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Streambank and Shoreline Protection

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Chapter 16 Streambank and Shoreline Protection

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Cover: Little Yellow Creek, Cumberland Gap National Park, Kentucky
(photograph by Robbin B. Sotir & Associates)

Preface

Chapter 16, Streambank and Shoreline Protection, is one of 18 chapters of the U.S. Department of Agriculture, Natural Resources Conservation Service, Engineering Field Handbook, previously referred to as the Engineering Field Manual. Other chapters that are pertinent to, and should be referenced in use with, Chapter 16 are:

Chapter 1: Engineering Surveys
Chapter 2: Estimating Runoff
Chapter 3: Hydraulics
Chapter 4: Elementary Soils Engineering
Chapter 5: Preparation of Engineering Plans
Chapter 6: Structures
Chapter 7: Grassed Waterways and Outlets
Chapter 8: Terraces
Chapter 9: Diversions
Chapter 10: Gully Treatment
Chapter 11: Ponds and Reservoirs
Chapter 12: Springs and Wells
Chapter 13: Wetland Restoration, Enhancement, or Creation
Chapter 14: Drainage
Chapter 15: Irrigation
Chapter 17: Construction and Construction Materials
Chapter 18: Soil Bioengineering for Upland Slope Protection and Erosion Reduction

This is the second edition of chapter 16. Some techniques presented in this text are rapidly evolving and improving; therefore, additions to and modifications of chapter 16 will be made as necessary.

Acknowledgments

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Robbin B. Sotir & Associates, Marietta, Georgia, was a major contributor to the inclusion of soil bioengineering and revision of the chapter. In addition to authoring sections of the revised manuscript, they supplied original drawings, which were adapted for NRCS use, and photographs.

Walter K. Twitty, drainage engineer (retired), NRCS, Fort Worth, Texas, and **Robert T. Escheman,** landscape architect, NRCS, Somerset, New Jersey, served a coordination role in the review and revision of the chapter. **Carolyn A. Adams,** director, Watershed Science Institute, NRCS, Seattle, Washington; **Leland M. Saele,** design engineer; **Gary E. Formanek,** agricultural engineer; and **Frank F. Reckendorf,** sedimentation geologist (retired), NRCS, Portland, Oregon, edited the manuscript to extend its applicability to most geographic regions. In addition these authors revised the manuscript to reflect new research on stream classification and design considerations for riprap, dormant post plantings, rootwad/boulder revetments, and stream barbs. **H. Wayne Everett,** plant materials specialist (retired), NRCS, Fort Worth, Texas, supplied the plant species information in the appendix. **Mary R. Mattinson,** editor, **John D. Massey,** visual information specialist, and **Wendy R. Pierce,** illustrator, NRCS, Fort Worth, Texas, provided editing assistance and desktop publishing in preparation for printing.

Chapter 16 Streambank and Shoreline Protection

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(a) Purpose and scope

Streambank and shoreline protection consists of restoring and protecting banks of streams, lakes, estuaries, and excavated channels against scour and erosion by using vegetative plantings, soil bioengineering, and structural systems. These systems can be used alone or in combination. The information in chapter 16 does not apply to erosion problems on ocean fronts, large river and lake systems, or other areas of similar scale and complexity.

(b) Categories of protection

The two basic categories of protection measures are those that work by reducing the force of water against a streambank or shoreline and those that increase their resistance to erosive forces. These measures can be combined into a system.

Stormwater reduction or retention methods, grade reduction, and designs that reduce flow velocity fall into the first category of protection. Examples include permeable fence design, tree or brush revetments, jacks, groins, stream jetties, barbs, drop structures, increasing channel sinuosity, and log, rootwad, and boulder combinations. The second category includes channels lined with grass, concrete, riprap, gabions, cellular concrete, and other revetment designs. These measures can be used alone or in combination. Most designs that employ brushy vegetation, e.g., soil bioengineering, either alone or in combination with structures, protect from erosion in both ways.

Revetment designs do not reduce the energy of the flow significantly, so using revetments for spot protection may move erosion problems downstream or across the stream channel.

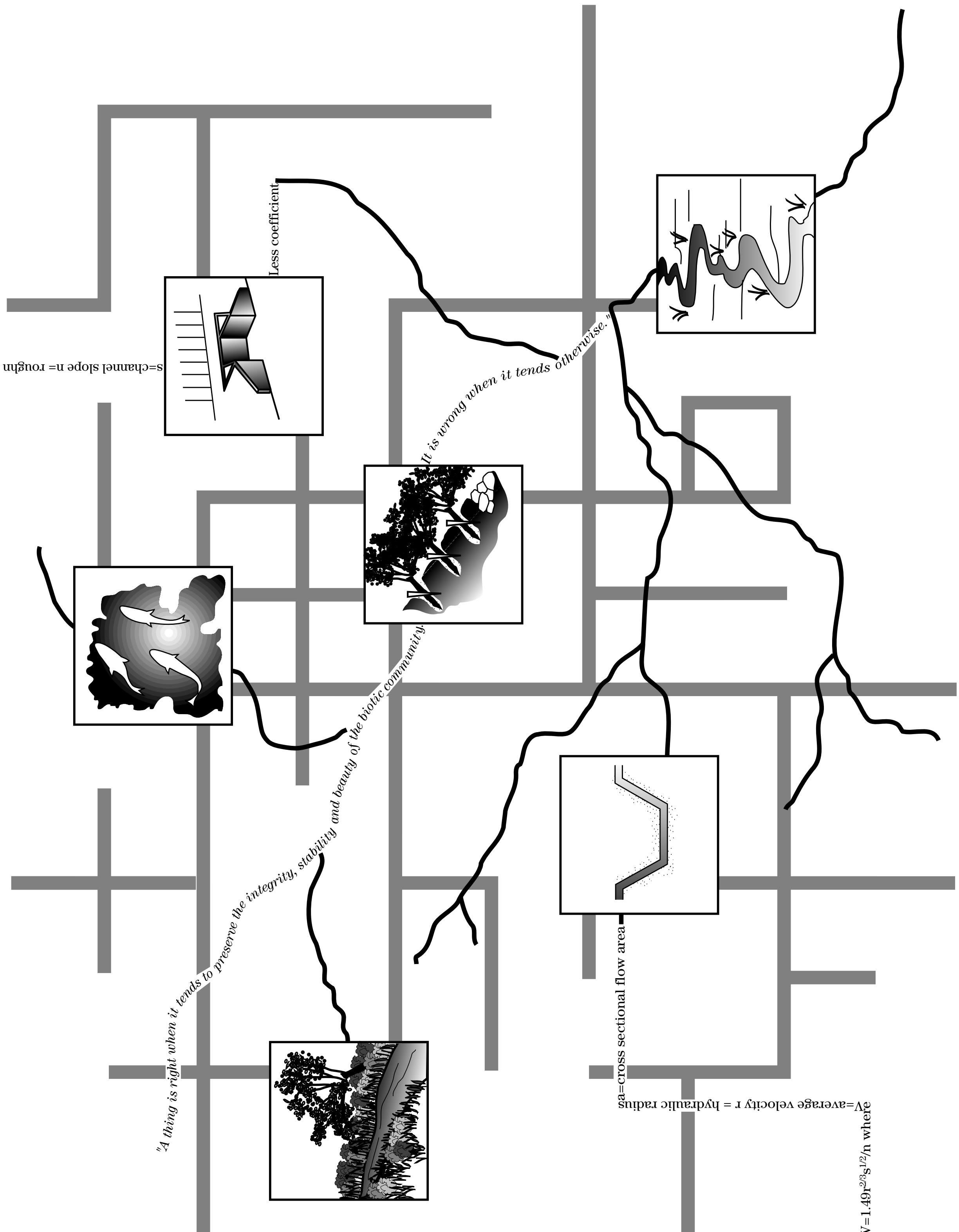
(c) Selecting streambank and shoreline protection measures

This document recognizes the need for intervention into stream corridors to affect rehabilitation; however, it is also acknowledged that this should be done on a selective basis. When selecting a site or stream reach for treatment, it is most effective to select areas within relatively healthy systems. Projects planned and installed in this context are more likely to be successful, and it is often critically important to prevent the decline of these healthier systems while an opportunity remains to preserve their biological diversity. Rehabilitation of highly degraded systems is also important, but these systems often require substantial investment of resources and may be so modified that partial success is often a realistic goal.

After deciding rehabilitation is needed, a variety of remedies are available to minimize the susceptibility of streambanks or shorelines to disturbance-caused erosive processes. They range from vegetation-oriented remedies, such as soil bioengineering, to engineered grade stabilization structures (fig. 16–1). In the recent past, many organizations involved in water resource management have given preference to engineered structures. Structures may still be viable options; however, in a growing effort to restore sustainability and ensure diversity, preference should be given to those methods that restore the ecological functions and values of stream or shoreline systems.

As a first priority consider those measures that
- are self sustaining or reduce requirements for future human support;
- use native, living materials for restoration;
- restore the physical, biological, and chemical functions and values of streams or shorelines;
- improve water quality through reduction of temperature and chronic sedimentation problems;
- provide opportunities to connect fragmented riparian areas; and
- retain or enhance the stream corridor or shoreline system.

Figure 16–1 Appropriate selection and application of streambank or shoreline protection measures should vary in response to specific objectives and site conditions (Aldo Leopold)



650.1601 Streambank protection

(a) General

The principal causes of streambank erosion may be classed as geologic, climatic, vegetative, and hydraulic. These causes may act independently, but normally work in an interrelated manner. Direct human activities, such as channel confinement or realignment and damage to or removal of vegetation, are major factors in streambank erosion.

Streambank erosion is a natural process that occurs when the forces exerted by flowing water exceed the resisting forces of bank materials and vegetation. Erosion occurs in many natural streams that have vegetated banks. However, land use changes or natural disturbances can cause the frequency and magnitude of water forces to increase. Loss of streamside vegetation can reduce resisting forces, thus streambanks become more susceptible to erosion. Channel realignment often increases stream power and may cause streambeds and banks to erode. In many cases streambed stabilization is a necessary prerequisite to the placement of streambank protection measures.

(b) Planning and selecting streambank protection measures

The list that follows, although not exhaustive, includes data commonly needed for planning purposes.

(1) Watershed data

When analyzing the source of erosion problems, consider the stream as a system that is affected by watershed conditions and what happens in other stream reaches. An analysis of stream and watershed conditions should include historical information on land use changes, hydrologic conditions, and natural disturbances that might influence stream behavior. It should anticipate the changes most likely to occur or that are planned for the near future:

- Climatic regime.
- Land use/land cover.
- History of land use, prior stream modifications, past stability problems, and previous treatments.
- Projected development over anticipated project life.

(2) Causes and extent of erosion problems

- If bank failure problems are the result of widespread bed degradation or headcutting, determine what triggered the problem.
- If bank erosion problems are localized, determine the cause of erosion at each site.

(3) Hydrologic/hydraulic data

- Flood frequency data (if not available, estimate using regional equations or other procedures).
- Estimates of stream-forming flow at 1- to 2-year recurrence interval and flow velocities.
- Estimates of width and depth at stream-forming flow conditions.
- Channel slope, width, depth, meander wavelength, and shape (width/depth, wetted perimeter).
- Sediment load (suspended and bedload).
- Water quality.

(4) Stream reach characteristics

- Soil and streambank materials at site.
- Potential streambank failures.
- Vegetative condition of banks.
- Channel alignment.
- Present stream width, depth, meander amplitude, belt width, wavelength, and sinuosity to determine stream classification.
- Identification of specific problems arising from flow deflection caused by sediment buildup, boulders, debris jams, bank irregularities, or constrictions.
- Bed material d_{50} based on a pebble count.
- Quality, amount, and types of terrestrial and aquatic habitat.
- Suspended load and bedload as needed, to determine if incoming sediment load can be transported through the restored reach.
- When selecting protective measures, analyze the needs of the entire watershed, the effects that stream protection may have on other reaches, surrounding wetlands, the riparian corridor, terrestrial habitat, aquatic habitat, water quality, and aesthetics. Reducing runoff and soil loss from the upland portions of the watershed using sound land treatment and management measures normally makes the streambank protection solution less expensive and more durable.

(5) Stream classification

Stream classification has evolved significantly over the past 100 years. William Davis (1899) first divided streams into three stages as youthful, mature and old age. Streams were later classified by their pattern as straight, meandering, or braided (Leopold & Wolman, 1957) or by stability and mode of sediment transport (Schumm, 1963 and 1977). Although all these systems served their intended purposes, they were not particularly helpful in establishing useful criteria for streambank protection and design. Rosgen (1985) developed a stream classification system that categorizes essentially all types of stream channels on the basis of measured morphological features. This system has been updated several times (Rosgen, 1992) and has broad applicability for communication among users and to predict a stream's behavior based on its appearance.

Predicting a stream's behavior based on appearance is also a feature of the Schumm, Harvey, and Watson (1984) channel evolution model developed for Oaklimeter Creek in Mississippi. This model discusses channel conditions extending from total disequilibrium to a new state of dynamic equilibrium. Such a model is useful in stream restoration work because streams can be observed in the field and their dominant process determined in the reach under consideration (i.e., active headcutting and transport of sediment, through aggradation and stabilization of alternate bars, and approaching a stage of dynamic equilibrium).

Rosgen's (1992) stream classification system goes beyond the channel evolution model as it is based on determining hydraulic geometry of stable stream reaches. This geometry is then extrapolated to unstable stream reaches to derive a template for potential channel design and reconstruction.

The present version of Rosgen's stream classification has several types (A, B, C, D, DA, E, F, and G), based on a hierarchical system. The first level of classification distinguishes between single or multiple thread channels. The streams are then separated based on degrees of entrenchment, width-to-depth ratio, and stream sinuosity. They are further subdivided by slope range and channel materials. Several stream subtypes are based on other criteria, such as average riparian vegetation, organic debris and channel blockages, flow regimes, stream size, depositional features, and meander pattern.

(6) Soils

A particular soil's resistance to erosion depends on its cohesiveness and particle size. Sandy soils have low cohesion, and their particles are small enough to be entrained by velocity flows of 2 or 3 feet per second. Lenses or layers of erodible material are frequent sources of erosion. Fines are selectively removed from soils that are heterogeneous mixtures of sand and gravel, leaving behind a layer of gravel that may protect or armor the streambed against further erosion. However, the hydraulic removal of fines and sand from a gravel matrix may cause it to collapse, resulting in sloughing of the streambank and its overlying material.

The resistance of cohesive soils depends on the physical and chemical properties of the soil as well as the chemical properties of the eroding fluid. Cohesive soils often contain montmorillonite, bentonite, or other expansive clays. Because unvegetated banks made up of expansive clays are subject to shrinkage during dry weather, tension cracks may develop parallel to and several feet below the top of the bank. These cracks may lead to slab failures on oversteepened banks, especially in places where bank support has been reduced by toe erosion. Tension cracks can also contribute to piping and related failures.

