Section 3 Streambank and Shoreline Erosion

Figure 3.1 Shoreline Erosion: Before and After Photos
(Source: http://www.dcr.state.va.us/sw/seas.htm)

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

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

increasing the velocity of the water and thus its erosive potential. In addition, newly constructed banks are generally more prone to erosion than "seasoned" banks and are more likely to require bank stabilization.

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

Case Study: Disappearing Sand on California Beaches

In recent decades, California's beaches have been disappearing. Seventy to ninety percent of sand on California beaches comes from inland rivers, but dams and seawalls block sediment from being carried to the coast. Constructed between 1850 and 1970, California's 1,400 dams have trapped millions of tons of sand-laden sediments. Sea walls can also be a threat to beaches. Twenty percent of the sand on beaches comes from the natural erosion of bluffs. Building seawalls stops this erosion and instead accelerates the loss of sand on beaches.

In 1999 Friends of the River (FOR) published a report on dam removal entitled *Rivers Reborn*, which outlines the growing body of scientific evidence that removing some dams can lead to riparian restorations that are feasible and economically beneficial. FOR's report includes information on two in Southern California are of special interest to surfers. Just upstream from Malibu, one of California's most famous surfing beaches, is the 100 foot high Rindge Dam, built in 1926. The reservoir behind the dam is now completely filled with sediment. FOR report estimates that the dam traps between 800,000 and 1,600,000 cubic yards of sand and sediment. In addition to trapping sediment, the dam has been cited as an impediment to steelhead fish passage as well as to natural flow conditions. 1999 estimates for removing the dam and trapped sediment range from $4 million to $18 million. The USACE, with matching funds from California State Parks and local agencies, will examine the utility of removing Rindge dam and restoring Malibu Creek. This study should be completed by 2005.

Sources:

Becher, B. 2002. New Study Could Bring Back Steelhead: Returning the Fish to Malibu Creek Still a Dam Problem. *Daily News of Los Angeles*. Page S13.

Caughlan, R. 2000. *Damn the Torpedoes and Torpedo the Dams: Surfers in Danger of Becoming the Beachless Boys*. EcoIQ Magazine. http://www.ecoiq.com/magazine/opinion/opinion61.html. Accessed June 2003.

Friends of the River. 1999. *Rivers Reborn: Removing Dams and Restoring Rivers in California.* http://www.friendsoftheriver.org/Publications/PDF/RiversReborn.pdf. Accessed March 2004.

U.S. Army Corps of Engineers. 2002. *National Regional Sediment Management Demonstration Program, South Pacific Division, State of California*. http://www.spd.usace.army.mil/csmwonline/rsm-spd-april02.pdf. Accessed March 2004.

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

- Hydrology
- Stream hydraulics

- Morphology
- Factors such as sediment transport and storage
- Alterations to the biological community

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

As evidenced by the examples above, many activities can have a profound effect on the stability of streambanks and shorelines. Section 3 outlines some of the techniques available to stabilize streambanks and shorelines affected by these types of activities.

Case Study: Shore Erosion Control

Shore Erosion Control, a Maryland Department of Natural Resources program, was established in 1968 by Maryland's General Assembly to address shoreline and streambank erosion along the Chesapeake Bay and its tributaries. In a 2000 report by the Shore Erosion Task Force, 1,341 miles of nearly 4,360 miles of tidal shoreline within Maryland's portion of the Chesapeake Bay watershed were identified as eroding. The Task Force also determined that erosion was a problem in all 16 coastal counties along the Chesapeake Bay and in all Coastal Bays watersheds. Problems associated with shoreline and streambank erosion include loss of land and the reduction of riparian buffer areas and wildlife habitat, and sediment deposition in the waters of Maryland. Estimates from 2002 indicated that approximately 5.1 million cubic yards of sediments are delivered annually to the Chesapeake Bay. Deposited sediment is associated with problems such as increased nitrogen and phosphorus input into the Bay, and dredging may be required to removed excess sediments.

The Shore Erosion Control program provides technical and financial assistance to Maryland property owners in resolving shoreline and streambank erosion problems, both through structural (e.g., barrier type structures) and non-structural (e.g., improvements of vegetated areas) controls. Since 1968, Shore Erosion Control has provided technical assistance to Maryland's property owners and established more than 800 structural projects and 325 non-structural projects. These projects have resulted in more than 483,000 tons of sediment retained.

Sources:
MDNR. 2002. *Shore Erosion Control*. Maryland Department of Natural Resources. http://www.dnr.state.md.us/grantsandloans/secintro.html. Accessed March 2004.

MDNR. 2000. *State of Maryland Shore Erosion Task Force, Final Repor*t. Maryland Department of Natural Resources. http://www.dnr.state.md.us/download/shoreerosion.pdf. Accessed April 2004.

Management Measure for Eroding Streambanks and Shorelines

Management Measure

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

A. Introduction

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

Stabilization practices involving vegetation or engineering structures should be properly designed and installed. These techniques should be applied only when there will be no adverse effects to aquatic or riparian habitat, or to the stability of adjacent shorelines. Finally, it is the intent of this measure to promote institutional measures that establish minimum setback requirements or measures that allow a buffer zone to reduce concentrated flows and promote infiltration of surface water runoff in areas adjacent to the shoreline.

Stream-friendly Project Tips

Before Construction

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

During Construction

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

After Construction

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

Source: SWCD. No date. *Protecting Streambanks from Erosion: Tips for Small Acreages in Oregon*. Washington County Soil and Water Conservation District and the Small Acreage Steering Committee, Oregon Association of Conservation Districts. http://www.oacd.org/fs04ster.htm. Accessed June 2003.

The initial consideration when faced with the need for streambank restoration is whether a complete removal or reversal of the causative effects is possible. For example, when evaluating restoration sites affected by dams, an initial consideration should be whether changes in operations are possible. Then management measures to improve existing erosion damage should be examined. The alteration of operation approaches in combination with best management and restoration efforts can reduce future impacts. Although dam removal may be the only way to fully restore a stream and its corridors back towards a pre-impounded state, the impacts of dam removal need to be carefully assessed and thoroughly considered before proceeding (FISRWG, 1998). Similarly, removal of channelization structures may allow for a greater recovery of the integrity of a stream corridor. If feasible, the objective of a restoration design should be to eliminate or moderate disruptive influences to allow for equilibrium (NRC, 1992). If this is not possible, restoration may have limited effectiveness in the long term or may require a closer look at an entire watershed to determine alternate restoration activities.

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

This management measure was selected for the following reasons:

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

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

Case Study: He'eia Coastal Restoration Project

He'eia State Park is located on an elevated peninsula on the shores of Kaneohe Bay on Oahu, Hawaii. Bordering the park are a unique fringing reef, a mountain stream, and an ancient Hawaiian fishpond. In 2000 the State's Department of Health designated Kaneohe Bay a Water Quality Limited Segment because of the NPS pollution, specifically sediments and nutrients. Kaneohe Bay and He'eia Stream are part of Koolaupoko watershed, which was designated a priority watershed in need of restoration in Hawaii's 1998 Unified Watershed Assessment (UWA) Plan. In the UWA, Koolaupoko watershed was found not to be meeting water quality and other resource goals and was designated a priority watershed in an effort to reduce NPS runoff, and thus enhance recreational use of streams and nearshore waters. Alien coastal plants were causing problems by preventing adequate filtering of waters that emanate from the watershed above before they entered the bay.

Replacing alien plants with native species
The major goal of the project was to expand and enhance the He'eia stream and coastal area by replacing existing alien coastal plants with native strand species. The area was surveyed and plans were developed for removing the alien plants. The project was very successful in removing alien flora, such as mangrove, from the streambanks and in planting native species, such as milo, naupaka, kou ,and puhala in their place. The native species are expected to provide continuous protection to Kaneohe Bay by filtering waters that come from the watershed above. Establishment of the native plants has helped to stabilize streambanks and mitigate erosion.

Benefits to waters and the community
Students and professors from local colleges monitor the water quality of He'eia Stream at multiple sites in the watershed. This restoration project was part of a larger master planning effort to rehabilitate portions of the entire He'eia watershed. The success of this project has given Friends of He'eia State Park a huge boost in their continuing efforts throughout the watershed. The total cost of this project was $155,000; funding included $60,000 in Clean Water Act Section 319 grant funds. An additional Section 319 grant has been awarded to Friends of He'eia State Park to continue this riparian restoration project, water quality monitoring, curriculum development, and public education through August 2005.

Sources:

Hawaii Department of Health. 1998. *Hawai'i Unified Watershed Assessment*. State of Hawaii, Department of Health, Clean Water Branch, Polluted Runoff Control Program.

Hawaii Department of Health. 2000. *2000 305(b) Report, Appendix A: Water Quality Limited Segments*. http://www.hawaii.gov/health/environmental/water/cleanwater/reports/2000-305b/index.html. Accessed December 2005.

USEPA. 2002. *He'eia Coastal Restoration Project: Thousands of Volunteers Replace Alien Plants with Native Species*. U.S. Environmental Protection Agency, Section 319 Success Stories. http://www.epa.gov/owow/nps/Section319III/HI.htm. Accessed June 2003.

B. Management Practices

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

Nonstructural Practices

Soil bioengineering is used here to refer to the installation of living plant material as a main structural component in controlling problems of land instability where erosion and sedimentation are occurring (USDA-NRCS, 1992). Soil bioengineering can be defined as, "the use of live and dead plant materials, in combination with natural and synthetic support materials, for slope stabilization, erosion reduction, and vegetative establishment" (FISRWG, 1998). Soil bioengineering largely uses native plants collected in the immediate vicinity of a project site. This ensures that the plant material will be well adapted to site conditions. While a few selected species may be installed for immediate protection, the ultimate goal is for the natural invasion of a diverse plant community to stabilize the site through development of a vegetative cover and a reinforcing root matrix (USDA-NRCS, 1992).

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

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

Additional information about soil bioengineering principles is available from the *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992). Local agencies, such as the USDA Natural Resources Conservation Service (NRCS) and the Cooperative Extension Service, can be a useful source of information on appropriate native plant species to consider in bioengineering projects. Another useful source of information, USDA NRCS' *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992), contains information about locating and selecting plant species (e.g., availability, size, tolerance to deposition, flooding, drought, and salt), installation information, maintaining quality control, establishment period, and maintenance. The soil bioengineering chapter of the handbook is available at http://www.info.usda.gov/CED/ftp/CED/EFH-Ch18.pdf. For the Great Lakes, the USACE has identified 33 upland plant species that have the potential to effectively decrease surface erosion of shorelines resulting from wind action and runoff (Hall and Ludwig, 1975). Michigan Sea Grant has also published two useful guides for shorefront property owners that provide information on vegetation and its role in reducing Great Lakes shoreline erosion (Tainter, 1982; Michigan Sea Grant College Program, 1988).

The USDA Forest Service has published *A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization*, which provide information on how to successfully plan and implement a soil bioengineering project, including the application of soil bioengineering techniques. The guide also provides specific tips for using soil bioengineering techniques successfully and is available at http://www.fs.fed.us/publications/soil-bio-guide. USDA-NRCS's *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992) also provides guidance for soil bioengineering that includes characteristics, principles, design, and construction techniques of soil bioengineering. The chapter is national in scope and should be supplemented with regional and local information. Experts should also be consulted for planning and design of systems.

A good understanding of current and projected flooding is necessary for designing appropriately restored plant communities in the floodplain (FISRWG, 1998). Assessing critical flow is crucial and would include consideration of the magnitude, frequency, and duration of the bankfull and overbank flows. This information is key to decide which plants and materials can be successfully established. For example, a live fascine (described below) can withstand a velocity of 6 to 8 ft/sec, while one-inch gravel can withstand a velocity of 2.5 to 5 ft/sec (Fischenich, 2001).

Soil bioengineering provides an array of practices that are effective for both prevention and mitigation of NPS problems. This applied technology combines mechanical, biological, and ecological principles to construct protective systems that prevent slope failure and erosion. Adapted types of woody vegetation (shrubs and trees) are initially installed as key structural components, in specified configurations, to offer immediate soil protection and reinforcement. Soil bioengineering systems normally use cut, unrooted plant parts in the form of branches or rooted plants. As the systems establish themselves, resistance to sliding or shear displacement increases in streambanks and upland slopes (Gray and Leiser, 1989; Porter, 1992).

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

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

Marsh Creation and Restoration

Marsh creation and restoration is a useful vegetative technique that can address problems with erosion of shorelines. Marsh plants perform two functions in controlling shore erosion (Knutson, 1988). First, their exposed stems form a flexible mass that dissipates wave energy. As wave energy is diminished, the offshore transport and longshore transport of sediment are reduced. Ideally, dense stands of marsh vegetation can create a depositional environment, causing accretion of sediments along the intertidal zone rather than continued shore erosion. Second, marsh plants form a dense mat of roots, which can add stability to the shoreline sediments. The basic approach for marsh creation is to plant a shoreline area in the vicinity of the tide line with appropriate marsh grass species. Suitable fill material may be placed in the intertidal zone to create a wetlands planting terrace of sufficient width (at least 18 to 25 feet) if such a terrace does not already exist at the project site. For shoreline sites that are highly sheltered from the effects of wind, waves, or boat wakes, the fill material is usually stabilized with small structures, similar to groins, which extend out into the water from the land. For shorelines with higher levels of wave energy, the newly planted marsh can be protected with an offshore installation of stone that is built either in a continuous configuration or in a series of breakwaters.

Case Study: Galilee Salt Marsh Restoration

The coastal features of southern Rhode Island provide a variety of special habitats. The Galilee Bird Sanctuary is a 128-acre coastal wetland complex owned and managed by the Rhode Island Department of Environmental Management (RIDEM), Division of Fish and Wildlife. Unfortunately, much of the Galilee Salt Marsh has faced many challenges in its history. During the 1950s, unconfined dredge materials from the Port of Galilee were deposited over portions of the western side of the salt marsh where the Galilee Bird Sanctuary is located. These materials filled in a tidal channel and significantly altered the natural hydrology of the marsh.

Following a hurricane in 1954, the State Division of Public Works constructed the Galilee Escape Road to ensure that residents of Great Island would not be trapped by floods. The new road fragmented the previously continuous salt marsh and eliminated about 7 acres of marsh habitat. Changes in hydrology included restriction of tidal flushing, which transformed the once-productive salt marsh into dense thickets of invasive *Phragmites* and shrubs, and lead to reduction of natural coastal wetland habitats for migratory waterfowl, shorebirds, fish, and shellfish. Prior to the beginning of the restoration project, fewer than 20 aces of salt mash and open water existed in the sanctuary and only nine or so of those acres were vegetated salt marsh supported by tidal flow.

A number of partners, including the Rhode Island Department of Transportation, U.S. Army Corp of Engineers, Ducks Unlimited, U.S. Fish and Wildlife Service, RIDEM Fish and Wildlife, and other agencies, under the auspices of the Coastal America Program, participated in the Galilee Salt Marsh Restoration Project. Clean Water Act Section 319 funding contributed to the restoration efforts with a $64,300 grant to replace the undersized culverts and install self-regulating sluice and tide gates. The gates operate using a system of floats and balances that are precisely calibrated to close when water reaches a preset level.

Restoration of approximately 84 acres of salt marsh habitats and 14 acres of tidal creeks and ponds was completed and dedicated in October 1997. By the end of the 1999 growing season, *Phragmites* had been reduced by 68 percent. Positive effects on fish and wildlife populations have been noted. Finfish began to recolonized the tidal creeks within days following opening of the tide gates and waterfowl (duck and geese), including the American black duck, have use the restored marsh for nesting and feeding and during migration. Complete restoration is expected to take 10 years or more. The project has been an enormous success, and the salt marsh has been designated a bird sanctuary. The project is an excellent demonstration of collaboration among various branches of government.

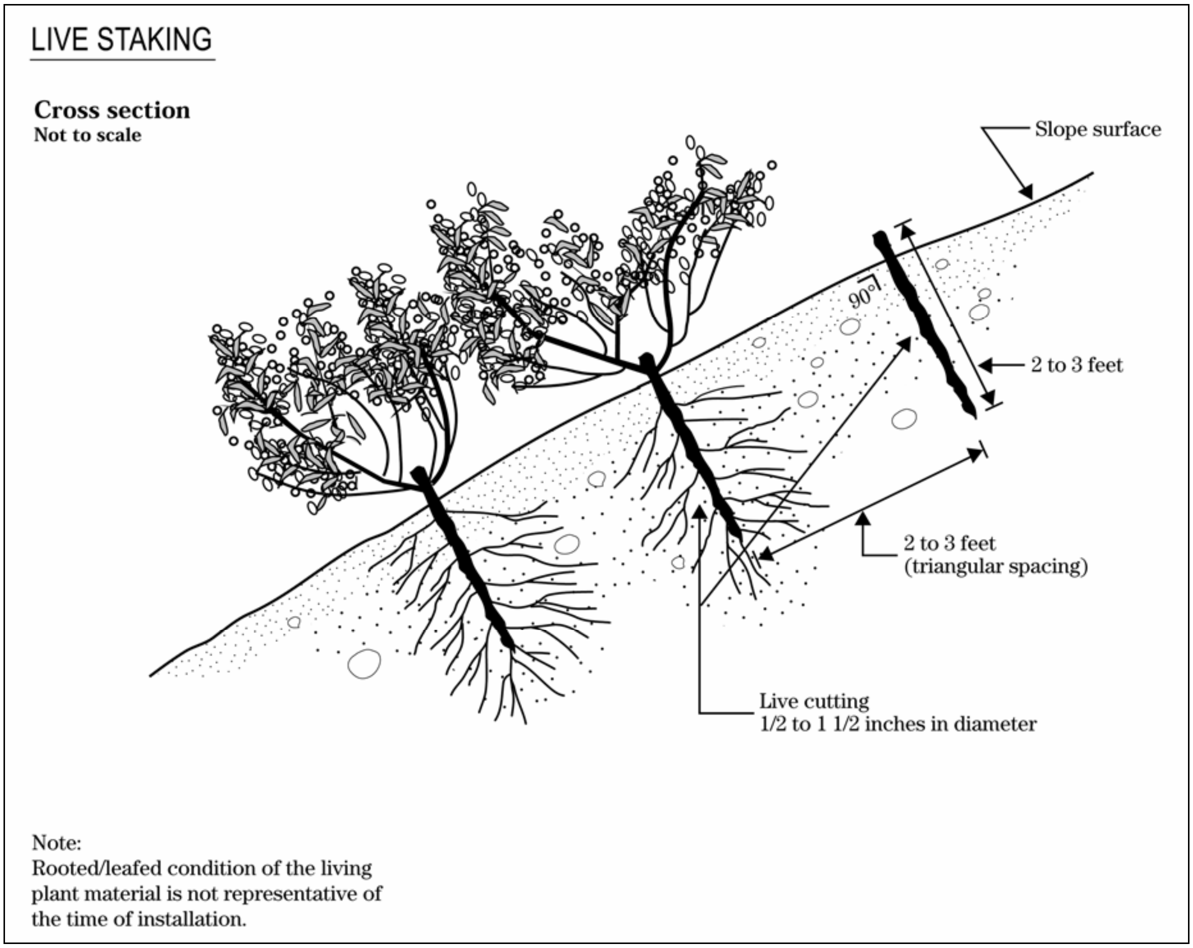
Sources:

RIDEM. 1997. *DEM, ARMY Corps Hold Galilee Salt Marsh Restoration Ceremony*. Rhode Island Department of Environmental Management Press Release. http://www.state.ri.us/dem/news/1997/pr/1105971.htm. Accessed March 2004.

