8

Restoration Design

8.A Valley Form, Connectivity, and Dimension

- *How do you incorporate all the spatial dimensions of the landscape into stream corridor restoration design?*
- *What criteria can be applied to facilitate good design decisions for stream corridor restoration?*

8.B Soil Properties

- *How do soil properties impact the design of restoration activities?*
- *What are the major functions of soils in the stream corridor?*
- *How are important soil characteristics, such as soil microfauna and soil salinity, accounted for in the design process?*

8.C Vegetative Communities

- *What is the role of vegetative communities in stream corridor restoration?*
- *What functions do vegetative communities fulfill in a stream corridor?*
- *What are some considerations in designing plant community restoration to ensure that all landscape functions are addressed?*
- *What is soil bioengineering and what is its role in stream corridor restoration?*

8.D Riparian / Terrestrial Habitat Recovery

- *What are some specific tools and techniques that can be used to ensure recovery of riparian and terrestrial habitat recovery?*

8.E Stream Channel Restoration

- *When is stream channel reconstruction an appropriate restoration option?*
- *How do you delineate the stream reach to be reconstructed?*
- *How is a stream channel designed and reconstructed?*
- *What are important factors to consider in the design of channel reconstruction (e.g., alignment and average slope, channel dimensions)?*
- *Are there computer models that can assist with the design of channel reconstruction?*

8.F Streambank Restoration Design

- *When should streambank stabilization be included in a restoration?*
- *How do you determine the performance criteria for streambank treatment, including the methods and materials to be used?*
- *What are some streambank stabilization techniques that can be considered for use?*

8.G In-Stream Habitat Recovery

- *What are the principal factors controlling the quality of instream habitat?*
- *How do you determine if an instream habitat structure is needed, and what type of structure is most appropriate?*
- *What procedures can be used to restore instream habitat?*
- *What are some examples of instream habitat structures?*
- *What are some important questions to address before designing, selecting or installing an instream habitat structure?*

8.H Land Use Scenarios

- *What role does land use play in stream corridor degradation and restoration?*
- *What design approaches can be used to address the impacts of various land uses (e.g., dams, agriculture, forestry, grazing, mining, recreation, urbanization)?*
- *What are some disturbances that are often associated with specific land uses?*
- *What restoration measures can be used to mitigate the impacts of various land uses?*
- *What are the potential effects of the restoration measures?*

8 Restoration Design (cont'd)

8.A Valley Form, Connectivity, and Dimension
8.B Soil Properties
8.C Plant Communities
8.D Habitat Measures
8.E Stream Channel Restoration
8.F Streambank Restoration
8.G Instream Habitat Recovery
8.H Land Use Scenarios

Design can be defined as the intentional shaping of matter, energy, and process to meet an expressed need. Planning and design connect natural processes and cultural needs through exchanges of materials, flows of energy, and choices of land use and management. One test of a successful stream corridor design is how well the restored system sustains itself over time while accommodating identified needs.

*To achieve success, those carrying out restoration design and implementation in variable-land-use settings must understand the stream corridor, watershed, and landscape as a complex of working ecosystems that influence and are influenced by neighboring ecosystems (**Figure 8.1**). The probability of achieving long-term, self-sustaining functions across this spatial complex increases with*

Figure 8.1: Stream running through a wet meadow. *Restoration design must consider site-specific conditions as an integral part of larger systems.*

“Leave It Alone / Let It Heal Itself”

There is a renewed emphasis on recovering damaged rivers (Barinaga 1996). Along with this concern, however, people should be reminded periodically that they serve as stewards of watersheds, not just tinkerers with stream sites. Streams in pristine condition, for example, should not be artificially “improved” by active rehabilitation methods.

At the other end of the spectrum, and particularly where degradation is caused by off-stream activities, the best solution to a river management problem might be to remove the problem source and “let it heal itself.” Unfortunately, in severely degraded streams this process can take a long time. Therefore the “leave it alone” concept can be the most difficult approach for people to accept (Gordon et al. 1992).

an understanding of these relationships, a common language for expressing them, and subsequent response. Designing to achieve stream- or corridor-specific solutions might not resolve problems or recognize opportunities in the landscape.

Stream corridor restoration design is still largely in an experimental stage. It is known however, that restoration design must consider site-specific or local conditions to be successful. That is, the design criteria, standards, and specifications should be for the specific project in a specific physical, climatic, and geographic location. These initiatives, however, can and should work with, rather than against, the larger systems of which they are an integral part.

This approach produces multiple benefits, including:

- *A healthy, sustainable pattern of land uses across the landscape.*
- *Improved natural resource quality and quantity.*
- *Restored and protected stream corridors and associated ecosystems.*
- *A diversity of native plants and animals.*
- *A gene pool that promotes hardiness, disease resistance, and adaptability.*
- *A sense of stewardship for private landowners and the public.*
- *Improved management measures that avoid narrowly focused and fragmented land treatment.*

Building on information presented in Parts I and II, this chapter contains design guidance and techniques to address changes caused by major disturbances and to restore stream corridor structure and function to a desired level. It begins with larger-scale influences that design may have on stream corridor ecosystems, offers design guidance primarily at the stream corridor and stream scales, and concludes with land use scenarios.

The chapter is divided into seven sections.

Section 8.A: Valley Form, Connectivity, and Dimension

This section focuses on restoring structural characteristics that prevail at the stream corridor and landscape scales.

Section 8.B: Soil Properties

The restoration of soil properties that are critical to stream corridor structure and functions are addressed in this section.

Section 8.C: Plant Communities

Restoring vegetative communities is a highly visible and integral component of a functioning stream corridor.

Section 8.D: Habitat Measures

This section presents design guidance for some habitat measures. They are often integral parts of stream corridor structure and functions.

Section 8.E: Stream Channel Restoration

Restoring stream channel structure and functions is often a fundamental step in restoring stream corridors.

Section 8.F: Streambank Restoration

This section focuses on design guidelines and related techniques for streambank stabilization. These measures can help reduce surface runoff and sediment transport to the stream.

Section 8.G: Instream Habitat Recovery

Restoring instream habitat structure and functions is often a key component of stream corridor restoration.

Section 8.H: Land Use Scenarios

This final section offers broad design concepts in the context of major land use scenarios.

8.F Streambank Restoration

Even where streams retain relatively natural patterns of flow and flooding, stream corridor restoration might require that streambanks be temporarily (years to decades) stabilized while floodplain vegetation recovers. The objective in such instances is to arrest the accelerated erosion often associated with unvegetated banks, and to reduce erosion to rates appropriate for the stream system and setting. In these situations, the initial bank protection may be provided primarily with vegetation, wood, and rock as necessary (refer to Appendix A).

In other cases, land development or modified flows may dictate the use of hard structures to ensure permanent stream stability, and vegetation is used primarily to address specific ecological deficiencies such as a lack of channel shading. In either case (permanent or temporary bank stabilization), streamflow projections are used (as described in Chapter 7) to determine the degree to which vegetation must be supplemented with more resistant materials (natural fabrics, wood, rock, etc.) to achieve adequate stabilization.

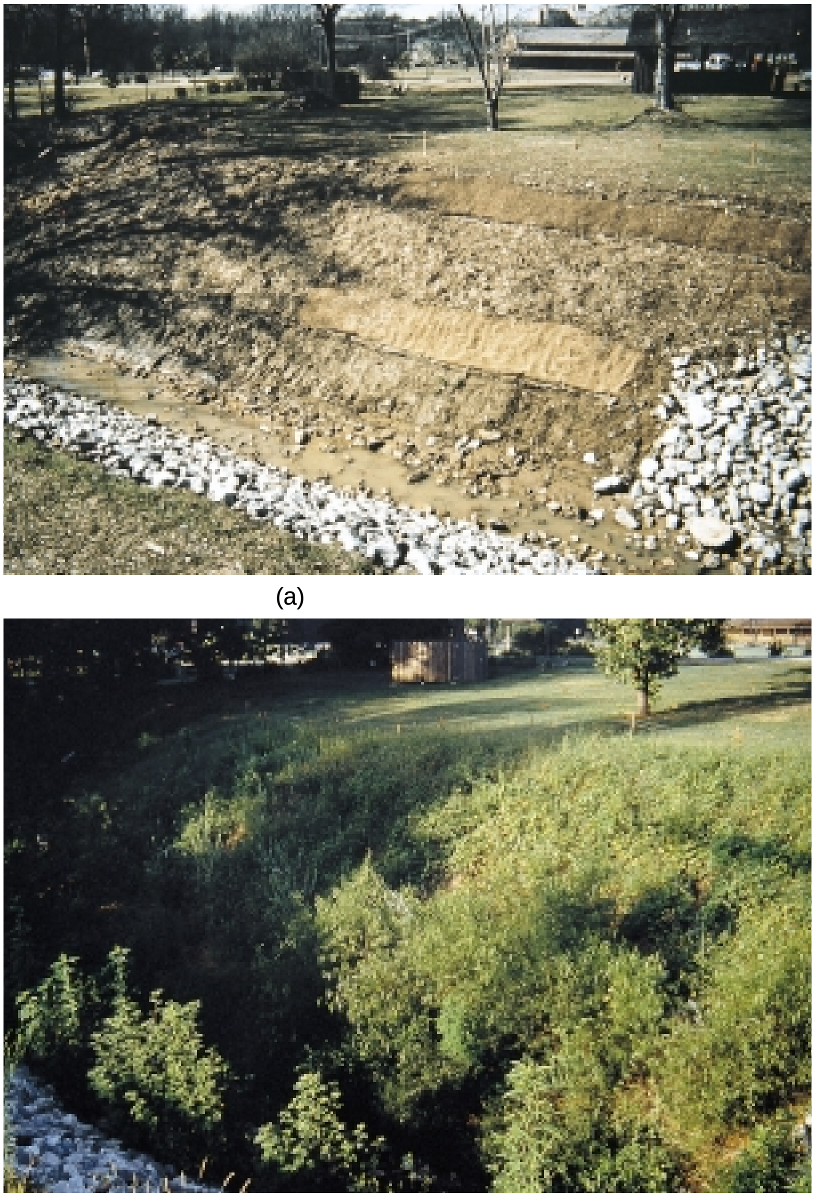
The causes of excessive erosion may be reversible through changes in land use, livestock management, floodplain restoration, or water management. In some cases, even normal rates of bank erosion and channel movement might be considered unacceptable due to adjacent development, and vegetation might be used primarily to recover some habitat functions in the vicinity of “hard” bank stabilization measures. In either case, the considerations discussed above with respect to soils, use of native plant species, etc., are applicable within the bank zone. However, a set of specialized techniques can be employed to help ensure plant establishment and improve habitat conditions.

As discussed earlier in this chapter, integration of woody vegetative cuttings, independently or in combination with other natural materials, in streambank erosion control projects is generally referred to as soil bioengineering. Soil-bioengineered bank stabilization systems have not been standardized for general application under particular flow conditions, and the decision as to whether and how to use them requires careful consideration of a variety of factors. On larger streams or where erosion is severe, an effective approach involves a team effort that includes expertise in soils, biology, plant sciences, landscape architecture, geology, engineering, and hydrology.

Soil bioengineering approaches usually employ plant materials in the form of live woody cuttings or poles of readily sprouting species, which are inserted deep into the bank or anchored in various other ways. This serves the dual purposes of resisting washout of plants during the early establishment period, while providing some immediate erosion protection due to the physical resistance of the stems. Plant materials alone are sufficient on some streams or some bank zones, but as erosive forces increase, they can be combined with other materials such as rocks, logs or brush, and natural fabrics (**Figure 8.37**). In some cases, woody debris is incorporated specifically to improve habitat characteristics of the bank and near-bank channel zones.

Preliminary site investigations (see **Figure 8.38**) and engineering analyses must be completed, as described in Chapter 7, to determine the mode of bank failure and the feasibility of using vegetation as a component of bank stabilization work. In addition to the technical analyses of flows and soils, preliminary investigations must include consideration of access, maintenance, urgency, and availability of materials.

Generalizations regarding water levels and flow velocities should be taken only as indications of the experiences reported from various bank stabilization projects. Any particular site must be evaluated to determine how vegetation can or cannot be used. Soil cohesiveness, the presence of gravel lenses, ice accumulation patterns, the amount of sunlight reaching the bank, and the ability to ensure that grazing will be precluded are all considerations in assessing the suitability of vegetation to achieve bank stabilization. In addition, modified flow patterns may make portions of the bank inhospitable to plants because of inappropriate timing of inundation rather than flow velocities and durations (Klimas 1987). The need to extend protection well beyond the immediate focus of erosion and to protect against flanking is an important design consideration.



(a)

(b)

Figure 8.37: A stabilized streambank. *Plant materials can be combined with other materials such as rocks, logs or brush, and natural fabrics. [(a) during and (b) after.]*

As noted in Section 8.E, streambank stabilization techniques can generally be classified as armor, indirect methods, or vegetative methods. The selection of the appropriate stabilization technique is extremely important and can be expressed in terms of the factors discussed below.

Effectiveness of Technique

The inherent factors in the properties of a given bank stabilization technique, and in the physical characteristics of a proposed work site, influence the suitability of that technique for that site. Effectiveness refers to the suitability and adequacy of the technique. Many techniques can be designed to adequately solve a specific bank stability problem by resisting erosive forces and geotechnical failure. The challenge is to recognize which technique matches the strength of protection against the strength of attack and therefore performs most efficiently when tested by the strongest process of erosion and most critical mechanism of failure. Environmental and economic factors are integrated into the selection procedure, generally making soil bioengineering methods very attractive. The chosen so-

CASE STUDY

Careless Creek, Montana

In the Big Snowy Mountains of central Montana, Careless Creek begins to flow through rangelands and fields until it reaches the Musselshell River. At the beginning of the century, the stream was lined with a riparian cover, primarily of willow. This stream corridor was home to a diversity of wildlife such as pheasant, beaver, and deer.

In the 1930s, a large reservoir was constructed to the west with two outlets, one connected to Careless Creek. These channels were meant to carry irrigation water to the area fields and on to the Musselshell River. Heavy flows during the summer months began to erode the banks (Figure 8.39a). In the following years, ranchers began clearing more and more brush for pasture, sometimes burning it out along a stream.

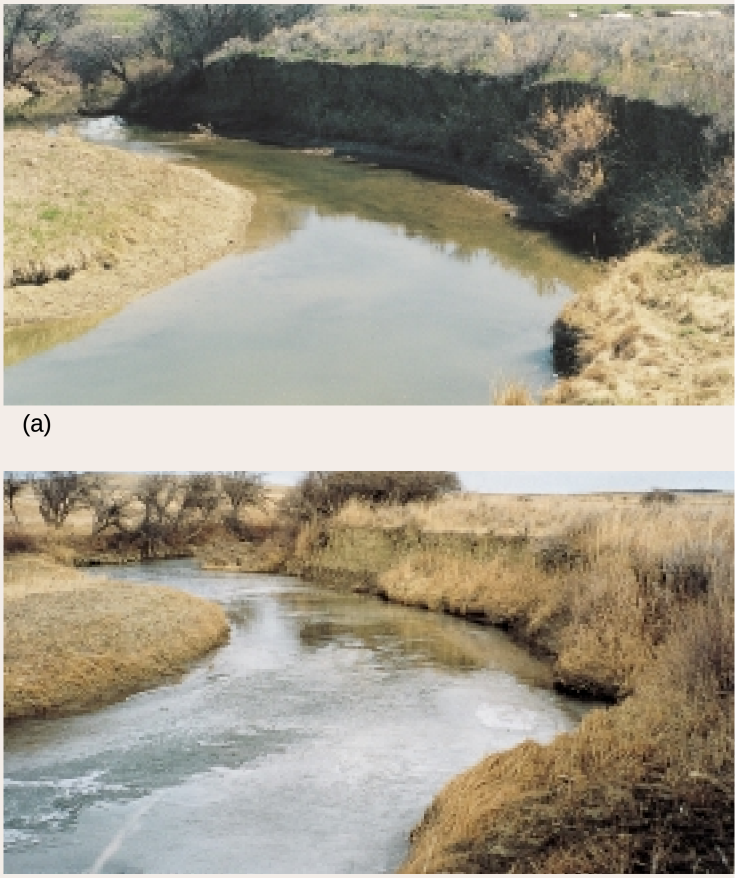
"My Dad carried farmer's matches in his pocket. There was a worn spot on his pants where he would strike a match on his thigh," said Jessie Zeier, who was raised on a ranch near Careless Creek, recalling how his father often cleared brush.