(7) Hydrologic, climatic, and vegetative conditions

Stream erosion is largely a function of the magnitude and frequency of flow events. Flow duration is of secondary importance except for flows that exceed stream-forming flow stage for extended periods. A streambank's position (outside curve or inside) can also be a major factor in determining its erosion potential.

Watershed changes that increase magnitude and frequency of flooding, such as urbanization, deforestation, and increased surface runoff, contribute to streambank erosion. Associated changes, such as loss of streamside vegetation from human or animal trampling, often compound the streambank erosion effect.

In cold climates where streams normally freeze or partly freeze during winter, erosion caused by ice is an additional problem. Streambanks are affected by ice scour in several ways:

- Streambanks and associated vegetation can be forcibly damaged during freezing or thawing action.

- Floating ice can cause gouging of streambanks.
- Acceleration of flow around and under ice rafts can cause damage to streambanks.

Erosion from ice may be minimized or reduced by vegetation for the following reasons:

- Streambank vegetation reduces damaging cycles of freeze-thaw by maintaining the temperature of bank materials, thus preventing ice from forming and encouraging faster thawing.
- Vegetation tends to be flexible and absorbs much of the momentum of drifting ice.
- Vegetation helps protect the bank from ice damage.
- Woody vegetation has deeply embedded roots that reinforce soils.
- Deeply rooted, woody vegetation helps to control erosion by adding strength to streambank materials, increasing flow resistance, reducing flow velocities in the vicinity of the bank, and retarding tension crack development.

(8) Hydraulic data

Stream power is a function of velocity, flow depth, and slope. Channelization projects that straighten or enlarge channels often increase one or more of these factors enough to cause widespread erosion and associated problems, especially if soils are easily erodible.

Headcuts often develop in the modified reach or at the transition from the modified reach to the unaltered reach. They move upstream, causing bed erosion and bank failure on the main stream and its tributaries. Returning the stream to its former meander geometry is generally the most reliable way to stop headcuts or prevent their development. Installing grade control structures that completely cross a stream and act as a very low head dam may initiate other channel instabilities by:

- inducing bank erosion around the ends of the structure;
- raising flood levels and causing out-of-bank flows to erode new channels;
- trapping sediment, thus decreasing channel capacity, inducing bank erosion and flood plain scour; and
- increasing width-to-depth ratio with subsequent lateral migration, increased bank erosion, and increased bar deposition or formation.

Grade control structures should be designed to maintain low channel width-to-depth ratios, maintain the sediment transport capacity of the channel, and provide for passing a wide range of flow velocities without creating backwater and causing sediment deposition. Vortex rock weirs, "W" rock weirs, and other rock/boulder structures that protect the channel without creating backwater should be considered instead of small rock and log dams.

Local obstructions to flow, channel constrictions, and bank irregularities cause local increases in the energy slope and create secondary currents that produce accelerations in velocity sufficient to cause localized streambank erosion problems. These localized problems often are treated best by eliminating the source of the problem and providing remedial bank protection. However, secondary cross currents are also a natural feature around the outside curves of meanders, and structural features may be required to modify these cross currents.

Streamflows that transport sustained heavy loads of sediment are less erosive than clear flows. This can easily be seen where dams are constructed on large sediment-laden streams. Once a dam is operational, the sediment drops out into the reservoir pool, so the water leaving the structure is clear. Several feet of degradation commonly occurs in the reach below the dam before an armor layer develops or hydraulic parameters are sufficiently altered to a stable grade. In watersheds that have high sediment yields, conservation treatments that significantly reduce sediment loads can trigger stream erosion problems unless runoff is also reduced.

(9) Habitat characteristics

The least-understood aspect of designing and analyzing streambank protection measures is often the impact of the protective measures on instream and riparian habitats. Commonly, each stage of the life cycle of aquatic species requires different habitats, each having specific characteristics. These diverse habitats are needed to meet the unique demands imposed by spawning and incubation, summer rearing, and overwintering. The productivity of most aquatic systems is directly related to the diversity and complexity of available habitats.

Fish habitat structures are commonly an integral part of stream protection measures, but applicability of habitat structures varies by classified stream type. Work by Rosgen and Fittante (1992) resulted in a guide for evaluating suitability of various proposed fish habitat structures for a wide range of morphological stream types. They divide structures into those for rearing habitat enhancement and those for spawning habitat enhancement. The structures for rearing habitat enhancement include low stage check dam, medium stage check dam, boulder placement, bank-placed materials, single wing deflector, channel constrictor, bank cover, floating log cover, submerged shelter, half log cover, and migration barrier. U-shaped gravel traps, log sill gravel traps, and gravel placement are for spawning habitat enhancement.

Since a multitude of interrelated factors influence the productivity of streams, the response of fish and wildlife populations to changes in habitat is often difficult to predict with confidence.

(10) Environmental data

Environmental goals should be set early in the planning process to ensure that full consideration is given to ecological stability and productivity during the selection and design of streambank protection measures. Special care should be given to consideration of terrestrial and aquatic habitat benefits of alternative types of protection and to maintenance needs on a site specific basis.

In general, the least disturbance to the existing stream system during construction and maintenance produces the greatest environmental benefits. Damages to the environment can be limited by:

- Using small equipment and hand labor.
- Limiting access.
- Locating staging areas outside work area boundaries.
- Avoiding or altering construction procedures during critical times, such as fish spawning or bird nesting periods.
- Coordinating construction on a stream that involves more than one job or ownership.
- Adopting maintenance plans that maximize riparian vegetation and allow wide, woody vegetative buffers.
- Scheduling construction activities to avoid expected peak flood season(s).

(11) Social and economic factors

Initial installation cost and long-term maintenance are factors to be considered when planning streambank and shoreline protection. Other factors include the suitability of construction material for the use intended, the cost of labor and machinery, access for equipment and crews at the site, and adaptations needed to adjust designs to special conditions and the local environment.

Some protection measures seem to have apparent advantages, such as low cost or ease of construction, but a more expensive alternative might best meet planned objectives when maintenance, durability of material, and replacement costs are considered. Effect upon resources and environmental values, such as aesthetics, wildlife habitat, and aquatic requirements, are also integral factors.

The need for access to the stream or shoreline and the effects of protection measures upon adjacent property and land uses should be analyzed.

Minor protective measures can be installed without using contract labor or heavy equipment. However, many of the protective measures presented in this chapter require evaluation, design, and implementation to be done by a knowledgeable interdisciplinary team because precise construction techniques and costly construction materials may be required.

(c) Design considerations for streambank protection

(1) Channel grade

The channel grade may need to be controlled before any permanent type of bank protection can be considered feasible unless the protection can be safely and economically constructed to a depth well below the anticipated lowest depth of bed scour. Control can be by natural or artificial means. Reconstructing stream channels to their historical stream type (i.e., stream geometry) has been successfully used to achieve grade control. Artificial measures typically include rock, gabions and reinforced concrete grade control structures.

(2) Discharge frequency

Maximum floods are rarely used for design of streambank protection measures. The design flood frequency should be compatible with the value or safety of the property or improvements being protected, the repair cost of the streambank protection, and the sensitivity and value of ecological systems within the planning unit. Bankfull discharge (stream-forming flow) of natural streams tends to have a recurrence interval of 1 to 2 years based on the annual flood series (Leopold and Rosgen, 1991). The discharge at this frequency is commonly used as a design discharge for stream restoration (Rosgen, 1992). For modified streams, the 1- to 2-year frequency discharge is also useful for design discharge because it is the flow that has the most impact upon the stability of the stream channel.

(3) Discharge velocities

Where the flow entering the section to be protected carries only clay, silt, and fine sand in suspension, the maximum velocity should be limited to that which is nonscouring on the least resistant material occurring in any appreciable quantity in the streambed and bank. The minimum velocity should be that required to transport the suspended material. The depth-area-velocity relationship of the upstream channel should be maintained through the protected reach. Where the flow entering the section is transporting bedload, the minimum velocity should be that which will transport the entering bedload material through the section.

The minimum design velocity should also be compatible with the needs of the various fish species present or those targeted for recovery. Velocity changes can reduce available habitat or create physical barriers that restrict fish passage. Further information on fish habitat is available in publications cited in the reference section.

Streambank protection measures on large, wide channels most likely will not significantly change streamflow velocity. On smaller streams, however, the protective measures can influence the velocity throughout the reach.

In calculating these velocities, the Manning's n values selected should represent the stream condition after the channel has matured, which normally requires several years. Erosion or sedimentation may occur if this is not anticipated.

(4) Freeboard

Freeboard should be provided to prevent overtopping of the revetment at curves and other points where high velocity flow contacts the revetment. In these areas a potential supercritical velocity can set up waves, and the climb on sloping revetments may be appreciable. Because an accurate method to determine freeboard requirements is not available for sloping revetments in critical zones, the allowance for freeboard should be based on sound judgment and experience. Under similar conditions, the freeboard required for a sloping revetment is always greater than that for a vertical revetment.

(5) Alignment

Changes in channel alignment affect the flow characteristics through, above, and below the changed reach. Straightening without extensive channel hardening does not eliminate a stream's tendency to meander. An erosion hazard may often develop at both ends of the channel because of velocity increases, bar formations, and current direction changes. Changes in channel alignment are not recommended unless the change is to reconstruct the channel to its former meander geometry.

Alignment of the reach must also be carefully considered in designing protective measures. Because of major changes in hydraulic characteristics, streambanks for channels having straight alignment generally require a continuous scour-resistant lining or revetment. To prevent scour by streamflow as the stream attempts to recreate its natural meander pattern, most banks must be sloped to a stable grade before the lining is applied. For nonrigid lining, the slope must be flat enough to prevent the lining material from sliding.

Curved revetments are subjected to increased forces because of the secondary currents acting against them. More substantial and permanent types of construction may be needed on curved channel sections because streambank failures at these vulnerable points could result in much greater damage than that along unobstructed straight reaches of channel.

(6) Stream type and hydraulic geometry

Stream rehabilitation should be considered in the context of the historically stable stream type and its geometry. If stream modification has caused shortened meander wavelength, amplitude, and radius of curvature, the stream being treated might be best stabilized by restoring the historical geometry. The width-to-depth ratio of the stream being treated may be too high to transport the sediment load, and a lower ratio may be needed in the design channel.

(7) Sediment load and bed material

To determine the potential for stream aggradation, the sediment load (bedload and suspended) for storm and snowmelt runoff periods must frequently be determined before reconstruction. The size distribution of the streambed and bar material also should be determined. These measurements are important above and below the reconstruction reach under consideration as well as in the main tributary streams above the reach. This information is used with appropriate shear stress equations to determine the size of material that would be entrained at bankfull discharge (stream-forming flow) for both the tributary streams and in the restored reach. The sediment transport rate must be sufficient to prevent aggradation of the newly restored channel. As shown by studies in Colorado (Andrews, 1983) on gravelbed rivers, it is anticipated that particles as large as the median diameter of the bed surface will be entrained by discharge equal to the bankfull stage (stream-forming flow) or less.

(8) Protection against failure

Measures should be designed to provide against loss of support at the revetment's boundaries. This includes upstream and downstream ends, its base or toe, and the crest or top.

(9) Undermining

Undermining or scouring of the foundation material by high velocity currents is a major cause of bank protection failure. In addition to protecting the lowest expected stable grade, additional depth must be provided to reach a footing that most likely will not be scoured out during floods or lose its stability through saturation. Deep scour can be expected where construction is on an erodible streambed and high velocity currents flow adjacent to it.

Methods used to provide protection against undermining at the toe are:

- Extending the toe trench down to a depth below the anticipated scour and backfilling with heavy rock.
- Anchoring a heavy, flexible mattress to the bottom of the revetment, which at the time of installation will extend some distance out into the channel. This mattress will settle progressively as scour takes place, protecting the revetment foundation.
- Installing a massive toe of heavy rock where excavation for a deep toe is not practical. This allows the rock forming the toe to settle in place if scour occurs. However, because of the forces of flow, the settlement direction of the rock is not always straight down.
- Driving sheet piling to form a continuous protection for the revetment foundation. Such piling should be securely anchored against lateral pressures. To provide for a remaining embedment after scour, piling should be driven to a depth equal to about twice the exposed height.
- Installing toe deflector groins to deflect high velocity currents away from the toe of the revetment.
- Installing submerged vanes to control secondary currents.

Since most of these measures have direct impacts on aquatic habitat and other stream functions and values, their use should be considered carefully when planning a streambank protection project.

(10) Ends of revetment

The location of the upstream and downstream ends of revetments must be selected carefully to avoid flanking by erosion. Wherever possible, the revetment should tie into stable anchorage points, such as bridge abutments, rock outcrops, or well-vegetated stable sections. If this is not practical, the upstream and downstream ends of the revetment must be positioned well into a slack water area along the bank where bank erosion is not a problem.

(11) Debris removal

Streambank protection may require the selective removal or repositioning of debris, such as fallen trees, sediment bars, or other obstructions. Because logs and other woody debris are the major habitat-forming components in many stream systems, a plan for debris removal should be developed in consultation with qualified fish and wildlife specialists. Small accumulations of debris and sediment generally do not cause problems and should be left undisturbed.

When planning streambank stabilization work, select access routes for equipment that minimize disturbance to the flood plain and riparian areas. All debris removal, grading, and material delivery and placement should be accomplished in a manner that uses the smallest equipment feasible and minimizes disturbance of riparian vegetation. Excavated material should be disposed of in such a way that it does not interfere with overbank flooding, flood plain drainage, or associated wetland hydrology. In high velocity streams it may be necessary to remove floating debris selectively from flood-prone areas or anchor it so that it will not float back into the channel.

Sediment bars, snags, trees, and other debris drifts that create secondary currents or deflect flow toward the banks may require selective removal or relocation in the stream channel. The entire plant structure does not always need to be dislodged when considering the removal of trees and snags; rooted stumps should be left in place to prevent erosion. Isolated or single logs that are embedded, lodged, or rooted in the channel and not causing flow problems should not be disturbed. Fallen trees may be used to construct bank protection systems. Trees and other large vegetation are important to aquatic, aesthetic and riparian habitat systems, and removal should be done judiciously and with great care.

(12) Vegetative systems

Vegetative systems provide many benefits to fish and wildlife populations as well as increasing the streambank's resistance to erosive forces. Vegetation near the channel provides shade to help maintain suitable water temperature for fish, provides habitat for wildlife and protection from predators, and contributes to aesthetic quality. Leaves, twigs, and insects drop into the stream, providing nutrients for aquatic life (fig. 16–2).

Figure 16–2 Vegetative system along streambank

Although woody brush is preferable for habitat reasons, suitable herbaceous ground cover can provide desirable bank protection in areas of marginal erosion. Perennial grasses and forbes, preferably those native to the area, should be used rather than annual grasses. Woody vegetation may also be used to control undesirable access to the stream.