USEPA. 2002. *Galilee Salt Marsh Restoration: Undersized Culverts Replaced with Self-Regulating Gates*. U.S. Environmental Protection Agency, Section 319 Success Stories, Vol. III. http://www.epa.gov/owow/nps/Section319III/RI.htm. Accessed June 2003.

Live Staking

Live staking (Figure 3.2) is appropriate for relatively uncomplicated site conditions when construction time is limited. It can also be used to stabilize intervening area between other soil bioengineering techniques, such as live fascines (USDA-NRCS, 1992). Live staking involves the insertion and tamping of live, rootable vegetative cuttings into the ground. If correctly prepared and placed, the live stake will root and grow. A system of stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture. Stakes are generally 1 to 2 inches in diameter and 2 to 3 feet long. Specific site requirements and available cutting source will determine size. Vegetation selected should be able to withstand the degree of anticipated inundation, provide year round protection, have the capacity to become well established under sometimes adverse soil conditions, and have root, stem, and branch systems capable of resisting erosive flows. Most willow species are ideal for live staking because they root rapidly and begin to dry out a slope soon after installation. Sycamore and cottonwood are also species commonly used for live staking. This is an appropriate technique for repair of small earth slips and slumps that are frequently wet. Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002) and the USDA NRCS *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992).


LIVE STAKING

Cross section
Not to scale

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

Figure 3.2 Live Staking (Source: USDA-NRCS, 1992)

Live Fascines

Live fascines are long bundles of branch cuttings bound together in a cylindrical structure (Figure 3.3). They are suited to steep, rocky slopes, where digging is difficult (USDA-NRCS, 1992). When cut from appropriate species (e.g., young willows or shrub dogwoods) that root easily and have long straight branches, and when properly installed, they immediately begin to stabilize slopes. The cuttings (0.5 to 1.5 inches in diameter) form live fascine bundles that vary in length from 5 to 10 feet or longer, depending on site conditions and handling limitations. Completed bundles should be 6 to 8 inches in diameter. The goal is for natural recruitment to follow once slopes are secured. Live fascines should be placed in shallow contour trenches on dry slopes and at an angle on wet slopes to reduce erosion and shallow face sliding. Live fascines should be applied above ordinary high-water mark or bankfull level except on very small drainage area sites. In arid climates, they should be used between the high and low water marks on the bank. This system, installed by a trained crew, does not cause much site disturbance.

Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002) and the USDA NRCS *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992). Under their Ecosystem Management and Restoration Research Program (EMRRP), the U.S. Army Corps of Engineers presents research on live fascines in a technical note (*Live and Inert Fascine Streambank Erosion Control*), at http://el.erdc.usace.army.mil/elpubs/pdf/sr31.pdf.

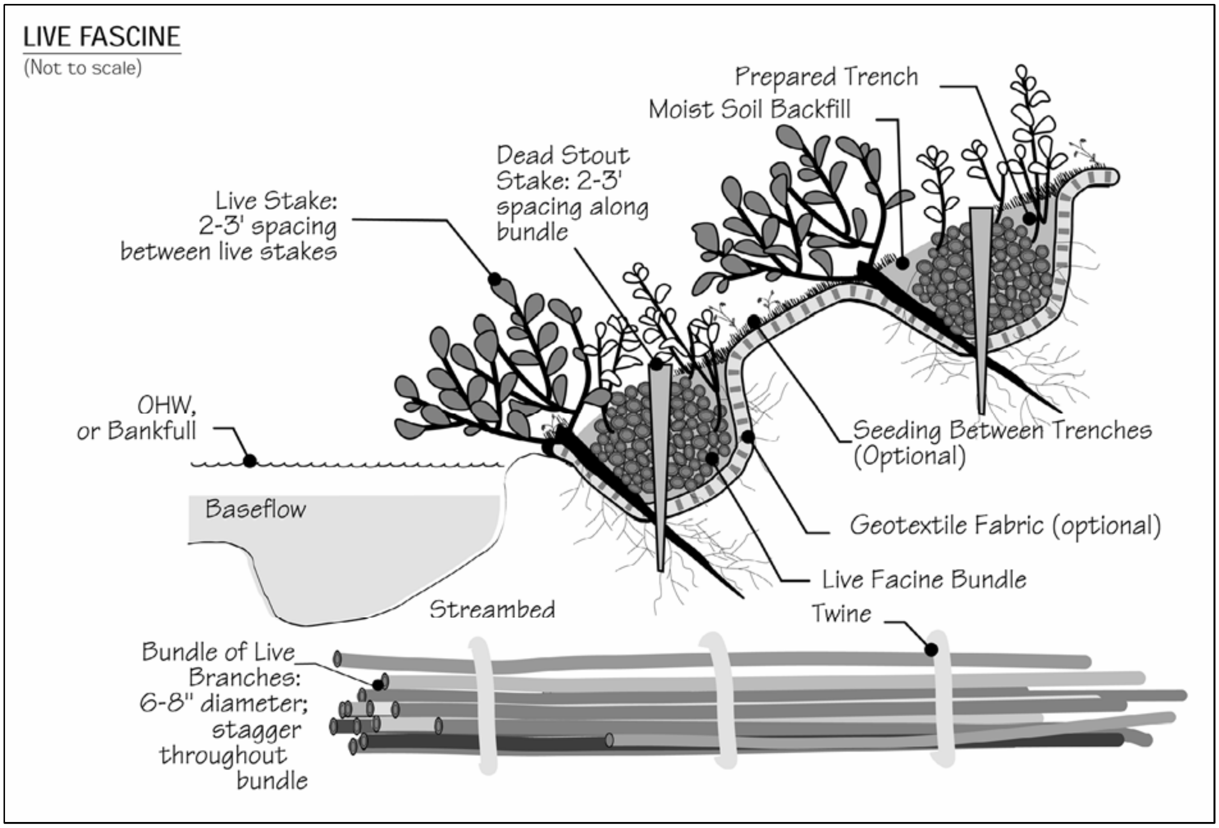


Figure 3.3 Live Fascine (Source: USDA-FS, 2002)

Note: OHW (Ordinary High Water) is the mark along a streambank where the waters are common and usual. This mark is generally recognized by the difference in the character of the vegetation above and below the mark or the absence of vegetation below the mark (USDA-FS, 2002).

Case Study: Red River Basin Riparian Project: Turtle River Site Passes the Test

Initiated in 1994, the Red River Basin Riparian Project seeks to restore degraded riparian corridors in the Red River Basin in North Dakota, caused by activities such as overgrazing, intensive agriculture, and indiscriminate logging. According to estimates, more than 50 percent of the original forest cover in many watersheds in eastern North Dakota has been cleared for agricultural use. An advisory committee with representatives from several state and federal agencies advises the project on behalf of the project's sponsor, the Red River Resource Conservation and Development Council. Healthy riparian corridors offer benefits for water quality, as well as flood damage reduction and wildlife habitat. The project sponsors' original goal was to establish demonstration sites in the Red River Basin, restoring at least 100 river miles over 5-years.

At one demonstration site, the Turtle River site, the lack of woody vegetation had left the streambank vulnerable to severe erosion. In addition, groundwater seeps above the baseflow elevation of the river were leading to erosion. Between 1978 and 1995, the river migrated approximately 3.5 feet per year to the east until it was only 80 feet from the county road. When the bioengineering project was initiated 1995, the site had a vertical bank about 14 feet high.

In 1995, efforts were made to stabilize the bank and stop further migration toward the road using multiple bioengineering techniques. The first step was to create a stable slope for the vegetation. The 14-foot vertical bank was reshaped to a 3:1 slope, using the waste from the top as fill at the toe. Riprap, willow fascines, a brush mattress, and grasses and shrubs were installed along the bank to aid in the revegetation process.

The Natural Resources Conservation Service demonstrated the implementation of several bioengineering techniques during a workshop (left). Willows were planted along the restoration site to provide long-term stability (right).

Although some maintenance was required each spring in 1996 and 1997, the project has survived spring floods and a 17-inch rainstorm in July 2000. Red River Riparian Projects continue to lessen erosion in demonstration sites in North Dakota.

In North Dakota riparian areas are essential factors in the long-term protection and enhancement of the streams, rivers, and lakes. Well-managed riparian zones may provide optimum food and habitat for stream communities and serve as buffer strips for controlling nonpoint source pollution. Riparian buffers, when used as part of an integrated management system, can greatly benefit the quality of the state's surface waters.

Sources:

Kingerly, L. 1997. Bioengineering Used to Stabilize Streambank Site on Turtle River. *Quality Water: Newsletter of the North Dakota Nonpoint Source Pollution Task Force*. Vo. 8, No. 2. http://www.health.state.nd.us/rrbrp/reports/Bioengineering.pdf. Accessed March 2004.

Red River Basin Riparian Project. 2003. http://www.health.state.nd.us/rrbrp. Accessed March 2004.

USEPA. 2002. *Red River Basin Riparian Project: Turtle River Site Passes the Test*. U.S. Environmental Protection Agency, Section 319 Success Stories, Vol. III. http://www.epa.gov/owow/nps/Section319III/ND.htm. Accessed June 2003.

Brush Layering

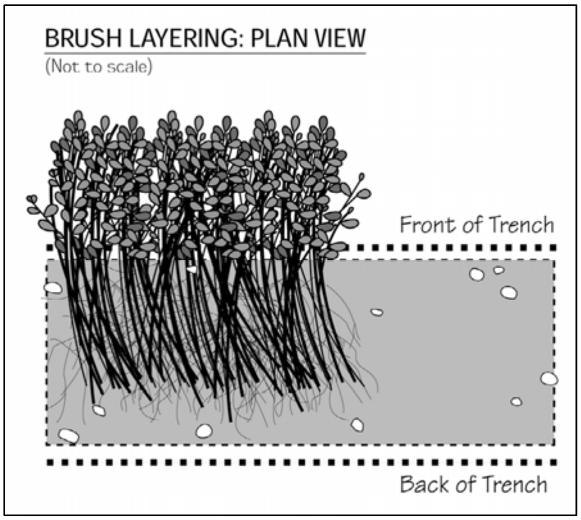


Figure 3.4 Brush Layering: Plan View (Source: USDA-FS, 2002)

Brush layering consists of placing live branch cuttings in small benches excavated into the slope (Figures 3.4 and 3.5). The width of the benches can range from 2 to 3 feet. These systems are recommended on slopes up to 2:1 in steepness and not to exceed 15 feet in vertical height. Branch cuttings should be 0.5 to 2 inches in diameter and be long enough to reach the back of the bench and still protrude from the bank. The portions of the brush that protrude from the slope face assist in retarding runoff and reducing surface erosion. Brush layering is somewhat similar to live fascine systems because both involve the cutting and placement of live branch cuttings on slopes. The two techniques differ principally in the orientation of the branches and the depth to which they are placed in the slope. In brush layering, the cuttings are oriented more or less perpendicular to the slope contour. In live fascine systems, the cuttings are oriented more or less parallel to the slope contour. The perpendicular orientation is more effective from the point of view of earth reinforcement and mass stability of the slope (USDA-NRCS, 1992). Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002) and the USDA NRCS *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992).

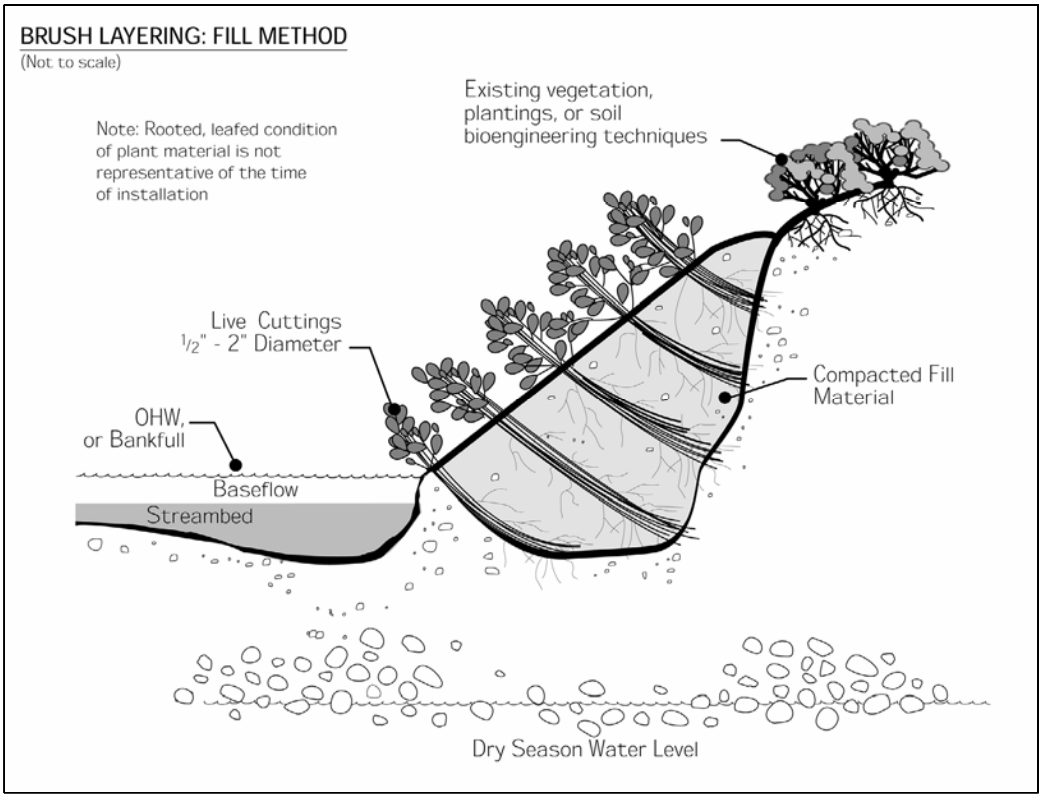
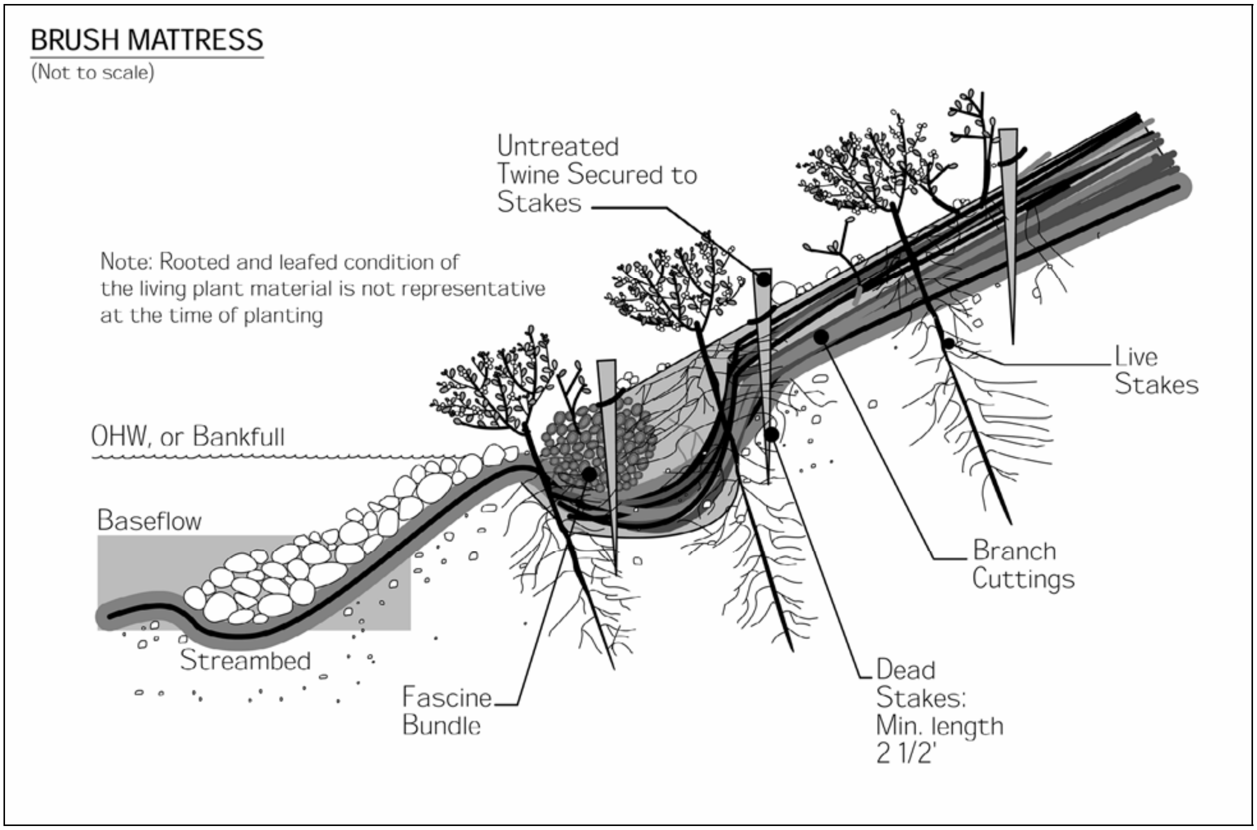


Figure 3.5 Brush Layering: Fill Method (Source: USDA-FS, 2002)

Brush Mattressing

Brush mattressing is commonly used in Europe for streambank protection (Figure 3.6). It involves digging a slight depression on the bank and creating a mat or mattress from woven wire or single strands of wire and live, freshly cut branches from sprouting trees or shrubs. Branches approximately 1 inch in diameter are normally cut 6 to 9 feet long (the height of the bank to be covered) and laid in criss-cross layers with the butts in alternating directions to create a uniform mattress with few voids. The mattress is then covered with wire secured with wooden stakes 2.5 to 4 feet long. It is then covered with soil and watered repeatedly to fill voids with soil and facilitate sprouting; however, some branches should be left partially exposed on the surface. The structure may require protection from undercutting by placement of stones or burial of the lower edge. Brush mattresses are generally resistant to waves and currents and provide protection from the digging out of plants by animals. Disadvantages include possible burial with sediment in some situations and difficulty in making later plantings through the mattress.

Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002). Under EMRRP, the U.S. Army Corps of Engineers has presented research on brush mattresses in a technical note (*Brush Mattresses for Streambank Erosion Control*), which is available at http://el.erdc.usace.army.mil/elpubs/pdf/sr23.pdf.



Note: Rooted and leafed condition of the living plant material is not representative at the time of planting

Figure 3.6 Brush Mattress (Source: USDA-FS, 2002)

Case Study: Middle Carson River Restoration: Using Bioengineering to Restore Unstable Banks

In 1997, the Carson River watershed (located in Nevada) experienced a 100-year flood event, which caused severe erosion and damage to riverbanks and the nearby riparian habitat along the Carson River. In response, the Middle Carson River Coordinated Resource Management Planning Committee (a group of ranchers and other concerned local citizens) began a project to restore the streambanks and riparian area. Due to the severity of the flood, and the lack of existing vegetation, the project used bioengineering in addition to hard structures to achieve bank stabilization and revegetation.