Any remaining willows or other species were eliminated in the following years as ranchers began spraying riparian areas to control sagebrush. This accelerated the streambank erosion as barren, sometimes vertical, banks began sloughing off chunks of salted g<None>s developed to help the planning effort. Many organizations took part, including the Upper and Lower Musselshell Conservation Districts; Natural Resources Conservation Service; Montana Department of Natural Resources and Conservation; Montana Department of Fish; Wildlife and Parks; Deadman's Basin Water Users Association; U.S. Bureau of Reclamation; Central Montana RC&D; City of Roundup; Roundup Sportsmen; county commissioners; and local landowners.

As part of the planning effort, a geographic information system resource inventory was begun in 1993. The inventory revealed about 50 percent of the banks along the 18 miles of Careless Creek were eroding. The inventory helped to locate the areas causing the most problems. Priority was given to headquarters, corrals, and croplands, where stabilization of approximately 5,000 feet of streambank has taken place, funded by EPA monies.

Passive efforts have also begun to stabilize the banks. Irrigation flows in Careless Creek have been decreased for the past 5 years, enabling some areas, such as the one pictured, to begin to self-heal (Figure 8.39b). Vegetation has been given a chance to root as erosion has begun to stabilize. Other practices, such as fencing, are being implemented, and future treatments are planned to provide a long-term solution.

Figure 8.39: Careless Creek. *(a) Eroded streambank (May 1995) and (b) streambank in recovery (December 1997).*



(a)

(b)

Figure 8.38: ***Eroded bank.*** *Preliminary site investigation and analyses are critical to successful streambank stabilization design.*

lution, however, must first fulfill the requirement of being effective as bank stabilization; otherwise, environmental and economic attributes will be irrelevant. Soil bioengineering can be a useful tool in controlling streambank erosion, but it should not be considered a panacea. It must be performed in a judicious manner by personnel experienced in channel processes, biology, and streambank stabilization techniques.

Stabilization Techniques

Plants may be established on upper bank and floodplain areas by using traditional techniques for seeding or by planting bare-root and container-grown plants. However, these approaches provide little initial resistance to flows, and plantings may be destroyed if subjected to high water before they are fully established. Cuttings, pole plantings, and live stakes taken from species that sprout readily (e.g., willows) are more resistant to erosion and can be used lower on the bank (**Figure 8.40**). In addition, cuttings and pole plantings can provide immediate moderation of flow velocities if planted at high densities. Often, they can be placed deep enough to maintain contact with adequate soil moisture levels, thereby eliminating the need for irrigation. The reliable sprouting properties, rapid growth, and general availability of cuttings of willows and other pioneer species makes them particularly appropriate for use in bank revegetation projects, and they are used in most of the integrated bank protection approaches described here (see **Figure 8.41**).

Anchored Cutting Systems

Several techniques are available that employ large numbers of cuttings arranged in layers or bundles, which can be secured to streambanks and partially buried. Depending on how these systems are arranged, they can provide direct protection from erosive flows, prevent erosion from upslope water sources, promote trapping of sediments, and quickly develop dense roots and sprouts. Brush mattresses and woven mats are typically used on the face of a bank and consist of cuttings laid side by side and interwoven or pinned down with jute cord or wire held in place by stakes. Brush layers are cuttings laid on terraces dug into the bank, then buried so that the branch ends extend from the bank. Fascines or wattles are bundles of cuttings tied together, placed in shallow trenches arranged horizontally on the bank face, partially buried, and staked in place. A similar system, called a reed roll, uses partially buried and staked burlap rolls filled with soil and root material or rooted shoots to establish herbaceous species in appropriate habitats. Anchored bundles of live cuttings also have been installed perpendicular to the channel on newly constructed gravel floodplain areas to dissipate floodwater energy and encourage deposition of sediment (Karle and Densmore 1994).

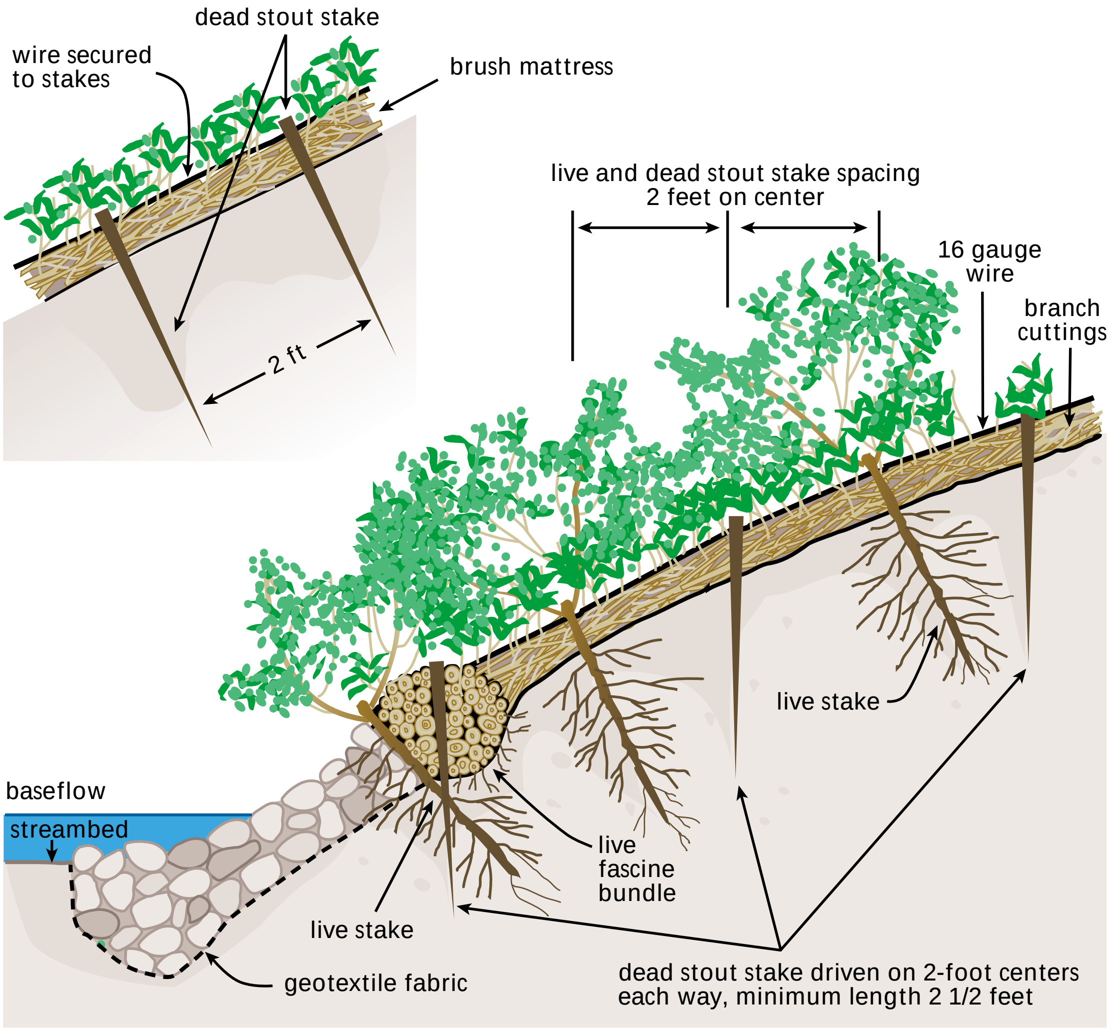


***Figure 8.40*: Cutting systems.** *Details of brushmattress technique.*

Source: USDA-NRCS 1996a.

Note: Rooted/leafed condition of the living plant material is not representative at the time of installation.

Geotextile Systems

Geotextiles have been used for erosion control on road embankments and other upland settings, usually in combination with seeding, or with plants placed through slits in the fabric. In self-sustaining streambank applications, only natural, biodegradable materials should be used, such as jute or coconut fiber (Johnson and Stypula 1993). The typical streambank use for these materials is in the construction of vegetated geogrids, which are similar to brush layers except that the fill soils between the layers of cuttings are encased in fabric, allowing the bank to be constructed of successive “lifts” of soil, alternating with brush layers. This approach allows reconstruction of a bank and provides considerable erosion resistance (see Green River case study). Natural fibers are also used in “fiber-schines,” which are sold specifically for streambank applications. These are cylindrical fiber bundles that can be staked to a bank with cuttings or rooted plants inserted through or into the material.

Vegetated plastic geogrids and other nondegradable materials can also be used where geotechnical problems require drainage or additional strength.

Figure 8.41: ***Results of live staking along a streambank.*** *Pioneer species are often most appropriate for use in bank revegetation projects.*

Integrated Systems

A major concern with the use of structural approaches to streambank stabilization is the lack of vegetation in the zone directly adjacent to the water. Despite a long-standing concern that vegetation destabilizes stone revetments, there has been little supporting evidence and even some evidence to the contrary (Shields 1991). Assuming that loss of conveyance is accounted for, the addition of vegetation to structures should be considered. This can involve placement of cuttings during construction, or insertion of cuttings and poles between stones on existing structures. Timber cribwalls may also be constructed with cuttings or rooted plants extending through the timbers from the backfill soils.

Trees and Logs

Tree revetments are made from whole tree trunks laid parallel to the bank, and cabled to piles or deadman anchors. Eastern red cedar (Juniperus virginiana) and other coniferous trees are used on small streams, where their springy branches provide interference to flow and trap sediment. The principal objective to these systems is the use of large amounts of cable and the potential for trees to be dislodged and cause downstream damage.

Some projects have successfully used large trees in conjunction with stone to provide bank protection as well as improved aquatic habitat (see case study). Large logs with intact root wads are placed in trenches cut into the bank, such that the root wads extend beyond the bank face at the toe (**Figure 8.42**). The logs are overlapped and/or braced with stone to ensure stability, and the protruding rootwads effectively reduce flow velocities at the toe and over a range of flow elevations (**Figure 8.43**). A major advantage of this approach is that it reestablishes one of the natural roles of large woody debris in streams by creating a dynamic near-bank environment that traps organic material and provides colonization substrates for invertebrates and refuge habitats for fish. The logs eventually rot, resulting in a more natural bank. The revetment stabilizes the bank until woody vegetation has matured, at which time the channel can return to a more natural pattern.

In most cases, bank stabilization projects use combinations of the techniques described above in an integrated approach. Toe protection often requires the use of stone, but amounts can be greatly reduced if large logs can also be used. Likewise, stone blankets on the bank face can be replaced with geogrids or supplemented with interstitial plantings. Most upper bank areas can usually be stabilized using vegetation alone, although anchoring systems might be required. The Green River bank restoration case study illustrates one successful application of an integrated approach on a moderate-sized river in Washington State.

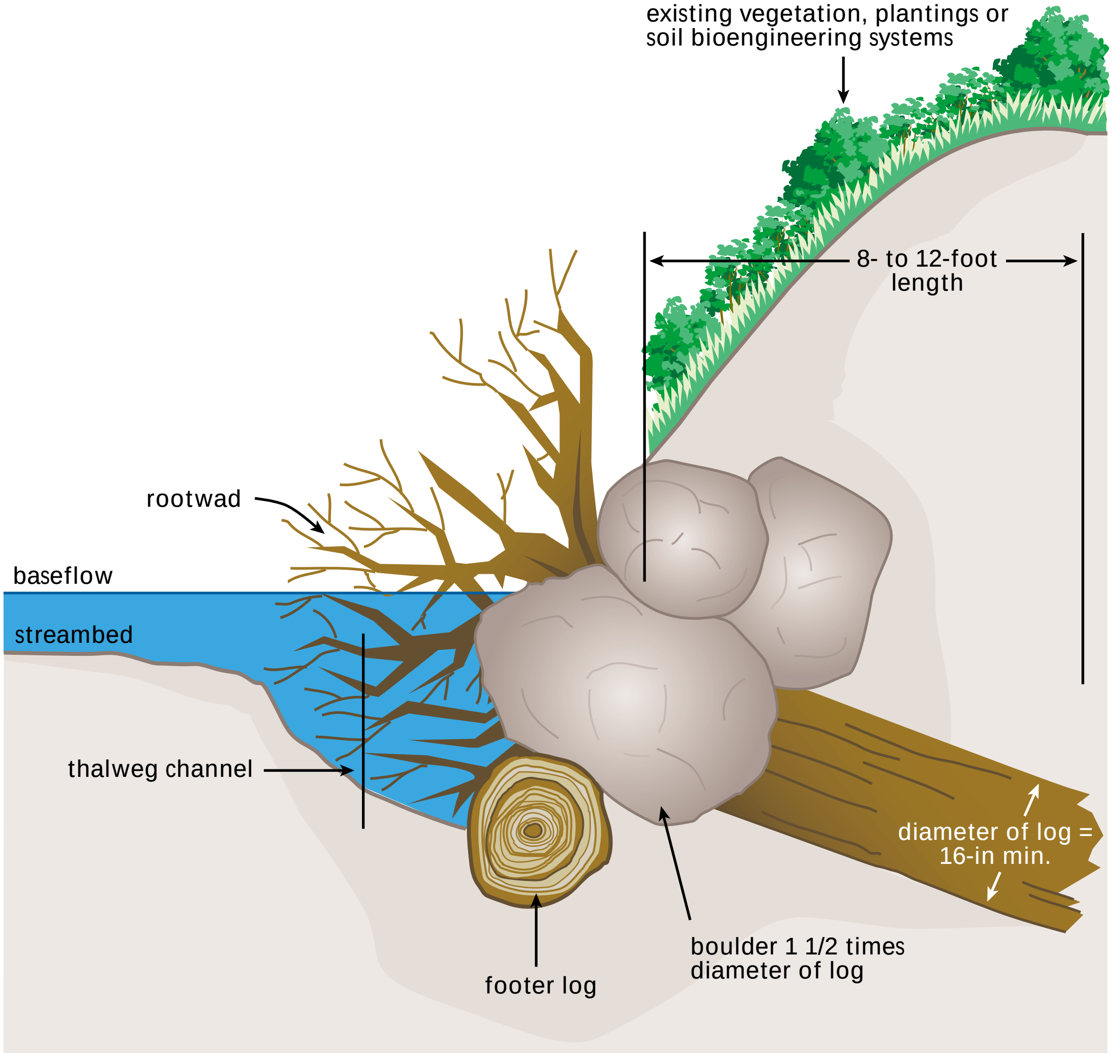


Figure 8.42: Revetment system. *Details of rootwad and boulder technique.* Source: USDA-NRCS 1996a.

