- Pennsylvania Department of Environmental Protection, Division of Dam Safety, Dam Safety Program: http://www.dep.state.pa.us/dep/deputate/watermgt/we/damprogram/Main.htm
- Pennsylvania Fish & Boat Commission: http://www.fish.state.pa.us
- River Recovery—Restoring Rivers through Dam Decommissioning: http://www.recovery.bcit.ca/index.html
- United States Society on Dams: http://www.ussdams.org
- Wisconsin Department of Natural Resources: http://www.dnr.state.wi.us/org/water/wm/dsfm/dams/removal.html

Additional information about dam removal is available from the following resources:

- ASCE. 1997. *Guidelines for the Retirement of Hydroelectric Facilities*. American Society of Civil Engineers.
- Bednarek, A.T. 2001. Undamming rivers: A review of the ecological impacts of dam removal. *Environmental Management* 27(6):803-814.
- Bioscience. 2002. Dam removal and river restoration: Linking scientific, socioeconomic, and legal perspectives. Summer (special issue).
- Born, S.M., et al. 1998. Socioeconomic and institutional dimensions of dam removals: The Wisconsin experience. *Environmental Management* 22(3):359-370.

- Hart, D.D. and N.L. Poff. 2002. A special section on dam removal and river restoration. *BioScience* 52:653-655.
- Heinz Center. 2002. *Dam Removal: Science and Decision Making*. Available at: http://www.heinzctr.org/Programs/SOCW/dam_removal.htm.
- International Rivers Network: http://www.irn.org/pubs/wrr.
- Niemi, G.J., et al. 1990. Overview of case studies on recovery of aquatic systems from disturbance. *Environmental Management* 14(5):571-587.
- United States Society on Dams Publications: http://www.ussdams.org/pubs.html.
- University of Wisconsin-Madison/Extension. 1996. *The Removal of Small Dams: An Institutional Analysis of the Wisconsin Experience*. Extension Report 96-1, May. Department of Urban and Regional Planning.
- Wisconsin Department of Natural Resources Projects: http://www.dnr.state.wi.us/org/gmu/sidebar/iem/lowerwis/index.htm#baraboo or http://www.dnr.state.wi.us/org/gmu/lowerwis/baraboo.htm; http://www.dnr.state.wi.us/org/gmu/sidebar/iem/milw/index.htm; http://www.dnr.state.wi.us/org/gmu/sidebar/iem/superior/index.htm; http://www.dnr.state.wi.us/org/gmu/sidebar/iem/sheboygan/index.htm

Noneroding Roadways

The following sources may be used to obtain additional information on noneroding roadways:

- *Controlling Nonpoint Source Runoff Pollution from Roads, Highways, and Bridges* http://www.epa.gov/owow/nps/roads.html
- *Erosion, Sediment, and Runoff Control for Roads and Highways* http://www.epa.gov/owow/nps/education/runoff.html
- *Gravel Roads: Maintenance and Design Manual*—the purpose of the manual is to provide clear and helpful information for doing a better job of maintaining gravel roads. The manual is designed for the benefit of elected officials, mangers, and grader operators who are responsible for designing and maintaining gravel roads. http://www.epa.gov/owow/nps/gravelroads
- *Low-Volume Roads Engineering Best Management Practices Field Guide* http://zietlow.com/manual/gk1/web.doc
- *Massachusetts Unpaved Roads BMP Manual* http://berkshireplanning.org/4/download/dirt_roads.pdf
- *Planning Considerations for Roads, Highways, and Bridges* http://www.epa.gov/owow/nps/education/planroad.html
- *Pollution Control Programs for Roads, Highways, and Bridges* http://www.epa.gov/owow/nps/education/control.html
- *Recommended Practices Manual: A Guideline for Maintenance and Service of Unpaved Roads* http://www.epa.gov/owow/nps/unpavedroads.html
- The "Road Maintenance Video Set" is a five-part video series developed for USDA Forest Service equipment operators that focuses on environmentally sensitive ways of maintaining low volume roads. http://www.epa.gov/owow/nps/maint_videoset.html

Additional Information

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish*, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C. http://www.epa.gov/owow/monitoring/rbp/ Accessed July 2007.

International Commission on Large Dams
http://www.icold-cigb.org

International Rivers Network
http://www.irn.org

U.S. Army Corps of Engineers, Engineer Research and Development Center
http://www.erdc.usace.army.mil

U.S. Department of Agriculture, Farm Service Agency
http://www.fsa.usda.gov/pas

U.S. Department of Agriculture, Natural Resources Conservation Service
http://www.nrcs.usda.gov

U.S. Department of the Interior, Bureau of Reclamation
http://www.usbr.gov

U.S. Department of the Interior, National Park Service
http://www.nps.gov

U.S. Department of the Interior, U.S. Fish and Wildlife Service
http://www.fws.gov

U.S. Department of the Interior, U.S. Geological Survey
http://www.usgs.gov

USEPA. 1994. *A State and Local Government Guide to Environmental Program Funding Alternatives*. EPA 841-K-94-001. http://www.epa.gov/owow/nps/MMGI/funding.html

USEPA. 1994. *A Tribal Guide to the Section 319(h) Nonpoint Source Grant Program*. EPA 841-S-94-003.