Restoring Streambanks with Bioengineering

In 1998, construction of five stream barbs to redirect flow away from the unstable banks began on the Glancy property near Dayton. Behind the structures, quiescent areas collect sediment and allow natural regeneration of native vegetation. For bioengineering, several vegetative treatments, including brush mattress layering, brush trenches, juniper revetments, willow clump planting, and seeding, were used. These treatments provide bank stability, reduce erosion, trap sediment, provide shading, encourage natural plant growth, and restore wildlife habitat.

Monitoring to Document Improvements

Long-term monitoring will evaluate the effectiveness of the best management practices used in this project. Aerial photography; annual survey of channel cross sections; monitoring of vegetation growth; analysis of soil characteristics to document particle size, erodibility, and sediment transport potential; and hydraulic modeling are part of the monitoring program. Public education also enhances community awareness and involvement.

Nine months after project's November 1998 completion, monitoring showed an average of 74 percent cover on all vegetative treatments, with about 35 percent regeneration of the willow clumps. A topographical survey indicated deposition of about 430 cubic yards of sediment between the stream barbs. Stream barbs appear to be functioning as designed to deflect higher stream flow away from the bank, such that the low-flow channel has moved away from the bendway.

As part of the public education component, bimonthly water quality monitoring of the Middle Carson River is conducted. River Wranglers, a volunteer group, has worked with local schools to educate students about river and lake ecology. Students measure dissolved oxygen, pH, and turbidity, and take macroinvertebrate samples in the field.

In July 2000, the Nevada Division of Environmental Protection awarded Kevin Piper and the Middle Carson River Coordinated Resource Management Group the Wendell McCurry Excellence in Water Quality Award. This award is to recognize individuals, firms, organizations, and governmental entities that have made significant contributions to improving the quality of Nevada's water resources. As of 2000, funding to date includes approximately $30,000 of Clean Water Act Section 319(h) funds and $30,000 in local matching funds. The strength of the Middle Carson group is their ability to work together to implement "on-the-ground" projects.

Sources:
Allen, H., C.J. Fischenich, and R. Seal. 2000. Bioengineering for erosion control and environmental improvements, Carson River, NV. In *Best Management Practices for Soft Engineering of Shorelines*, ed. A.D. Caulk, J.E. Gannon, J.R. Shaw, and J.H. Hartig. Greater Detroit American Heritage River Initiative.

Piper, K.L., J.C. Hoag, H.H. Allen, G. Durham, J.C. Fischenich, and R.O. Anderson. 2001. *Bioengineering as a tool for restoring ecological integrity to the Carson River.* ERDC TN-WRAP-01-05. U.S. Army Corps of Engineers, Wetlands Regulatory Assistance Program.

USEPA. 2002. *Middle Carson River Restoration Project: Bioengineering Used to Restore Unstable Banks.* U.S. Environmental Protection Agency, Section 319 Success Stories. http://www.epa.gov/owow/nps/Section319III/NV.htm. Accessed June 2003.

Branch Packing

Branch packing consists of alternating layers of live branch cuttings and compacted backfill to repair small, localized slumps and holes in slopes (Figure 3.7). Live branch cuttings may range from 0.5 to 2 inches in diameter. They should be long enough to touch the undisturbed soil at the back of the trench and extend slightly outward from the rebuilt slope face. Wooden stakes should be 5 to 8 feet long, depending on the depth of the slump or hole being repaired. These stakes should also be made from poles that are either 3 to 4 inches in diameter or 2 by 4 feet lumber. Live posts can be substituted. As plant tops begin to grow, the branch packing system becomes increasingly effective in retarding runoff and reducing surface erosion. Trapped sediment refills the localized slumps or holes, while roots spread throughout the backfill and surrounding earth to form a unified mass. Branch packing is not effective in slump areas greater than 4 feet deep or 5 feet wide (USDA-NRCS, 1992). Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002) and the USDA NRCS *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992).

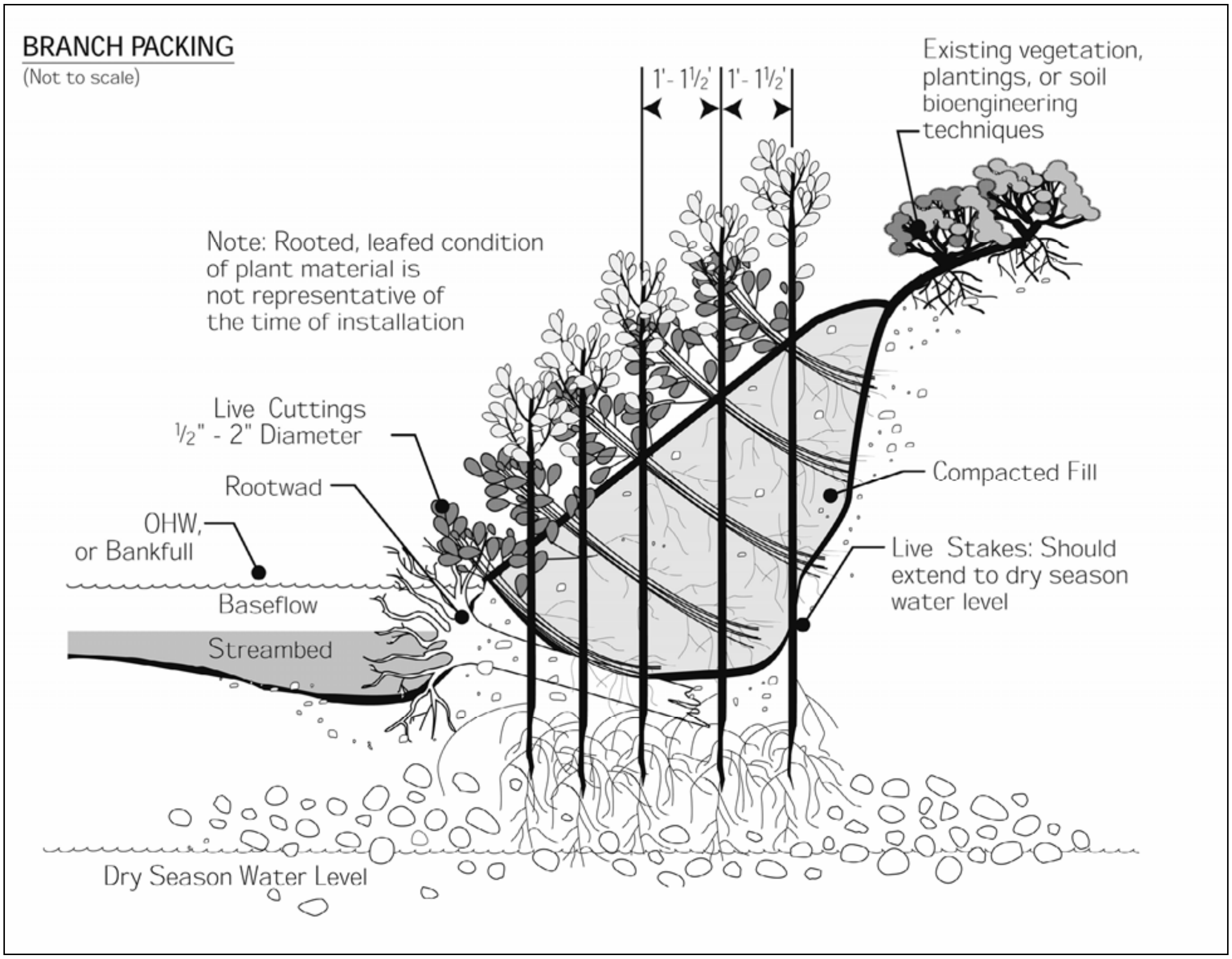


Figure 3.7 Branch Packing (Source: USDA-FS, 2002)

Coconut Fiber Roll

Figure 3.8 Coconut Fiber Roll Picture (Source: Montgomery Watson, 2001)

The coconut fiber roll technique consists of cylindrical structures composed of coconut husk fibers held together with twine woven from coconut material (Figures 3.8 and 3.9). It is typically manufactured in 12-inch diameters and lengths of 20 feet. This serves to protect slopes from erosion, trap sediment, and as a result, encourage plant growth within the fiber roll. The method is typically installed near the toe of the streambank with dormant cuttings and rooted plants inserted into holes cut into the fiber rolls. This provides a good substrate for promoting plant growth and is appropriate where short-term moderate toe stabilization is needed. Installation of this design requires minimal site disturbance and is ideal for sites that are especially sensitive to disturbance. A limitation of this system is that it cannot withstand high velocities or large ice buildup and it can be fairly expensive to construct. Coconut fiber rolls have an effective life of 6 to 10 years. In some locations, similar and abundant locally available materials, such as corn stalks, are being used instead of coconut materials (FISRWG, 1998).

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

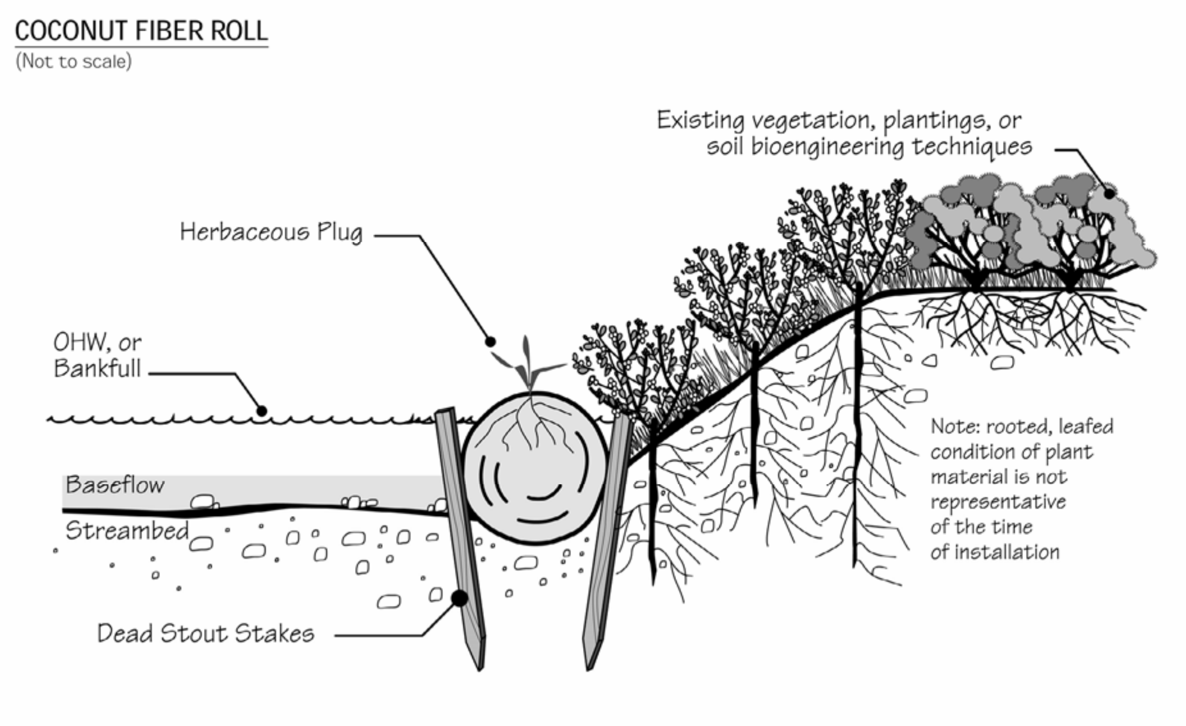


Figure 3.9 Coconut Fiber Roll (Source: USDA-FS, 2002)

Dormant Post Plantings

Dormant post plantings include planting of either cottonwood, willow, poplar or other sprouting species embedded vertically into streambanks to increase channel roughness, reduce flow velocities near the slope face, and trap sediment (Figure 3.10). Dormant posts are made up of large cuttings installed in streambanks in square or triangular patterns. Live posts should be 7 to 20 feet long and 3 to 5 inches in diameter. This method is effective for quickly establishing riparian vegetation particularly in arid regions. By decreasing near bank flow velocities, this design causes sediment deposition and reduces streambank erosion. This design is more resistant to erosion than live staking or similar designs that use smaller cuttings. Success of this design is most likely on streambanks that are not gravel dominated and where ice build up is not common. The exclusion of certain herbivores aids in the success of this design. This method should be combined with other soil bioengineering techniques to achieve a comprehensive streambank restoration design (FISRWG, 1998). Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002).

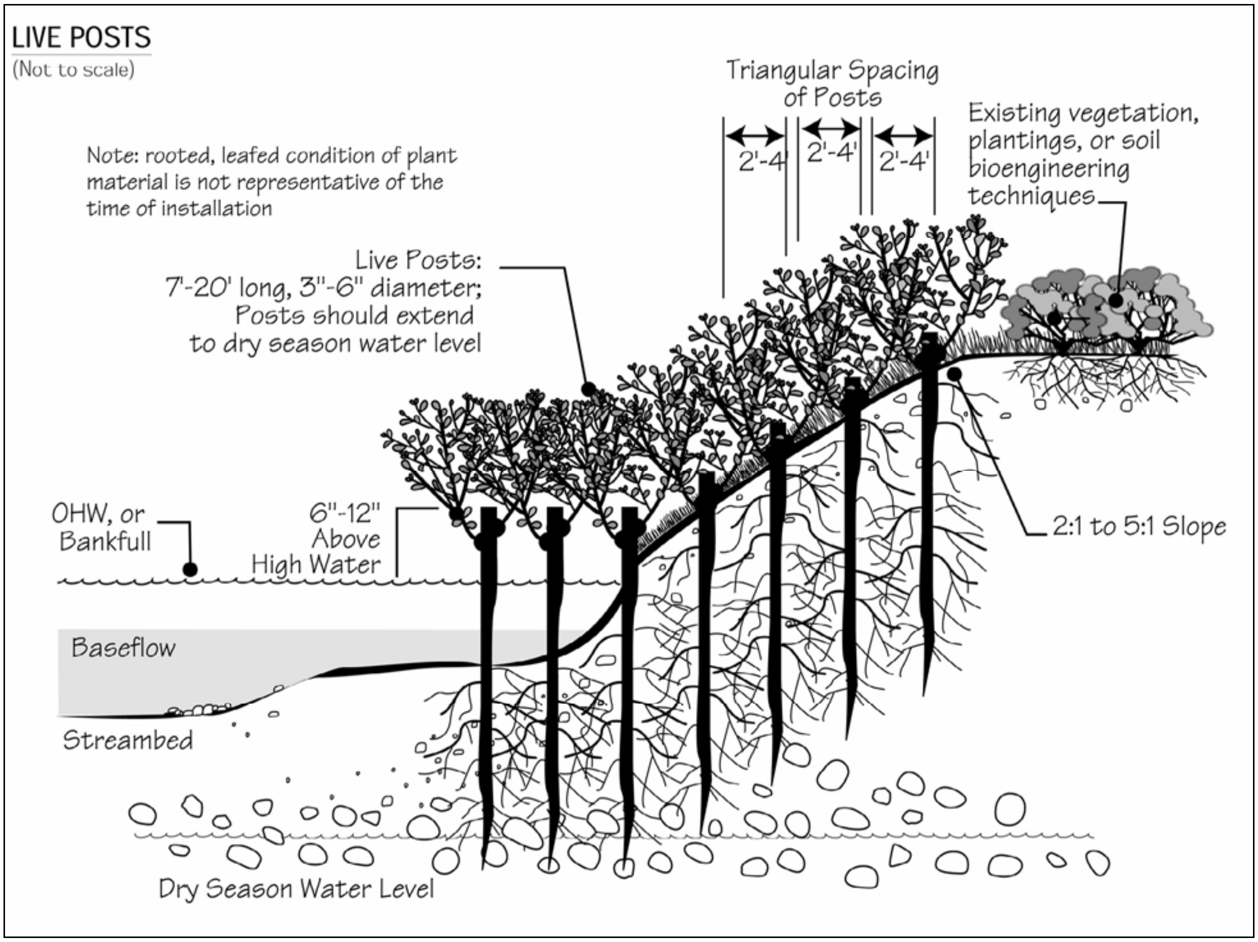


Figure 3.10 Live Posts (Source: USDA-FS, 2002)

Tree Revetments

Tree revetments consist of a row of interconnected trees anchored to the toe of the streambank or to the upper streambank (Figures 3.11 and 3.12). This serves to reduce flow velocities along eroding streambanks, trap sediment, and provide a substrate for plant establishment and erosion control. This design relies on the installation of an adequate anchoring system and is best suited for streambank heights under 12 feet and bankfull velocities under 6 feet per second. In addition, this structure should occupy no more than 15 percent of the channel at bankfull. Toe protection is needed to accompany this design if scour is anticipated and upper bank soil bioengineering techniques are recommended to ensure streamside regeneration. This design allows for the use of local materials if they are readily available. Decay resistant species are recommended for the logs to extend the life of the structure and thus the ability of vegetation to become established. Due to decomposition, these structures have a limited life and might require periodic replacement. It is considered beneficial that decomposition of the logs overtime allows the streambank to return to a natural state with protection provided by mature streambank vegetation. There is a potential for the logs to dislodge and these structures should not be located upstream of bridges or other structures sensitive to damage. Tree revetments are susceptible to damage by ice (FISRWG, 1998). Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002).