Figure 8.43: Installation of logs with intact root wads. *An advantage to using tree revetments is the creation of habitat for invertebrates and fish along the streambank.*

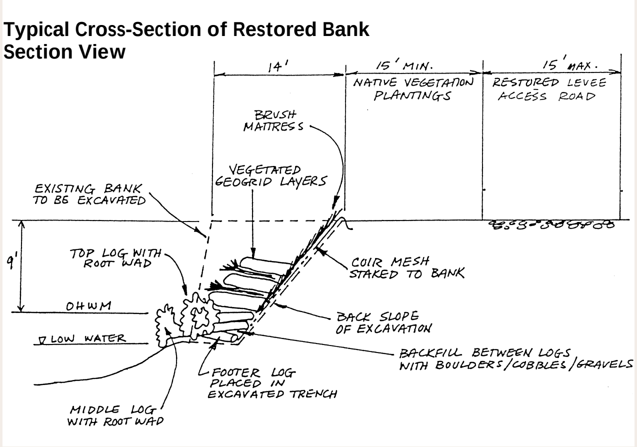
CASE STUDY

Green River Bank Restoration Initiative

King County, Washington

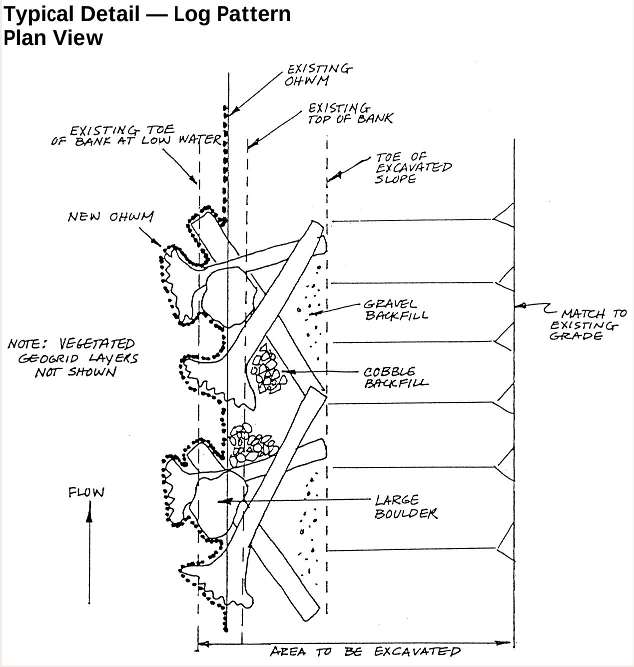
*The King County, Washington, Surface Water Management Division initiated a bank restoration initiative in 1994 that illustrates a variety of project objectives and soil bioengineering approaches (**Figure 8.44**). The project involved stabilization of the bank of the Green River along a 500-foot section of a meander bend that was rapidly migrating into the adjacent farm field. The project objectives included improvement of fish and wildlife habitat, particularly for salmonids.*

Typical Cross-Section of Restored Bank
Section View



(a)

Typical Detail — Log Pattern
Plan View



(b)

***Figure 8.44**: Construction details.*

Source: King County Surface Water Management Division.

Site investigations included surveys of stream cross sections, velocity measurements at two discharge levels, soil characterizations, and assessment of fish use of existing habitat features in the area. The streambank was vertical, 5 to 10 feet high, and composed of silty-clay-loam alluvium with gravel lenses. Flow velocities were 2 to 5 fps for flows of 200 and 550 cfs. Fish were primarily observed in areas of low velocities and/or near woody debris, and along the channel margins.

*In August, large woody debris was installed along the toe of the bank. The logs were cedar and fir, 25 feet long and 28 to 36 inches in diameter, with root wads 6 to 8 feet in diameter. The logs were placed in trenches cut 15 feet back into the bank so that the root wads extended into the channel, and large (3- to 4-foot diameter) boulders were placed among the logs at the toe. Log and boulder placement was designed to interlock and brace the logs and prevent movement. The project used approximately 10 logs and 20 boulders per 100 lineal feet of bank. In September, vegetated geogrids were installed above the toe zone to stabilize the high bank (**Figure 8.45**). The project was completed with installation of a variety of plants, including container-grown conifers and understory species, in a minimum 25-foot buffer along the top of the bank.*

*Within 2 months of completion, the site was subjected to three high flows, including an 8,430-cfs event in December 1994. Measured velocities along the bank were less than 2 fps at the surface and less than 1 fps 2 feet below the surface, indicating the effectiveness of the root wads in moderating flow velocities (**Figure 8.46**). Some surface erosion and washout of plants along the top bank occurred, and a subsequent event caused minor damage to the geogrid at one location. The maintenance repairs consisted of replanting and placement of additional logs to*

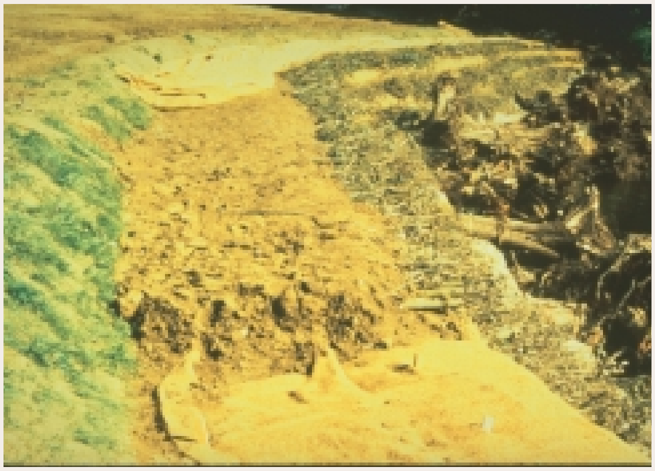


Figure 8.45: Partially installed vegetated geogrid. Installed above the toe to stabilize high bank.

Figure 8.46: Completed system. Note calm water along bankline during high flow.

halt undermining of the geogrid. The 1995 growing season produced dramatic growth of the willow cuttings in the geogrid, although many of the planted trees in the overbank zone died (**Figure 8.47**). Initial observations have documented extensive fish use of the slow-water habitats among the root wads at the toe of the bank, and in scour holes created by flows deflected toward the channel bottom.

The site continues to be carefully monitored, and the effectiveness of the approach has led to the implementation of similar designs elsewhere in the region. The project designers have concluded that future projects of this type should use small plants rather than large rooted material in the overbank zone to reduce costs, improve survival, and minimize damage due to equipment access for maintenance or repair. Based on their observations of fish response along the restored bank and in nearby stream reaches, they also recommend that future projects incorporate a greater variety of woody debris, including brushy material and tree tops, along the toe and lower bank.

Figure 8.47: Completed system after one year. Note dramatic willow growth from vegetated geogrid.

8.G Instream Habitat Recovery

As described in Chapter 2, habitat is the place where a population lives and includes living and nonliving components. For example, fish habitat is a place, or set of places, in which a single fish, a population, or an assemblage of fish can find the physical, chemical, and biological features needed for life, including suitable water quality, passage routes, spawning grounds, feeding and resting sites, and shelter from predators and adverse conditions (**Figure 8.48**). Principal factors controlling the quality of the available aquatic habitat include:

- Streamflow conditions.
- Physical structure of the channel.
- Water quality (e.g., temperature, pH, dissolved oxygen, turbidity, nutrients, alkalinity).
- The riparian zone.
- Other living components.

The existing status of aquatic habitats within the stream corridor should be assessed during the planning stage (Part II). Design of channels, structures, or restoration features can be guided and fine tuned by assessing the quality and quantity of habitats provided by the proposed design. Additional guidance on assessing the quantity and quality of aquatic habitat is provided in Chapter 7.

This section discusses the design of instream habitat structures for the purpose of enhancing physical aquatic habitat quality and quantity. It should be noted, however, that the best approach to habitat recovery is to restore a fully functional, well-vegetated stream corridor within a well-managed watershed. Man-made structures are less sustainable and rarely as effective as a stable channel. Over the long term, design should rely on natural fluvial processes interacting with floodplain vegetation and associated woody debris to provide high-quality aquatic habitat. Structures have little effect on populations that are limited by factors other than physical habitat.

Figure 8.48: Instream habitat. *Suitable water quality, passage routes, and spawning grounds are some of the characteristics of fish habitat.*

Instream Habitat Features

The following procedures to restore instream habitat are adapted from Newbury and Gaboury (1993) and Garcia (1995).

- Select stream. Give priority to reaches with the greatest difference between actual (low) and potential (high) fish carrying capacity and with a high capacity for natural recovery processes.
- Evaluate fish populations and their habitats. Give priority to reaches with habitats and species of special interest. Is this a biological, chemical, or physical problem? If a physical problem:
- Diagnose physical habitat problems.
    - Drainage basin. Trace watershed lines on topographical and geological maps to identify sample and rehabilitation basins.
    - Profiles. Sketch main stem and tributary long profiles to identify discontinuities that might cause abrupt changes in stream characteristics (falls, former base levels, etc.).
    - Flow. Prepare flow summary for rehabilitation reach using existing or nearby records if available (flood frequency, minimum flows, historical mass curve). Correct for drainage area differences. Compare magnitude and duration of flows during spawning and incubation to year class strength data to determine minimum and maximum flows required for successful reproduction.
    - Channel geometry survey. Select and survey sample reaches to establish the relationship between channel geometry, drainage area, and bankfull channel-forming discharge (**Figure 8.49**). Quantify hydraulic parameters at design discharge.
    - Rehabilitation reach survey. Survey rehabilitation reaches in sufficient detail to prepare channel cross section profiles and construction drawings and to establish survey reference markers.
    - Preferred habitat. Prepare a summary of habitat factors for biologically preferred reaches using regional references and surveys. Identify multiple limiting factors for the species and life stages of greatest concern. Where possible, undertake reach surveys in reference streams with proven populations to identify local flow conditions, substrate, refugia, etc.
- Design a habitat improvement plan. Quantify the desired results in terms of hydraulic changes, habitat improvement, and population increases. Integrate selection and sizing of rehabilitation works with instream flow requirements.
    - Select potential schemes and structures that will be reinforced by the

Man-made structures are less sustainable and rarely as effective as a stable channel.

Figure 8.49: Surveying a stream. *Channel surveys establish baseline information needed for restoration design.*

    existing stream dynamics and geometry. The following section provides additional detail on use of habitat structures.
    - Test designs for minimum and maximum flows and set target flows for critical periods derived from the historical mass curve.
- Implement planned measures.
    - Arrange for on-site location and elevation surveys and provide advice for finishing details in the stream.
- Monitor and evaluate results.
    - Arrange for periodic surveys of the rehabilitated reach and reference reaches, to improve the design, as the channel ages.

FAST FORWARD

Preview Chapter 9 for an ntroduction to construction and monitoring ollow-up activities.

Instream Habitat Structures

Aquatic habitat structures (also called instream structures and stream improvement structures) are widely used in stream corridor restoration. Common types include weirs, dikes, random rocks, bank covers, substrate reinstatement, fish passage structures, and off-channel ponds and coves. Institutional factors have favored their use over more holistic approaches to restoration. For example, it is often easier to obtain authority and funding to work within a channel than to influence riparian or watershed land use. Habitat structures have been used more along cold water streams supporting salmonid fisheries than along warm water streams, and the voluminous literature is heavily weighted toward cold water streams.

In a 1995 study entitled Stream Habitat Improvement Evaluation Project, 1,234 structures were evaluated according to their general effectiveness, the habitat quality associated with the given structure type, and actual use of the structures by fish (Bio West 1995). The study determined approximately 18 percent of the structures need maintenance. Where inadequate flows and excessive sediment delivery occur, structures have a brief lifespan and limited value in terms of habitat improvement. Furthermore, the study concluded that instream habitat structures generally provided increased fish habitat.

Before structural habitat features are added to a stream corridor restoration design, project managers should carefully determine whether they address the real need and are appropriate. Major caveats include the following:

- Structures should never be viewed as a substitute for good riparian and upland management.
- Defining the ecological purpose of a structure and site selection are as important as construction technique.
- Scour and deposition are natural stream processes necessary to create fish habitat. Overstabilization therefore limits habitat potential, whereas properly designed and sited structures can speed ecological recovery.
- Use of native materials (stone and wood) is strongly encouraged.
- Periodic maintenance of structures will be necessary and must be incorporated into project planning.

Instream Habitat Structure Design

Design of aquatic habitat structures should proceed following the steps presented below (Shields 1983). However, the process should be viewed as iterative, and considerable recycling among steps should be expected.

- Plan layout.
- Select types of structures.
- Size the structures.
- Investigate hydraulic effects.

- Consider effects on sediment transport.
- Select materials and design structures.

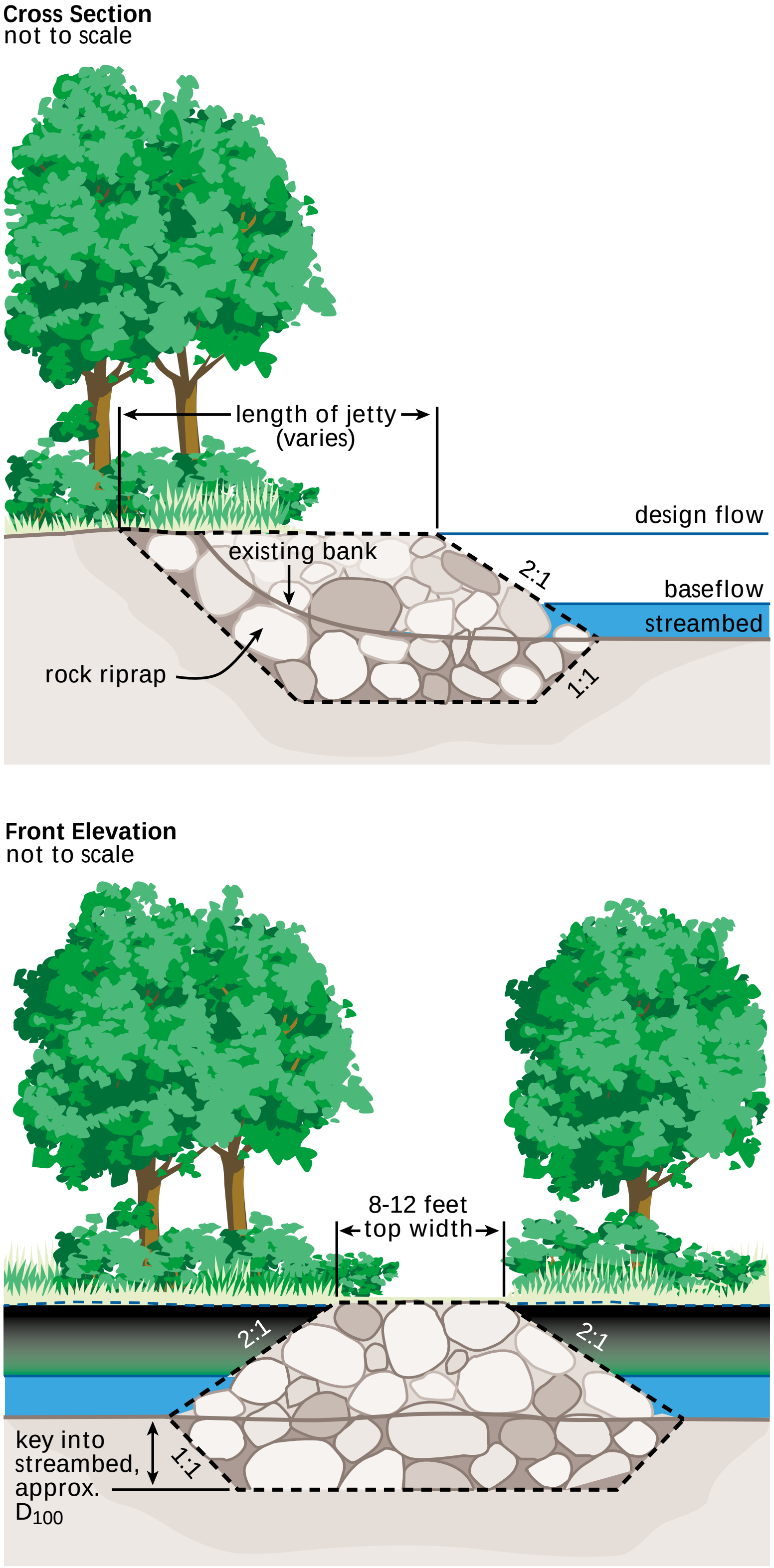
Each step is described below. Construction and monitoring follow-up activities are described in Chapter 9.