USEPA. 1994. *Section 319 Success Stories: Volume I*. EPA 841-S-94-004.
http://www.epa.gov/owow/nps/Success319

USEPA. *Catalog of Federal Funding Sources for Watershed Protection*
http://cfpub.epa.gov/fedfund

USEPA. 1997. *Section 319 Success Stories: Volume II—Highlights of State and Tribal Nonpoint Source Programs*. EPA 841-R-97-001.
http://www.epa.gov/owow/nps/Section319II

USEPA. 2002. *Section 319 Success Stories: Volume III*.
http://www.epa.gov/owow/nps/Section319III

USEPA Clean Lakes Program
http://www.epa.gov/owow/lakes/cllkspgm.html

USEPA Environmental Finance Information Network (EFIN)
http://www.epa.gov/efinpage/efin.htm

USEPA Nonpoint Source Pollution Control Program Homepage
http://www.epa.gov/OWOW/NPS

USEPA Surf Your Watershed
http://www.epa.gov/surf

USEPA Watershed Academy
http://www.epa.gov/owow/watershed/wacademy

Watershedss, (Water, Soil, and HydroEnvironmental Decision Support System)—North Carolina State University
http://www.water.ncsu.edu/watershedss

Appendix A
U.S. Environmental Protection Agency Contacts

This appendix provides wetlands contacts, nonpoint source regional contacts, and Clean Water State Revolving Fund Contacts.

U.S. Environmental Protection Agency Contacts

EPA is grouped into 10 Regions. For questions about a particular state, contact the appropriate EPA Regional Coordinator listed below.

EPA Region	Wetland Contact	Nonpoint Source Regional Coordinators	Clean Water State Revolving Fund Regional Coordinators
Region 1: CT, MA, ME, NH, RI, VT http://www.epa.gov/region01/	U.S. EPA-Region 1 Wetlands Protection Unit One Congress Street Boston, MA 02114-2023 http://www.epa.gov/region01/topics/ecosystems/wetlands.html	U.S. EPA-Region 1 Nonpoint Source Coordinator One Congress Street, Boston, MA 02114-2023 http://www.epa.gov/region01/topics/water/npsources.html	U.S. EPA-Region 1 SRF Program Contact One Congress Street Boston, MA 02114-2023 http://www.epa.gov/ne/cwsrf/index.html
Region 2: NJ, NY, PR, VI http://www.epa.gov/Region2	U.S. EPA-Region 2 Water Programs Branch Wetlands Section 290 Broadway New York, NY 10007-1866 http://www.epa.gov/region02/water/wetlands/	U.S. EPA-Region 2 Water Programs Branch Nonpoint Source Coordinator 290 Broadway New York, NY 10007-1866 http://www.epa.gov/region02/water/npspage.htm	U.S. EPA-Region 2 Water Programs Branch SRF Program Contact 290 Broadway New York, NY 10007-1866 http://www.epa.gov/Region2/water/wpb/staterev.htm
Region 3: DC, DE, MD, PA, VA, WV http://www.epa.gov/region03	U.S. EPA-Region 3 Wetlands Protection Section 1650 Arch Street (3WP12) Philadelphia, PA 19103 http://www.epa.gov/reg3esd1/hydricsoils/index.htm	U.S. EPA-Region 3 Nonpoint Source Coordinator 1650 Arch Street (3WP12) Philadelphia, PA 19103 http://www.epa.gov/reg3wapd/nps/	U.S. EPA-Region 3 Construction Grants Branch SRF Program Contact 1650 Arch Street (3WP12) Philadelphia, PA 19103 http://www.epa.gov/reg3wapd/srf/index.htm
Region 4: AL, FL, GA, KY, MS, NC, SC, TN http://www.epa.gov/region4/	U.S. EPA-Region 4 Wetlands Section 61 Forsyth Street, SW Atlanta, GA 30303 http://www.epa.gov/region4/water/wetlands/	U.S. EPA-Region 4 Nonpoint Source Coordinator 61 Forsyth Street, SW Atlanta, GA 30303 http://www.epa.gov/region4/water/nps/	U.S. EPA-Region 4 Surface Water Permits & Facilities SRF Program Contact 61 Forsyth St. Atlanta GA, 30303 http://www.epa.gov/Region4/water/gtas/grantprograms.html
Region 5: IL, IN, MI, MN, OH, WI http://www.epa.gov/region5/	U.S. EPA-Region 5 Watersheds and Wetlands Water Division (W-15J) 77 West Jackson Blvd. Chicago, IL 60604 http://www.epa.gov/region5/water/wshednps/topic_wetlands.htm	U.S. EPA-Region 5 Nonpoint Source Coordinator Water Division (W-15J) 77 West Jackson Blvd. Chicago, IL 60604 http://www.epa.gov/region5/water/wshednps/topic_nps.htm	U.S. EPA-Region 5 SRF Program Contact Water Division (W-15J) 77 West Jackson Blvd. Chicago, IL 60604 http://www.epa.gov/region5/business/fs-cwsrf.htm