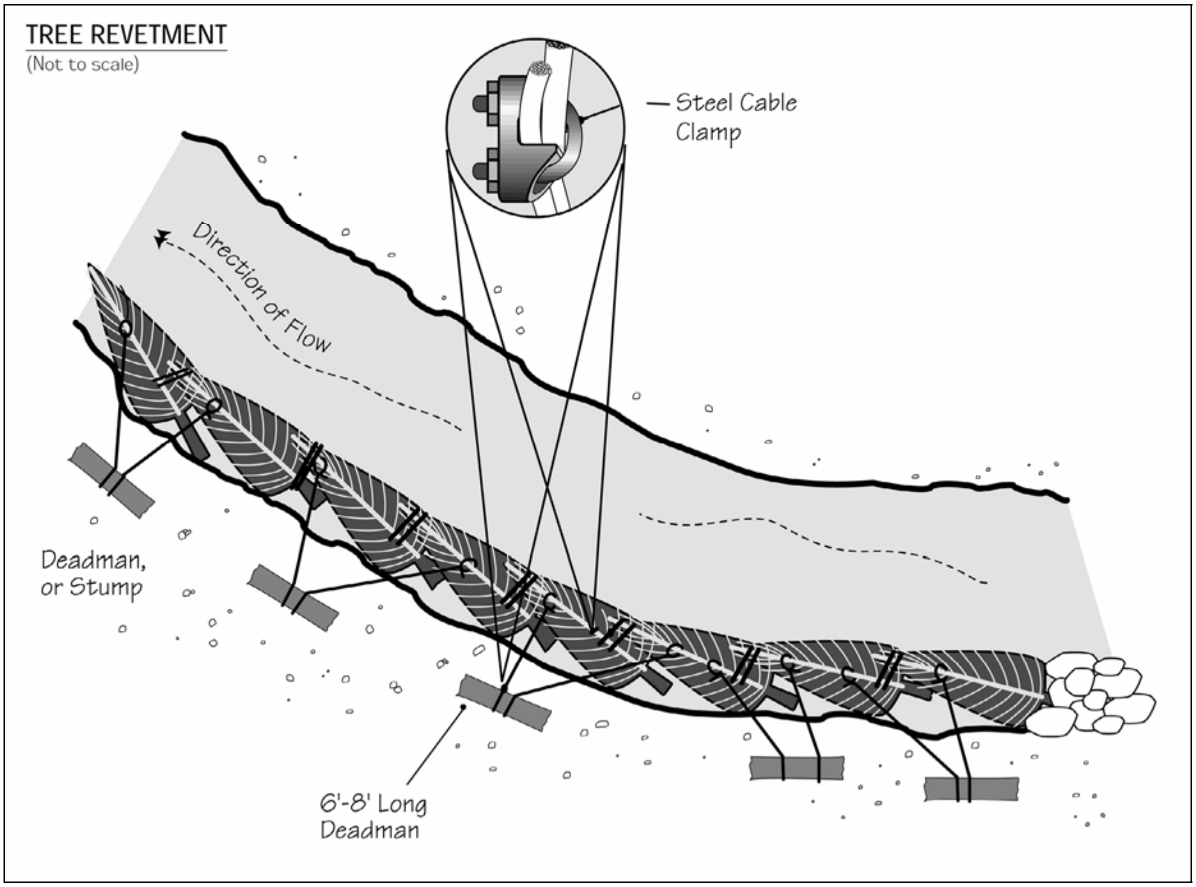


Figure 3.11 Tree Revetment (Source: USDA-FS, 2002)

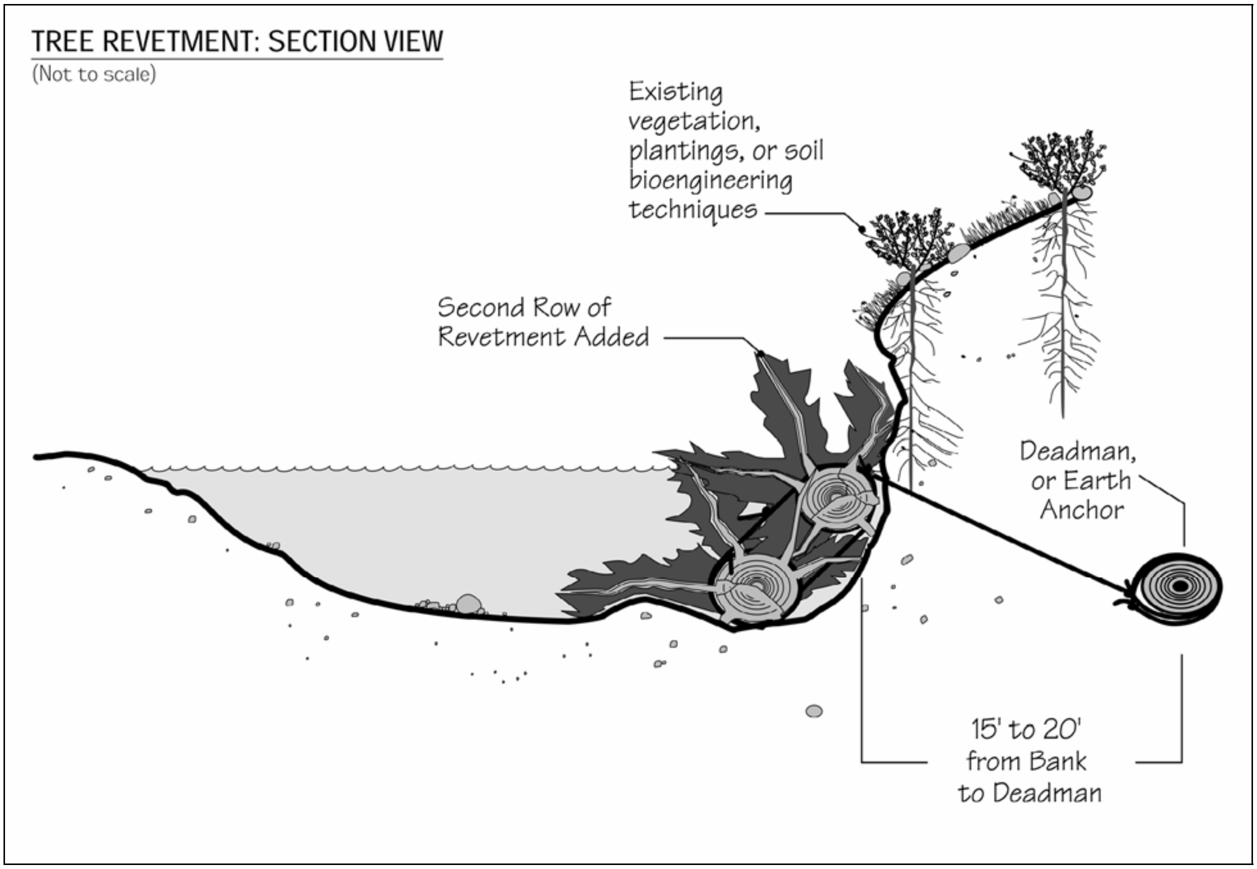


Figure 3.12 Tree Revetment: Section View (Source: USDA-FS, 2002)

Case Study: Streambank Stabilization Project: Tree Revetments Rescue Eroding Banks

Streambank erosion on Georgia's streams and rivers is a growing problem. Erosion has been particularly evident in the Broad River Watershed District of northeastern Georgia. Although it is much easier and more cost-effective to prevent erosion before it occurs than to restore streambanks after they are damaged, erosion already exists in many areas of Georgia. In the Broad River watershed, the Chestatee-Chattahoochee Resource Conservation and Development Council, through a Clean Water Act Section 319 grant from the Georgia Department of Natural Resources, Environmental Protection Division, has worked to combat these problems with "tree revetments." Through demonstration projects, the Council has shown landowners the positive effects of tree revetments on eroding streambanks. This technique is relatively inexpensive when compared to other streambank stabilization techniques used in the past. In addition, tree revetments are an environmentally-sound method of stabilization.

In a tree revetment, whole trees are cabled tightly together in giant bundles that are secured to the eroded streambank through an anchoring system of cables, in a shingled pattern, like the shingles on a roof. The technique is most useful when streambank heights are 6 feet or more, with a steep incline; revetments cannot be constructed on gradually sloped streambanks.

Tree revetments can greatly slow the stream current along an eroding bank, which decreases erosion and allows sediment to deposit in the revetment's tree branches. In addition to trapping sediment, the deposited materials form an excellent seedbed in which the seeds of riparian trees and other plants can sprout and grow. The resulting growth spreads roots throughout the revetment and into the streambank. Tree revetments also provide excellent habitat for birds, fish, and other wildlife.

The demonstration project was completed in March 2004, with a total of 16 tree revetment sites, plus additional BMPs throughout the Broad River watershed. The project has been deemed a success by many of the stakeholders, and landowners have been pleased with the results of the project. Monitoring has shown that stream erosion has been minimized, streambanks have been stabilized, vegetation has become established on streambanks, and the riparian habitats have been improved for wildlife.

Sources:
Personal communication with Jim Wren, Oconee River RC&D Council, Inc. April 28, 2004.

USEPA. 2002. *Broad River Streambank Stabilization Project: Tree Revetments Rescue Eroding Banks*. U.S. Environmental Protection Agency, Section 319 Success Stories, Vol. III. http://www.epa.gov/owow/nps/Section319III/GA.htm. Accessed June 2003.

Nonstructural techniques have been used extensively in Europe for streambank and shoreline protection and for slope stabilization. They have been practiced in the United States only to a limited extent primarily because other engineering options, such as the use of riprap, have been more commonly accepted practices (Allen and Klimas, 1986). With the costs of labor, materials, and energy rapidly rising, however, less costly alternatives of stabilization are being pursued as alternatives to engineering structures for controlling erosion of streambanks and shorelines.

Additionally, bioengineering has the advantage of providing food, cover, and instream and riparian habitat for fish and wildlife and results in a more aesthetically appealing environment than traditional engineering approaches (Allen and Klimas, 1986). Overall, site disturbance from the placement of soil bioengineering systems is limited due to the minimal site access required for materials and labor and the minimal disturbance caused by the installation of soil bioengineering systems (Gray and Sotir, 1996). Soil bioengineering tends to utilize native plants and materials that can be obtained from local stands of species. These plants are already well adapted to the climate and soil conditions of the area and thus have an increased chance of becoming established and surviving. The use of locally available plants also cuts the costs of a restoration project (Gray and Sotir, 1996). Thus, if a system is successful, it will blend in with the natural vegetation over time. Soil bioengineering techniques become more established and resistant to erosion and disturbance with time, as opposed to the traditional structural systems that often require reinforcement as time passes (Gray and Sotir, 1996). During the time period after installation, soil bioengineering systems are most vulnerable. As time passes the vegetation roots, the foliage leafs out, and the plants become well established. This causes the system to have increased resistance to erosion. The systems are often designed, however, to provide sufficient reinforcement directly after being installed (Gray and Sotir, 1996). This can make locating plant materials difficult (Gray and Sotir, 1996).

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

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

The limitations of soil bioengineering include the need for skilled laborers and the difficultly of locating plant materials during the dormant season, which is the optimal time for installation. To properly establish a soil bioengineering planting, orientation, on-site training, and careful supervision are required. The costs still tend to be lower than traditional methods. Additionally, construction is usually performed during the dormant season when labor tends to be more available (Gray and Sotir, 1996). Another limitation, which is avoidable, is that thick vegetation may increase roughness values or increase friction and raise floodwater elevations. This should be taken into consideration during the planning stages of a project and prevented.

Structural Approaches

Soil bioengineering alone is not suitable in all instances. When considering an approach to streambank or shoreline stabilization, it is important to take several factors into account. For example, it is inappropriate to stabilize slopes with soil bioengineering systems in areas that would not support plant growth, such as those areas with soils that are toxic to plants, areas of high water velocity, or significant wave action (Gray and Sotir, 1996). Shores subject to wave erosion will usually require structures or beach nourishment to dampen wave or stream flow energy. In particular, the principles of soil bioengineering, discussed previously, will most likely be ineffective at controlling that portion of streambank or shoreline erosion caused by wave energy. However, soil bioengineering will typically be effective on the portion of the eroding streambank or shoreline located above the extent of the current or the zone of wave attack. Subsurface seepage and soil slumping may need to be prevented by dewatering the bank material. Steep banks may need to be reshaped to a gentler slope to accommodate the plant material (Hall and Ludwig, 1975). As an alternative, an integrated system that combines soil bioengineering measures with structural measures can be installed.

Properly designed and constructed shoreline and streambank erosion control structures are used in areas where higher water velocity or wave energy make biostabilization and marsh creation ineffective. There are many sources of information concerning the proper design and construction of shoreline and streambank erosion control structures. In addition to careful consideration of the engineering design, the proper planning for a shoreline or streambank protection project will include a thorough evaluation of the physical processes causing the erosion. To complete the analysis of physical factors, the following steps are suggested (Hobbs et al., 1981):

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

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

Fixed engineering structures are built to protect upland areas when resources are affected by erosive processes. Sound design practices for these structures are essential (Kraus and Pilkey, 1988). Not only are poorly designed structures typically unsuccessful in protecting the intended stretch of shoreline, but they also have a negative impact on other stretches of streambanks and shoreline as well.

Examples of structural approaches include:

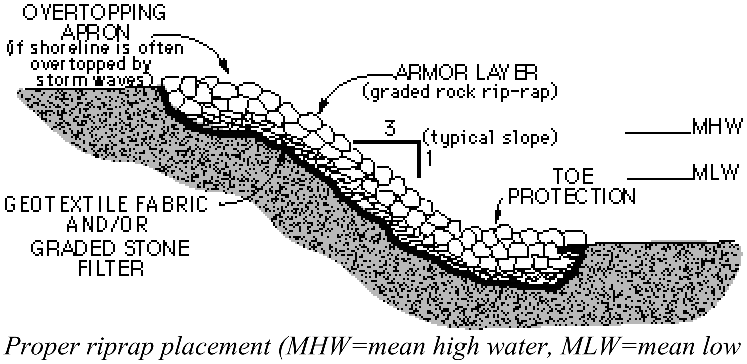
- Riprap
- Bulkheads and seawalls
- Revetment
- Groins
- Breakwaters
- Beach nourishment
- Toe protection
- Return walls
- Wing deflectors

Riprap

Riprap is a blanket of appropriately sized stones extending from the toe of the slope to a height needed for long term durability (Figures 3.13 and 3.14). (Joint plantings is an integrated version of the riprap method). This method is suitable where stream flow velocity is high or where there is a threat to life or property. This method can be expensive particularly if materials are not locally available. This method should be combined with soil bioengineering techniques, particularly revegetation efforts, to achieve a comprehensive streambank restoration design (FISRWG, 1998).

Figure 3.13 Riprap (Source: http://www.dnrec.state.de.us/dnrec2000/Divisions/Soil/dcmp/cdhydro.htm)

Placement of large rock, usually referred to as riprap, is the preferred and most common form of shore protection. Technical methods are available to determine rock size, placement geometry, and elevations to ensure the best protection. Specific county Soil and Water Conservation District (SWCD), the Minnesota Board of Water and Soil Resources (BWSR), and the federal Natural Resources Conservation Service (NRCS) can provide technical assistance.



Proper riprap placement (MHW=mean high water, MLW=mean low water).

Figure 3.14 Riprap Diagram
(Source: http://www.extension.umn.edu/distribution/naturalresources/components/DD6946g.html)

Bulkheads and Seawalls

Bulkheads (Figure 3.15) are primarily soil-retaining structures designed to also resist wave attack. Seawalls are principally structures designed to resist wave attack, but they also may retain some soil (USACE, 1984). Both bulkheads and seawalls may be built of many materials, including steel, timber, or aluminum sheet pile, gabions, or rubble-mound structures. Although bulkheads and seawalls protect the upland area against further erosion and land loss, they often create a local problem. Downward forces of water, produced by waves striking the wall, can produce a transfer of wave energy and rapidly remove sand from the wall (Pilkey and Wright, 1988). A stone apron is often necessary to prevent scouring and undermining. With vertical protective structures built from treated wood, there are also concerns about the leaching of chemicals used in the wood preservatives. Chromated copper arsenate (CCA), the most popular chemical used for treating the wood used in docks, pilings, and bulkheads, contains elements of chromium, copper, and arsenic, that are toxic above trace levels (CSWRCB, 2005; Kahler et al., 2000).

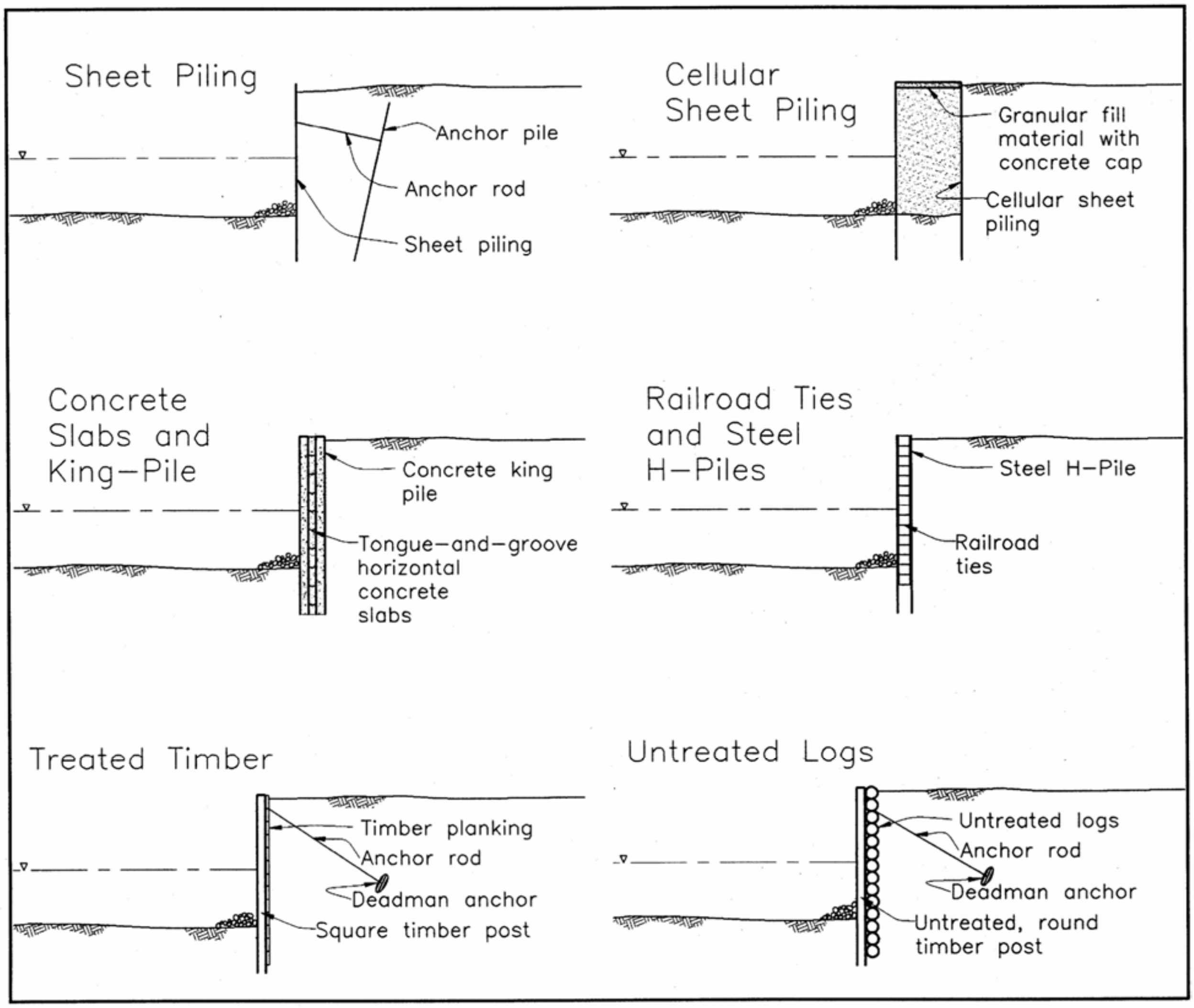


Figure 3.15 Typical Bulkhead Types (Source: USACE, 2003)

Revetment

A revetment (Figure 3.16) is a type of vertical protective structure used for shoreline protection. One revetment design contains several layers of randomly shaped and randomly placed stones, protected with several layers of selected armor units or quarry stone. The armor units in the cover layer should be placed in an orderly manner to obtain good wedging and interlocking between individual stones. The cover layer may also be constructed of specially shaped concrete units (USACE, 1984). Sometimes gabions (stone-filled wire baskets) or interlocking blocks of precast concrete are used in the construction of revetments. In addition to the surface layer of armor stone, gabions, or rigid blocks, successful revetment designs also include an underlying layer composed of either geotextile filter fabric and gravel or a crushed stone filter and bedding layer. This lower layer functions to redistribute hydrostatic uplift pressure caused by wave action in the foundation substrate. Precast cellular blocks, with openings to provide drainage and to allow vegetation to grow through the blocks, can be used in the construction of revetments to stabilize banks. Vegetation roots add additional strength to the bank. In situations where erosion can occur under the blocks, fabric filters can be used to prevent the erosion. Technical assistance should be obtained to properly match the filter and soil characteristics. Typically blocks