Plan Layout

The location of each structure should be selected. Avoid conflicts with bridges, riparian structures, and existing habitat resources (e.g., stands of woody vegetation). The frequency of structures should be based on the habitat requirements previously determined, within the context of the stream morphology and physical characteristics (see Chapter 7). Care should be taken to place structures where they will be in the water during baseflow. Structures should be spaced to avoid large areas of uniform conditions. Structures that create pools should be spaced five to seven channel widths apart. Weirs placed in series should be spaced and sized carefully to avoid placing a weir within the backwater zone of the downstream structure, since this would create a series of pools with no intervening riffles or shallows.

Select Types of Structures

The main types of habitat structures are weirs, dikes (also called jetties, barbs, deflectors (**Figure 8.50**), spurs, etc.), random rocks (also called boulders), and bank covers (also called lunkers). Substrate reinstatement (artificial riffles), fish passage structures, and off-channel ponds and coves have also been widely employed. Fact sheets on several of these techniques are provided in the *Techniques Appendix*, and numerous design web sites are available (White and Brynildson 1967, Seehorn 1985, Wesche 1985, Orsborn et al. 1992, Orth and White 1993, Flosi and Reynolds 1994).


Cross Section
not to scale

Front Elevation
not to scale

Figure 8.50: Instream habitat structure.
Wing deflector habitat structure.
Source: USDA-NRCS 1996a.

Evidence suggests that traditional design criteria for widespread bank and bed stabilization measures (e.g., concrete grade control structures, homogeneous riprap) can be modified, with no functional loss, to better meet environmental objectives and improve habitat diversity. **Table 8.7** may be used as a general guide to relate structural type to habitat requirement. Weirs are generally more failure-prone than deflectors. Deflectors and random rocks are minimally effective in environments where higher flows do not produce sufficient local velocities to produce scour holes near structures. Random rocks (boulders) are especially susceptible to undermining and burial when placed in sand-bed channels, although all types of stone structures experience similar problems. Additional guidance for evaluating the general suitability of various fish habitat structures for a wide range of morphological stream types is provided by Rosgen (1996). Seehorn (1985) provides guidance for small streams in the eastern United States. The use of any of these guides should also consider the relative stability of the stream, including aggradation and incision trends, for final design.

Size the Structures

Structures should be sized to produce the desired aquatic habitats at the normal range of flows from baseflow to bankfull discharge. A hydrological analysis can provide an estimate of the normal range of flows (e.g., a flow duration curve), as well as an estimate of extreme high and low flows that might be expected at the site (see Chapter 7). In general, structures should be low enough that their effects on the water surface profile will be slight at bankfull discharge. Detailed guidance by structural type is presented in the Techniques Appendix. For informal design, empirical equations like those presented by Heiner (1991) can be used to roughly estimate the depth of scour holes at weirs and dikes.

Investigate Hydraulic Effects

Hydraulic conditions at the design flow should provide the desired habitat; however, performance should also be evaluated at higher and lower flows. Barriers to movement, such as extremely shallow reaches or vertical drops not submerged at higher flows, should be avoided. If the conveyance of the channel is an issue, the effect of the proposed structures on stages at high flow should be investigated. Structures may be included in a standard backwater calculation model as contractions, low weirs, or increased flow resistance (Manning) coefficients, but the amount of increase is a matter of judgment or limited by National Flood Insurance Program ordinances. Scour holes should be included in the channel geometry downstream of weirs and dike since a major portion of the head loss occurs in the scour hole. Hydraulic analysis should include estimation or computation of velocities or shear stresses to be experienced by the structure.

Consider Effects on Sediment Transport

If the hydraulic analysis indicates a shift in the stage-discharge relationship, the sediment rating curve of the restored reach may change also, leading to deposition or erosion. Although modeling analyses are usually not cost-effective for a habitat structure design effort, informal analyses based on assumed relationships between velocity and sediment discharge at the bankfull discharge may be helpful in detecting potential problems. An effort should be made to predict the locations and magnitude of local scour and deposi-

Table 8.7: Fish habitat improvement structures—suitability for stream types.
Source: Rosgen 1996.

Channel Type	Low St. Check Dam	Medium St. Check Dam	Boulder Placement	Bank Boulder Placement	Single Wing Deflector	Double Wing Deflector	Channel Constrictor	Bank Cover
A1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
A2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
B1-1	Poor	Poor	Good	Excellent	Poor	Poor	Poor	Good
B1	Excellent	Excellent	N/A	N/A	Excellent	Excellent	N/A	Excellent
B2	Excellent	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
B3	Fair	Poor	Poor	Good	Poor	Poor	Poor	Poor
B4	Fair	Poor	Poor	Good	Poor	Poor	Poor	Poor
B5	Fair	Poor	Poor	Good	Poor	Poor	Poor	Poor
C1-1	Poor	Poor	Fair	Excellent	Poor	Poor	Poor	Good
C1	Good	Fair	Fair	Excellent	Good	Good	Fair	Good
C2	Excellent	Good	Good	Excellent	Good	Excellent	Excellent	Good
C3	Fair	Poor	Poor	Good	Fair	Fair	Fair	Good
C4	Fair	Poor	Poor	Good	Poor	Poor	Poor	Fair
C5	Fair	Poor	Poor	Good	Poor	Poor	Poor	Poor
C6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D1	Fair	Poor	Poor	Fair	Fair	Fair	Fair	Poor
D2	Fair	Poor	Poor	Fair	Fair	Fair	Fair	Poor

Channel Type	Half Log Cover	Floating Log Cover	Submerged Shelter		Migration Barrier	Gravel Traps		Gravel Placement
			Meander	Straight		"V" Shaped	Log	
A1	N/A	N/A	N/A	N/A	Excellent	Good	Poor	Poor
A2	N/A	N/A	N/A	N/A	Excellent	Excellent	Excellent	Poor
B1-1	Good	Good	Good	Excellent	Fair	Good	Good	Fair
B1	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Fair
B2	Excellent	Excellent	Good	Excellent	Good	Good	Good	Good
B3	Poor	Fair	Fair	Fair	Poor	Poor	Poor	Poor
B4	Poor	Fair	Fair	Fair	Poor	Poor	Poor	Poor
B5	Poor	Fair	Fair	Fair	Poor	Poor	Poor	Poor
C1-1	Good	Good	Good	Excellent	Poor	Fair	Fair	Fair
C1	Good	Good	Good	Excellent	Poor	Fair	Good	Fair
C2	Good	Excellent	Excellent	Excellent	Poor	Good	Excellent	Excellent
C3	Fair	Good	Fair	Good	Poor	N/A	N/A	N/A
C4	Poor	Good	Fair	Good	Poor	Poor	Poor	Poor
C5	Poor	Good	Fair	Good	Poor	Poor	Poor	Poor
C6	N/A	N/A	N/A	N/A	Poor	Poor	Fair	Fair
D1	Poor	Poor	Poor	Poor	Poor	Poor	N/A	Poor
D2	Poor	Poor	Poor	Poor	Poor	N/A	Poor	Poor

Key:
Excellent - No limitation to location of structure placement or special modification in design.
Good - Under most conditions, very effective. Minor modification of design or placement required.
Fair - Serious limitation which can be overcome by placement location, design modification, or stabilization techniques. Generally not recommended due to difficulty of offsetting potential adverse consequences and high probability of reduced effectiveness.
Poor - Not recommended due to morphological character of stream type and very low probability of success.
Not Applicable- Generally not considered since habitat components are not limiting.

Note : A3, A3-a, A4, A4-a, A5, A5-a channel types are not evaluated due to limited fisheries value.

tion. Areas projected to experience significant scour and deposition should be prime sites for visual monitoring after construction.

Select Materials

Materials used for aquatic habitat structures include stone, fencing wire, posts, and felled trees. Priority should be given to materials that occur on site under natural conditions. In some cases, it may be possible to salvage rock or logs generated from construction of channels or other project features. Logs give long service if continuously submerged. Even logs not continuously wet can give several decades of service if chosen from decay-resistant species. Logs and timbers must be firmly fastened together with bolts or rebar and must be well anchored to banks and bed. Stone size should be selected based on design velocities or shear stress.

8.H Land Use Scenarios

As discussed in Chapter 3, most stream corridor degradation is directly attributable to land use practices and/or hydrologic modifications at the watershed level that cause fundamental disruption of ecosystem functions (Beschta et al. 1994) (**Figure 8.51**). Ironically, land use practices, including hydrologic modifications, can offer the opportunity for restoring these same degraded stream corridors. Where feasible, the objective of the restoration design should be to eliminate or moderate disruptive influences sufficiently to allow recovery of dynamic equilibrium over time (NRC 1992).

Figure 8.51**: Sediment-laden stream.** *Most stream corridor degradation can be attributed to impacts resulting from surrounding land uses.*

If chronic land use impacts on the stream or riparian system cannot be controlled or moderated, or if some elements of the stream network (e.g., headwaters) are not included in the restoration design, it must be recognized that the restoration action may have limited effectiveness in the long-term.

Restoration measures can be designed to address particular, site-specific deficiencies (an eroding bank, habitat features), but if they do not restore self-maintaining processes and the functions of a stream corridor, they must be regarded as a focused "fix" rather than an ecosystem restoration. In cases where land use practices are the direct cause of stream corridor degradation and there is a continuing downward trend in landscape condition, there is little point in expending resources to address symptoms of the problem rather than the problem itself (DeBano and Schmidt 1989).

Design Approaches for Common Effects

Agriculture, forestry, grazing, mining, recreation, and urbanization are some of the principal land uses that can result in disturbance of stream corridor structure and functions. A watershed analysis will help prioritize and coordinate restoration actions (Platts and Rinne 1985, Swanson 1989) and may indicate critical or chronic land use activities causing disturbance both inside and outside the stream corridor. Addressing these in the restoration plan and design, may greatly improve the effectiveness and success of restoration work.

Restoration measures designed in response to these effects may be similar across land uses. Sediment and nutrient management in urban, agricultural, and forest settings, for instance, may require the use of buffer strips. Although the buffer strips have many common design characteristics, each setting has site-specific factors.

Dams

Dams alter the flow of water, sediment, organic matter, and nutrients, resulting in both direct physical and indirect biological effects in tailwaters and downstream riparian and floodplain areas (see Chapter 3). Stream corridors below dams can be partially restored by modifying operation and management approaches. Impacts from the operation of dams on surface water quality and aquatic and riparian habitat should be assessed and the potential for improvement evaluated. The modification of operation approaches, where possible, in combination with the application of properly designed and applied best management practices, can reduce the impacts caused by dams on downstream riparian and floodplain habitats.

Best management practices can be applied individually or in combination to protect and improve surface water quality and aquatic habitat in reservoirs as well as downstream. Several approaches have been designed for improving or maintaining acceptable levels of dissolved oxygen (DO), temperature, and other constituents in reservoirs and tailwaters. One design approach uses pumps, air diffusers, or air lifts to induce circulation and mixing of the oxygen-poor but cold hypolimnion with the oxygen-rich but warm epilimnion, resulting in a more thermally uniform reservoir with increased DO. Another design approach for improving water quality in tailwaters for trout fisheries involves mixing of air or oxygen with water passing through the turbines at hydropower dams to improve concentrations of DO. Reservoir waters can also be aerated by venting turbines to the atmosphere or by injecting compressed air into the turbine chamber (USEPA 1993).

Modification to the intakes, the spillway, or the tailrace of a dam can also be designed to improve temperature or DO levels in tailwaters. Installing various types of weirs downstream of a dam achieves similar results. These design practices rely on agitation and turbulence to mix reservoir releases with atmospheric air to increase levels of DO (USEPA 1993).

Adequate fish passage around dams, diversions, and other obstructions may be a critically important component of restoring healthy fish populations to previously degraded rivers and streams. A fact sheet in Appendix A shows an example for fish passages. However, designing, installing, and operating fish passage facilities at dams are beyond the scope of this handbook. Further, the type of fish passage facility and the flows necessary for operation are generally site specific. Further information on fish passage technology can be found in other references, including Environmental Mitigation at Hydroelectric Projects - Volume II. Benefits and Costs of Fish Passage and Protection (Francfort et al., 1994); and Fish Passage Technologies: Protection at Hydropower Facilities (Office of Technology Assessment, Congress of the United States, Washington DC, OTA-ENV-641).

Adjusting operation procedures at some dams can also result in improved quality of reservoir releases and downstream conditions. Partial restoration of stream corridors below dams can be achieved by designing operation procedures that mimic the natural hydrograph, or desirable aspects of the hydrograph. Modifications include scheduling releases or the duration of shutoff periods, instituting procedures for the maintenance of minimum flows, and making seasonal adjustments in pool levels and in the timing and variation of the rates of drawdowns (USEPA 1993).

Modifying operation and management approaches, in combination with the application of properly designed best management practices, can be an effective approach to partially restoring stream corridors below dams. However, dam removal is the only way to begin to fully restore a stream to its natural condition. It is important to note, however, that unless accomplished very carefully, with sufficient studies and modeling and at significant cost, removing a dam can cause more damage downstream (and upstream) than the dam is currently causing until a state of dynamic equilibrium is reached. Dam removal lowers the base level of upstream tributaries, which can cause rejuvenation, bed and bank instability, and increased sediment loads. Dam removal can also result in the loss of wetlands and habitat in the reservoir and tributary deltas.

Three options should be considered—complete removal, partial removal, and staged breaching. The option is selected based on the condition of the dam and future maintenance required if not completely removed, and on the best way to deal with the sediment now stored behind the dam. The following elements must be considered in managing sediment:

- Removing features of dams necessary to restore fish passage and ensure safety.
- Revegetation of the reservoir areas.
- Long-term monitoring of sediment transport and river channel topography, water quality, and aquatic ecology.
- Long-term protection of municipal and industrial water supplies.
- Mitigation of flood impacts caused by long-term river aggradation.
- Quality of sediment, including identification of the lateral and vertical occurrence of toxic or otherwise poor-quality sediment.

Water quality issues are primarily related to suspended sediment concentration and turbidity. These are important to municipal, industrial, and private water users, as well as to aquatic communities. Water quality will primarily be affected by any silt and clay released from the reservoirs and by reestablishment of the natural sediment loads downstream. During removal of the dam and draining of the lake, the unvegetated reservoir bottoms will be exposed. Lakebeds will be expected to have large woody debris and other organic material. A revegetation program is necessary to control dust, surface runoff, and erosion and to restore habitat and aesthetic values. A comprehensive sediment management plan is needed to address the following:

- Sediment volume and physical properties.
- Sediment quality and associated disposal requirements.
- Hydraulic and biological characteristics of the reservoir and downstream channel.
- Alternative measures for sediment management.
- Impacts on downstream environment and channel hydraulics.
- Recommended measures to manage sediment properly and economically.