Associated emergent aquatic plants serve multiple functions, including the protection of woody streambank or shoreline vegetation from wave or current wave action, which tend to undercut them.

Vegetation protects streambanks in several ways:

- Root systems help hold the soil particles together increasing bank stability.
- Vegetation may increase the hydraulic resistance to flow and reduce local velocities in small channels.
- Vegetation acts as a buffer against the hydraulic forces and abrasive effect of transported materials.
- Dense vegetation on streambanks can induce sediment deposition.
- Vegetation can redirect flow away from the bank.

(d) Protective measures for streambanks

Protective measures for streambanks can be grouped into three categories: vegetative plantings, soil bioengineering systems, and structural measures. They are often used in combination.

(1) Vegetative plantings

Conventional plantings of vegetation may be used alone for bank protection on small streams and on locations having only marginal erosion, or it may be used in combination with structural measures in other situations. Considerations in using vegetation alone for protection include:

- Conventional plantings require establishment time, and bank protection is not immediate.
- Maintenance may be needed to replace dead plants, control disease, or otherwise ensure that materials become established and self-sustaining.
- Establishing plants to prevent undercutting and bank sloughing in a section of bank below baseflow is often difficult.
- Establishing plants in coarse gravely material may be difficult.
- Protection and maintenance requirements are often high during plant establishment.

Woody vegetation, which is seeded or planted as rooted stock, is used most successfully above baseflow on properly sloped banks and on the flood plain adjacent to the banks. Vegetation should always be used behind revetments and jetties in the area where sediment deposition occurs, on the banks above baseflow, and on slopes protected by cellular blocks or similar type materials.

Many species of plants are suitable for streambank protection (see appendix 16B). Use locally collected native species as a first priority. Exotic or introduced species should be used only if there is no alternative. They should never be invasive species. Locally available erosion-resistant species that are suited to the soil, moisture, and climatic conditions of a particular site are desirable. Aesthetics may also play an important role in selecting plants for certain areas.

In many instances streambank erosion is accelerated by overgrazing, cultivating too close to the banks, or by overuse. In either case the treated area should be protected by adequate streamside buffers and appropriate management practices. If the stream is the source of livestock drinking water, access can be provided by establishing a ramp down to the water. Such ramps should be located where the bank is not steep and, preferably, in straighter sections or at the inside of curves in the channel where velocities are low. Providing watering facilities out of the channel (i.e., on the flood plain or terrace) for the livestock is often a preferred alternative to using ramps.

The visual impact, habitat value, and other environmental effects of material removal or relocation must also be considered before performing any work.

Protective measures reduce streambank erosion and prevent land losses and sediment damages, but do not directly stabilize the channel grade. However, if the channel is restored to a stable stream type, vegetative protective measures, such as soil bioengineering, can be used to stabilize the streambanks. Vegetation assists in bank stabilization by trapping sediment, reducing tractive stresses acting on the bank, redirecting the flow, and holding soil. The boundary shear stress provided by vegetation, however, is much less than that provided by structural elements.

(2) Soil bioengineering systems

Properly designed and constructed soil bioengineering systems have been used successfully to stabilize streambanks (figs. 16–3a, 16–3b, 16–3c, and 16–3d).

Soil bioengineering is a system of living plant materials used as structural components. Adapted types of woody vegetation (shrubs and trees) are initially installed in specified configurations that offer immediate soil protection and reinforcement. In addition, soil bioengineering systems create resistance to sliding or shear displacement in a streambank as they develop roots or fibrous inclusions. Environmental benefits derived from woody vegetation include diverse and productive riparian habitats, shade, organic additions to the stream, cover for fish, and improvements in aesthetic value and water quality.

Under certain conditions, soil bioengineering installations work well in conjunction with structures to provide more permanent protection and healthy function, enhance aesthetics, and create a more environmentally acceptable product. Soil bioengineering systems normally use unrooted plant parts in the form of cut branches and rooted plants. For streambanks, living systems include brushmattresses, live stakes, joint plantings, vegetated geogrids, branchpacking, and live fascines.

Major attractions of soil bioengineering systems are their natural appearance and function and the economy with which they can often be constructed. As discussed in chapter 18 of this Engineering Field Handbook, the work is normally done in the dormant months, generally September to March, which is the off season for many laborers. The main construction materials are live cuttings from suitable plant species. Species must be appropriate for the intended use and adapted to the site's climate and soil conditions.

Consult a plant materials specialist for guidance on plant selection. Ideally plant materials should come from local ecotypes and genetic stock similar to that within the vicinity of the stream. Species that root easily, such as willow, are required for measures, such as live fascines and live staking, or where unrooted cuttings are used with structural measures. Suitable plant materials are listed in appendix 16B. They may also be identified in Field Office Technical Guides for specific site conditions or by contacting Plant Materials Centers.

Many sites require some earthwork before soil bioengineering systems are installed. A steep undercut or slumping bank, for example, may require grading to a 3:1 or flatter slope. Although soil bioengineering systems are suitable for most sites, they are most successful where installed in sunny locations and constructed during the dormant season.

Rooted seedlings and rooted cuttings are excellent additions to soil bioengineering projects. They should be installed for species diversification and to provide habitat cover and food for fish and wildlife. Optimum establishment is usually achieved shortly after earth work, preferably in the spring.

Some of the most common and useful soil bioengineering structures for restoration and protection of streambanks are described in the following sections.

Figure 16–3a Eroding bank, Winooski River, Vermont, June 1938

Figure 16–3b Bank shaping prior to installing soil bioengineering practices, Winooski River, Vermont, September 1938

Figure 16–3c Three years after installation of soil bioengineering practices, 1941

Figure 16–3d Soil bioengineering system, Winooski River, Vermont, June 1993 (55 years after installation)

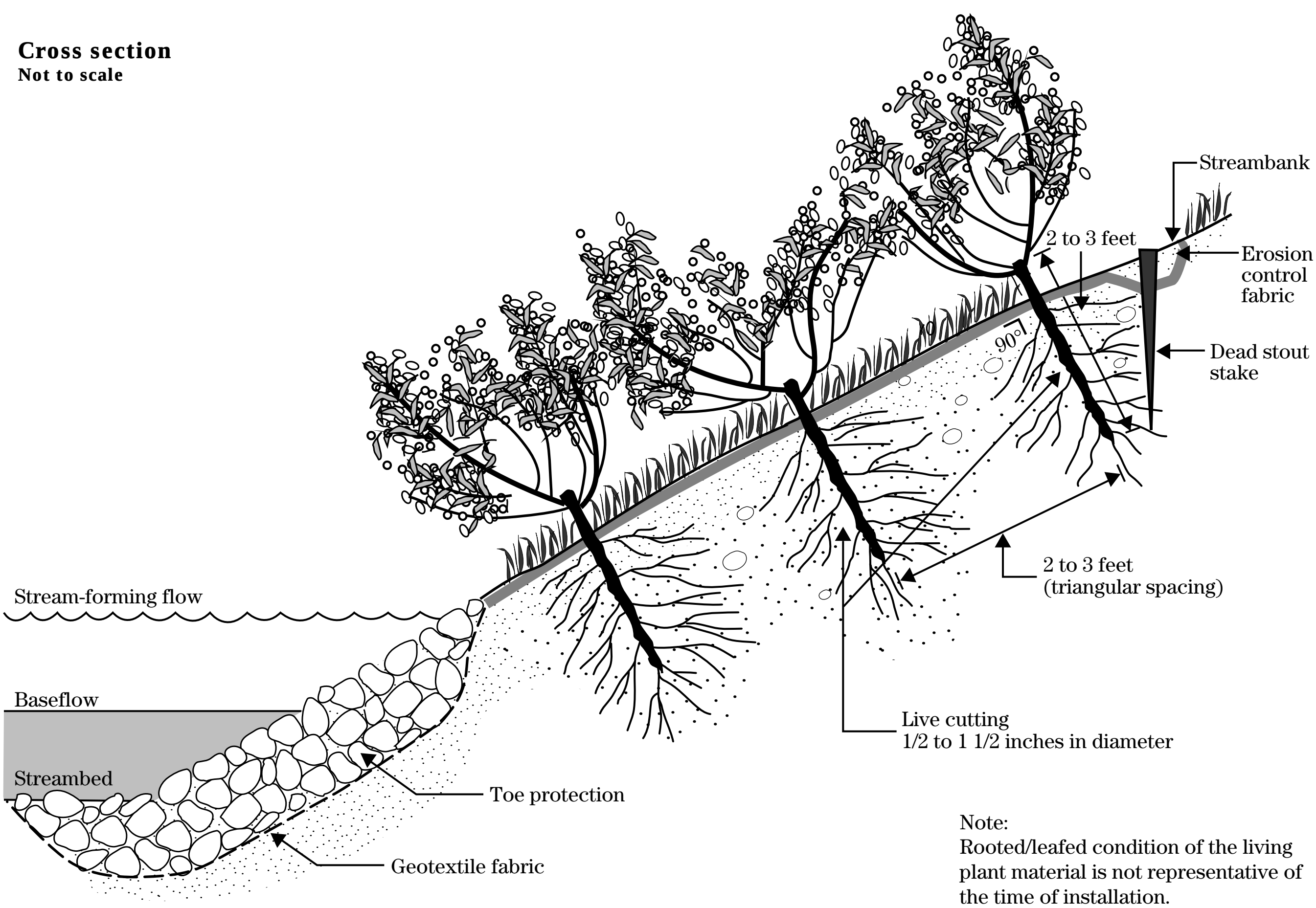
(i) Live stakes—Live staking involves the insertion and tamping of live, rootable vegetative cuttings into the ground (figs. 16–4 and 16–5). If correctly prepared, handled, and placed, the live stake will root and grow (fig. 16–6).

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. Most willow species root rapidly and begin to dry out a bank soon after installation.

Applications and effectiveness

- Effective streambank protection technique where site conditions are uncomplicated, construction time is limited, and an inexpensive method is needed.
- Appropriate technique for repair of small earth slips and slumps that frequently are wet.
- Can be used to peg down and enhance the performance of surface erosion control materials.
- Enhance conditions for natural colonization of vegetation from the surrounding plant community.
- Stabilize intervening areas between other soil bioengineering techniques, such as live fascines.
- Produce streamside habitat.

Figure 16–4 Live stake details



Construction guidelines

Live material sizes—The stakes generally are 0.5 to 1.5 inches in diameter and 2 to 3 feet long. The specific site requirements and available cutting source determine sizes.

Live material preparation

- The materials must have side branches cleanly removed with the bark intact.
- The basal ends should be cut at an angle or point for easy insertion into the soil. The top should be cut square.
- Materials should be installed the same day that they are prepared.

Installation

- Erosion control fabric should be placed on slopes subject to erosive inundation.
- Tamp the live stake into the ground at right angles to the slope and diverted downstream. The installation may be started at any point on the slope face.
- The live stakes should be installed 2 to 3 feet apart using triangular spacing. The density of the installation will range from 2 to 4 stakes per square yard. Site variations may require slightly different spacing.
- Placement may vary by species. For example, along many western streams, tree-type willow species are placed on the inside curves of point bars where more inundation occurs, while shrub willow species are planted on outside curves where the inundation period is minimal.
- The buds should be oriented up.
- Four-fifths of the length of the live stake should be installed into the ground, and soil should be firmly packed around it after installation.
- Do not split the stakes during installation. Stakes that split should be removed and replaced.
- An iron bar can be used to make a pilot hole in firm soil.
- Tamp the stake into the ground with a dead blow hammer (hammer head filled with shot or sand).

Figure 16–5 Prepared live stake (Robbin B. Sotir & Associates photo)

Figure 16–6 Growing live stake

(ii) Live fascines—Live fascines are long bundles of branch cuttings bound together in cylindrical structures (fig. 16–7). They should be placed in shallow contour trenches on dry slopes and at an angle on wet slopes to reduce erosion and shallow sliding.

Applications and effectiveness

- Apply typically above bankfull discharge (stream-forming flow) except on very small drainage area sites (generally less than 2,000 acres).
- Effective stabilization technique for streambanks. When properly installed, this system does not cause much site disturbance.
- Protect slopes from shallow slides (1 to 2 foot depth).
- Offer immediate protection from surface erosion.
- Capable of trapping and holding soil on a streambank by creating small dam-like structures, thus reducing the slope length into a series of shorter slopes.
- Serve to facilitate drainage where installed at an angle on the slope.
- Enhance conditions for colonization of native vegetation by creating surface stabilization and a microclimate conducive to plant growth.

Construction guidelines

Live materials—Cuttings must be from species, such as young willows or shrub dogwoods, that root easily and have long, straight branches.

Live material sizes and preparation

- Cuttings tied together to form live fascine bundles normally vary in length from 5 to 10 feet or longer, depending on site conditions and limitations in handling.
- The completed bundles should be 6 to 8 inches in diameter, with all of the growing tips oriented in the same direction. Stagger the cuttings in the bundles so that tops are evenly distributed throughout the length of the uniformly sized live fascine.
- Live stakes should be 2.5 feet long.

Inert materials—String used for bundling should be untreated twine.

Dead stout stakes used to secure the live fascines should be 2.5-foot long, untreated, 2 by 4 lumber. Each length should be cut again diagonally across the 4-inch face to make two stakes from each length (fig 16–8). Only new, sound lumber should be used, and any stakes that shatter upon installation should be discarded.