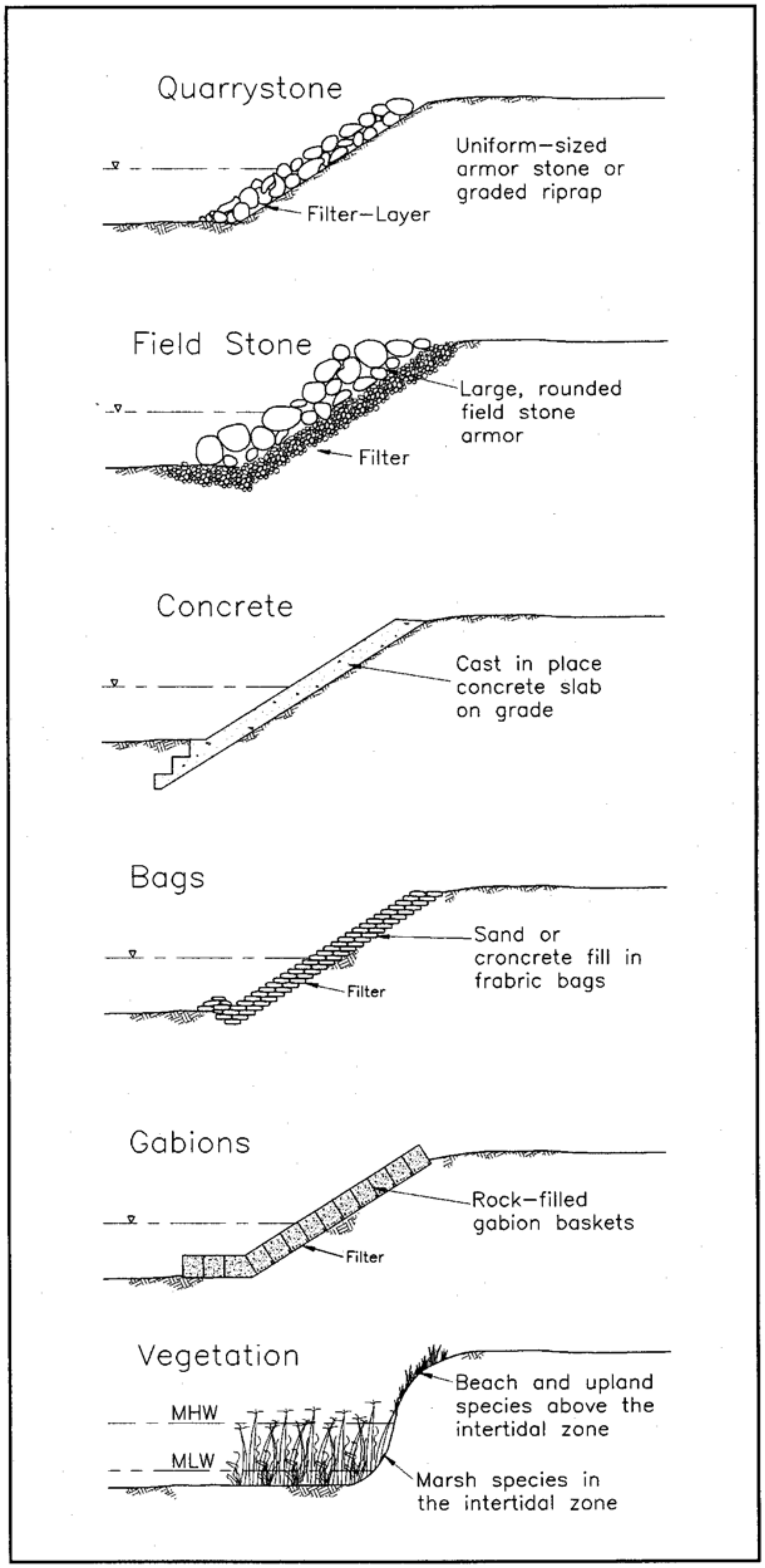


Figure 3.16 Revetment Alternatives (Source: USACE, 2003)

are hand placed when mechanical access to the bank is limited or costs need to be minimized. Cellular block revetments have the additional benefit of being flexible to conform to minor changes in the bank shape (USACE, 1983).

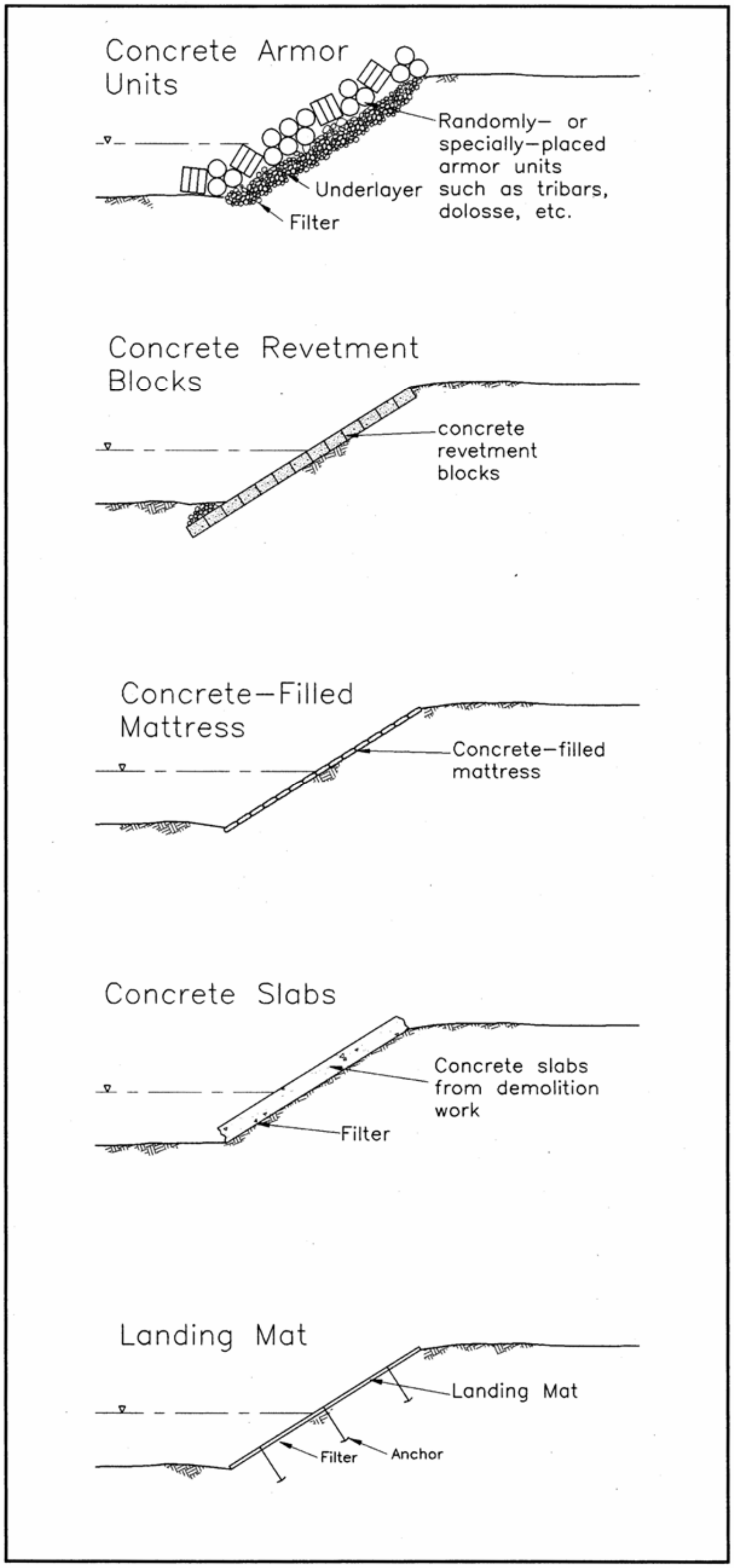


Figure 3.16 Revetment Alternatives, Continued (Source: USACE, 2003)

Groins

Groins are structures that are built perpendicular to the shore and extend into the water. Examples of possible planform shapes for groins are illustrated in Figure 3.17. They are generally constructed in series, referred to as a groin field, along the entire length of shore to be protected. Groins trap sand in littoral drift and halt its longshore movement along beaches. The sand beach trapped by each groin acts as a protective barrier that waves can attack and erode without damaging previously unprotected upland areas. Unless the groin field is artificially filled with sand from other sources, sand is trapped in each groin by interrupting the natural supply of sand moving along the shore in the natural littoral drift. This frequently results in an inadequate natural supply of sand to replace that which is carried away from beaches located farther along the shore in the direction of the littoral drift. If these "downdrift" beaches are kept starved of sand for sufficiently long periods of time, severe beach erosion in unprotected areas can result. As with bulkheads and revetments, the most durable materials used in the construction of groins are timber and stone. Less expensive techniques for building groins use sand- or concrete-filled bags or tires. It must be recognized that the use of lower-cost materials in the construction of bulkheads, revetments, or groins frequently results in less durability and reduced project life. Figure 3.18 illustrates transition from a groin field to a natural shoreline.

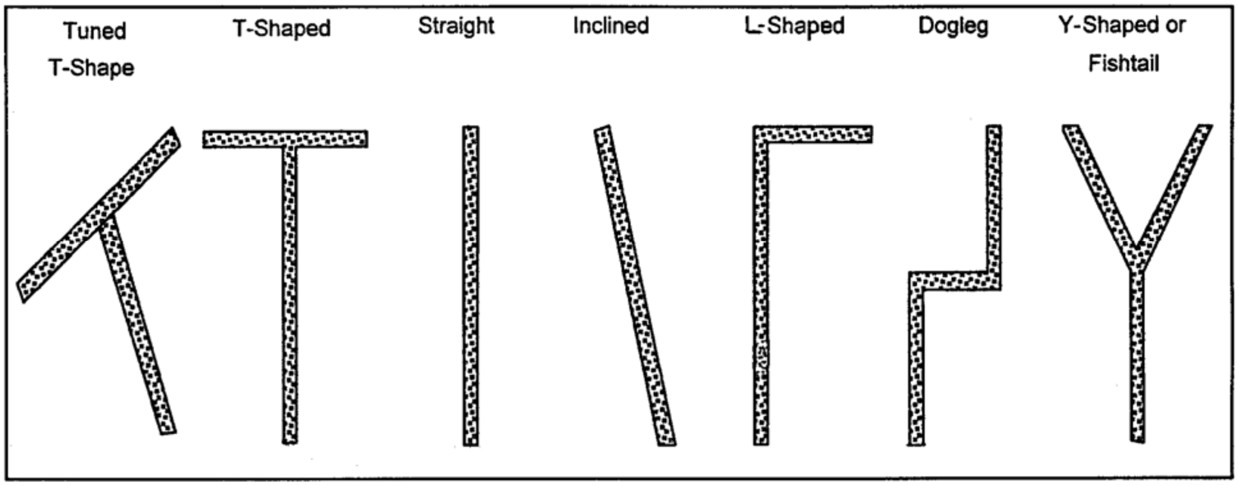


Figure 3.17 Possible Planform Shapes for Groins (Source; USACE, 2003)

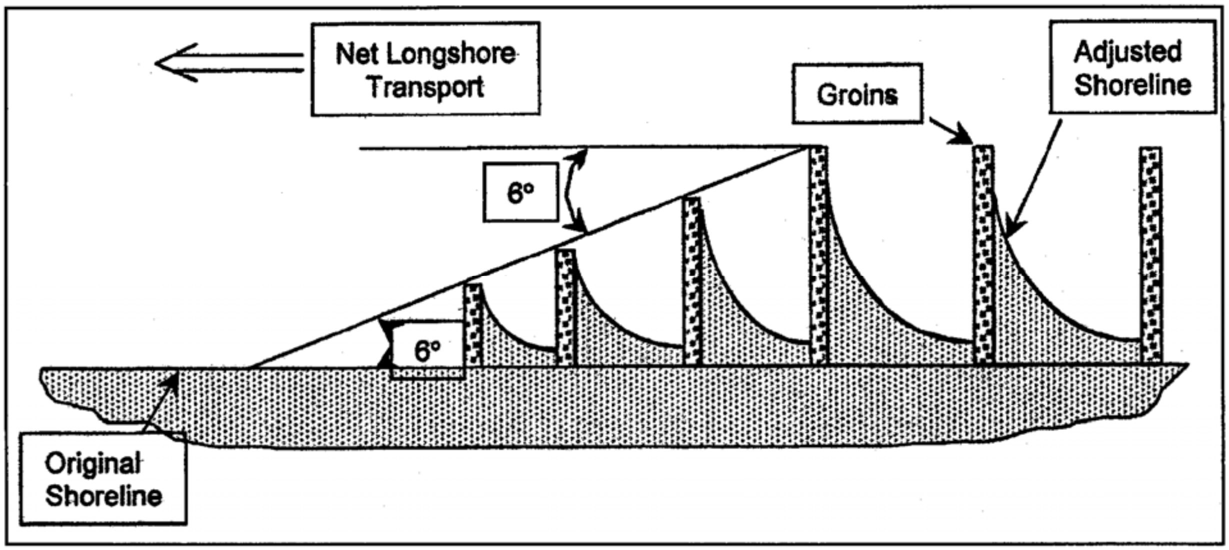


Figure 3.18 Transition from Groin Field to Natural Shoreline (Source: USACE, 2003)

Breakwaters

Figure 3.19 Breakwaters – View of Presque Isle, Pennsylvania (Source: USACE, 2003)

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

Figure 3.19 provides a view of breakwaters off the coast of Pennsylvania and Figure 3.20 illustrates single and multiple breakwaters.

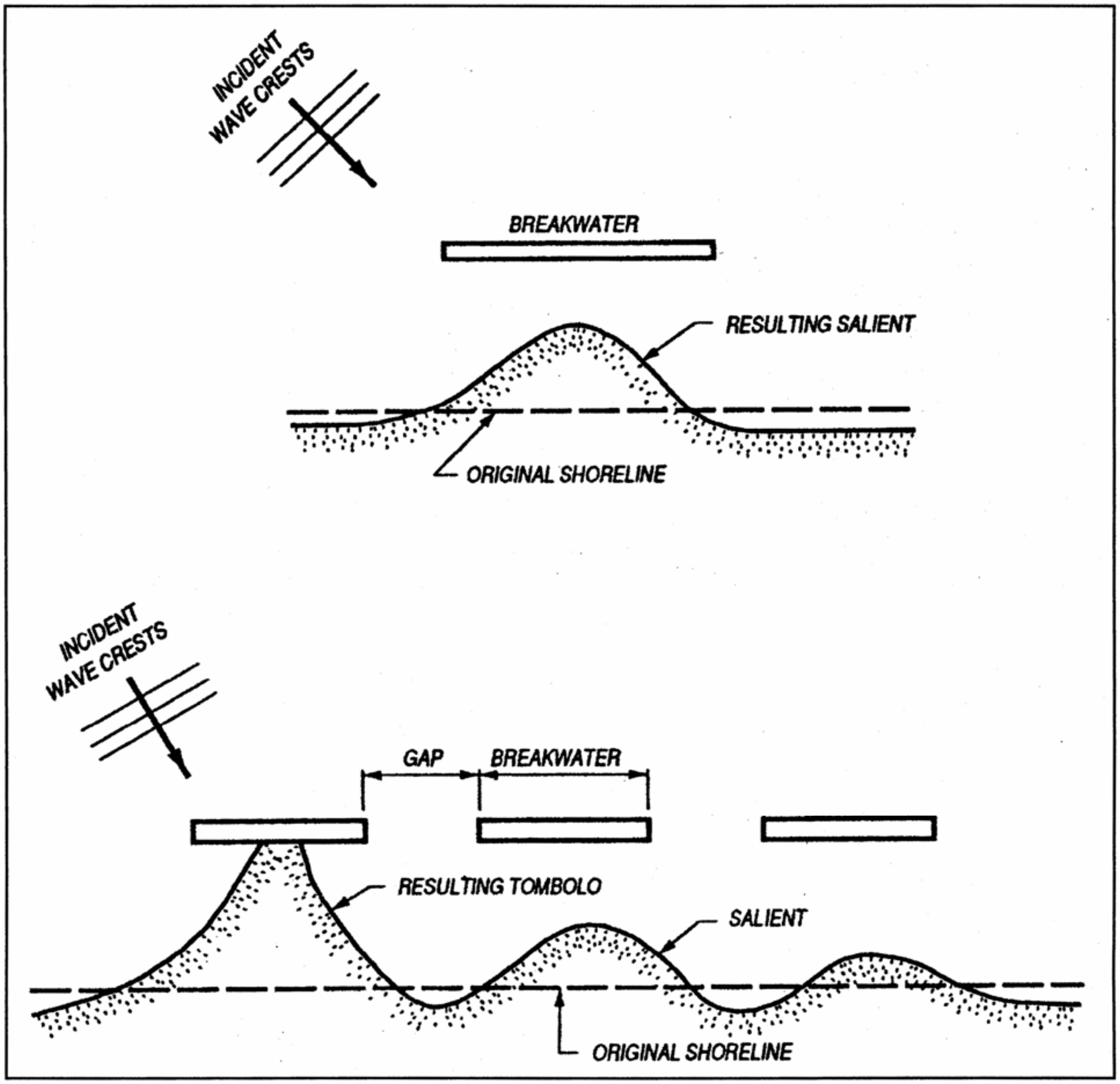


Figure 3.20 Single and Multiple Breakwaters (Source: USACE, 2003)

Beach Nourishment

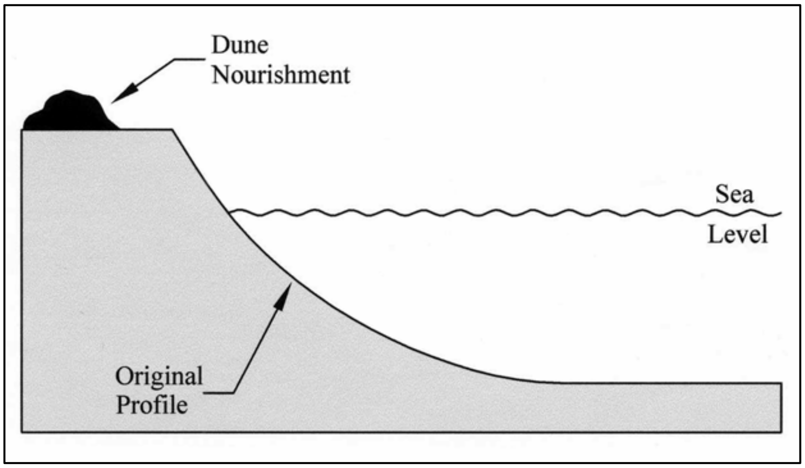


Figure 3.21 Dune Nourishment (Source: California Department of Boating and Waterways and State Coastal Conservancy, 2002)

The creation or nourishment of existing beaches provides protection to the eroding area and can also provide a riparian habitat function, particularly when portions of the finished project are planted with beach or dune grasses (Woodhouse, 1978). Beach nourishment (Figures 3.21 through 3.24) requires a readily available source of suitable fill material that can be effectively transported to the erosion site for reconstruction of the beach (Hobson, 1977). Dredging or pumping from offshore deposits is the method most frequently used to obtain fill material for beach nourishment. A second possibility is the mining of suitable sand from inland areas and overland hauling and dumping by trucks. To restore an eroded beach and stabilize it at the restored position, fill is placed directly along the eroded sector (USACE, 1984). In most cases, plans must be made to periodically obtain and place additional fill on the nourished beach to replace sand that is carried offshore into the zone of breaking waves or alongshore in littoral drift (Houston, 1991; Pilkey, 1992).