Objectives of sediment management should include flood control, water quality, wetlands, fisheries, habitat, and riparian rights.

For hydropower dams, the simplest decommissioning program is to dismantle the turbine-generator and seal the water passages, leaving the dam and water-retaining structures in place. No action is taken concerning the sediments since they will remain in the reservoir and the hydraulic and physical characteristics of the river and reservoir will remain essentially unchanged. This approach is viable only if there are no deficiencies in the water-retaining structures (such as inadequate spillway capacity or inadequate factors of safety for stability) and long-term maintenance is ensured. In some cases, decommissioning can include partial removal of water-retaining structures. Partial removal involves demolition of a portion of the dam to create a breach so that it no longer functions as a water-retaining structure.

For additional information, see Guidelines for the Retirement of Hydroelectric Facilities published by the American Society of Civil Engineers (ASCE) in 1997.

Channelization and Diversions

Channelization and flow diversions represent forms of hydrologic modification commonly associated with most principal land uses, and their effects should be considered in all restoration efforts (see Chapter 3). In some cases, restoration design can include the removal or redesign of channel modifications to restore preexisting ecological and flow characteristics.

Modifications of existing projects, including operation and maintenance or management, can improve some negative effects without changing the existing benefits or creating additional problems. Levees may be set back from the stream channel to better define the stream corridor and reestablish some or all of the natural floodplain functions. Setback levees can be constructed to allow for overbank flooding, which provides surface water contact with streamside areas such as floodplains and wetlands.

Instream modifications such as uniform cross sections or armoring associated with channelization or flow diversions may be removed, and design and placement of meanders can be used to reestablish more natural channel characteristics. In many cases, however, existing land uses might limit or prevent the removal of existing channel or floodplain modifications. In such cases, restoration design must consider the effects of existing channel modifications or flow diversions, in the corridor and the watershed.

Exotic Species

Exotic species are another common problem of stream corridor restoration and management. Some land uses have actually introduced exotics that have become uncontrolled, while others have merely created an opportunity for such

CASE STUDY

The Multispecies Riparian Buffer System in the Bear Creek, IA Watershed

Introduction

The Bear Creek Watershed in central Iowa is a small (26.8 mi2) drainage basin located within the Des Moines Lobe subregion of the Western Corn Belt Plains ecoregion, one of the youngest and flattest ecological subregions in Iowa. In general, the land is level to gently rolling with a poorly developed stream network. Soils of the region are primarily developed in glacial till and alluvial, lacustrine, and windblown deposits. Prior to European settlement of the region (ca 1847) the watershed consisted of the vast tallgrass prairie ecosystem, interspersed with wet prairie marshes in topographic lows and gallery forests along larger order streams and rivers. Native forest was limited to the Skunk River corridor into which Bear Creek flows.

Subsequent conversion of the land, including the riparian zone, from native vegetation to row crops, extensive subsurface drainage tile installation, dredge ditching, and grazing of fenced riparian zones have resulted in substantial stream channel modification. Records suggest that artificial drainage of marshes and low prairies in the upper reaches of the Bear Creek watershed was completed about 1902, with ditch dredging completed shortly thereafter. While the main stream pattern appears to have remained about the same since that time, significant channelization continued into the 1970s. Additional intermittent channels have developed in association with new drainage tile and grass waterway installation. Present land use in the Bear Creek watershed is typical of the region, with over 87% of the land area devoted to row crop agriculture.

Landscape modifications and present land-use practices have produced nonpoint source pollution in the watershed, which landowners have addressed by implementing soil conservation practices (e.g. reduced tillage, terracing, grass waterways) and better chemical input management (e.g. more accurate and better timed applications). It has only been recently that placement or enhancement of riparian vegetation or "streamside filter strips" has been recommended to reduce sediment and chemical loading, modify flow regime by reducing discharge extremes, improve structural habitat, and restore energy relationships through the addition of organic matter and reduction in temperature and dissolved oxygen extremes.

The Riparian Management System (RiMS)

The Agroecology Issue Team of the Leopold Center for Sustainable Agriculture, Iowa State University, Ames, IA, is conducting research on the design and establishment of an integrated riparian management system (RiMS) to demonstrate the benefits of properly functioning riparian buffers in the heavily row-cropped landscape of the midwestern U.S. The purpose of the RiMS is to restore the essential ecological functions that riparian ecosystems once provided. Specific objectives of such buffers are to intercept eroding soil and agricultural chemicals from adjacent crop fields, slow floodwaters, stabilize streambanks, provide wildlife habitat, and improve the biological integrity of aquatic ecosystems. The regionalization of this system has been accomplished by designing it with several components, each of which can be modified to fit local landscape conditions and landowner objectives.

The Agroecology Issue Team is conducting detailed studies of important biological and physical processes at both the field and watershed scale to provide the necessary data to allow resource managers to make credible recommendations of buffer placement and design in a wide variety of landscapes. In addition, socioeconomic data collected from landowners in the watershed are being used to identify landowner criteria for accepting RiMS. The team also is quantifying the non-market value placed on the improvement in surface and ground water quality.

The actual development and establishment of the RiMS along Bear Creek was initiated in 1990 along a 0.6-mile length of Bear Creek on the Ron and Sandy Risdal Farm. The buffer strip system has subsequently been planted along 3.5 miles of Bear Creek upstream from this original site. The RiMS consists of three components: 1) a multi-species riparian buffer (MRB), 2) soil bioengineering technologies for streambank stabilization, and 3) constructed wetlands to intercept and process nonpoint source pollutants in agricultural drainage tile water.

Multi-species Riparian Buffer (MRB)

The general MRB consists of three zones. The rapid growth of this buffer community can change a heavily impacted riparian zone into a functioning riparian ecosystem in a few short years. The combinations of trees, shrubs, and native grasses can be modified to fit site conditions (e.g. soils, slope), major buffer biological and physical function(s), owner objectives, and cost-share program requirements.

Soil Bioengineering

It has been estimated that greater than 50% of the stream sediment load in small watersheds in the Midwest is the result of channel erosion. This problem has been worsened by the increased erosive power of streams resulting from stream channelization and loss of riparian vegetation. Several different soil bioengineering techniques have been employed in the Bear Creek watershed. These include the use of willow posts and stakes driven into the bank, live willow fascines, live willow brush mattresses, and biodegradable geotextile anchored with willow stakes on bare slopes. Alternatives used to stabilize the base of the streambank include rock and anchored dead plant material such as cedar or bundled maple.

Constructed Wetlands

Small, constructed wetlands which are integrated into the riparian buffer have considerable potential to remove nitrate and other chemicals from the extensive network of drain tile in the Midwest. To demonstrate this technology, a small (600^{yd2}) wetland was constructed to process drainage tile water from a 12-acre cropped field. The wetland was constructed by excavating a depressional area near the creek and constructing a low berm. The subsurface drainage tile was rerouted to enter the wetland at a point that maximizes residence time of drainage tile water within the wetland. A simple gated water level control structure at the wetland outlet provides control of the water level maintained within the wetland. Cattail rhizomes (Typha glauca Godr.) collected from a local marsh and road ditch were planted within the wetland and native grasses and forbs planted on the constructed berm. Future plans include the construction of additional tile drainage wetlands within the Bear Creek watershed.

System Effectiveness

Long-term monitoring has demonstrated the significant capability of the RiMS to intercept eroding soil from adjacent cropland, intercept and process agricultural chemicals moving in shallow subsurface water, stabilize stream channel movement, and improve instream environments, while also providing wildlife habitat and quality timber products. The buffer traps 70-80% of the sediment carried in surface runoff and has reduced nitrate and atrazine moving in the soil solution to levels well below the maximum contaminant levels specified by the USEPA. Streambank bioengineering systems have virtually stopped bank erosion along treated reaches and are now trapping channel sediment. The constructed wetland has reduced nitrate in the tile drainage water by as much as 80% depending on the season of the year. Wildlife benefits have also appeared in a very short time, with a nearly fivefold increase in bird species diversity observed within the buffer strip versus an adjacent, unprotected stream reach.

While the RiMS function is being assessed through experimental plot work with intensive process monitoring, economic benefits and costs to landowners and society also are being determined. Landowners surveys, focus groups, and one-on-one interviews have identified the concern that water quality should be improved by reducing chemical and sediment inputs by as much as 50%. Landowners are willing to pay for this improved water quality as well as volunteer their time to help initiate the improvements.

CASE STUDY

The Multispecies Riparian Buffer System in the Bear Creek, IA Watershed (continued)

While the RiMS can effectively intercept and treat nonpoint source pollution from the uplands, it should be stressed that a riparian management system cannot replace upland conservation practices. In a properly functioning agricultural landscape, both upland conservation practices and an integrated riparian system contribute to achieving environmental goals and improved ecosystem functioning.

Support for this work is from the Leopold Center for Sustainable Agriculture, the Iowa Department of Natural Resources through a grant from the USEPA under the Federal Nonpoint Source Management Program (Section 319 of the Clean Water Act), and the USDA (Cooperative State Research Education and Extension Service), National Research Initiative Competitive Grants Program, and the Agriculture in Concert with the Environment Program.

exotics to spread. Again, control of exotic species has some common aspects across land uses, but design approaches are different for each land use.

Control of exotics in some situations can be extremely difficult and may be impractical if large acreages or well-established populations are involved. Use of herbicides may be tightly regulated or precluded in many wetland and streamside environments, and for some exotic species there are no effective control measures that can be easily implemented over large areas (Rieger and Kreager 1990). Where aggressive exotics are present, every effort should be made to avoid unnecessary soil disturbance or disruption of intact native vegetation, and newly established populations of exotics should be eradicated.

Nonnative species such as salt cedar (Tamarix spp.) and Russian olive (Elaeagnus angustifolia) can outcompete native plantings and negatively affect their establishment and growth. The likelihood of successful reestablishment often increases when artificial flows created by impoundments are altered to favor native species and when exotics such as salt cedar are removed before revegetation is attempted (Briggs et al. 1994).

Salt cedar is an aggressive, exotic colonizer in the West due to its long period and high rate of seed production, as well as its ability to withstand long periods of inundation. Salt cedar can be controlled either by clearing with a bulldozer or by direct application of herbicide (Sudbrock 1993); however, improper treatments may actually increase the density of salt cedar (Neill 1990).

Controlling exotics and weeds can be important because of potential competition with established native vegetation, colonized vegetation, and artificially planted vegetation in restoration work. Exotics compete for moisture, nutrients, sunlight, and space and can adversely influence establishment rates of new plantings. To improve the effectiveness of revegetation work, exotic vegetation should be cleared prior to planting; nonnative growth must also be controlled after planting. General techniques for control of exotics and weeds are mechanical (e.g., scalping or tilling), chemical (herbicides), and fire. For a review of treatment methods and equipment, see U.S. Forest Service (1965) and Yoakum et al. (1980).

Agriculture

America's Private Land—A Geography of Hope (USDA-NRCS 1996b) challenges all of us to "regain our sense of place and renew our commitment to private landowners and the public." It suggests that as we learn more about the complexity of our environment, harmony with ecological processes that extend across all landscapes becomes more of an imperative than an ideal. Furthermore, conservation provisions of the 1996 Farm Bill and accompanying endeavors such as the National Conservation Buffer Initiative (USDA-NRCS 1997) offer flexibility to care for the land as never before. The following land use scenario attempts to express this flexibility in the context of comprehensive, locally led conservation work, including stream corridor restoration.

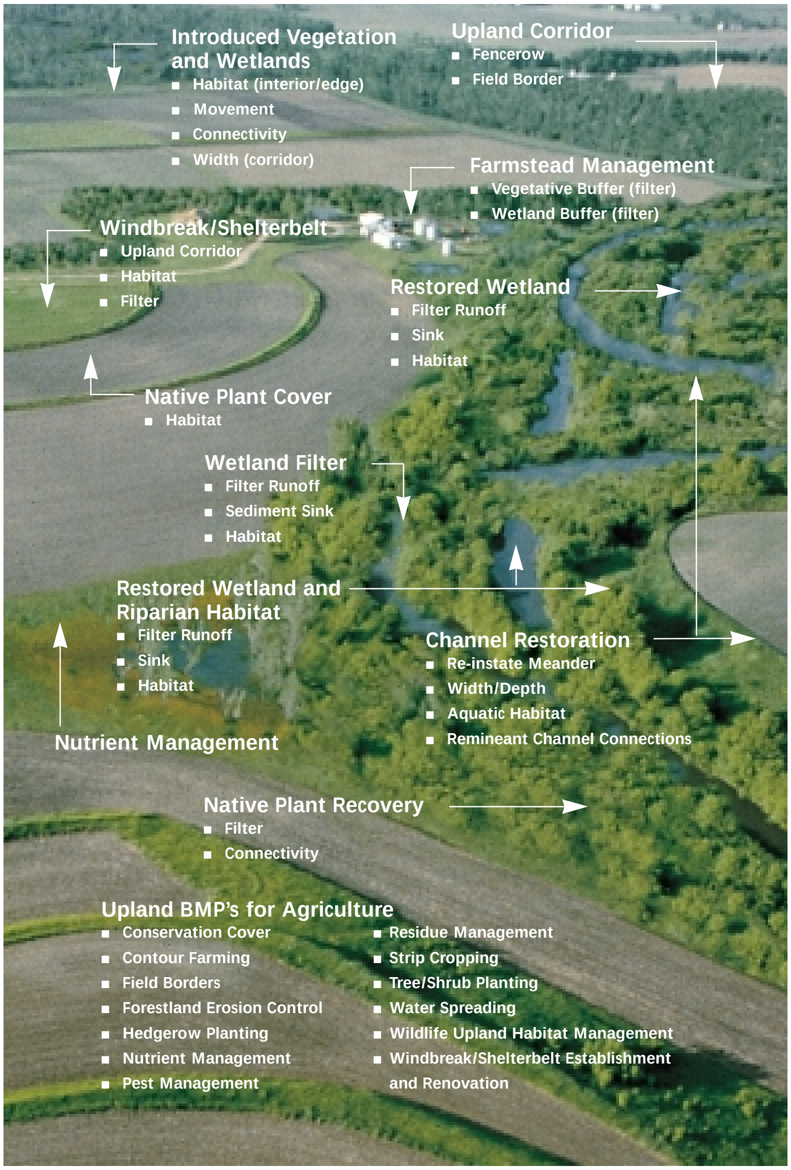
This scenario offers a brief glimpse into a hypothetical agricultural setting where the potential results of stream corridor restoration might begin to take form. Computer-generated simulations are used to graphically illustrate potential changes brought about by restoration work and associated comprehensive, on-farm conservation planning. It focuses, conceptually, on vegetative clearing, instream modifications, soil exposure and compaction, irrigation and drainage, and sediment or contaminants as the most disruptive activities associated with agricultural land use. Although an agricultural landscape typical of the Midwest was selected for illustrative purposes, the concepts shown can apply in different agricultural settings.