Installation

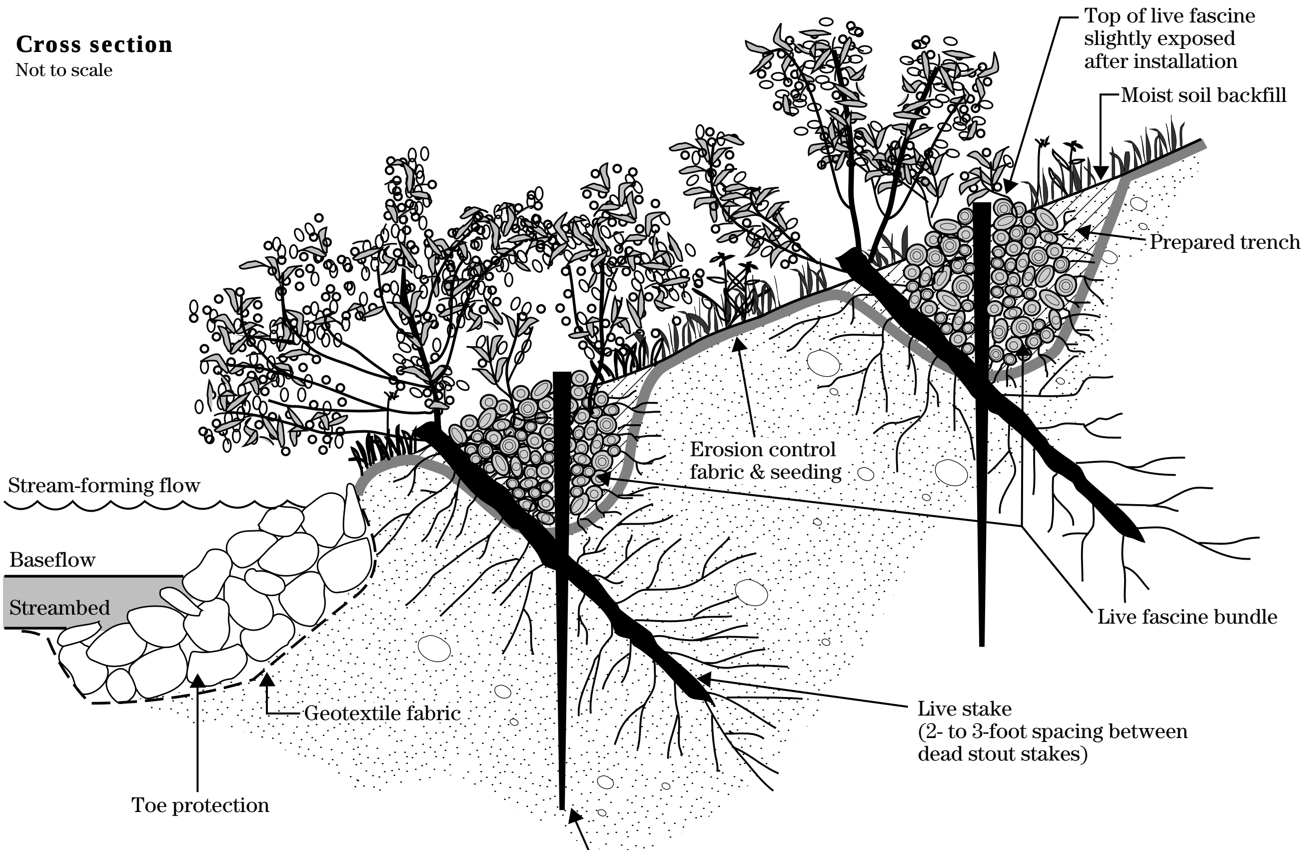
- Prepare the live fascine bundle and live stakes immediately before installation.
- Beginning at the base of the slope, dig a trench on the contour approximately 10 inches wide and deep.
- Excavate trenches up the slope at intervals specified in table 16–1. Where possible, place one or two rows over the top of the slope.
- Place long straw and annual grasses between rows.
- Install jute mesh, coconut netting, or other acceptable erosion control fabric. Secure the fabric.
- Place the live fascine into the trench (fig. 16–9a).
- Drive the dead stout stakes directly through the live fascine. Extra stakes should be used at connections or bundle overlaps. Leave the top of the dead stout stakes flush with the installed bundle.
- Live stakes are generally installed on the downslope side of the bundle. Tamp the live stakes below and against the bundle between the previously installed dead stout stakes, leaving 3 inches to protrude above the top of the ground (fig. 16–9b). Place moist soil along the sides of the bundles. The top of the live fascine should be slightly visible when the installation is completed. Figure 16–9c shows an established live fascine system 2 years after installation is completed.

Table 16–1 Live fascine spacing

Slope steepness	Soils Erosive (feet)	Soils Non-erosive (feet)	Soils Fill (feet)
3:1 or flatter	3 – 5	5 – 7	3 – 5 1/
Steeper than 3:1 (up to 1:1)	3 1/	3 – 5	2/

1/ Not recommended alone.
2/ Not a recommended system.

Figure 16–7 Live fascine details



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

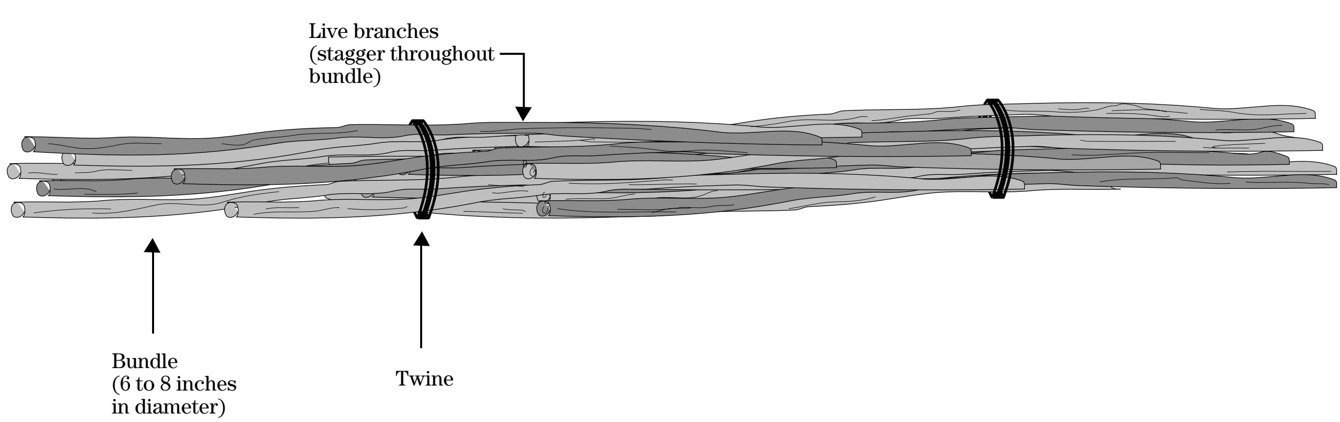


Figure 16–8 Preparation of a dead stout stake

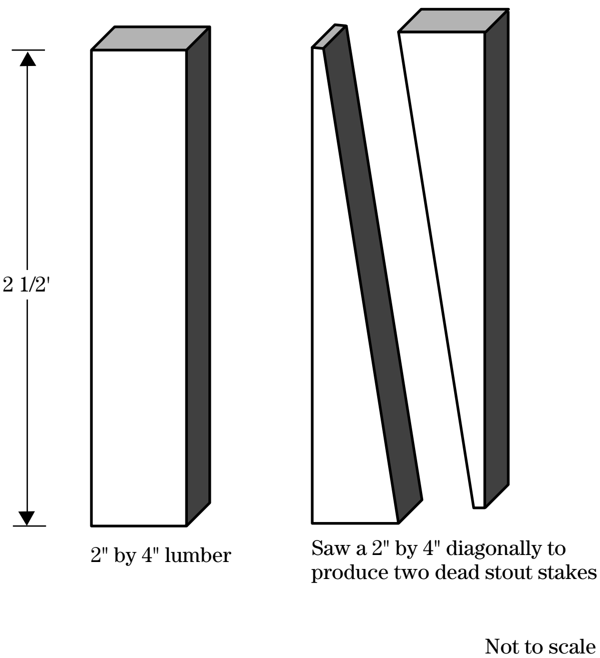


Figure 16–9a Placing live fascines (Robbin B. Sotir & Associates photo)

Figure 16–9b Installing live stakes in live fascine system (Robbin B. Sotir & Associates photo)

Figure 16–9c An established 2-year-old live fascine system (Robbin B. Sotir & Associates photo)

(iii) Branchpacking—Branchpacking consists of alternating layers of live branches and compacted backfill to repair small localized slumps and holes in streambanks (figs. 16–10, 16–11a, 16–11b, and 16–11c).

Applications and effectiveness

- Effective and inexpensive method to repair holes in streambanks that range from 2 to 4 feet in height and depth.
- Produces a filter barrier that prevents erosion and scouring from streambank or overbank flow.
- Rapidly establishes a vegetated streambank.
- Enhances conditions for colonization of native vegetation.
- Provides immediate soil reinforcement.
- Live branches serve as tensile inclusions for reinforcement once installed. As plant tops begin to grow, the branchpacking system becomes increasingly effective in retarding runoff and reducing surface erosion. Trapped sediment refills the localized slumps or hole, while roots spread throughout the backfill and surrounding earth to form a unified mass.
- Typically branchpacking is not effective in slump areas greater than 4 feet deep or 4 feet wide.

Construction guidelines

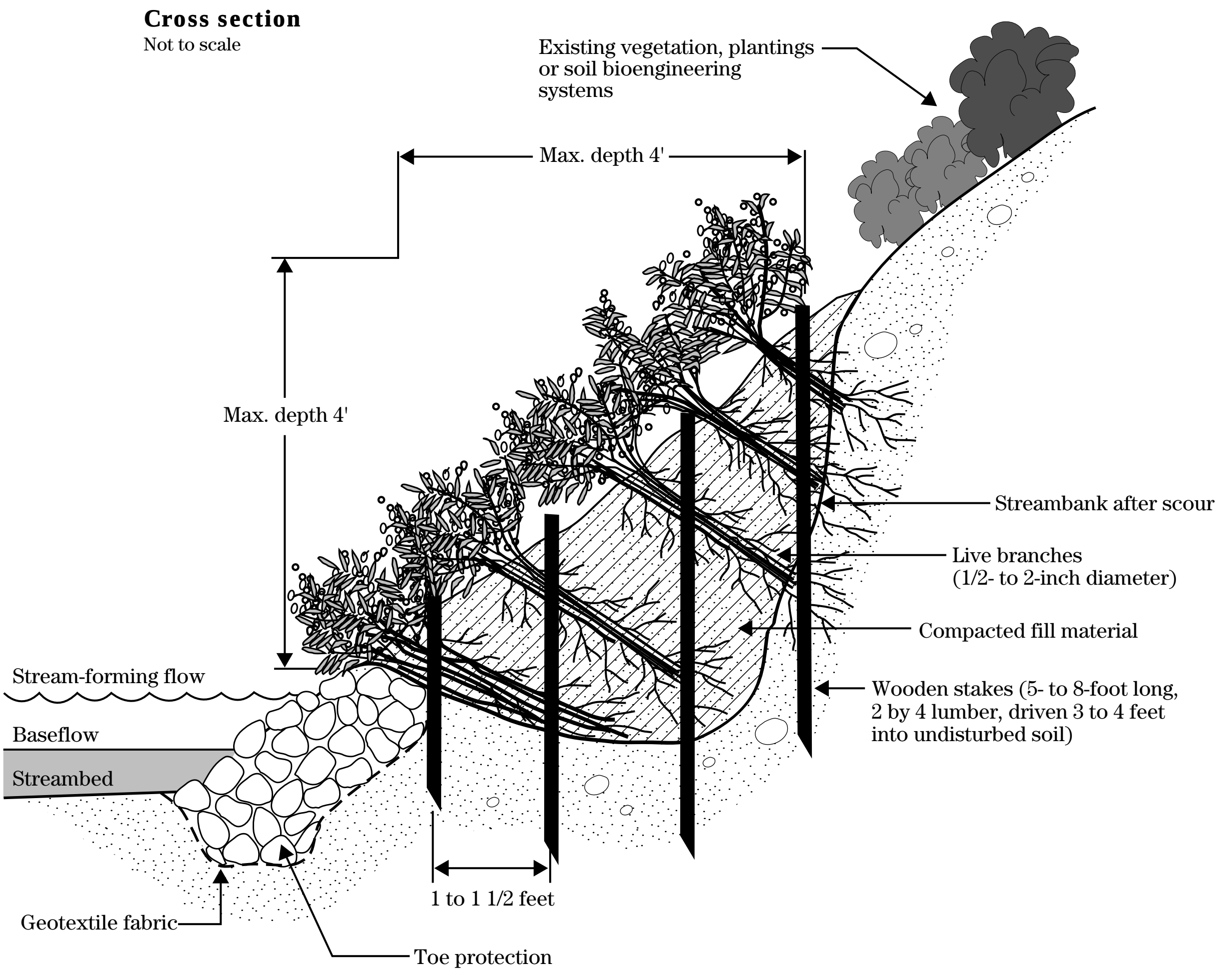
Live materials—Live branches may range from 0.5 to 2 inches in diameter. They should be long enough to touch the undisturbed soil of the back of the trench and extend slightly from the rebuilt streambank.

Inert materials—Wooden stakes should be 5 to 8 feet long and made from 3- to 4-inch diameter poles or 2 by 4 lumber, depending upon the depth of the particular slump or hole being repaired.

Installation

- Starting at the lowest point, drive the wooden stakes vertically 3 to 4 feet into the ground. Set them 1 to 1.5 feet apart.
- Place an initial layer of living branches 4 to 6 inches thick in the bottom of the hole between the vertical stakes, and perpendicular to the slope face (fig. 16–10). They should be placed in a criss-cross configuration with the growing tips generally oriented toward the slope face. Some of the basal ends of the branches should touch the undisturbed soil at the back of the hole.
- Subsequent layers of branches are installed with the basal ends lower than the growing tips of the branches.
- Each layer of branches must be followed by a layer of compacted soil to ensure soil contact with the branches.
- The final installation should conform to the existing slope. Branches should protrude only slightly from the filled installation.
- Water must be controlled or diverted if the original streambank damage was caused by water flowing over the bank. If this is not done, erosion will most likely occur on either or both sides of the new branchpacking installation.

Figure 16–10 Branchpacking details



Note:
Root/leafed condition of the living plant material is not representative of the time of installation
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Figure 16–11a Live branches installed in criss-cross configuration (Robbin B. Sotir & Associates photo)

Figure 16–11b Each layer of branches is followed by a layer of compacted soil (Robbin B. Sotir & Associates photo)

Figure 16–11c A growing branchpacking system (Robbin B. Sotir & Associates photo)

(iv) Vegetated geogrids—Vegetated geogrids are similar to branchpacking except that natural or synthetic geotextile materials are wrapped around each soil lift between the layers of live branch cuttings (figs. 16–12, 16–13a, 16–13b, and 16–13c).

Applications and effectiveness

- Used above and below stream-forming flow conditions.
- Drainage areas should be relatively small (generally less than 2,000 acres) with stable streambeds.
- The system must be built during low flow conditions.
- Can be complex and expensive.
- Produce a newly constructed, well-reinforced streambank.
- Useful in restoring outside bends where erosion is a problem.
- Capture sediment, which rapidly rebuilds to further stabilize the toe of the streambank.
- Function immediately after high water to rebuild the bank.
- Produce rapid vegetative growth.
- Enhance conditions for colonization of native vegetation.
- Benefits are similar to those of branchpacking, but a vegetated geogrid can be placed on a 1:1 or steeper slope.