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

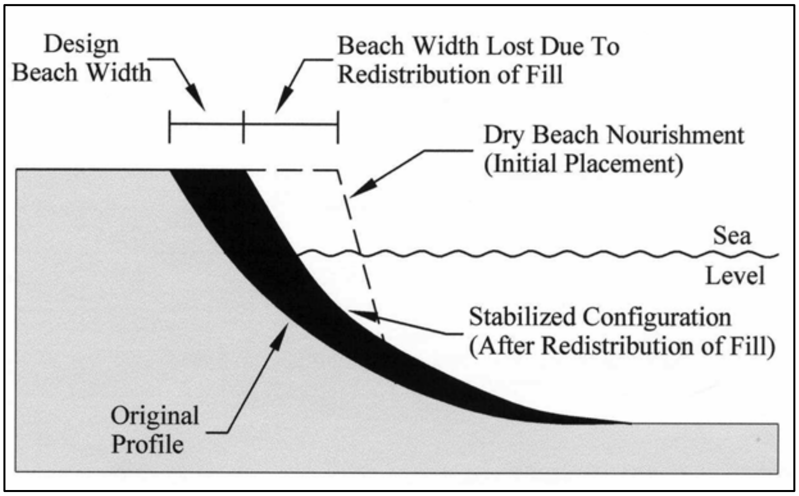


Figure 3.22 Dry Beach Nourishment (Source: California Department of Boating and Waterways and State Coastal Conservancy, 2002)

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

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

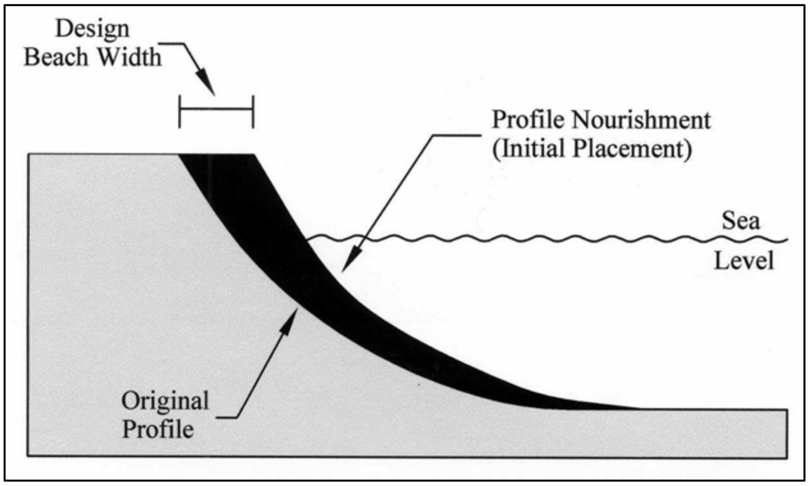


Figure 3.23 Profile Nourishment (Source: California Department of Boating and Waterways and State Coastal Conservancy, 2002)

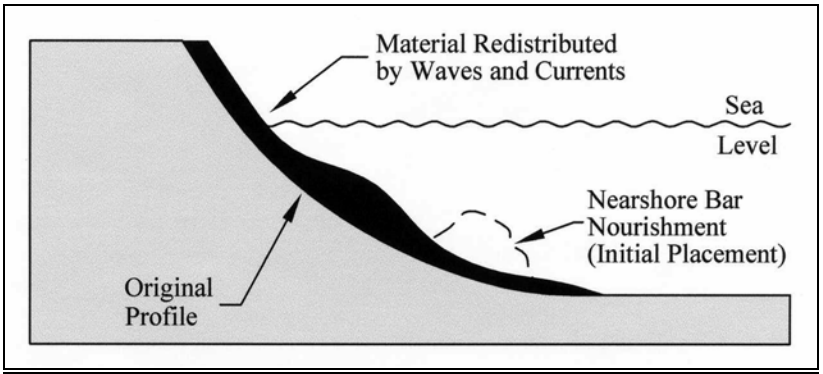


Figure 3.24 Nearshore Bar Nourishment (Source: California Department of Boating and Waterways and State Coastal Conservancy, 2002)

Toe Protection

A number of qualitative advantages are to be gained by providing toe protection for vertical bulkheads. Toe protection usually takes the form of a stone apron installed at the base of the vertical structure to reduce wave reflection and scour of bottom sediments during storms. The installation of rubble toe protection should include filter cloth and perhaps a bedding of small stone to reduce the possibility of rupture of the filter cloth. Ideally, the rubble should extend to an elevation such that waves will break on the rubble during storms.

Return Walls

In areas where existing protection methods are being flanked or are failing, implement properly designed and constructed shore erosion control methods such as returns or return walls, toe protection, and proper maintenance or total replacement.

Whenever shorelines or streambanks are "hardened" through the installation of bulkheads, seawalls, or revetments, the design process must include consideration that waves and currents can continue to dislodge the substrate at both ends of the structure, resulting in very concentrated erosion and rapid loss of fastland. This process is called flanking. To prevent flanking, return walls should be provided at either end of a vertical protective structure and should extend landward for a horizontal distance consistent with the local erosion rate and the design life of the structure.

Wing Deflectors

Wing deflectors are structures that protrude from either streambank but do not extend entirely across a channel. The structures are designed to deflect flows away from the bank, and create scour pools by constricting the channel and accelerating flow. The structures can be installed in series on alternative streambanks to produce a meandering thalweg and stream diversity. The most common design is a rock and rock-filled log crib deflector structure. The design bases the size of the structure on anticipated scour. These structures need to be installed far enough downstream from riffle areas to avoid backwater effects that could drown out or damage the riffle. This design should be employed in streams with low physical habitat diversity, particularly channels that lack pool habitats. Construction on a sand bed stream may be susceptible to failure and should be constructed with the use a filter layer or geotextile fabric beneath the wing deflector structure (FISRWG, 1998).

Integrated Systems

The use of structural systems alone may raise concern because these systems lack vegetation, which can often be effective at stabilizing soils in most conditions. Additionally, vegetated systems can help to restore damaged habitat along shorelines and streambanks. Although there is little evidence to confirm this, in the past, some thought that vegetation could destabilize structures, such as stone revetments. However, integrated systems, which combine structural systems and vegetation, can be very effective in many settings where vegetation adds support and habitat to structural systems. An example of an integrated system is the use of stones for toe protection (structural) and soil bioengineering techniques (vegetative) for the upper banks.

Integrated slope protection designs that employ the traditional structural methods and the soil bioengineering techniques have proven to be more cost effective than either method independently. Where construction methods are labor-intensive and labor costs are reasonable, the combination of methods may be especially cost effective (Gray and Sotir, 1996).

Integrated systems include:

- Joint planting
- Live cribwalls
- Bank shaping and planning
- Vegetated gabions

- Rootwad revetments
- Vegetated geogrids
- Vegetated reinforced soil slope (VRSS)

Joint Planting

Joint planting (or vegetated riprap) involves tamping live cuttings of rootable plant material into soil between the joints or open spaces in rocks that have previously been placed on a slope (Figure 3.25). Alternatively, the cuttings can be tamped into place at the same time that rock is being placed on the slope face. Joint planting is useful where rock riprap is required or already in place. It is successful 30 to 50 percent of the time, with first year irrigation improving survival rates. Live cuttings must have side branches removed and bark intact. They should range from 0.5 to 1.5 inches in diameter and be long enough to extend well into the soil, reaching into the dry season water level. Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002) and the USDA NRCS *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992).

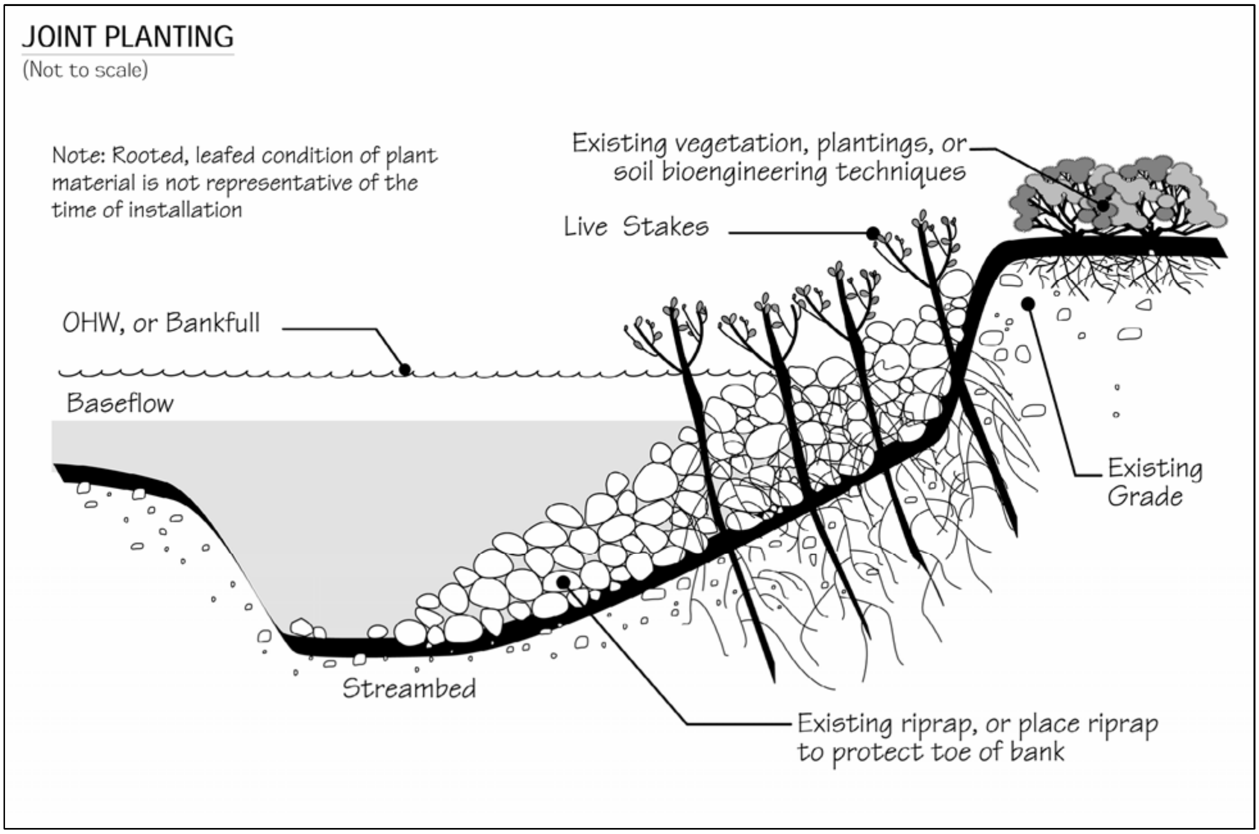


Figure 3.25 Joint Planting (Source: USDA-FS, 2002)

Live Cribwalls

A live cribwall is used to rebuild a bank in a nearly vertical setting. It consists of a hollow, box-like interlocking arrangement of untreated log or timber members (Figure 3.26). The structure is filled with suitable backfill material and layers of live branch cuttings, which root inside the crib structure and extend into the slope. Logs or untreated timbers should range from 4 to 6 inches in diameter. Lengths will vary with the size of the crib structure. Fill rock should be 6 inches in diameter. Live branch cuttings should be 0.5 to 2.5 inches in diameter and long enough to reach the back of the wooden crib structure. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members. Live cribwalls are appropriate where space is limited and at the base of a slope where a low wall may be required to stabilize the toe of the slope and to reduce its steepness. They are also appropriate above and below the water level where stable streambeds exist. They are not designed for or intended to resist large, lateral earth stress. Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002) and the USDA NRCS *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992).

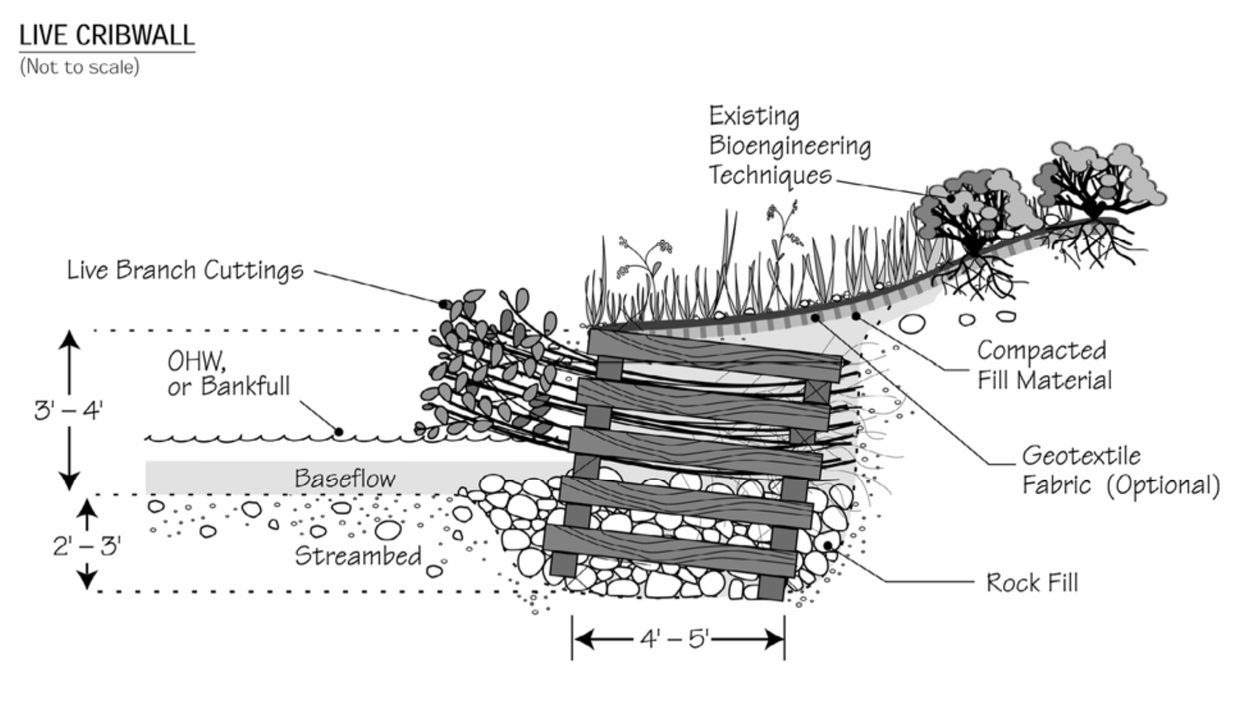


Figure 3.26 Live Cribwall (Source: USDA-FS, 2002)

Bank Shaping and Planting

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

Case Study: Streambank Stabilization in the Thomas Fork Watershed

The Thomas Fork watershed covers 150,100 acres in Bear Lake County, Idaho and Lincoln County, Wyoming. Due to its latitude and elevation, the watershed typically experiences short, cool summers and long, cold winters. Approximately 50 percent of the watershed's annual precipitation occurs during the winter months as snow. This snow is stored in the snowpack at higher elevations and results in runoff in spring and summer. Thomas Fork is a tributary to the Bear River, upstream from where the Bear River is diverted into Bear Lake. In Idaho, the lake has been designated a Special Resource Water. Bear Lake also contains five endemic fish species.

The designated uses of Thomas Fork are cold-water biota and salmonid spawning, as well as primary and secondary recreation. The stream was first listed among Idaho's 303(d) "water quality limited stream segments" in 1996. The State's 1998 303(d) report identified sediment and nutrients as contributors to water quality impairment. The primary nonpoint sources of pollutants are cropland and rangeland, animal feeding areas, riparian areas, stream channelization, and streambank modification.

Since the mid-1990s, the Bear Lake Regional Commission has worked with partners, including the Bear Lake Soil and Water Conservation District, U.S. Department of Agriculture's Natural Resources Conservation Service, and local landowners to reduce the pollutant loading from Bear River and Thomas Fork to Bear Lake. The Soil Conservation District developed a watershed management plan, with funds provided by an Idaho state agricultural water quality project. The Bear Lake Regional Commission also received Clean Water Act Section 319 funding to work with landowners to develop and install BMPs.

Riparian and instream restoration activities began with a focus on riparian and streambank problems. Examples of BMPs installed include rock stream barbs, bank shaping and reseeding, tree revetment, rock riprap, channel armoring, fencing, animal water gaps, manure management facilities, and constructed wetlands. In addition to these measures, landowners agreed to help maintain the projects after installation.

The stabilization work resulted in a marked decrease in the amount of sediment entering Thomas Fork. Photo points, water chemistry, and surveyed stream transects were used to monitor effectiveness of the activities. The stream transects have revealed that for each foot of treated streambank, 50 cubic feet of streambank material was retained on the banks, as compared to an untreated site. Other trends show a 75% decrease in phosphorus loadings, as well as significant decreases total suspended solids and nitrogen.

Sources:
Idaho Department of Environmental Quality. 2001. *Taking Plans to Action: State of Idaho Nonpoint Source Management Program*. 2001 Report to Congress. http://www.deq.state.id.us/water/data_reports/surface_water/nps/congress_report_2001_entire.pdf. Accessed December 2005.

Poulson, M. 2003. Thomas Fork Streambank Stabilization Project. *Getting It Done: The Role of TMDL Implementation in Watershed Restoration, October 29-30, 2003, Stevenson, WA*. http://www.swwrc.wsu.edu/conference2003/pdf/Proceedings/Proceedings/Session%208B/POWERPOINT_Poulsen.pdf. Accessed March 2004.

USEPA. 1998. Idaho's Impaired Waters List Approved by EPA for 1998 (CWA Section 303(d) List). http://yosemite.epa.gov/r10/water.nsf/0/5c6b7bf2420c272888256a4800613a68/$FILE/1998303dlist.pdf. Accessed December 2005.

USEPA. 2002. *Streambank Stabilization in the Thomas Fork Watershed: Photo Monitoring Sells Landowners on Bank Stabilization*. U.S. Environmental Protection Agency, Section 319 Success Stories, Vol. III http://www.epa.gov/owow/nps/Section319III/ID.htm. Accessed June 2003.