Hypothetical Existing Conditions

Reminiscent of the highly disruptive agricultural activities discussed in Chapter 3, **Figure 8.52** illustrates hypothetical conditions that focus primarily on production agriculture. Although functionally isolated contour terraces and a waterway have been installed in the nearby cropland, the scene depicts an ecologically deprived landscape. Many of the potential disturbance

Figure 8.52: ***Hypothetical conditions.*** *Activities causing change in this agricultural setting.*

Figure 8.53: Hypothetical restoration response. *Possible results of stream corridor restoration are presented in this computer-altered photograph.*



activities and subsequent changes outlined in Chapter 3 come to mind. Those hypothetically reflected in the figure are highlighted in **Table 8.8**.

Hypothetical Restoration Response

Previous sections of this chapter and earlier chapters identified connectivity and dimension (width) as important structural attributes of stream corridors. Nutrient and water flow, sediment trapping during floods, water storage, movement of flora and fauna, species diversity, interior habitat conditions, and provision of organic materials to aquatic communities were described as just a few of the functional conditions affected by these structural attributes. Continuous indigenous vegetative cover across the widest possible stream corridor was generally identified as the most conducive to serving the broadest range of functions. This discussion went on to suggest that a long, wide stream corridor with contiguous vegetative cover is a favored overall characteristic. A contiguous, wide stream corridor may be unachievable, however, where competing land uses prevail. Furthermore, gaps caused by disturbances (utility crossings, highways and access lanes, floods, wind, fire, etc.) are commonplace.

Restoration design should establish functional connections within and external to stream corridors. Landscape elements such as remnant patches of riparian vegetation, prairie, or forest exhibiting diverse or unique vegetative communities; productive land that can support ecological functions; reserve or abandoned land; associated wetlands or meadows; neighboring springs and stream systems; ecologically innovative residential areas; and movement corridors for flora and fauna (field borders, windbreaks, waterways, grassed terraces, etc.) offer opportunities to establish these connections. An edge (transition zone) that gradually changes from one land use into another will soften environmental gradients and minimize disturbance.

With these and the broad design guidelines presented in previous sections of this chapter in mind, **Figure 8.53** presents a conceptual computer-generated illustration of hypothetical restoration

Table 8.8: Summary of prominent agriculturally related disturbance activities and potential effects.

	Existing Disturbance Activities						
Potential Effects	Vegetative Clearing	Channelization	Streambed Disturbance	Soil Exposure or Compaction	Contaminants	Woody Debris Removal	Piped Discharge/Cont. Outlets
Decreased landscape diversity	■	■	□	□	□	□	□
Point source pollution	□	□	□	□	■	□	■
Nonpoint source pollution	■	■	■	□	■	■	■
Dense compacted soil	■	□	□	■	□	□	□
Increased upland surface runoff	■	□	□	■	□	□	□
Increased sheetflow with surface erosion rill and gully flow	■	□	□	■	□	□	□
Increased levels of fine sediment and contaminants in stream corridor	■	■	■	■	■	■	■
Increased soil salinity	□	□	□	□	■	□	□
Increased peak flood elevation	■	■	□	■	□	■	■
Increased flood energy	■	■	■	■	□	■	■
Decreased infiltration of surface runoff	■	□	□	■	□	□	■
Decreased interflow and subsurface flow to and within the stream corridor	■	■	□	■	■	□	■
Reduced ground water recharge and aquifer volumes	■	□	□	■	□	□	■
Increased depth to ground water	■	■	□	■	□	□	□
Decreased ground water inflow to stream	■	■	□	■	□	□	■
Increased flow velocities	■	■	■	■	□	■	■
Reduced stream meander	□	■	■	□	□	■	■
Increased or decreased stream stability	■	■	■	□	□	■	■
Increased stream migration	■	□	■	□	□	■	■
Channel widening and downcutting	■	■	■	□	□	■	■
Increased stream gradient and reduced energy dissipation	□	■	■	□	□	■	■
Increased flow frequency	■	□	□	■	□	□	■
Reduced flow duration	■	■	■	■	□	■	■
Decreased capacity of floodplain and upland	■	□	□	■	■	□	■
Increased sediment and contaminants	■	□	□	■	■	■	■
Decreased capacity of stream	□	■	■	□	■	■	■
Reduced stream capacity to assimilate nutrients/pesticides	■	■	■	■	■	■	■
Confined stream channel with little opportunity for habitat development	□	■	■	□	□	□	□
Increased streambank erosion and channel scour	■	■	■	■	□	■	■
Increased bank failure	■	■	□	■	□	■	■
Loss of instream organic matter and related decomposition	■	■	■	□	□	■	■
Increased instream sediment, salinity, or turbidity	■	■	■	□	■	■	■
Increased instream nutrient enrichment, sedimentation, and contaminants leading to eutrophication	■	□	■	■	■	■	■

■ Activity has potential for direct impact.

□ Activity has potential for indirect impact.

Table 8.8: Summary of prominent agriculturally related disturbance activities and potential effects (continued).

Potential Effects	Existing Disturbance Activities: Vegetative Clearing	Channelization	Streambed Disturbance	Soil Exposure or Compaction	Contaminants	Woody Debris Removal	Piped Discharge/Cont. Outlets
Highly fragmented stream corridor with reduced linear distribution of habitat and edge effect	■	■	□	□	□	■	□
Loss of edge and interior habitat	■	■	■	□	□	■	□
Decreased connectivity and dimension (width) within corridor and to associated ecosystems	■	■	■	□	□	□	□
Decreased movement of flora and fauna species for seasonal migration, dispersal repopulation	■	■	■	□	□	□	□
Reduced stream capacity to assimilate nutrients/pesticides	■	■	■	■	■	■	■
Increase of opportunistic species, predators	■	■	□	□	■	■	■
Increased exposure to solar radiation, weather, and temperature	■	■	■	■	□	■	□
Magnified temperature and moisture extremes in corridor	■	■	□	■	□	□	□
Loss of riparian vegetation	■	■	■	■	□	■	■
Decreased source of instream shade, detritus, food, and cover	■	■	■	□	□	□	■
Loss of edge diversity	■	■	□	□	□	□	□
Increased water temperature	■	■	■	□	□	□	■
Impaired aquatic habitat	■	■	■	□	■	□	■
Reduced invertebrate population	■	■	■	□	■	□	■
Loss of wetland function	□	■	■	□	□	□	□
Reduced instream oxygen	□	■	■	□	■	□	■
Invasion of exotic species	■	■	■	□	□	□	□
Reduced gene pool	■	■	■	□	□	□	■
Reduced species diversity	■	■	■	■	□	□	■

■ Activity has potential for direct impact.

□ Activity has potential for indirect impact.

results. **Table 8.9** identifies some of the restoration measures hypothetically implemented and their potential effects on restoring conditions within the stream corridor and surrounding landscape.

Forestry

Stream corridors are a source of large volumes of timber. Timber harvesting and related forest management practices in riparian corridors often necessitate stream corridor restoration. Forest management may be an on-going land use and part of the restoration effort. Regardless, accessing and harvesting timber affects streams in many ways including:

- Alteration of soil conditions.
- Removal of the forest canopy.
- Reduction in the potential supply of large organic (woody) debris (Belt et al. 1992).

Table 8.9: Summary of prominent restoration measures and potential resulting effects.

Potential Resulting Effects	Restoration Measures: Wetlands	Riparian Habitat	Upland Corridors	Windbreaks/Shelterbelts	Native Plant Cover	Stream Channel Restoration	Upland BMPs for Agriculture
Increased landscape diversity	■	■	■	■	■	■	■
Increased stream order	□	□	□	□	□	■	□
Reduced point source pollution	■	□	□	□	□	□	□
Reduced nonpoint source pollution	■	■	■	■	■	■	■
Increased soil friability	□	□	□	□	■	□	■
Decreased upland surface runoff	□	□	□	■	■	□	■
Decreased sheetflow, width, surface erosion, rill and gully flow	□	■	□	□	■	□	■
Decreased levels of fine sediment and contaminants in stream corridor	■	■	■	■	■	□	■
Decreased soil salinity	□	■	□	□	■	□	■
Decreased peak flood elevation	■	■	■	■	■	■	■
Decreased flood energy	■	■	■	■	■	■	■
Increased infiltration of surface runoff	■	■	■	■	■	■	■
Increased interflow and subsurface flow to and within stream corridor	■	■	□	□	■	■	■
Increased ground water recharge and aquifer volumes	■	■	■	■	■	■	■
Decreased depth to ground water	■	■	■	■	■	■	■
Increased ground water inflow to stream	■	■	■	□	■	■	■
Decreased flow velocities	■	■	■	■	■	■	■
Increased stream meander	□	□	□	□	□	■	□
Increased stream stability	■	■	■	□	■	■	■
Decreased stream migration	■	■	■	□	■	■	■
Reduced channel widening and downcutting	■	■	■	□	■	■	■
Decreased stream gradient and increased energy dissipation	■	■	□	□	□	■	■
Decreased flow frequency	■	■	■	□	■	□	■
Increased flow duration	■	■	■	□	■	■	■
Increased capacity of floodplain and upland	■	■	■	■	■	□	■
Decreased sediment and contaminants	■	■	■	■	■	□	■
Increased capacity of stream	■	■	□	□	□	■	□
Increased stream capacity to assimilate nutrients/pesticides	■	■	□	□	□	■	□
Enhanced stream channel with more opportunity for habitat development	■	■	□	□	□	■	□
Decreased streambank erosion and channel scour	■	■	□	□	□	■	■
Decreased bank failure	■	■	□	□	□	■	□
Gain of instream organic matter and related decomposition	■	■	□	□	□	■	□
Decreased instream sediment, salinity, or turbidity	■	■	■	■	■	■	■

■ Measure contributes directly to resulting effect. □ Measure contributes little to resulting effect.

Table 8.9: Summary of prominent restoration measures and potential resulting effects (continued).

Potential Resulting Effects	Restoration Measures: Wetlands	Riparian Habitat	Upland Corridors	Windbreaks/Shelterbelts	Native Plant Cover	Stream Channel Restoration	Upland BMPs for Agriculture
Decreased instream nutrient enrichment, siltation, and contaminants leading to eutrophication	■	■	■	■	■	■	■
Connected stream corridor with increased linear distribution of habitat and edge effect	■	■	□	□	■	■	■
Gain of edge and interior habitat	■	■	■	■	■	■	■
Increased connectivity and dimension (width) within corridor and to associated ecosystems	■	■	■	■	■	■	■
Increased movement of flora and fauna species for seasonal migration, dispersal repopulation	■	■	■	■	■	■	■
Decrease of opportunistic species, predators	■	■	□	□	■	■	■
Decreased exposure to solar radiation, weather, and temperature	■	■	■	■	■	■	■
Decreased temperature and moisture extremes in corridor	■	■	■	■	■	■	■
Increased riparian vegetation	■	■	□	□	■	■	■
Increased source of in stream shade, detritus, food, and cover	■	■	□	□	■	■	■
Increase of edge diversity	■	■	■	■	■	■	■
Decreased water temperature	■	■	■	■	■	■	■
Enhanced aquatic habitat	■	■	□	□	□	■	□
Increased invertebrate population	■	■	□	□	□	■	□
Increased wetland function	■	■	□	□	□	■	■
Increased instream oxygen	■	■	■	□	□	■	■
Decrease of exotic species	■	■	□	□	■	□	■
Increased gene pool	■	■	■	■	■	■	■
Increased species diversity	■	■	■	■	■	■	■

■ Measure contributes directly to resulting effect.

□ Measure contributes little to resulting effect.

Forest Roads

The vast majority of the restoration design necessary following timber harvest is usually devoted to the road system, where the greatest alteration of soil conditions has taken place. Inadequate drainage, poor location, improperly sized and maintained culverts, and lack of erosion control measures on road prisms, cut-and-fill slopes, and ditches are problems common to a poor road design (Stoner and McFall 1991). The most extreme road system rehabilitation requires full road closure. Full road closure involves removal of culverts and restoration of the streams that were crossed. It can also involve the ripping or tilling of road surfaces to allow plant establishment. If natural vegetation has not already invaded areas of exposed soils, planting and seeding might be necessary.

Full closure might not be a viable alternative if roads are needed to provide access for other uses. In these circumstances a design to restrict traffic might be appropriate. Voluntary traffic control usually cannot be relied on, so traffic barriers like gates, fences, or earth berms could be necessary. Even with traffic restriction, roads require regular inspection for existing or potential maintenance needs. The best time for inspection is during or immediately after large storms or snowmelt episodes so the effectiveness of the culverts and road drainage features can be witnessed first-hand. Design should address regular maintenance activities including road grading, ditch cleaning, culvert cleaning, erosion control vegetation establishment, and vegetation management.

BMP Implementation and Section 319 of the Clean Water Act

Section 319 of the Clean Water Act of 1987 required the states to identify and submit BMPs for USEPA approval to help control nonpoint sources of pollution. As of 1993, 41 of 50 states had EPA-approved voluntary or regulatory BMP programs dealing with silvicultural (forest management) activities. The state BMPs are all similar; the majority deal with roads. Montana, for example, has a total of 55 specifically addressed forest practices. Of those 55 practices, 35 deal with road planning and location, road design, road maintenance, road drainage, road construction, and stream crossings.

Buffer Strips in Forestry

Forested buffer strips are generally more effective in reducing sediment and chemical loadings in the stream corridor than vegetated filter strips (VFS). However, they are susceptible to similar problems with concentrated flows. Buffers constructed as part of a conservation system increase effectiveness. A stiff-stemmed grass hedge could be planted upslope of either a VFS or a woody riparian forest buffer. The stiff-stemmed grass hedge keeps sediment out of the buffer and increases shallow sheet flow through the buffer.

Most state BMPs also have special sections devoted to limitations for forest management activities in riparian “buffer strips” (also referred to as Streamside Management Zones or Streamside Protection Zones).

Budd et al. (1987) developed a procedure for determining buffer widths for streams within a single watershed in the Pacific Northwest. They focused their attention primarily on maintenance of fish and wildlife habitat quality (stream temperature, food supply, stream structure, sediment control) and found that effective buffer widths varied with the slope of adjacent uplands, the distribution of wetlands, soil and vegetation characteristics, and land use. They concluded that practical determinations of stream buffer width can be made using such analyses, but it is clear that a generic buffer width which would provide habitat maintenance while satisfying human demands does not exist. The determination of buffer widths involves a broad perspective that integrates ecological functions and land use. The section on design approaches to common effects at the beginning of this chapter also includes some discussion on stream buffer width.

Stream corridors have varied dimensions, but stream buffer strips have legal dimensions that vary by state (**Table 8.10**). The buffer may be only part of the corridor or it may be all of it. Unlike designing stream corridors for recreation features or grazing use, designing for timber harvest and related forest management activities is quite regimented by law and regulation. Specific requirements vary from state to state; the state Forester's office or local Extension Service can provide guidance on regulatory issues. USDA Natural Resource Conservation Service offices and Soil and Water Conservation District offices also are sources of information. Refer to Belt et al. (1992) and Welsch (1991) for guidance on riparian buffer strip design, function, and management. Salo and Cundy (1987) provide information on forestry effects on fisheries.

Grazing

The closer an ecosystem is managed to allow for natural ecological processes to function, the more successful a restoration strategy will be. In stream corridors that have been severely degraded by grazing, rehabilitation should begin with grazing management to allow for vegetative recovery.