Construction guidelines

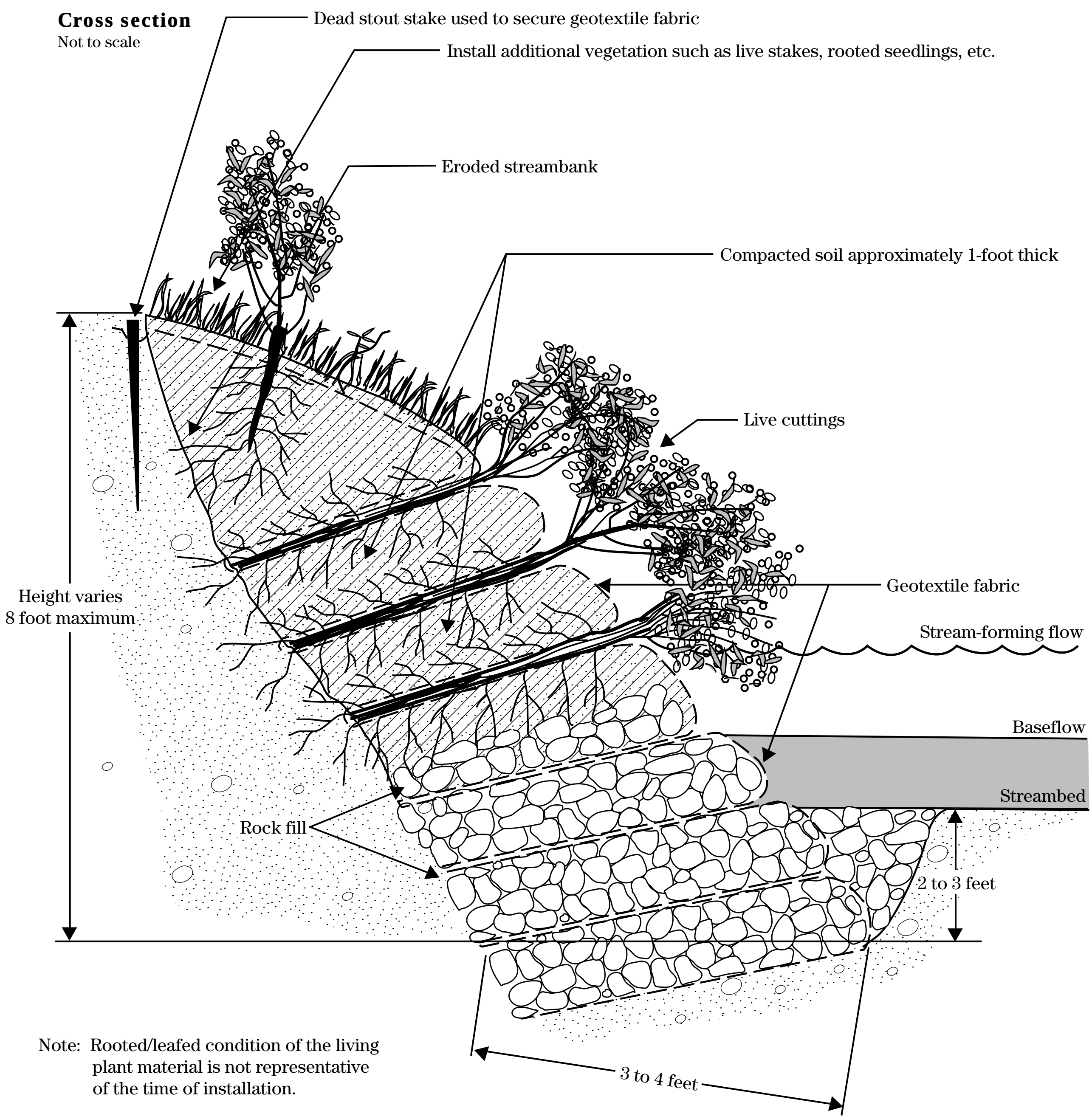
Live materials—Live branch cuttings that are brushy and root readily are required. They should be 4 to 6 feet long.

Inert materials—Natural or synthetic geotextile material is required.

Installation

- Excavate a trench that is 2 to 3 feet below streambed elevation and 3 to 4 feet wide. Place the geotextile in the trench, leaving a foot or two overhanging on the streamside face. Fill this area with rocks 2 to 3 inches in diameter.
- Beginning at the stream-forming flow level, place a 6- to 8-inch layer of live branch cuttings on top of the rock-filled geogrid with the growing tips at right angles to the streamflow. The basal ends of branch cuttings should touch the back of the excavated slope.
- Cover this layer of cuttings with geotextile leaving an overhang. Place a 12-inch layer of soil suitable for plant growth on top of the geotextile before compacting it to ensure good soil contact with the branches. Wrap the overhanging portion of the geotextile over the compacted soil to form the completed geotextile wrap.
- Continue this process of excavated trenches with alternating layers of cuttings and geotextile wraps until the bank is restored to its original height.
- This system should be limited to a maximum of 8 feet in total height, including the 2 to 3 feet below the bed. The length should not exceed 20 feet for any one unit along the stream. An engineering analysis should determine appropriate dimensions of the system.
- The final installation should match the existing slope. Branch cuttings should protrude only slightly from the geotextile wraps.

Figure 16–12 Vegetated geogrid details



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

Figure 16–13a A vegetated geogrid during installation (Robbin B. Sotir & Associates photo)

Figure 16–13b A vegetated geogrid immediately after installation (Robbin B. Sotir & Associates photo)

Figure 16–13c Vegetated geogrid 2 years after installation (Robbin B. Sotir & Associates photo)

***(v) Live cribwall*—**A live cribwall consists of a box-like interlocking arrangement of untreated log or timber members. The structure is filled with suitable backfill material and layers of live branch cuttings that root inside the crib structure and extend into the slope. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members (fig. 16–14).

Applications and effectiveness

- Effective on outside bends of streams where strong currents are present.
- Appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Appropriate above and below water level where stable streambeds exist.
- Useful where space is limited and a more vertical structure is required.
- Effective in locations where an eroding bank may eventually form a split channel.
- Maintains a natural streambank appearance.
- Provides excellent habitat.
- Provides immediate protection from erosion, while established vegetation provides long-term stability.
- Supplies effective bank erosion control on fast flowing streams.
- Should be tilted back or battered if the system is built on a smooth, evenly sloped surface.
- Can be complex and expensive.

Construction guidelines

Live materials—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.

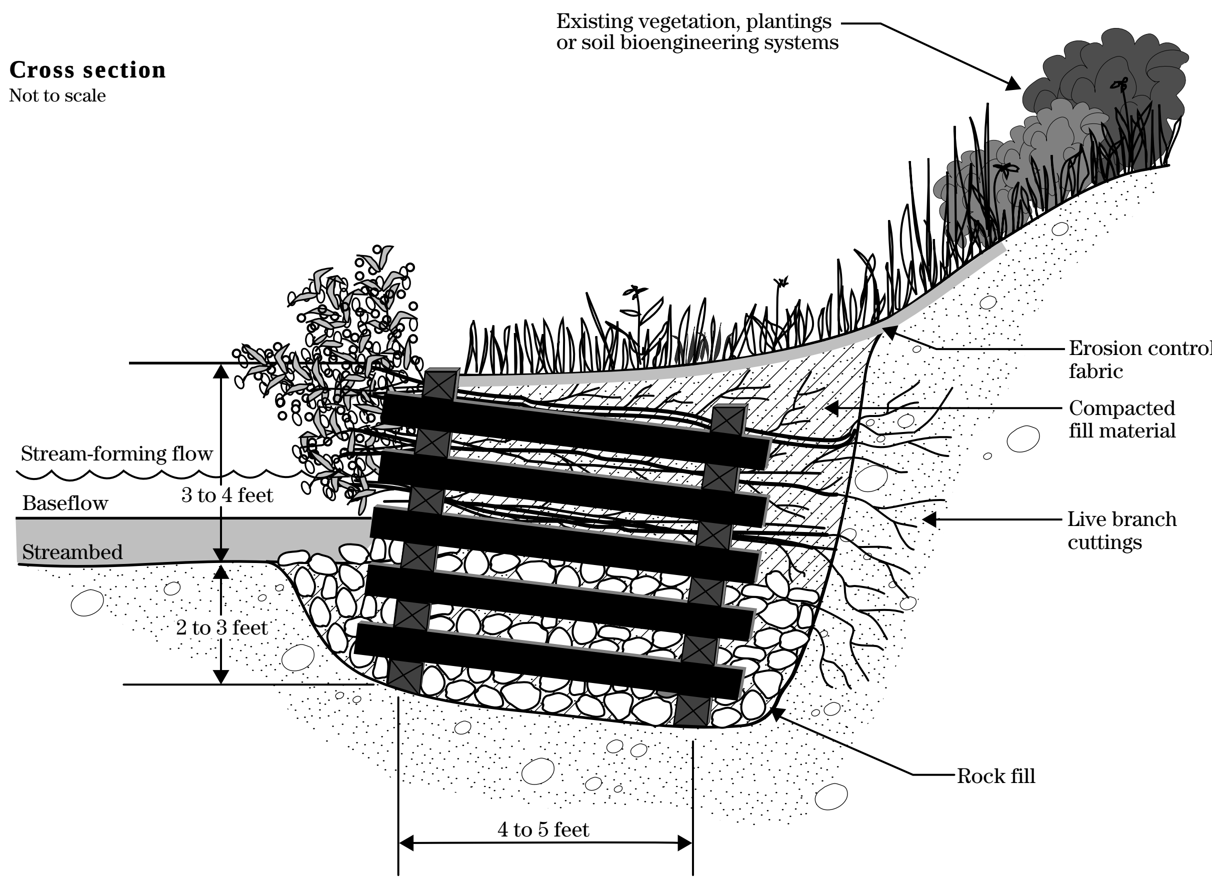
Inert materials—Logs or timbers should range from 4 to 6 inches in diameter or dimension. The lengths will vary with the size of the crib structure.

Large nails or rebar are required to secure the logs or timbers together.

Installation

- Starting at the base of the streambank to be treated, excavate 2 to 3 feet below the existing streambed until a stable foundation 5 to 6 feet wide is reached.
- Excavate the back of the stable foundation (closest to the slope) 6 to 12 inches lower than the front to add stability to the structure.
- Place the first course of logs or timbers at the front and back of the excavated foundation, approximately 4 to 5 feet apart and parallel to the slope contour.
- Place the next course of logs or timbers at right angles (perpendicular to the slope) on top of the previous course to overhang the front and back of the previous course by 3 to 6 inches. Each course of the live cribwall is placed in the same manner and secured to the preceding course with nails or reinforcement bars.
- Place rock fill in the openings in the bottom of the crib structure until it reaches the approximate existing elevation of the streambed. In some cases it is necessary to place rocks in front of the structure for added toe support, especially in outside stream meanders.
- Place the first layer of cuttings on top of the rock material at the baseflow water level, and change the rock fill to soil fill capable of supporting plant growth at this point. Ensure that the basal ends of some of the cuttings contact undisturbed soil at the back of the cribwall.
- When the cribwall structure reaches the existing ground elevation, place live branch cuttings on the backfill perpendicular to the slope; then cover the cuttings with backfill and compact.
- Live branch cuttings should be placed at each course to the top of the cribwall structure with growing tips oriented toward the slope face. Follow each layer of branches with a layer of compacted soil. Place the basal ends of the remaining live branch cuttings so that they reach to undisturbed soil at the back of the cribwall with growing tips protruding slightly beyond the front of the cribwall (figs. 16–15a, 16–15b, and 16–15c).
- The live cribwall structure, including the section below the streambed, should not exceed a maximum height of 7 feet. An engineering analysis should determine appropriate dimensions of the system.
- The length of any single constructed unit should not exceed 20 feet.

Figure 16–14 Live cribwall details



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

Figure 16–15a Pre-construction streambank conditions

Figure 16–15b A live cribwall during installation

Figure 16–15c An established live cribwall system

(vi) Joint planting—Joint planting or vegetated riprap involves tamping live stakes into joints or open spaces in rocks that have been previously placed on a slope (fig 16–16). Alternatively, the stakes can be tamped into place at the same time that rock is being placed on the slope face.

Applications and effectiveness

- Useful where rock riprap is required or already in place.
- Roots improve drainage by removing soil moisture.
- Over time, joint plantings create a living root mat in the soil base upon which the rock has been placed. These root systems bind or reinforce the soil and prevent washout of fines between and below the rock.
- Provides immediate protection and is effective in reducing erosion on actively eroding banks.
- Dissipates some of the energy along the streambank.

Construction guidelines

Live material sizes—The stakes must have side branches removed and bark intact. They should be 1.5 inches or larger in diameter and sufficiently long to extend well into soil below the rock surface.

Installation

- Tamp live stakes into the openings of the rock during or after placement of riprap. The basal ends of the material must extend into the backfill or undisturbed soil behind the riprap. A steel rod or hydraulic probe may be used to prepare a hole through the riprap.
- Orient the live stakes perpendicular to the slope with growing tips protruding slightly from the finished face of the rock (figs. 16–17a, 16–17b, and 16–17c).
- Place the stakes in a random configuration.

Figure 16–16 Joint planting details

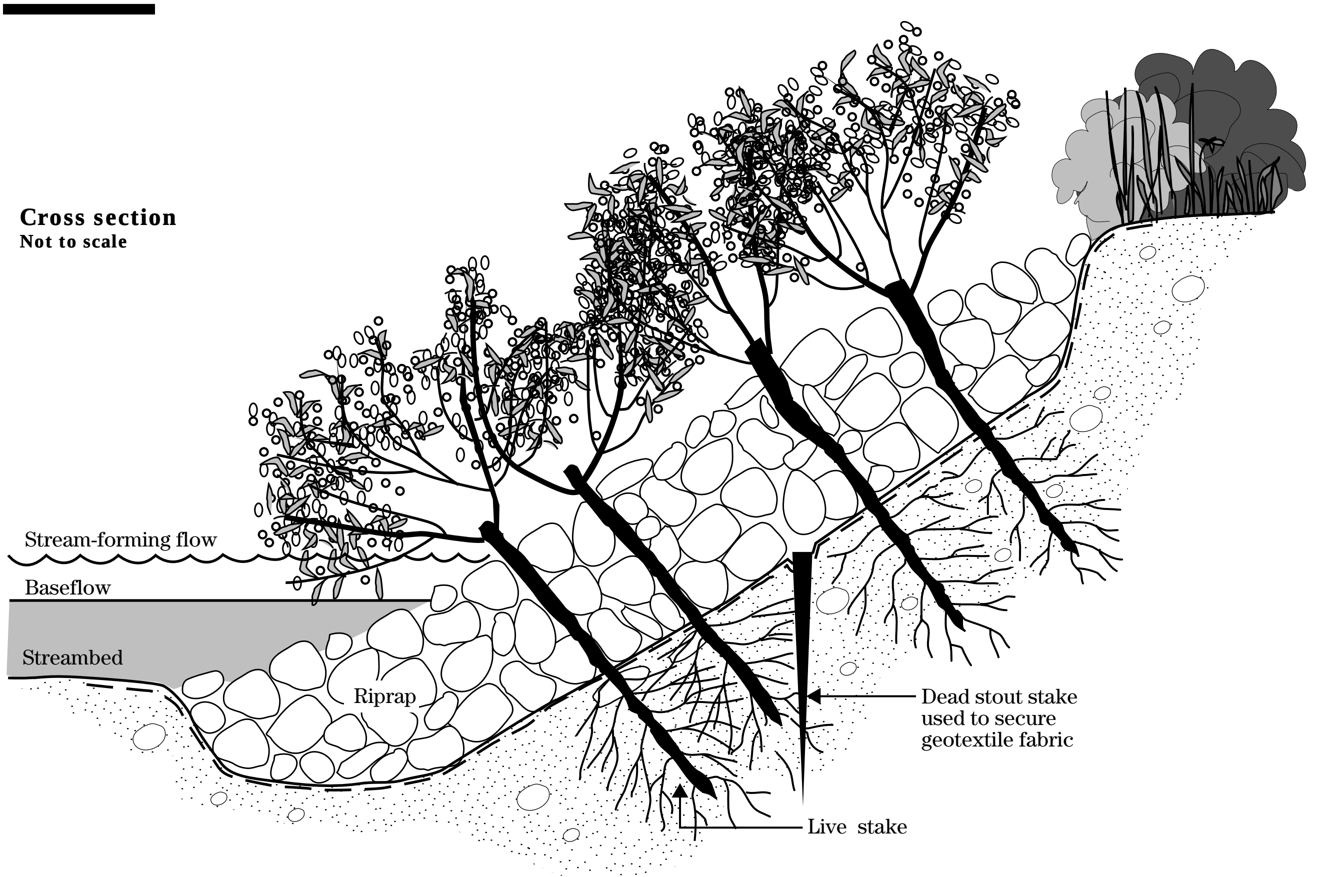


Figure 16–17a Live stake tamped into rock joints (joint planting) (Robbin B. Sotir & Associates photo)

Figure 16–17b An installed joint planting system (Robbin B. Sotir & Associates photo)

Figure 16–17c An established joint planting system (Robbin B. Sotir & Associates photo)

(vii) Brushmattress—A brushmattress is a combination of live stakes, live fascines, and branch cuttings installed to cover and stabilize streambanks (figs. 16–18, 16–19a through 16–19d). Application typically starts above stream-forming flow conditions and moves up the slope.