Vegetated Gabions

Vegetated gabions (Figure 3.27) start with wire-mesh, rectangular baskets filled with small to medium rock and soil. The baskets are then laced together to form a structural toe or sidewall. Live branches (0.5 to 1 inch in diameter) are then placed on each consecutive layer between the rock filled baskets to take root, join together the structure and bind it to the slope. This method is effective for protecting steep slopes where scouring or undercutting is occurring. However, this method is not appropriate in streams with heavy bed load or where severe ice damage occurs. This method provides moderate structural support and should be placed at the base of a slope to stabilize the slope and reduce slope steepness. A stable foundation is required for the installation of these structures. When the rock size needed is not locally available, this design is effective because smaller rocks can be used. A limiting factor of this method is that it is expensive to install and to replace. These structures are relatively expensive to construct and frequently require costly repairs. This method should be combined with other soil bioengineering techniques, particularly revegetation efforts, to achieve a comprehensive streambank restoration design (FISRWG, 1998). There is often opposition to these structures based on their inability to blend in with natural settings and their general lack of aesthetically pleasing qualities (Gore, 1985).

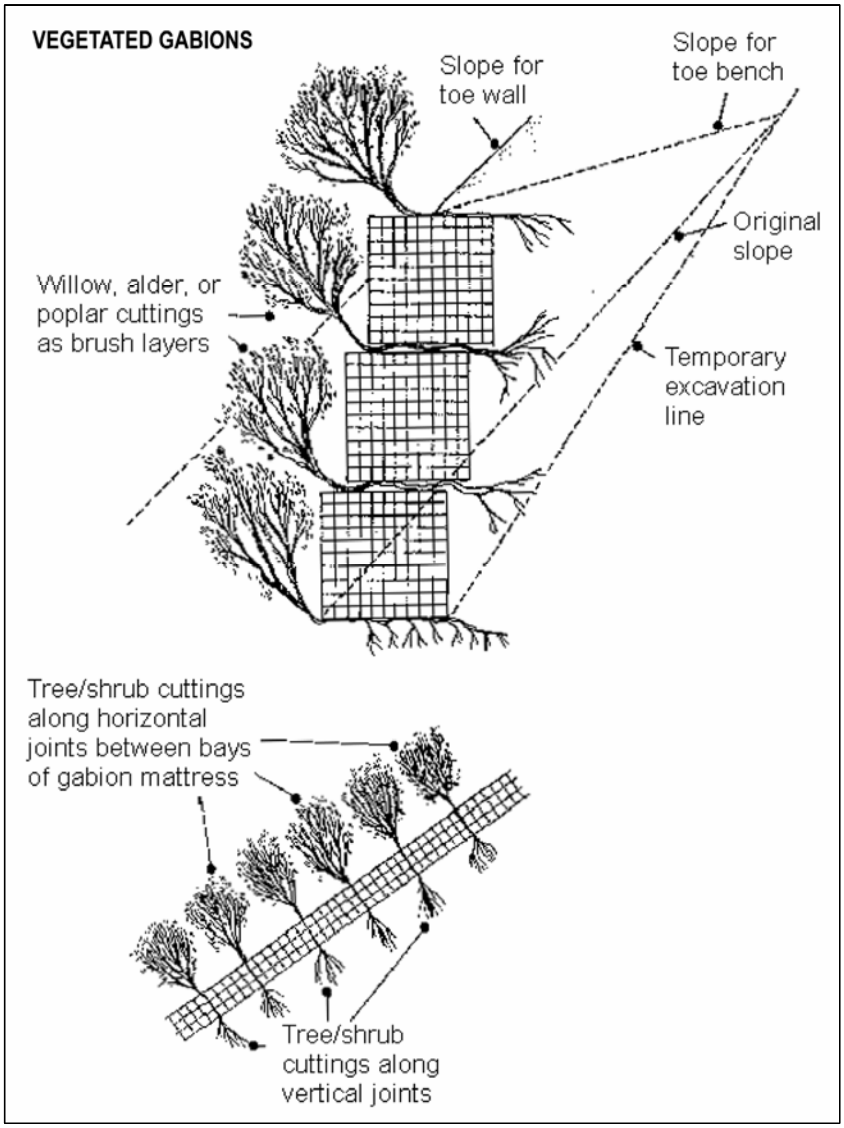


Figure 3.27 Vegetated Gabion (Source: Allen and Leech, 1997)

Installation guidelines are available from the USDA NRCS *Engineering Field Handbook, Chapter 18* (USDA-NRCS, 1992). Under EMRRP, the U.S. Army Corps of Engineers has presented research on vegetated gabions in a technical note (*Gabions for Streambank Erosion Control*), which is available at http://el.erdc.usace.army.mil/elpubs/pdf/sr22.pdf.

Rootwad Revetments

Root wads armor a bank by keeping faster moving currents away from the bank (Figures 3.28 and 3.29). They are most useful for low energy streams that meander and have out-of-bank flow conditions. Root wads should be used in combination with other soil bioengineering techniques to stabilize a bank and ensure plant establishment on the upper portions of the streambank. Stabilizing the bank will reduce streambank erosion, trap sediment, and improve habitat diversity. There are a number of ways to install root wads. The trunk can be driven into the bank, laid in a deep trench, or installed as part of a log and boulder revetment. Use tree wads that have brushy top and durable wood, such as Douglas fir, oak, hard maple, juniper, spruce, cedar, red pine, white pine, larch, or beech. Ponderosa pine and aspen are too inflexible and alder decomposes rapidly.

With the added support of a log and boulder revetment, root wads can stabilize banks of high-energy streams. Root wad span should be approximately 5 feet with numerous root protrusions. The trunk should be at least 8 to 12 feet long. Boulders should be as large as possible, but at least one and a half times the log's diameter. They should also have an irregular surface. Logs are to be used as footers or revetments and should be over 16 inches in diameter.

When logs and rootwads are well anchored, this design will tolerate high boundary shear stress. However, local scour and erosion is possible. Varying with climate and tree species used, the decomposition of the logs and rootwads will limit the life span of this design. If colonization of streambank vegetation does not take place, replacement may be required. The project site must be accessible to heavy equipment. Locating materials may be difficult in some locations and this method can be expensive (FISRWG, 1998).

Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002). Under EMRRP, the U.S. Army Corps of Engineers has presented research on rootwad composites in a technical note (*Rootwad Composites for Streambank Erosion Control and Fish Habitat Enhancement*), which is available at http://el.erdc.usace.army.mil/elpubs/pdf/sr21.pdf.

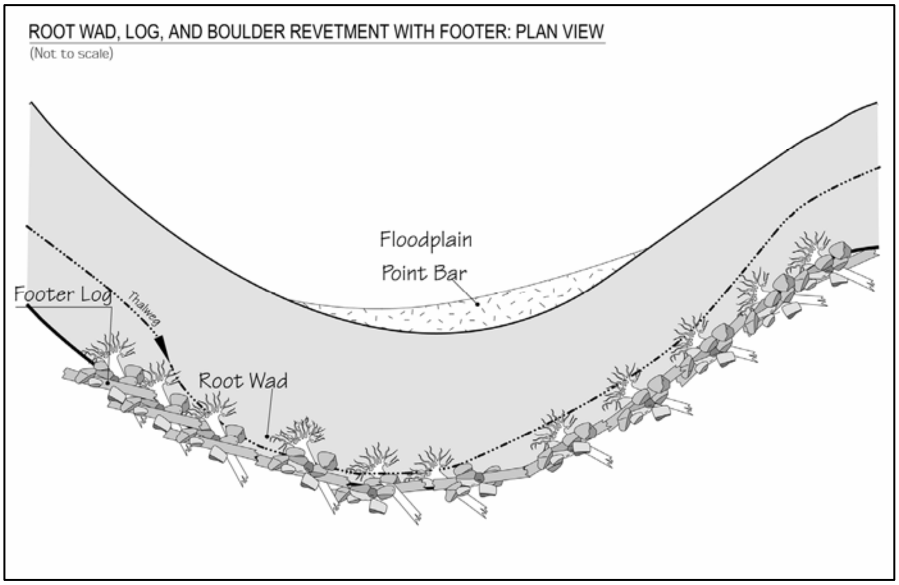


Figure 3.28 Rootwad, Log, and Boulder Revetment with Footer: Plan View (Source: USDA-FS, 2002)

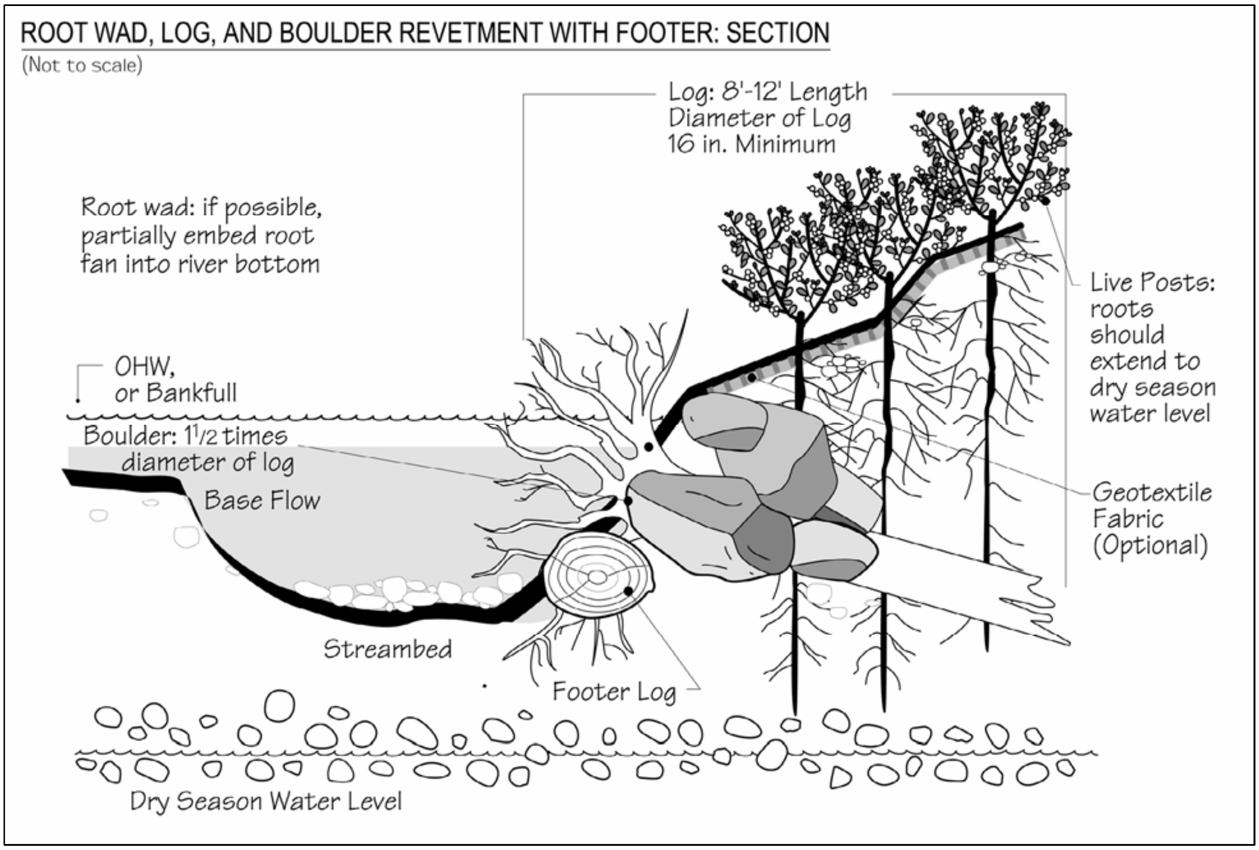


Figure 3.29 Rootwad, Log, and Boulder Revetment with Footer: Section (Source: USDA-FS, 2002)

Case Study: Coldwater Fishery Restored Through Bioengineering

Conewago Creek, just north of Arendtsville in Adams County, Pennsylvania (also known as "The Narrows") is considered one of the most scenic stream corridors in the county. The creek is listed as a "high quality coldwater fishery" and a wild trout stream by the Pennsylvania Fish and Boat Commission and is actively stocked by several local private clubs.

In the summer and early fall of 1996, Adams County received more than 90 inches of rain during severe storms, nearly 4 feet more than the county average. As a result, two sections of Conewago Creek in The Narrows were heavily damaged, resulting in severe streambank erosion. On the upper of the two sites, damage was enhanced by fallen trees, leading to erosion and channel scour. Furthermore, bedload deposits coming primarily from the upper site caused erosion on the lower section. The eroding streambanks were filling up pools, degrading the conditions necessary for fish to thrive in the creek.

In 1998, an EPA Section 319 nonpoint source grant was awarded for the restoration and stabilization of approximately 800 feet of streambank at the two sites on Conewago Creek.

The streambank at the McDannel site was severely eroded at the beginning of the project in February 1999.

Improvements to the area included measures such as smoothing and reducing the bank slope and installation of native rock and root wads along the streambank. Fallen trees at the site were used as root wads to help stabilize the toe of the bank, and the root wads and rock provided the large, heavy material necessary to stabilize the toe of the eroding slope and prevent further undercutting. The steep bank was regraded using the gravel material removed from the adjacent streambank. This process "softened" the streambank, allowing the stream to flow away from the newly stabilized banks. Following construction, local groups assisted in revegetation of the sites. The Adams County Chapter of Trout Unlimited donated trees for planting. The planted trees and grass improved the aesthetics of the site and further reduced erosion.

The project was completed on March 27, 1999. Seedlings planted continue to grow and deep pools have formed, particularly at the root wad structures. The root wads are providing excellent fish habitat and have improved trout populations at this site. Estimates from 2001 indicate that these efforts have reduced the erosion of approximately 8,000 tons of sediment from streambanks into this creek.

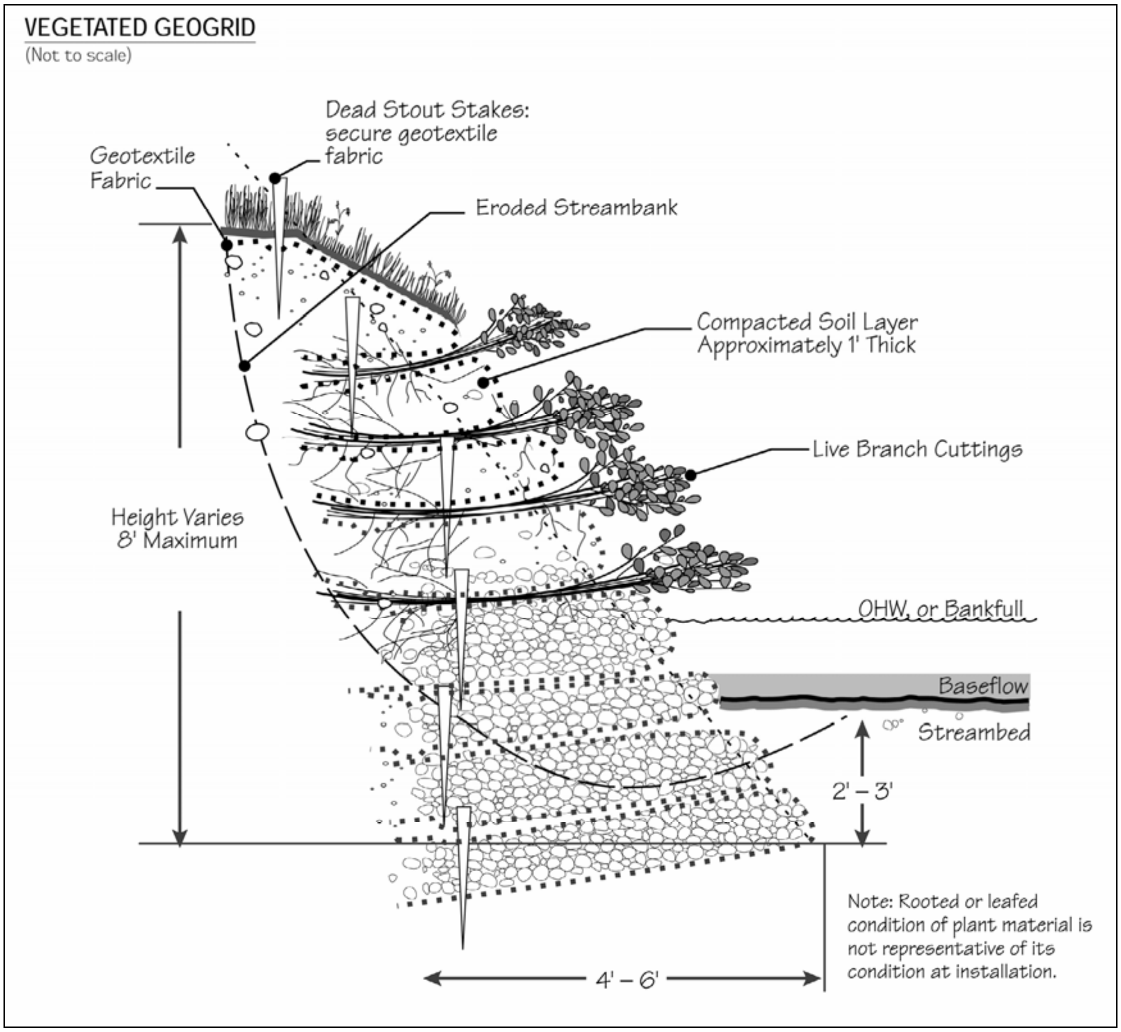
Sources:

USEPA. n.d. The Narrows Stream Bank Restoration and Protection Project. http://www.epa.gov/reg3wapd/nps/successstories/PApdf/narrows.pdf. Accessed March 2004.

USEPA. 2002. *Narrows Bioengineering Project: Cold-Water Fishery Restored Through Bioengineering*. U.S. Environmental Protection Agency, Section 319 Success Stories, Vol. III. http://www.epa.gov/owow/nps/Section319III/PA.htm. Accessed June 2003.

Vegetated Geogrids

Vegetated geogrids consist of layers of live branch cuttings and compacted soil with natural or synthetic geotextile materials wrapped around each soil layer (Figure 3.30). This serves to rebuild and vegetate eroded streambanks particularly on outside bends where erosion can be a problem. This system is designed to capture sediment providing a substrate for plant establishment and if properly designed and installed, these systems help to quickly establish riparian vegetation. Its benefits are similar to those of brush layering (e.g., dries excessively wet sites, reinforces soil as roots develop, which adds significant resistance to sliding or shear displacement). Due to the strength of this design and the higher initial tolerance to flow velocity, these systems can be installed on a 1:1 or steeper streambank or lakeshore. Limitations of this design include the complexity involved with constructing this system and the fairly high expense (FISRWG, 1998). When constructing this type of system, use live branch cuttings that are brushy and root readily. Also use cuttings that are 0.5 to 2 inches in diameter and 4 to 6 feet long. This type of system requires biodegradable erosion control fabric. Installation guidelines are available from the USDA-FS Soil Bioengineering Guide (USDA-FS, 2002).



Note: Rooted or leafed condition of plant material is not representative of its condition at installation.

Figure 3.30 Vegetated Geogrid (Source: USDA-FS, 2002)

Vegetated Reinforced Soil Slope (VRSS)

The vegetated reinforced soil slope (VRSS) soil bioengineering system (Figures 3.31 and 3.32) is an earthen structure constructed from living, rootable, live-cut, woody plant material branches, bare root, tubling or container plant stock, along with rock, geosynthetics, geogrids, and/or geocomposites. The VRSS system is useful for immediately repairing or preventing deeper failures, providing a structurally sound system with soil reinforcement, drainage, and erosion control (typically on steepened slope sites where space is limited). With this system, living cut branches and plants are expected to grow and perform additional soil reinforcement via the roots and surface protection via the top growth (Sotir and Fischenich, 2003).