Vegetative recovery is often more effective than installing a structure. The vegetation maintains itself in perpetuity, allows streams to function in ways that artificial structures cannot replicate, and provides resiliency that allows riparian systems to withstand a variety of environmental conditions (Elmore and Beschta 1987)

Designs that promote vegetative recovery after grazing are beneficial in a number of ways. Woody species can provide resistance to channel erosion and improve channel stability so that other species can become established. As vegetation becomes established, channel elevation will increase as sediment is deposited within and along the banks of the channel (aggradation), and water tables will rise and may reach the root zone of plants on former terraces or floodplains. This aggradation of the channel and the rising water table

State	Stream Class	Buffer Strip Requirements		
		Width	Shade or Canopy	Leave Trees
Idaho	**Class I***	Fixed minimum (75 feet)	75% current shade[a]	Yes, number per 1000 feet, dependent on stream width[b]
	Class II**	Fixed minimum (5 feet)	None	None
Washington	**Type 1, 2, and 3***	Variable by stream width (5 to 100 feet)	50%, 75% if temperature > 60ºF	Yes, number per 1000 feet, dependent on stream width and bed material
	Type 4**	None	None	25 per 1000 feet, 6 inches diameter
California	**Class I and Class II***	Variable by slope and stream class (50 to 200 feet)	50% overstory and/or understory; dependent on slope and stream class	Yes; number to be determined by canopy density
	Class III**	None[b]	50% understory[e]	None[e]
Oregon	**Class I****	Variable, 3 times stream width (25 to 100 feet)	50% existing canopy, 75% existing shade	Yes; number per 1000 feet and basal area per 1000 feet by stream width
	Class II special protection**	None[f]	75% existing shade	None

* Human water supply or fisheries use.

** Streams capable of sediment transport (CA) or other influences (ID and WA) or significant impact (OR) on downstream waters.

[a] In ID, the shade requirement is designed to maintain stream temperatures.

[b] In ID, the leave tree requirement is designed to provide for recruitment of large woody debris.

[c] May range as high as 300 feet for some types of timber harvest.

[d] To be determined by field inspection.

[e] Residual vegetation must be sufficient to prevent degradation of downstream beneficial uses.

[f] In eastern OR, operators are required to "leave stabilization strips of undergrowth... sufficient to prevent washing of sediment into Class I streams below."

Table 8.10: Buffer strip requirements by state.

CASE STUDY

Pacific Northwest Floods of 1996

Floods, Landslides, and Forest Management—'The Rest of The Story'

*Warm winds, intense rainfall, and rapid snowmelt during the winter of 1995-96 and again in the winter of 1996-97 caused major flooding, landslides, and related damage throughout the Pacific Northwest (**Figure 8.54**). Such flooding had not been seen for more than 30 years in hard-hit areas. Damage to roads, campgrounds, trails, watersheds, and aquatic resources was widespread on National Forest Service lands. These events offered a unique opportunity to investigate the effects of severe weather, examine the influence and effectiveness of various forest management techniques, and implement a repair strategy consistent with ecosystem management principles.*

The road network in the National Forests was heavily damaged during the floods. Decisions about the need to replace roads are based on long-term access and travel requirements. Relocation of roads to areas outside floodplains is a measure being taken. Examination of road crossings at streams concluded with design recommendations to keep the water moving, align culverts horizontally and longitudinally with the stream channel, and minimize changes in stream channel cross section at inlet basins to prevent debris plugs.

Many river systems were also damaged. In some systems, however, stable, well-vegetated slopes and streambanks combined with fully functioning floodplains buffered the effects of the floods. Restoration efforts will focus on aiding natural processes in these systems. Streambank stabilization and riparian plantings will be commonly used. Examination of instream structure durability concluded that structures are more likely to remain in place if they are in fourth-order or smaller streams and are situated in a manner that maintains a connection between the structure and the streambank. They will be most durable in watersheds with low landslide/debris torrent frequency.

(a)

(b)

Figure 8.54: 1996 Landslides. *(a) April landslide: debris took out the track into the Greenwater River and (b) July landslide: debris took out the road and deposited debris into the river.*

allow more water to be stored during wet seasons, thereby prolonging flow even during periods of drought (Elmore and Beschta 1987).

Kauffman et al. (1993) observed that fencing livestock out of the riparian zone is the only grazing strategy that consistently results in the greatest rate of vegetative recovery and the greatest improvement in riparian function. However, fencing is very expensive, requires considerable maintenance, and can limit wildlife access—a negative impact on habitat or conduit functions.

Some specialized grazing strategies hold promise for rehabilitating less severely impacted riparian and wetland areas without excluding livestock for long periods of time. The efficiency of a number of grazing strategies with respect to fishery needs are summarized in **Tables 8.11 and 8.12** (from Platts 1989). They summarize the influence of grazing systems and stream system characteristics on vegetation response, primarily from a western semiarid perspective. Some general design recommendations for selecting a strategy include the following (Elmore and Kauffmann 1994):

- Each strategy must be tailored to a particular stream or stream reach. Management objectives and components of the ecosystem that are of critical value must be identified (i.e., woody species recovery, streambank restoration, increased habitat diversity, etc.). Other information that should be identified includes present vegetation, potential of the site for recovery, the desired future condition, and the current factors causing habitat degradation or limiting its recovery.
- The relationships between ecological processes that must function for riparian recovery should be described. Factors affecting present condition (i.e., management stress vs. natural stress) and conditions required for the stream to resume natural functions need to be assessed. Anthropogenic factors causing stream degradation must be identified and changed.
- Design and implementation should be driven by attainable goals, objectives, and management activities that will achieve the desired structure and functions.
- Implementation should include a monitoring plan that will evaluate management, allowing for corrections or modifications as necessary, and a strong compliance and use supervision program.

The main consideration for selecting a grazing system is to have an adequate vegetative growing season between the period of grazing and timing of high-energy runoff. It is impossible to provide a cookie-cutter grazing strategy for every stream corridor; designs have to be determined on the ground, stream by stream, manager by manager. Simply decreasing the number of livestock is not a solution to degraded riparian conditions; rather, restoring these degraded areas requires fundamental changes in the ways that livestock are grazed (Chaney et al. 1990).

Clearly, the continued use of grazing systems that do not include the functional requirements of riparian vegetation communities will only perpetuate riparian problems (Elmore and Beschta 1987). Kinch (1989) and Clary and Webster (1989) provide greater detail on riparian grazing management and designing alternative grazing strategies. Chaney et al. (1990) present photo histories of a number of interesting grazing restoration case studies, and of the

Table 8.11: Evaluation and rating of grazing strategies.

Strategy[a]	Level to Which Riparian Vegetation is Commonly Used	Control of Animal Distribution (Allotment)	Streambank Stability	Brushy Species Condition	Seasonal Plant Regrowth	Stream Riparian Rehabilitation Potential	Fishery Needs Rating[b]
Continuous season-long (cattle)	Heavy	Poor	Poor	Poor	Poor	Poor	1
Holding (sheep or cattle)	Heavy	Excellent	Poor	Poor	Fair	Poor	1
Short duration-high intensity (cattle)	Heavy	Excellent	Poor	Poor	Poor	Poor	1
Three herd-four pasture (cattle)	Heavy to moderate	Good	Poor	Poor	Poor	Poor	2
Holistic (cattle or sheep)	Heavy to light	Good	Poor to good	Poor	Good	Poor to excellent	2-9
Deferred (cattle)	Moderate to heavy	Fair	Poor	Poor	Fair	Fair	3
Seasonal suitability (cattle)	Heavy	Good	Poor	Poor	Fair	Fair	3
Deferred-rotation (cattle)	Heavy to moderate	Good	Fair	Fair	Fair	Fair	4
Stuttered deferred-rotation (cattle)	Heavy to moderate	Good	Fair	Fair	Fair	Fair	4
Winter (sheep or cattle)	Moderate to heavy	Fair	Good	Fair	Fair to good	Good	5
Rest-rotation (cattle)	Heavy to moderate	Good	Fair to good	Fair	Fair to good	Fair	5
Double rest-rotation (cattle)	Moderate	Good	Good	Fair	good	Good	6
Seasonal riparian preference (cattle or sheep)	Moderate to light	Good	Good	Good	Fair	Fair	6
Riparian pasture (cattle or sheep)	As prescribed	Good	Good	Good	Good	Good	8
Corridor fencing (cattle or sheep)	None	Excellent	Good to excellent	Good to excellent	Good	Excellent	9
Rest-rotation with seasonal preference (sheep)	Light	Good	Good to excellent	Good to excellent	Good	Excellent	9
Rest or closure (cattle or sheep)	None	Excellent	Excellent	Excellent	Excellent	Excellent	10

[a] Jacoby (1989) and Platts (1989) define these management strategies

[b] Rating scale based on 1 (poorly compatible) to 10 (highly compatible with fishery needs)

Table 8.12: Generalized relationships between grazing systems, stream system characteristics, and riparian vegetation response.

Grazing System	Steep Low Sediment Load	Steep High Sediment Load	Moderate Low Sediment Load	Moderate High Sediment Load	Flat Low Sediment Load	Flat High Sediment Load
No grazing	Shrubs + Herbs + Banks 0	Shrubs + Herbs + Banks 0 to +	Shrubs + Herbs + Banks 0	Shrubs + Herbs + Banks +	Shrubs + Herbs + Banks +	Shrubs + Herbs + Banks +
Winter or dormant season	Shrubs + Herbs + Banks 0	Shrubs + Herbs + Banks 0 to +	Shrubs + Herbs + Banks +	Shrubs + Herbs + Banks +	Shrubs + Herbs + Banks +	Shrubs + Herbs + Banks +
Early growing season	Shrubs + Herbs + Banks 0	Shrubs + Herbs + Banks 0 to +	Shrubs + Herbs + Banks +	Shrubs + Herbs + Banks +	Shrubs + Herbs + Banks +	Shrubs + Herbs + Banks +
Deferred or late season	Shrubs – Herbs + Banks 0 to –	Shrubs – Herbs + Banks 0 to –	Shrubs – Herbs + Banks 0 to +	Shrubs – Herbs + Banks +	Shrubs – Herbs + Banks +	Shrubs – Herbs + Banks +
Three-pasture rest rotation	Shrubs – Herbs + Banks 0 to –	Shrubs – Herbs + Banks 0 to –	Shrubs – Herbs + Banks 0 to +	Shrubs – Herbs + Banks +	Shrubs – Herbs + Banks +	Shrubs – Herbs + Banks +
Deferred rotation	Shrubs – Herbs + Banks 0 to –	Shrubs – Herbs + Banks 0 to –	Shrubs – Herbs + Banks + to 0	Shrubs – Herbs + Banks +	Shrubs – Herbs + Banks +	Shrubs + Herbs + Banks +
Early rotation	Shrubs + Herbs + Banks 0 to –	Shrubs + Herbs + Banks 0 to +	Shrubs + Herbs + Banks + to 0	Shrubs + Herbs + Banks +	Shrubs + Herbs + Banks +	Shrubs + Herbs + Banks +
Rotation	Shrubs – Herbs + Banks 0 to –	Shrubs – Herbs + Banks 0 to –	Shrubs – Herbs + Banks 0 to +	Shrubs – Herbs + Banks +	Shrubs – Herbs + Banks +	Shrubs – Herbs + Banks +
Season-long	Shrubs – Herbs – Banks 0 to –	Shrubs – Herbs – Banks 0 to –	Shrubs – Herbs – Banks –	Shrubs – Herbs – Banks –	Shrubs – Herbs – Banks –	Shrubs – Herbs – Banks –
Spring and fall	Shrubs – Herbs – Banks 0 to –	Shrubs – Herbs – Banks 0 to –	Shrubs – Herbs – Banks –	Shrubs – Herbs – Banks –	Shrubs – Herbs – Banks – to 0	Shrubs – Herbs – Banks 0 to +
Spring and summer	Shrubs – Herbs – Banks 0 to –	Shrubs – Herbs – Banks 0 to –	Shrubs – Herbs – Banks –	Shrubs – Herbs – Banks – to 0	Shrubs – Herbs – Banks – to 0	Shrubs – Herbs – Banks 0 to +

Note: – = decrease; + = increase; 0 = no change. Stream gradient: 0 to 2% = flat; 2 to 4% = moderate; > 4% = steep. Banks refers to bank stability.

CASE STUDY

Oven Run, Pennsylvania

*The effects of abandoned mines draining into the surrounding lands cause dramatic changes in the area (**Figure 8.55**(a)). Runoff with high levels of minerals and acidity can denude the ground of vegetation, expose the soil, and allow erosion with the sediment further stressing streams and wetland. Any efforts to restore streams in this environment must deal with the problem if any success is to be likely.*

The Natural Resources Conservation Service, formerly known as the Soil Conservation Service, has been working on the Oven Run project along with the Stonycreek Conemaugh River Improvement (SCRIP) to improve water quality in a 4-mile reach above the Borough of Hooversville. SCRIP is a group of local and state government as well as hundreds of individuals interested in improving the water quality in an area on Pennsylvania's Degraded Watersheds list.

The initial goal of improving water quality resulted in improving habitat and aesthetic qualities. The water coming into Hooversville had higher-than-desired levels of iron, manganese, aluminum, sulfate, and acidity. Six former strip mines, which had a range of problems, were identified. They included deep mine openings that have large flows of acid mine drainage, acid mine seepage into streams, eroding spoil areas, areas of ponded water that infiltrate into ground water (adding to the acid mine drainage), and areas downhill of seepage and deep mine drainage that are denuded and eroding.

Control efforts included grading and vegetating the abandoned mine to reduce infiltration through acid-bearing layers and reduce erosion and sedimentation, surface water controls to carry water around the sites to safer outlets, and treating discharge flow with anoxic limestone drains and chambered passive wetland treatments (Figure 8.55(b)). Additionally, 1,000 feet of trees were planted along one of the site streams to shade the Stoneycreek River. Average annual costs for the six sites were estimated to be $503,000 compared to average annual benefits of $513,000.

The sites are being monitored on a monthly basis, and 4 years after work was begun the treatments have had a measurable success. The acid influent has been neutralized, and the effluent is now a net alkaline. Iron, aluminum, and manganese levels have been reduced, with iron now at average levels of 0.5 mg/L from average levels of 35 mg/L.

(a)

(b)

Figure 8.55: Stream corridor (a) before and (b) after restoration.

short-term results of some of the available grazing strategies.

Mining

Post-mining reclamation of stream corridors must begin with restoration of a properly functioning channel. Because many of the geologic and geomorphic controls associated with the pre-disturbance channel may have been obliterated by mining operations, design of the post-mining channel often requires approaches other than mimicking the pre-disturbance condition. Channel alignment, slope, and size may be determined on the basis of empirical relations developed from other streams in the same hydrologic and physiographic settings (e.g., Rechard and Schaefer 1984, Rosgen 1996). Others (e.g., Hasfurther 1985) have used a combination of empirical and theoretical approaches for design of reclaimed channels. Total reconstruction of stream channels is treated at length in Section 8.E. Other sections of the chapter address stabilization of streambanks, revegetation of floodplains and terraces, and restoration of aquatic and terrestrial habitats. Additional guidance is available in Interfluve, Inc. (1991).

Surface mining is usually associated with large-scale disturbances in the contributing watershed, therefore, a rigorous hydrological analysis of pre- and post-mining conditions is critical for stream corridor restoration of disturbed systems. The hydrologic analysis should include a frequency analysis of extreme high- and low-flow events to assess channel performance in the post-mining landscape.

Hydrologic modeling may be required to generate runoff hydrographs for the post-mining channel because watershed geology, soils, vegetation, and topography may be completely altered by mining operations. Thus, channel design and stability assessments will be based on modeled runoff rates reflecting expected watershed conditions. The hydrologic analysis for post-mining restoration should also address sediment production from the reclaimed landscape. Sediment budgets (see Chapter 7) will be needed for both the period of vegetation establishment and the final revegetated condition.