Applications and effectiveness

- Forms an immediate, protective cover over the streambank.
- Useful on steep, fast-flowing streams.
- Captures sediment during flood conditions.
- Rapidly restores riparian vegetation and streamside habitat.
- Enhances conditions for colonization of native vegetation.

Construction guidelines

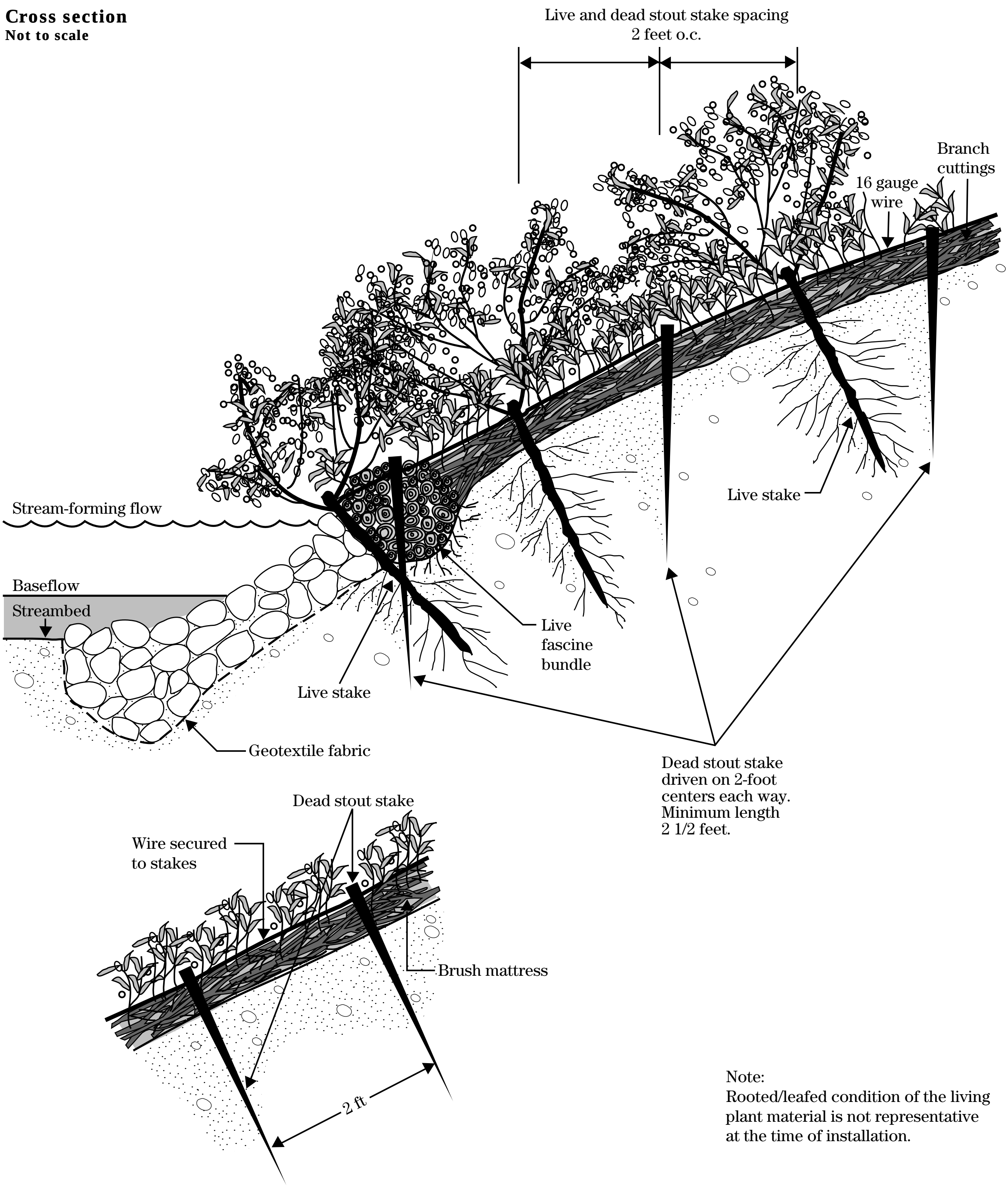
Live materials—Branches 6 to 9 feet long and approximately 1 inch in diameter are required. They must be flexible to enable installations that conform to variations in the slope face. Live stakes and live fascines are previously described in this chapter.

Inert materials—Untreated twine for bundling the live fascines and number 16 smooth wire are needed to tie down the branch mattress. Dead stout stakes to secure the live fascines and brushmattress in place.

Installation

- Grade the unstable area of the streambank uniformly to a maximum steepness of 3:1.
- Prepare live stakes and live fascine bundles immediately before installation, as previously described in this chapter.
- Beginning at the base of slope, near the stream-forming flow stage, excavate a trench on the contour large enough to accommodate a live fascine and the basal ends of the branches.
- Install an even mix of live and dead stout stakes at 1-foot depth over the face of the graded area using 2-foot square spacing.
- Place branches in a layer 1 to 2 branches thick vertically on the prepared slope with basal ends located in the previously excavated trench.
- Stretch No. 16 smooth wire diagonally from one dead stout stake to another by tightly wrapping wire around each stake no closer than 6 inches from its top.
- Tamp and drive the live and dead stout stakes into the ground until branches are tightly secured to the slope.
- Place live fascines in the prepared trench over the basal ends of the branches.
- Drive dead stout stakes directly through into soil below the live fascine every 2 feet along its length.
- Fill voids between brushmattress and live fascine cuttings with thin layers of soil to promote rooting, but leave the top surface of the brushmattress and live fascine installation slightly exposed.

Figure 16–18 Brushmattress details



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

Figure 16–19a Brushmattress during installation (Robbin B. Sotir & Associates photo)

Figure 16–19b An installed brushmattress system (Robbin B. Sotir & Associates photo)

Figure 16–19c Brushmattress system 6 months after installation (Robbin B. Sotir & Associates photo)

Figure 16–19d Brushmattress system 2 years after installation (Robbin B. Sotir & Associates photo)

(4) Structural measures

Structural measures include tree revetments; log, rootwad and boulder revetments; dormant post plantings; piling revetments with wire or geotextile fencing; piling revetments with slotted fencing; jacks or jack fields; rock riprap; stream jetties; stream barbs; and gabions.

(i) Tree revetment—A tree revetment is constructed from whole trees (except rootwads) that are usually cabled together and anchored by earth anchors, which are buried in the bank (figs. 16–20, 16–21a, and 16–21b).

Applications and effectiveness

- Uses inexpensive, readily available materials to form semi-permanent protection.
- Captures sediment and enhances conditions for colonization of native species.
- Has self-repairing abilities following damage after flood events if used in combination with soil bioengineering techniques.
- Not appropriate near bridges or other structures where there is high potential for downstream damage if the revetment dislodges during flood events.
- Has a limited life and may need to be replaced periodically, depending on the climate and durability of tree species used.
- May be damaged in streams where heavy ice flows occur.
- May require periodic maintenance to replace damaged or deteriorating trees.

Construction guidelines

- Lay the cabled trees along the bank with the basal ends oriented upstream.
- Overlap the trees to ensure continuous protection to the bank.
- Attach the trunks by cables to anchors set in the bank. Pilings can be used in lieu of earth anchors in the bank if they can be driven well below the point of maximum bed scour. The required cable size and anchorage design are dependent upon many variables and should be custom designed to fit specific site conditions.
- Use trees that have a trunk diameter of 12 inches or larger. The best type are those that have a brushy top and durable wood, such as douglas fir, oak, hard maple, or beech.
- Use vegetative plantings or soil bioengineering systems within and above structures to restore stability and establish a vegetative community. Tree species that will withstand inundation should be staked in openings in the revetment below stream-forming flow stage.

