EPA United States
Environmental Protection
Agency

National Management Measures
to Control Nonpoint Source Pollution from
Hydromodification

Chapter 3: Channelization and Channel Modification

Full document available at
http://www.epa.gov/owow/nps/hydromod/index.htm

Assessment and Watershed Protection Division
Office of Water
U.S. Environmental Protection Agency

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

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.

> 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.

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.

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

---

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

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.