The hydrologic analyses will provide restoration practitioners with the flow and sediment characteristics needed for restoration design. The analyses may also indicate a need for at least temporary runoff detention and sediment retention during the period of vegetation establishment. However, the post-mining channel should be designed for long-term equilibrium with the fully reclaimed landscape.

Water quality issues (e.g., acid mine drainage) often control the feasibility of stream restoration in mined areas and should be considered in design.

Recreation

Both concentrated and dispersed recreational use of stream corridors can cause damage and ecological change. Ecological damage primarily results from the need for access for the recreational user. A trail often will develop along the shortest or easiest route to the point of access on the stream. Additional resource damage may be a function of the mode of access to the stream: motorcycles and horses cause far more damage to vegetation and trails than do pedestrians. Control of streambank access in developed recreation sites must be part of a restoration design. On undeveloped or unmanaged sites, such control is more difficult but still very necessary (**Figure 8.56**).

Rehabilitation of severely degraded recreation areas may require at least temporary use restrictions. Even actively eroding trails, camp and picnic sites, and stream access points can be stabilized through temporary site closure and combinations of soil and vegetation restoration (Wenger 1984, Marion and Merriam 1985, Hammitt and Cole 1987). Closure will not provide a long-term solution if access is restored without addressing the cause of the original problem. Rather, new trails and recreation sites should be located and constructed based on an understanding of vegetation capabilities, soil limitations, and other physical site characteristics. Basically, the keys to a successful design are:

- Initially locating or moving use to the most damage-resistant sites.
- Influencing visitor use.
- Hardening use areas to make them more resistant.
- Rehabilitating closed sites.

Urbanization

Few land uses have the capacity to alter water and sediment yield from a drainage as much as the conversion of a watershed from rural to urban conditions; thus, few land uses have greater potential to affect the natural environment of a stream corridor.

As a first step in hydrologic analyses, designers should characterize the nature of existing hydrologic response and the likelihood for future shifts in water and sediment yield. Initially, construction activities create excess sediment that can be deposited in downstream channels and floodplains. As impervious cover increases, peak flows increase. Water becomes cleaner as more area is covered with landscaping or impervious material. The increased flows and cleaner water enlarge channels, which increases sediment loads downstream.

Figure 8.56: Controlled access. *Control of streambank access is an important part of the restoration design.*
Source: J. McShane.

Determine if the watershed is (a) fully urbanized, (b) undergoing a new phase of urbanization, or (c) is in the beginning stages of urbanization (Riley, 1998).

An increase in the amount of impervious cover in a watershed leads to increased peak flows and resulting channel enlargement (**Figure 8.57**). Research has shown that impervious cover of as little as 10 to 15 percent of a watershed can have significant adverse effects on channel conditions (Schueler 1996). Magnitudes of channel-forming or bankfull flood events (typically 1- to 3-year recurrence intervals) are increased significantly, and flood events that previously occurred once every year or two may occur as often as one or two times a month.

Enlargement of streams with subsequent increases in downstream sediment loads in urbanized watersheds should be expected and accommodated in the design of restoration treatments.

Figure 8.57: Storm water flow on a paved surface. *Impervious surfaces increase peak flows and can result in channel enlargement.* Source: M. Corrigan.

Procedures for estimating peak discharges are described in Chapter 7, and effects of urbanization on magnitude of peak flows must be incorporated into the analysis. Sauer et al. (1983) investigated the effect of urbanization on peak flows by analyzing 199 urban watersheds in 56 cities and 31 states. The objective of the analysis was to determine the increase in peak discharges due to urbanization and to develop regression equations for estimating design floods, such as the 100-year or 1 percent chance annual flood, for ungauged urban watersheds. Sauer et al. (1983) developed regression equations based on watershed, climatic, and urban characteristics that can be used to estimate the 2, 5, 10, 25, 50, 100, and 500-year urban annual peak discharges for ungauged urban watersheds. The equation for the 100-year flood in cubic feet per second (UQ100) is provided as an example:

$$UQ100 = 2.50\ A^{.29}\ SL^{.15}\ (RI2+3)^{1.26}$$

$$(ST+8)^{-.52}\ (13-BDF)^{-.28}\ IA^{.06}\ RQ100^{.63}$$

where the explanatory variables are drainage area in square miles (A), channel slope in feet per mile (SL), the 2-year, 2-hour rainfall in inches (RI2), basin storage in percent (ST), basin development factor (BDF), which is a measure of the extent of development of the drainage system (dimensionless, ranging from 0 to 12), percent impervious area (IA), and the equivalent rural peak discharge in cubic feet per second (RQ100) in the example equation above.

Sauer et al. (1983) provide the allowable range for each variable. The two indices of urbanization in the equation are BDF and IA. They can be used to adjust the rural peak discharge RQ100 (either estimated or observed) to urban conditions.

Sauer et al. (1983) provide equations like the one above and graphs that relate the ratio of the urban to rural peak discharge (UQx/RQx) for recurrence intervals x = 2, 10, and 100 years. The 2-year peak ratio varies from 1.3 to 4.3, depending on the values of BDF and IA; the 10-year ratio varies from 1.2 to 3.1; and the 100-year ratio varies from 1.1 to 2.6. These ratios indicate that urbanization generally has a lesser effect on higher-recurrence-interval floods because watershed soils are more saturated and floodplain storage more fully depleted in large floods, even in the rural condition.

More sophisticated hydrologic analyses than the above are often used, including use of computer models, regional regression equations, and statistical analyses of gauge data. Hydrologic models, such as HEC-1 or TR-20, are often already developed for some urban watersheds.

Once the flood characteristics of the stream are adjusted for urbanization, new equilibrium channel dimensions can be estimated from hydraulic geometry relationships developed using data from stable, alluvial channels in similar (soils, slope, degree of urbanization) watersheds, or other analytical approaches. Additional guidance for design of restored channels is provided earlier in this chapter in the section on channel reconstruction.

Changes in flooding caused by urbanization of a watershed can be mitigated during urban planning through practices designed to control storm runoff. These practices emphasize the use of vegetation and biotechnical methods, as well as structural methods, to maintain or restore water quality and dampen peak runoff rates. Strategies for controlling runoff include the following:

- Increasing infiltration of rainfall and streamflow to reduce runoff and to remove pollutants.
- Increasing surface and subsurface storage to reduce peak flows and induce sediment deposition.
- Filtration and biological treatment of suspended and soluble pollutants (i.e., constructed wetlands).
- Establishment and/or enhancement of forested riparian buffers.
- Management of drainage from the transportation network.
- Introduction of trees, shrubs, etc., for various restoration purposes.

In addition to changes in water yield, urbanization of a watershed frequently generates changes in its sediment yield. In humid climates, vegetative cover prior to urbanization often is adequate to protect soil resources and minimize natural erosion, and the combination of impervious area and vegetation of a fully urban watershed might be adequate to minimize sediment yield. During the period of urbanization, however, sediment yields increase significantly as vegetation is cleared and bare soil is exposed during the construction process. In more arid climates, sediment yield from an urban watershed may actually be lower than the yield from a rural watershed due to the increased impervious area and vegetation associated with landscaping, but the period of urbanization (i.e., construction) is still the time of greatest sediment production.

The effect of urbanization on sediment discharge is illustrated in **Figure 8.58**, which contains data from nine subbasins in a 32-square-mile area in the Rock Creek and Anacostia River Basins north of Washington, DC (Yorke and Herb 1978). During the period of data collection (1963-74), three subbasins remained virtually rural while the others underwent urban development. In 1974, urban land represented from 0 to 60 percent of land use in the nine subbasins. These data were used to develop a relation between suspended sediment yield and the percentage of land under construction. This relation indicated that suspended sediment yield increased about 3.5 times for watersheds with 10 percent of the land area under construction. However, suspended-sediment yields for watersheds where sediment controls (primarily sediment basins) were employed for 50 percent of the construction area were only about one-third of these for areas without controls. The effect of controls is seen in the figure. The three curves present growing season data for three periods of increasing sediment control: 1963-67, when no controls were used on construction sites; 1968-71, when controls were mandatory; and 1972-74, when controls were mandatory and subject to inspection by county officials. It further illustrates that storm runoff is not the only factor affecting storm sedi-

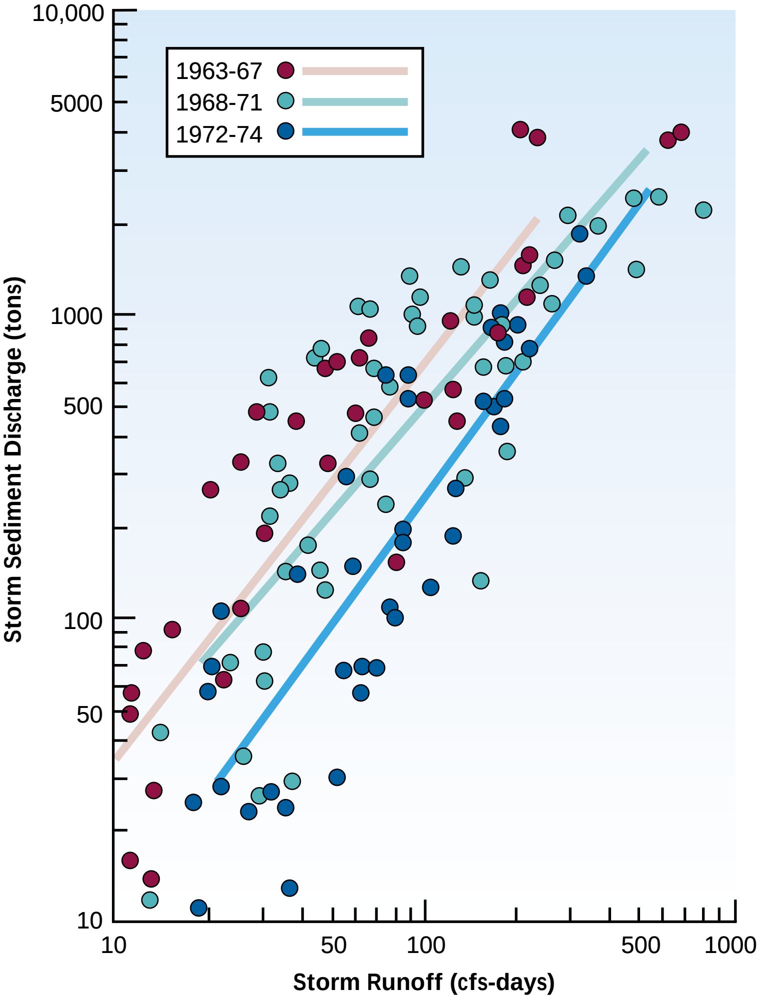


Figure 8.58: Sediment-transport curves for growing season storms. *The effect of urbanization on sediment discharge is illustrated from data collected in a 32-square-mile area.*

ment discharge as evidenced by the significant scatter about each relation.

In addition to sediment basins, management practices for erosion and sediment control focus on the following objectives:

- Stabilizing critical areas along and on highways, roads, and streets.
- Siting and placement of sediment migration barriers.
- Design and location of measures to divert or exclude flow from sensitive areas.
- Protection of waterways and outlets.
- Stream and corridor protection and enhancement.

All of these objectives emphasize the use of vegetation for sediment control. Additional information on BMPs for controlling runoff and sediment in urban watersheds can be found in the *Techniques Appendix*.

In theory, a local watershed management plan might be the best tool to protect a stream corridor from the cumulative impact of urban development; however, in practice, few such plans have realized this goal (Schueler 1996). To succeed, such plans must address the amount of bare ground exposed during construction and the amount of impervious area that will exist during and after development of the watershed. More importantly, success will depend on using the watershed plan to guide development decisions, and not merely archiving it as a one-time study whose recommendations were read once but never implemented (Schueler 1996).

Key Tools of Urban Stream Restoration Design

Restoration design for streams degraded by prior urbanization must consider pre-existing controls and their effects on restoration objectives. Seven restoration tools can be applied to help restore urban streams. (Schereler,1996) These tools are intended to compensate for stream functions and processes that have been diminished or degraded by prior watershed urbanization. The best results are usually obtained when the following tools are applied together.

Tool 1. Partially restore the predevelopment hydrological regime. The primary objective is to reduce the frequency of bankfull flows in the contributing watershed. This is often done by constructing upstream storm water retrofit ponds that capture and detain increased storm water runoff for up to 24 hours before release (i.e., extended detention). A common design storm for extended detention is the one-year, 24 hour storm event. Storm water retrofit ponds are often critical in the restoration of small and midsized streams, but may be impractical in larger streams and rivers.

Tool 2. Reduce urban pollutant pulses. A second need in urban stream restoration is to reduce concentrations of nutrients, bacteria and toxics in the stream, as well as trapping excess sediment loads. Generally, three tools can be applied to reduce pollutant inputs to an urban stream: storm water retrofit ponds or wetlands, watershed pollution prevention programs, and the elimination of illicit or illegal sanitary connections to the storm sewer network

Tool 3. Stabilize channel morphology. Over time, urban stream channels enlarge their dimensions, and are subject to severe bank and bed erosion. Therefore, it is important to stabilize the channel, and if possible, restore equilibrium channel geometry. In addition, it is also useful to provide undercuts or overhead cover to improve fish habitat. Depending on the stream order, watershed impervious cover and the height and angle of eroded banks, a series of different tools can be applied to stabilize the channel, and prevent further erosion. Bank stabilization measures include imbricated rip-rap, brush bundles, soil bioengineering methods such as willow stakes and bio-logs, lunker structures and rootwads. Grade stabilization measures are discussed earlier in this chapter and in Appendix A.

Tool 4. Restore Instream habitat structure. Most urban streams have poor instream habitat structure, often typified by indistinct and shallow low flow channels within a much larger and unstable storm channel. The goal is to restore instream habitat structure that has been blown out by erosive floods. Key restoration elements include the creation of pools and riffles, confinement and deepening of the low flow channels, and the provision of greater structural complexity across the streambed. Typical tools include the installation of log checkdams, stone wing deflectors and boulder clusters along the stream channel.

Tool 5. Reestablish Riparian Cover. Riparian cover is an essential component of the urban stream ecosystem. Riparian cover stabilizes banks, provides large woody debris and detritus, and shades the stream. Therefore, the fifth tool involves reestablishing the riparian cover plant community along the stream network. This can entail active reforestation of native species, removal of exotic species, or changes in mowing operations to allow gradual succession. It is often essential that the riparian corridor be protected by a wide urban stream buffer.

Tool 6. Protect critical stream substrates. A stable, well sorted streambed is often a critical requirement for fish spawning and secondary production by aquatic insects. The bed of urban streams, however, is often highly unstable and clogged by fine sediment deposits. It is often necessary to apply tools to restore the quality of stream substrates at points along the stream channel. Often, the energy of urban storm water can be used to create cleaner substrates—through the use of tools such as double wing deflectors and flow concentrators. If thick deposits of sediment have accumulated on the bed, mechanical sediment removal may be needed.

Tool 7. Allow for recolonization of the stream community. It may be difficult to reestablish the fish community in an urban stream if downstream fish barriers prevent natural recolonization. Thus, the last urban stream restoration tool involves the judgment of a fishery biologist to determine if downstream fish barriers exist, whether they can be removed, or whether selective stocking of native fish are needed to recolonize the stream reach.