Figure 16–20 Tree revetment details

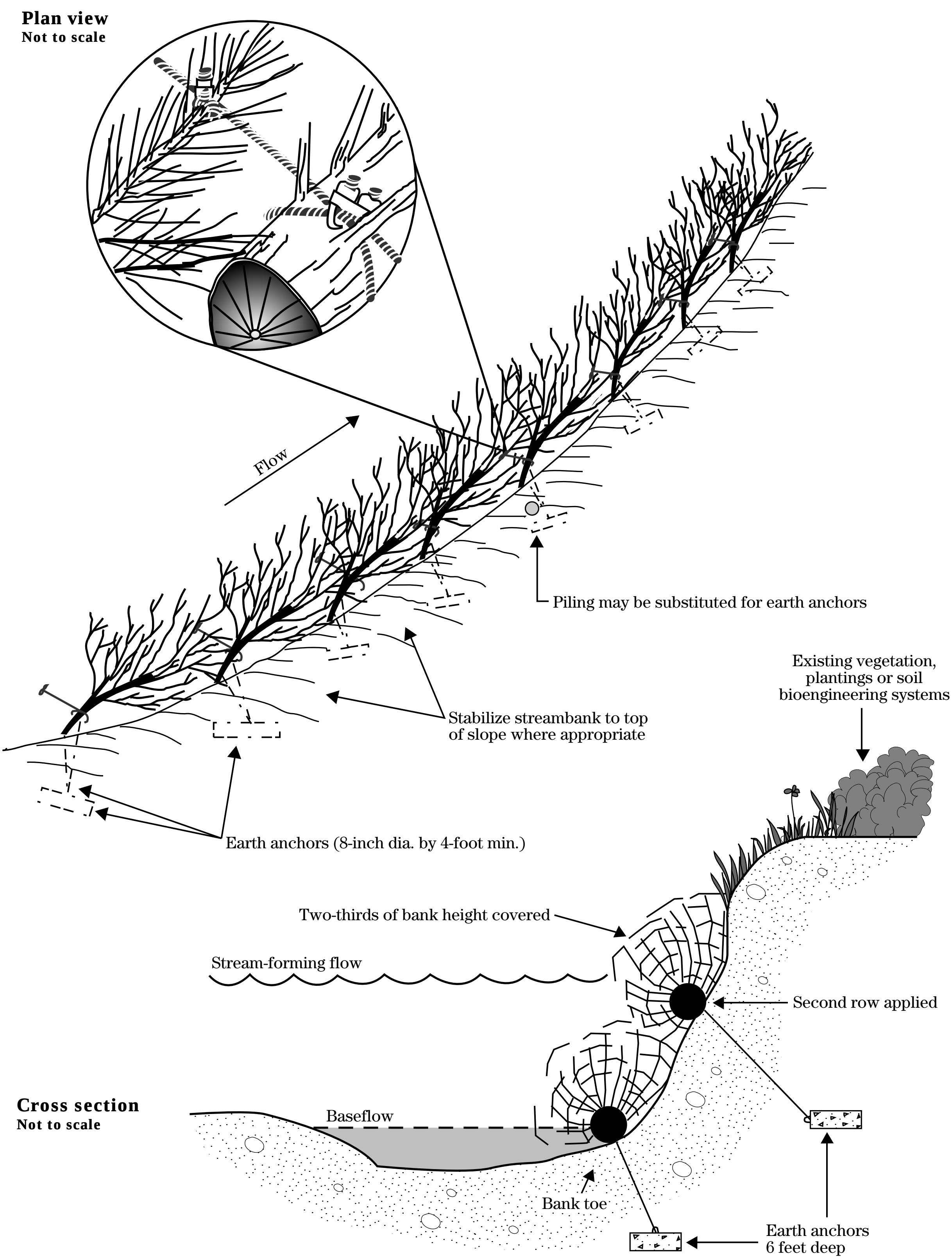


Figure 16–21a Tree revetment system with dormant posts

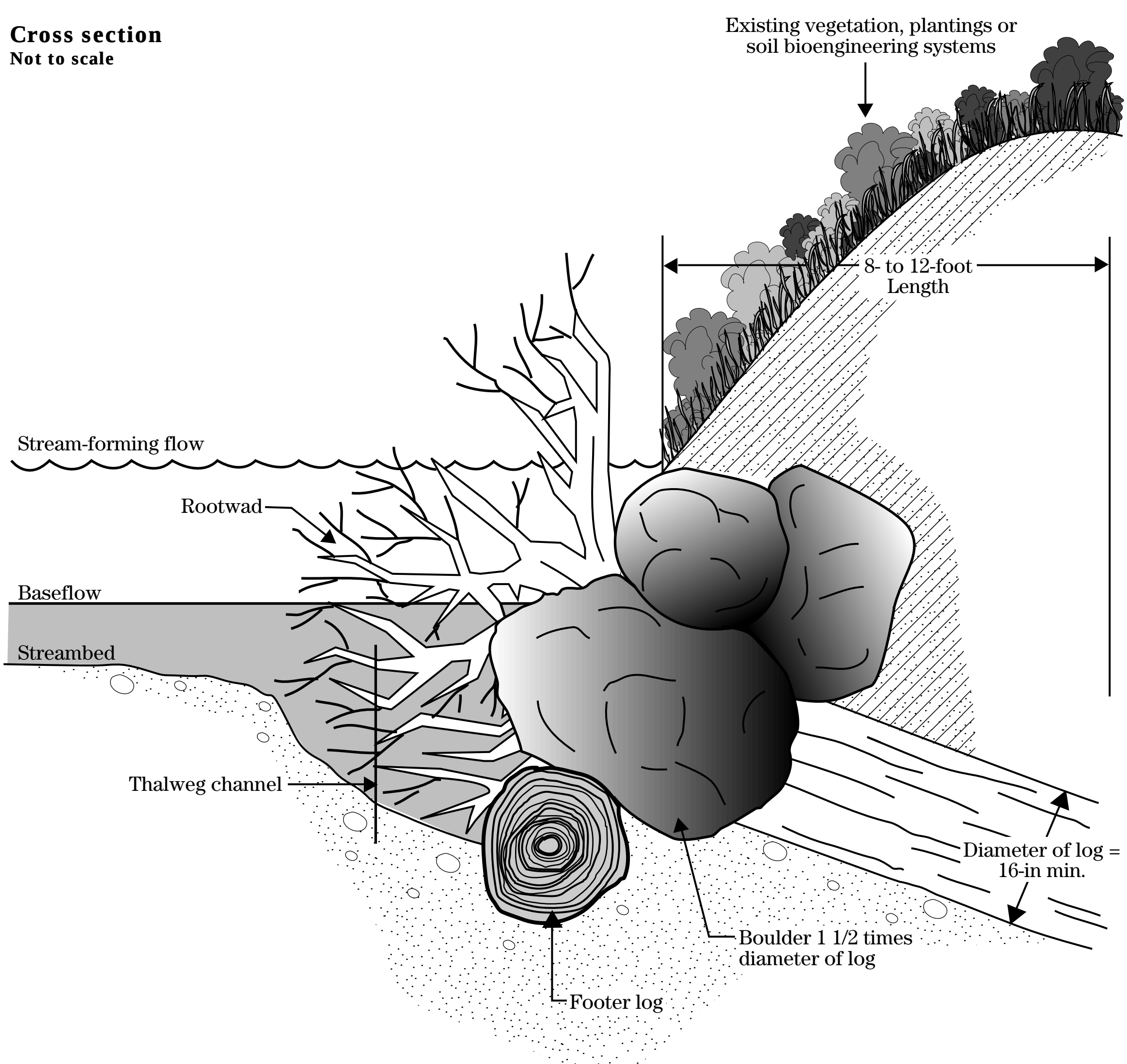
Figure 16–21b Tree revetment system with dormant posts, 2 years after installation

(ii) Log, rootwad and boulder revetments— These revetments are systems composed of logs, rootwads, and boulders selectively placed in and on streambanks (figs. 16–22 and 16–23). These revetments can provide excellent overhead cover, resting areas, shelters for insects and other fish food organisms, substrate for aquatic organisms, and increased stream velocity that results in sediment flushing and deeper scour pools. Several of these combinations are described in Flosi and Reynolds (1991), Rosgen (1992) and Berger (1991).

Applications and effectiveness

- Used for stabilization and to create instream structures for improved fish rearing and spawning habitat
- Effective on meandering streams with out-of-bank flow conditions.
- Will tolerate high boundary shear stress if logs and rootwads are well anchored.
- Suited to streams where fish habitat deficiencies exist.
- Should be used in combination with soil bioengineering systems or vegetative plantings to stabi-

Figure 16–22 Log, rootwad, and boulder revetment details (adapted from Rosgen 1993—Applied fluvial geomorphology short course)



lize the upper bank and ensure a regenerative source of streambank vegetation.
- Enhance diversity of riparian corridor when used in combination with soil bioengineering systems.
- Have limited life depending on climate and tree species used. Some species, such as cottonwood or willow, often sprout and accelerate natural colonization. Revetments may need eventual replacement if natural colonization does not take place or soil bioengineering methods are not used in combination.

Construction guidelines
Numerous individual organic revetments exist and many are detailed in the U.S. Forest Service publication, *Stream Habitat Improvement Handbook.* Chapter 16 only presents construction guidelines for a combination log, rootwad, and boulder revetment.
- Use logs over 16 inches in diameter that are crooked and have an irregular surface.
- Use rootwads with numerous root protrusions and 8- to 12-foot long boles.
- Boulders should be as large as possible, but at a minimum one and one-half the log diameter. They should have an irregular surface.
- Install a footer log at the toe of the eroding bank by excavating trenches or driving them into the bank to stabilize the slope and provide a stable foundation for the rootwad.
- Place the footer log to the expected scour depth at a slight angle away from the direction of the stream flow.
- Use boulders to anchor the footer log against flotation. If boulders are not available, logs can be pinned into gravel and rubble substrate with 3/4-inch rebar 54 inches or longer. Anchor rebar to provide maximum pull out resistance. Cable and anchors may also be used in combination with boulders and rebar.
- Drive or trench and place rootwads into the streambank so that the tree's primary brace roots are flush with the streambank. Place the rootwads at a slight angle toward the direction of the streamflow.
- Backfill and combine vegetative plantings or soil bioengineering systems behind and above rootwad. They can include live stakes and dormant post plantings in the openings of the revetment below stream-forming flow stage, live stakes, bare root, or other upland methods at the top of the bank.

Figure 16–23 Rootwad, boulder, and willow transplant revetment system, Weminuche River, CO (Rosgen, Wildland hydrology)

(iii) Dormant post plantings**—**Dormant post plantings form a permeable revetment that is constructed from rootable vegetative material placed along streambanks in a square or triangular pattern (figs. 16–24, 16–25a, 16–25b, 16–25c).

Applications and effectiveness

- Well suited to smaller, non-gravely streams where ice damage is not a problem.
- Quickly re-establishe riparian vegetation.
- Reduce stream velocities and causes sediment deposition in the treated area.
- Enhance conditions for colonization of native species.
- Are self-repairing. For example, posts damaged by beaver often develop multiple stems.
- Can be used in combination with soil bioengineering systems.
- Can be installed by a variety of methods including water jetting or mechanized stingers to form planting holes or driving the posts directly with machine mounted rams.
- Unsuccessfully rooted posts at spacings of about 4 feet can provide some benefits by deflecting higher streamflows and trapping sediment.

Construction guidelines

- Select a plant species appropriate to the site conditions. Willows and poplars have demonstrated high success rates.
- Cut live posts approximately 7 to 9 feet long and 3 to 5 inches in diameter. Taper the basal end of the post for easier insertion into the ground.
- Install posts into the eroding bank at or just above the normal waterline. Make sure posts are installed pointing up.
- Insert one-half to two-thirds of the length of post below the ground line. At least the bottom 12 inches of the post should be set into a saturated soil layer.
- Avoid excessive damage to the bark of the posts.
- Place two or more rows of posts spaced 2 to 4 feet apart using square or triangular spacing.
- Supplement the installation with appropriate soil bioengineering systems or, where appropriate, rooted plants.

Figure 16-24 Dormant post details

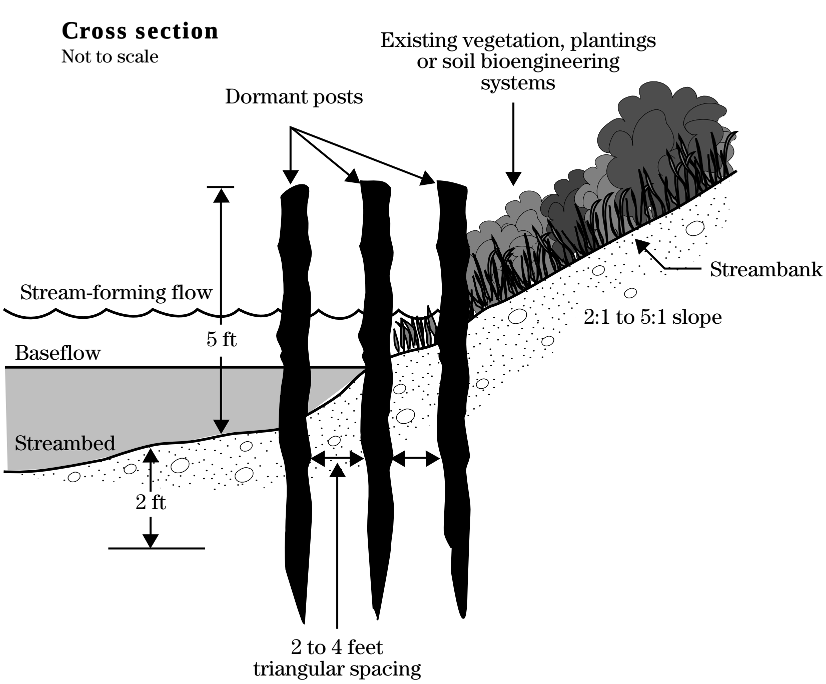


Figure 16–25a Pre-construction streambank conditions (Don Roseboom photo)

Figure 16–25b Installing dormant posts (Don Roseboom photo)

Figure 16–25c Established dormant post system (Don Roseboom photo)

(iv) Piling revetment with wire or geotextile fencing—Piling revetment is a continuous single or double row of pilings with a facing of woven wire or geogrid material (fig. 16–26). The space between double rows of pilings is filled with rock and brush.

Applications and effectiveness

- Particularly suited to streams where water next to the bank is more than 3 feet deep.
- Application is limited to a flow depth (and height of piling) of 6 feet.
- More economical than riprap construction in deep water because it eliminates the need to build a stable foundation under water for holding the riprap in place.
- Is easily damaged by ice flows or heavy flood debris and should not be used where these conditions occur.
- Do not use where the stream has fish or an abundance of riparian wildlife.
- Do not use without careful analysis of its long-term effects upon aesthetics, changes in flows where large amounts of debris will be collected, habitat damage caused by driving or installing pilings with water jets, and possible dangers for recreational uses (boating, rafting, swimming, or wading).

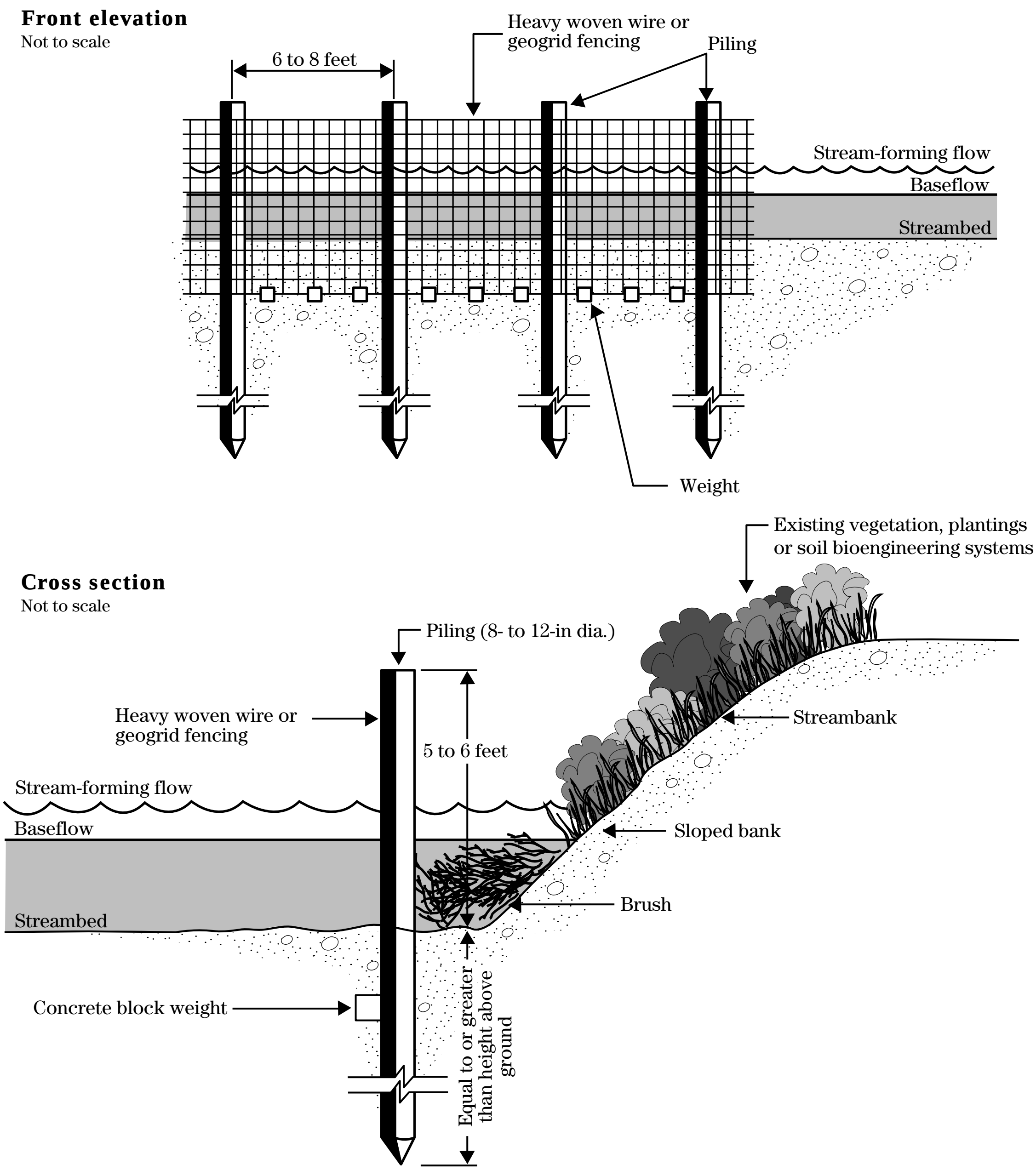
Construction guidelines

Inert materials—Used material, such as timbers, logs, railroad rails, or pipe, may be used for pilings. Logs should have a diameter sufficiently large to permit driving to the required depth. Avoid material that may produce toxicity effects in aquatic ecosystems.

Installation

- Beginning at the base of the streambank, near stream-forming flow stage, drive pilings 6 to 8 feet apart to a depth approximately half their length and below the point of maximum scour. If the streambed is firm and not subject to appreciable scour, the piling should be driven to refusal or to a depth of at least half the length of the piling.
- Additional rows of pilings may be installed at higher elevations on the streambank if required to protect the bank and if using vegetation or other methods is not practical.
- Fasten a heavy gauge of woven wire or geotextile material to the stream side of the pilings to form a fence. The purpose of this material is to collect debris while serving as a permeable wall to reduce velocities on the streambank.
- Double row piling revetment is typically constructed with 5 feet between rows. Fill the row space with rock and brush.
- If the streambed is subject to scour, extend the woven wire or geotextile material horizontally toward the center of the streambed for a distance at least equal to the anticipated depth of scour. Attach concrete blocks or other suitable weights at regular intervals to cause the fence to settle in a vertical position along the face of the pilings after scouring occurs.
- Place brush behind the piling to increase the system's effectiveness. Where piling revetments extend for several hundred feet in length, install permeable groins or tiebacks of brush and rock at right angles to the revetment at 50 foot intervals. This reduces currents developing between the streambank and the revetment.