Live vegetation in the VRSS is typically installed from just above the baseflow elevation and up the face of the reconstructed streambank, acting mainly to protect the bank through immediate mechanical soil reinforcement and confinement, drainage, and, in the toe area, with rock. The VRSS system extends below the depth of scour, typically with rock, which is useful in improving infiltration and supporting the riparian zone. The internal systems such as rock, live cut branches, geogrids, geosynthetics, and geocomposites can also be configured to act as drains that redirect and/or collect internal bank seepage and transport the water to the stream via a rock toe (Sotir and Fischenich, 2003).

Figure 3.31 VRSS Structure After Construction (Source: Sotir and Fischenich, 2003)

Plants within the VRSS structure may be selected to provide color, texture, and other attributes to add a pleasant, natural landscape appearance. Examples, of plants for the structure could include buttonbush, dogwood, willow, hybiscus, and *Viburnum* spp. Check with your local NRCS office to make sure these are appropriate for your location and for alternate suitable plant species. If a compound channel cross section is desirable near or just below the baseflow elevation, a step-back terrace may be incorporated to offer an enhanced riparian zone, where emergent aquatic plants, such as bulrush and sedges may invade over time. Although the total mass uptake may be small, they will assimilate contaminants within the water column. Aquatic wetland plants that may be installed in the VRSS adjacent to the stream include blueflag, pickerelweed, and monkey flower. Again, consult your local NRCS office for information on locally appropriate plants. VRSS systems can be constructed on slopes ranging from 1V on 2H (1:2) to 1:0.5. When constructed in step or terrace fashion, they can improve non-point pollution control by intercepting sediment and attached pollutants during overbank flows (Sotir and Fischenich, 2003).

Figure 3.32 Established VRSS Structure (Source: Sotir and Fischenich, 2003)

Additional information about VRSS systems is available from the U.S. Army Corps of Engineers technical note on VRSS (*Vegetated Reinforced Soil Slope Streambank Erosion Control*), which is available at http://el.erdc.usace.army.mil/elpubs/pdf/sr30.pdf.

Setbacks

Establish setbacks to minimize disturbance of land adjacent to streambanks and shorelines to reduce other impacts. Upland drainage from development should be directed away from bluffs and banks so as to avoid accelerating slope erosion.

In addition to the soil bioengineering, marsh creation, beach nourishment, and structural practices discussed on the preceding pages of this guidance, another approach that should be considered in the planning process for shoreline and streambank erosion involves the designation of setbacks. Setbacks most often take the form of restrictions on the siting and construction of new standing structures along the shoreline. Where setbacks have been implemented to reduce the hazard of coastal land loss, they have also included requirements for the relocation of existing structures located within the designated setback area. Setbacks can also include restrictions on uses of waterfront areas that are not related to the construction of new buildings (Davis, 1987).

In most cases, states have used the local unit of government to administer the program on either a mandatory or voluntary basis. This allows local government to retain control of its land use activities and to exceed the minimum state requirements if this is deemed desirable (NRC, 1990).

Technical standards for defining and delineating setbacks also vary from state to state. One approach is to establish setback requirements for any “high hazard area” eroding at greater than 1 foot per year. Another approach is to establish setback requirements along all erodible shores because even a small amount of erosion can threaten homes constructed too close to the streambank or shoreline. Several states have general setback requirements that, while not based on erosion hazards, have the effect of limiting construction near the streambank or shoreline.

The basis for variations in setback regulations between states seems to be based on several factors, including (NRC, 1990):

- The language of the law being enacted
- The geomorphology of the coast
- The result of discretionary decisions
- The years of protection afforded by the setback
- Other variables decided at the local level of government

From the perspective of controlling NPS pollution resulting from erosion of shorelines and streambanks, the use of setbacks has the immediate benefit of discouraging concentrated flows and other impacts of storm water runoff from new development in areas close to the streambank or shoreline. In particular, the concentration of storm water runoff can aggravate the erosion of shorelines and streambanks, leading to the formation of gullies, which are not easily repaired. Therefore, drainage of storm water from developed areas and development activities located along the shoreline should be directed inland to avoid accelerating slope erosion.

The best NPS benefits are provided by setbacks that not only include restrictions on new construction along the shore but also contain additional provisions aimed at preserving and protecting coastal features such as beaches, wetlands, and riparian forests. This approach promotes the natural infiltration of surface water runoff before it passes over the edge of the bank or bluff and flows directly into the coastal waterbody. Setbacks also help protect zones of naturally occurring vegetation growing along the shore. As discussed in the section on "bioengineering practices," the presence of undisturbed shoreline vegetation itself can help to control erosion by removing excess water from the bank and by anchoring the individual soil particles of the substrate.

Almost all states and territories with setback regulations have modified their original programs to improve effectiveness or correct unforeseen problems (NRC, 1990). Experiences have shown that procedures for updating or modifying the setback width need to be included in the regulations. For instance, application of a typical 30-year setback standard in an area whose rate of erosion is 2 feet per year results in the designation of a setback width of 60 feet. This width may not be sufficient to protect the beaches, wetlands, or riparian forests whose presence improves the ability of the streambank or shoreline to respond to severe wave and flood conditions, or to high levels of surface water runoff during extreme precipitation events. A setback standard based on the landward edge of streambank or shoreline vegetation is one alternative that has been considered (NRC, 1990; Davis, 1987).

From the standpoint of NPS pollution control, an approach that designates streambanks, shorelines, wetlands, beaches, or riparian forests as a special protective feature, allows no development on the feature, and measures the setback from the landward side of the feature is recommended (NRC, 1990). In some cases, provisions for soil bioengineering, marsh creation, beach nourishment, or engineering structures may also be appropriate since the special protective features within the designated setbacks can continue to be threatened by uncontrolled erosion of the shoreline or streambank. Finally, setback regulations should recognize that some special features of the streambank or shoreline will change position. For instance, beaches and wetlands can be expected to migrate landward if water levels continue to rise. Alternatives for managing these situations include flexible criteria for designating setbacks, vigorous maintenance of beaches and other special features within the setback area, and frequent monitoring of the rate of streambank or shoreline erosion and corresponding adjustment of the setback area.

Restoration Design Considerations

When designing a restoration project, it is important to consider the watershed as a whole as well as the specific site where restoration will occur. A watershed survey, or visual assessment, evaluates an entire watershed and can be used to help identify and verify pollutants, sources, and causes of impairments that lead to changes in streambank erosion. Additional monitoring of chemical, physical, and biological conditions may be necessary to determine if water quality is actually being affected by observed pollutants and sources. Watershed surveys can provide an accurate picture of what is occurring in the watershed. EPA's *Volunteer Stream Monitoring: A Methods Manual* (http://www.epa.gov/owow/monitoring/volunteer/stream/vms32.html) provides a watershed survey visual assessment form that may be used. In addition to EPA's method, a variety of visual assessment protocols have been developed by states and agencies. Designers of watershed restoration plans should look for assessment protocols that are already being used in their state or local area (USEPA, 2005c).

Photographs may also be a powerful tool that can be incorporated into watershed surveys. Photos serve as a visual reference for the site and provide before and after pictures that may be used to analyze restoration or remediation activities. In addition to taking individual photographs, aerial photographs may also provide important before and after information and can be obtained from USGS (Earth Science Information Center), USDA (Consolidated Farm Service Agencies, Aerial Photography Field Office), and other agencies (USEPA, 2005c). Refer to EPA's draft *Handbook for Developing Watershed Plans to Restore and Protect Our Waters* for more information about watershed assessments.

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

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

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

Before choosing a practice to restore or protect eroding sreambanks, it is also important to determine what biological endpoints are desired and to consider other environmental or water quality goals. Biological endpoints may include metrics such as the number of fish surviving, number of offspring produced, impairment of reproductive capability, or morbidity. Biological endpoints can be used to evaluate the effectiveness of treatment schemes and can serve as a design parameter during restoration planning. Water quality goals, such as increasing low dissolved oxygen levels, reducing high nutrient levels, or decreasing turbidity, are also important to consider when planning restoration. For example, if turbidity is a major problem in the waterbody, planners will want to choose a method of restoration that is efficient at trapping sediment before it enters the waterbody or one that will helps sediment to settle in the stream or river. Looking at endpoints and goals before designing the method of restoration can help planners and stakeholders achieve the desired results.

When choosing from the various alternatives of engineering practices for protection of eroding streambanks and shorelines, the following factors should be taken into consideration:

- Foundation conditions
- Level of exposure to erosive forces, such as periods of high stream flow or wave action
- Availability of materials
- Initial costs and repair costs
- Past performance

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

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

The availability of materials is another key factor influencing the selection of suitable structures for an eroding streambank or shoreline. A particular type of bulkhead, seawall, or revetment may not be economically feasible if materials are not readily available near the construction site. Installation methods may also preclude the use of specific structures in certain situations. For instance, the installation of bulkhead pilings in coastal areas near wetlands may not always be permissible due to disruptive impacts in locating pile-driving equipment at the project site.

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

Specific cost information for practices to protect or reduce streambank and shoreline erosion are available by contacting your local USDA Service Center, which makes available services provided by the NRCS. A list of USDA Service Centers is available at http://offices.usda.gov/scripts/ndCGI.exe/oip_public/USA_map. A list of regional and state NRCS offices is available at http://www.nrcs.usda.gov/about/organization/regions.html#state.

Information about the past performance of some of these practices (effectiveness and limitations) is available from a variety of sources, including:

- EPA's *National Menu of Best Management Practices for Storm Water Phase II* (http://cfpub.epa.gov/npdes/stormwater/menuofbmps/menu.cfm)
- EPA's *Development Document for Proposed Effluent Guidelines and Standards for the Construction and Development Category* EPA-821-R-02-007 (2002), (http://www.epa.gov/waterscience/guide/construction/devdoc.htm)
- The Stormwater Manager's Resource Center (http://www.stormwatercenter.net)
- National Association of Home Builders (NAHB). 1995. *Storm Water Runoff & Nonpoint Source Pollution Control Guide for Builders and Developers*. National Association of Home Builders, Washington, DC. (http://www.nahbrc.org)
- National Stormwater Best Management Practices (BMPs) Database, sponsored by the American Society of Civil Engineers (ASCE) and the U.S. Environmental Protection Agency (EPA) (http://www.bmpdatabase.org)
- Oregon Association of Conservation Districts, Oregon Small Acreage Fact Sheets: *Protecting Streambanks from Erosion* (http://www.oacd.org/fs04ster.htm)
- *Urban Storm Drainage Criteria Manual: Volume 3 – Best Management Practices*. Urban Drainage And Flood Control District, Denver, Colorado, September 1999. (http://www.udfcd.org)
- The Federal Interagency Stream Restoration Working Group. 1998. *Stream Corridor Restoration Principles, Processes, and Practices*. (http://www.usda.gov/stream_restoration)
- USDA-NRCS. 1992. *Engineering Field Handbook, Chapter 18 – Soil Bioengineering for Upland Slope and Protection and Erosion Reduction* (http://www.info.usda.gov/CED/ftp/CED/EFH-Ch18.pdf)

- USDA-FS. 2002. *A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization* (http://www.fs.fed.us/publications/soil-bio-guide)
- U.S. Army Corps of Engineers.2003. *Coastal Engineering Manual, Part V*. (http://www.usace.army.mil/publications/eng-manuals/em1110-2-1100/PartV/PartV.htm)
- Fischenich and Allen. 2000. *Stream Management*. U.S. Army Corps of Engineers, Engineer Research and Development Center.

Another factor to consider when choosing an engineering practice is the position of the site where the practice will be implemented, in relation to areas upstream (shoreline) and downstream (shoreline or streambank). Practices should be evaluated in the context of the site's surrounding area to ensure that implementation of the practice does not cause erosion or other problems in surrounding areas.

Planning a Restoration Project

Several resources are available that provide detailed guidance on watershed analysis for planning and implementing watershed restoration activities (see USEPA, 2005c and USDA-FS, 2002). When planning a restoration project, it is helpful to first determine the following (USDA–FS, 2002):

- Project goal(s)
- Desired future condition of the project site, which should outline what an area should look like (based on what is capable of sustaining) and describe how the project area should be managed
- Desired aesthetics and behaviors of the people who will use the restored area
- How management of an area needs to be changed to ensure the project is a success

Characteristics of the watershed should also be considered when planning a restoration project. The infiltration capacity of watersheds can vary widely according to the structure of the watershed. For example, heavily forested watersheds with many types of vegetation typically have high infiltration rates. Vegetation intercepts and dissipates energy from raindrops. Unimpeded raindrops that reach the ground can dislodge soil and cause erosion. The presence of vegetation typically results in an abundance of organic materials that help establish highly developed root systems, which keep the soil porous and well drained. Rapid infiltration in this type of watershed results in a significant portion of precipitation becoming ground water, which is later discharged to lakes, rivers, and streams. Watersheds with little vegetation have a lower infiltration capacity, which results in poorly drained soils and less ability to intercept rainfall (USDA–FS, 2002).

Without a watershed perspective and an understanding of the physical, biological, and human processes that regulate watershed ecosystem functions, adverse side effects from restoration attempts and use of streambank and shoreline stabilization techniques may result. With a greater understanding of structure and function at a watershed scale, planners can better predict the results of restoration and stabilization activities (USDA-FS, 2002).

As discussed under the section above on restoration design considerations, it is important to incorporate classification systems such as Rosgen's methodology or the modified Wolman methodology into a restoration plan. These types of systems can be useful in classifying streams and predicting future stream conditions, which can help in selecting suitable restoration or protection approaches. It is also important to incorporate monitoring in the restoration plan to evaluate the success of the restoration effort. Refer to EPA's *Volunteer Stream Monitoring: A Methods Manual* or EPA's *Elements of a State Water Monitoring and Assessment Program* for additional information about establishing monitoring plans. Also refer to EPA's *Draft Handbook for Developing Watershed Plans to Restore and Protect Our Waters* (USEPA, 2005c) for information on developing watershed plans that will help to restore and protect water quality. The handbook provides users with a variety of useful information that may be applied during the restoration design process, including:

- Building partnerships
- Defining the scope of the project
- Gathering data
- Analyzing the data
- Estimating pollutant loads
- Setting goals to reduce pollutant loads
- Identifying potential practices to implement
- Selecting final practices
- Implementing the chosen practices
- Measuring progress

According to USDA-FS (2002), a watershed analysis should precede any stabilization work. It should address, at a minimum, functional and structural characteristics of the watershed and answer basic questions, such as:

- *What erosion processes are dominant in the watershed (e.g., surface erosion or mass wasting)? Where have they occurred or are likely to occur?*
- *What are the dominant hydrologic characteristics (e.g., total discharge, peak flows) and other notable hydrologic features and processes in the watershed (e.g., cold water seeps or groundwater recharge areas)?*
- *What is the array and landscape pattern of plant communities, and what are the seral stages in the watershed (riparian and nonriparian)? What natural processes cause these patterns (e.g., fire, wind)? How do different systems react to these natural processes based on their seral stages?*
- *What are the basic morphological characteristics of stream valleys and segments and the general sediment transport and deposition processes in the watershed (e.g., stratification using accepted classification systems)?*
- *What beneficial uses depend on aquatic resources occurring in the watershed? Which water quality parameters are critical to these uses?*
- *What is the relative abundance and distribution of species of concern that are important in the watershed (e.g., threatened or endangered species, special status species, species emphasized in other plans)? What is the distribution and character of their habitats?*
- *What current and past human uses (e.g., Forest Service management practices and private and public use patterns), on and adjacent to forest land, may be affecting the watershed?*

USDA-FS (2002) provides a more detailed discussion of watershed analyses.

- Resources containing more detailed information
- Worksheets that help users work through the planning process

Reviewing and understanding the historic ecology of the site and of the undisturbed areas in similar ecological settings often serve as benchmarks for determining the desired future condition. Aerial photographs can be a valuable tool for comparing differences over time, including land- and social-use patterns (USDA–FS, 2002).

For a soil bioengineering project to be successful, it is critical that planners recognize the static and dynamic relationships in natural systems (e.g., the relationship between stream and riparian ecosystems). Failure to notice these types of relationships can interrupt the ecological integrity and prevent a successful restoration project from occurring. Planners should also understand the connection between areas and the people who will use them. Reviewing the historical photographs and written records, topographical maps, soil type, fishing productivity records, and stream and watershed analysis can assist planners with identifying the correct relationships (USDA–FS, 2002).

Planners should use long-term solutions for soil bioengineering projects that fix the problem, rather than quick-fix technologies that only treat symptoms. Determine the nature of the problem by using a holistic analytical approach, assessing upstream and downstream conditions, lateral and vertical conditions, and their connections to the problem area. This type of assessment will help determine whether the problem is unique or if it is symptomatic of other problems in the watershed. Planners should be certain to gain a through understanding of the underlying problem and how it interacts with other natural processes in the watershed (USDA-FS, 2002).

For stabilization projects to be successful, it must be a collaborative effort. Any person or group with a stake in clean water is a potential partner. Planners should look for partners in local and national land and wildlife conservation organizations and clubs, civic groups, faith-based groups, schools and colleges, and businesses. Other agencies, such as NRCS, the U.S. Fish and Wildlife Service, the U.S. Environmental Protection Agency, state fish and games departments, state departments of natural resources, and local water districts are potential partners that could contribute funding and expertise to a project (USDA-FS, 2002).

Monitoring and Maintenance of Structures

Monitoring is critical for a project to be successful. By monitoring a site, you may determine if any structures are in need of maintenance. When performing monitoring, note which plants are doing well and which did not survive. Does the site appear to be recovering? Also note conditions, such as soil moisture, aspect, sun-to-shade ratio, and degree of slope. Has the area been trampled, grazed, or driven over? Have any of the structures (e.g., tree revetments) shifted? Other aspects that you could monitor are (USDA-FS, 2002):

- Keeping track of where plants were harvested—is there a correlation between growth rate of certain cuttings and the “mother” plants?
- Is the installation functioning as designed?
- Which areas are maturing more rapidly than others?
- Are seeds sprouting in the newly formed beds?

- Which plants have invaded the site through natural succession?
- What has sprouted in the second season?
- Which areas are experiencing difficulty and why?
- Is the bank stabilizing or washing away and why?
- Is something occurring that is unexpected?
- Which techniques are succeeding?
- Are any of the structures failing?

USDA NRCS' *The Practical Streambank Bioengineering Guide* (Bentrup and Hoag, 1998) provides an example monitoring form and is available at http://www.engr.colostate.edu/~bbledsoe/CE413/idpmcpustguid.pdf. The monitoring sheet is also available in Appendix C of USDA-FS, 2002, at http://www.fs.fed.us/publications/soil-bio-guide/guide/appendices.pdf.

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

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

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

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

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

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

Maintenance varies with the structural type. For stone revetments, the replacement of stones that have been dislodged is necessary; timber bulkheads need to be backfilled if there has been a loss of upland material, and broken sheet pile should be replaced as necessary. Gabion baskets should be inspected for corrosion failure of the wire, usually caused

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

either by improper handling during construction or by abrasion from the stones inside the baskets. Baskets should be replaced as necessary since waves will rapidly empty failed baskets.

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