EPA Region	Wetland Contact	Nonpoint Source Regional Coordinators	Clean Water State Revolving Fund Regional Coordinators
Region 6: AR, LA, NM, OK, TX http://www.epa.gov/region6	U.S. EPA-Region 6 Marine and Wetlands Section 1445 Ross Ave., Suite 1200 Dallas, TX 75202 http://www.epa.gov/region6/water/ecopro/index.htm	U.S. EPA-Region 6 Nonpoint Source Coordinator 1445 Ross Ave., Suite 1200 Dallas, TX 75202 http://www.epa.gov/region6/water/ecopro/watershd/nonpoint/	U.S. EPA-Region 6 SRF Program Contact 1445 Ross Ave., Suite 1200 Dallas, TX 75202 http://www.epa.gov/Arkansas/6en/xp/enxp2c4.htm
Region 7: IA, KS, MO, NE http://www.epa.gov/region7	U.S. EPA-Region 7 Wetlands Protection Section (ENRV) 901 N. 5th St. Kansas City, KS 66101 http://www.epa.gov/region7/wetlands/index.htm	U.S. EPA-Region 7 Nonpoint Source Coordinator 901 N. 5th St. Kansas City, KS 66101	U.S. EPA-Region 7 SRF Program Contact 901 N. 5th St. Kansas City, KS 66101 http://www.epa.gov/Region7/water/srf.htm
Region 8: CO, MT, ND, SD, UT, WY http://www.epa.gov/region8	U.S. EPA-Region 8 Wetlands Program 999 18th Street, Suite 500 Denver, CO 80202-2405 http://www.epa.gov/region8/water/wetlands/wetlands.html	U.S. EPA-Region 8 Nonpoint Source Coordinator 999 18th Street, Suite 300 Denver, CO 80202-2405 http://www.epa.gov/region8/water/nps/contacts.html	U.S. EPA-Region 8 SRF Program Contact 999 18th Street, Suite 300 Denver, CO 80202-2405
Region 9: AZ, CA, HI, NV, Pacific Islands http://www.epa.gov/region9/	U.S. EPA-Region 9 Water Division, Wetlands 75 Hawthorne Street San Francisco, CA 94105 http://www.epa.gov/region09/water/wetlands/index.html	U.S. EPA-Region 9 Nonpoint Source Coordinator 75 Hawthorne Street San Francisco, CA 94105 http://www.epa.gov/region09/water/nonpoint/index.html	U.S. EPA-Region 9 Construction Grants Branch SRF Program Contact 75 Hawthorne Street San Francisco, CA 94105 http://www.epa.gov/region9/funding/
Region 10: AK, ID, OR, WA http://www.epa.gov/region10/	U.S. EPA-Region 10 Wetlands Section 1200 Sixth Ave. Seattle, WA 98101 http://yosemite.epa.gov/R10/ECOCOMM.NSF/webpage/Wetlands	U.S. EPA-Region 10 Nonpoint Source Coordinator 1200 Sixth Ave. Seattle, WA 98101	U.S. EPA-Region 10 Ecosystems & Communities SRF Program Contact 1200 Sixth Ave. Seattle, WA 98101 http://yosemite.epa.gov/r10/ecocomm.nsf/webpage/Clean+Water+State+Revolving+Fund+in+Region+10
General Program Information	U.S. EPA Wetlands Division (4502F) Mail Code RC-4100T 1200 Pennsylvania Ave., NW Washington, DC 20460 http://www.epa.gov/owow/wetlands/	U.S. EPA Nonpoint Source Control Branch (4503-T) Ariel Rios Bldg. 1200 Pennsylvania Ave., NW Washington, DC 20460 http://www.epa.gov/owow/nps	U.S. EPA The Clean Water State Revolving Fund Branch (4204M) 1201 Constitution Ave., NW Washington, DC 20004 http://www.epa.gov/owm/cwfinance/cwsrf/index.htm