Figure 16–26 Piling revetment details



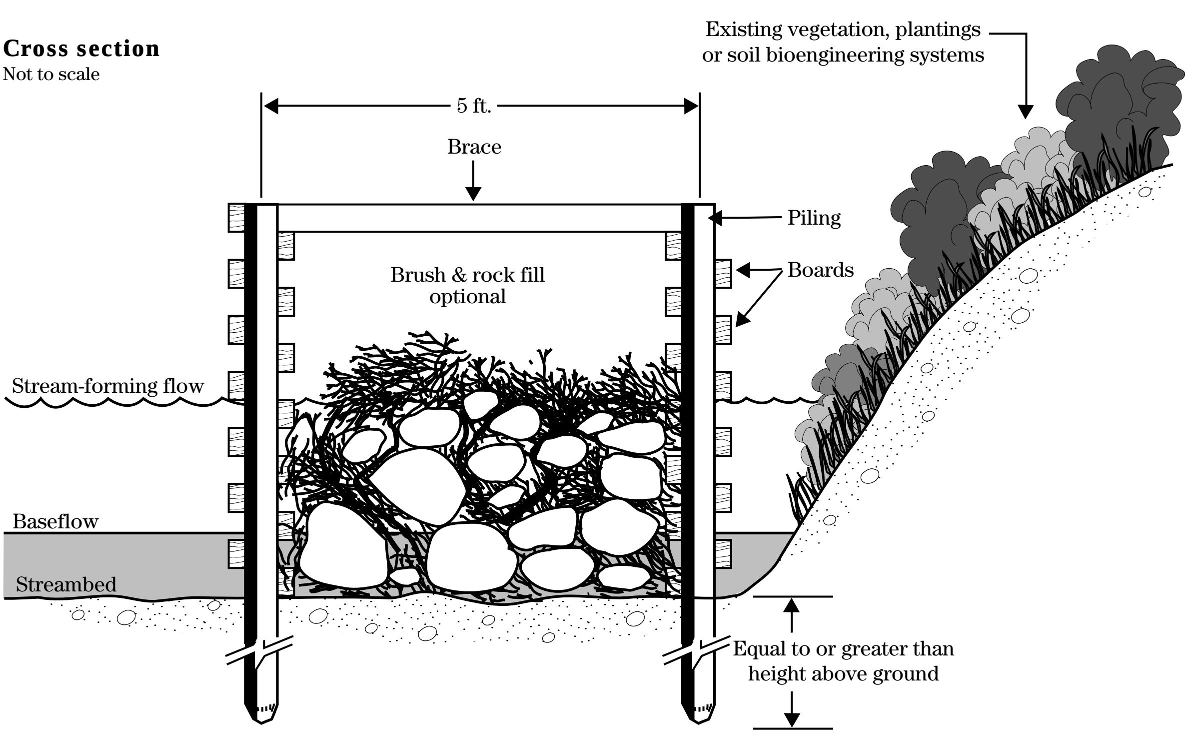
(v) Piling revetment with slotted board fencing —This type of revetment consists of slotted board fencing made of wood pilings and horizontal wood timbers (figs. 16–27 and 16–28). Variations include different fence heights, double rows of slotted fence, and use of woven wire in place of timber boards. The size and spacing of pilings, cross members, and vertical fence boards depend on height of fence, stream velocity, and sediment load.

Applications and effectiveness

- Most variations of slotted fencing include some bracing or tieback into the streambank to increase strength, reduce velocity against the streambank, and to trap sediment.
- Should not be constructed higher than 3 feet without an engineering analysis to determine sizes of the structural members.
- May be vulnerable to damage by ice or heavy flood debris; should not be used where these conditions occur.
- Usually complex and expensive.
- Most effective on streams that have a heavy sediment load of sand and silt.
- Can withstand a relatively high velocity attack force and, therefore, can be installed in sharper curves than jacks or other systems.
- Useful in deeper stream channels with large flow depths.
- Low slotted board fences, which do not control the entire flood flow, can be very effective for streambank toe protection where the toe is the weak part of the streambank.
- May not be appropriate where unusually hard materials are encountered in the channel bottom.

Figure 16–27 Slotted board fence details (double fence option)

Cross section
Not to scale



- Should not be used without careful consideration of its long-term effects upon aesthetics, changes in flows where large amounts of debris are collected, habitat damage caused by driving or installing pilings with water jets, and possible dangers for recreational uses (boating, rafting, swimming, or wading).

Construction guidelines
Inert materials—Slotted fencing is constructed of wood boards, wood pilings, and woven wire. Avoid materials that may produce toxicity effects in aquatic ecosystems.

Installation
- See *(iv) Piling revetment with wire or geotextile fencing* for general construction guidelines.
- Drive the timber piling to a depth below the channel bottom that is equal to the height of the slotted fence above the expected scour line when stream soils have a standard penetration resistance of 10 or more blows per foot. Increase the piling depth when penetration resistance is less than 10 blows per foot.
- Take great care during layout to tie in the upstream end adequately to prevent flanking and unraveling.

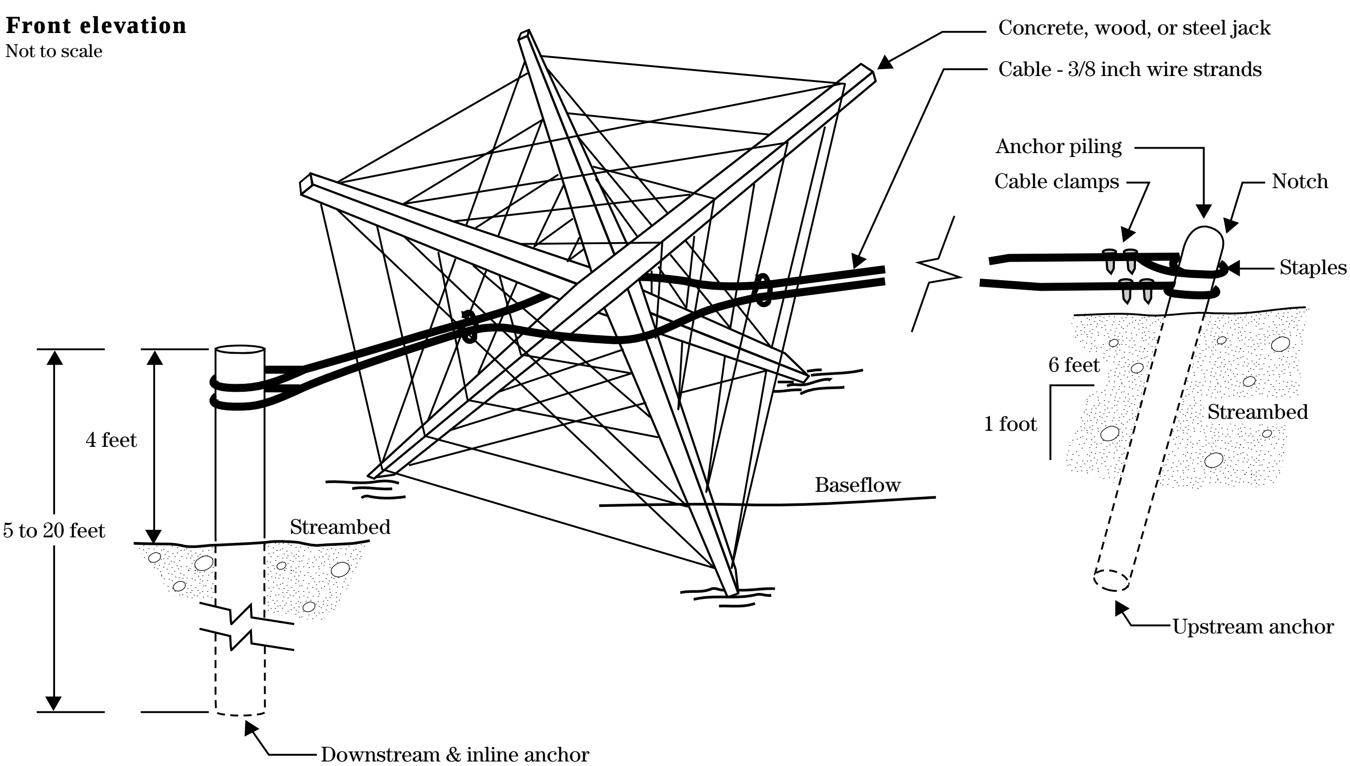
Figure 16–28 Slotted board fence system

(vi) Jacks or jack fields—Jacks are individual structures made of wood, concrete, or steel. The jacks are placed in rows parallel to the eroding streambank and function by trapping debris and sediment. They are often constructed in groups called jack fields (figs. 16–29, 16–30, and 16–31).

Applications and effectiveness

- May be an effective means of controlling bank erosion on sinuous streams carrying heavy bedloads of sand and silt during flood flows. This condition is generally indicated by the presence of extensive sandbar formations on the bed at low flow.
- Are complex systems requiring proper design and installation for effective results.
- Collect coarse and fine sediment, when functioning properly, and naturally revegetate as the systems, including cable, become embedded in the streambank.
- Do not use on high velocity, debris-laden streams.
- Somewhat flexible because of their physical configuration and installation techniques that allow them to adjust to slight changes in the channel grade.
- Most effective on long, radius curves.
- Not an effective alternative for redirecting flow away from the streambank.
- Do not use without careful analysis of its long-term effects upon aesthetics, changes in flows where large amounts of debris are collected, fish habitat damage, and possible dangers for recreational uses (boating, rafting, swimming, or wading).

Figure 16–29 Concrete jack details

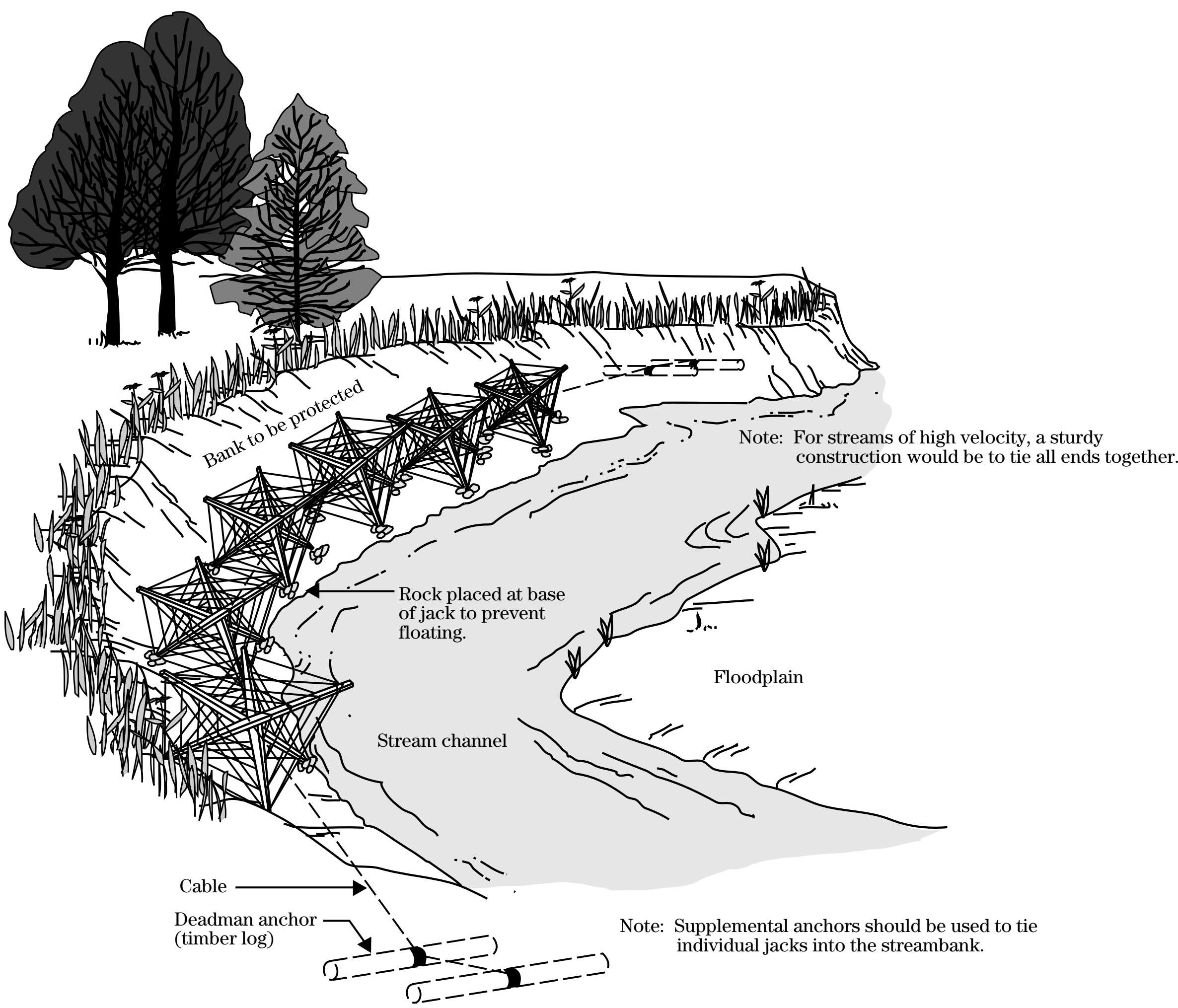


Construction guidelines

Inert materials—Jacks may be constructed of wood, steel, or concrete. Wooden jacks are constructed from three poles 10 to 16 feet long. They are crossed and wired together at the ends and midpoints with No. 9 galvanized wire. Cables used to anchor the wood jack systems should be 3/8-inch diameter or larger with a minimum breaking strength of 15,400 pounds. Wooden jack systems dimensioned in this chapter are limited to shallow flow depths of 12 feet or less.

Steel jacks are used in a manner similar to that of wood jacks; however, leg assemblies, cable size, anchor blocks, and anchor placement details vary. Concrete beams may be substituted for steel, but engineering design is required to determine different attachment methods, anchoring systems, and assembly configurations.

Figure 16–30 Wooden jack field



Installation

- Jack rows can be placed on a shelf 14 feet wide for one line and on two shelves, each 14 feet wide, for a double jack row. Grade the shelf to slope from 1 foot above the streambed at the side nearest the stream to 3 feet above the streambed at the side nearest the slope. This encourages a dry surface for construction and provides some additional elevation for protection from greater depths of flow. Alternatively, jacks can be constructed on the streambed or on the top of the bank and moved into place.
- Space jacks closely together with a maximum of one jack dimension between them to provide an almost continuous line of revetment.
- Anchor the jacks in place by a cable strung through and tied to the center of the jacks with cable clamps. The cable should be tied to a buried anchor or pilings, thereby securing all the jacks as a unit. Wooden jacks are weighted by rocks, which should be wired onto the jack poles. The first two pilings at the upstream end of the jack line should be driven no more than 12 feet apart to reduce the effect of increased water force from trash buildup.
- Bury anchors or drive anchor pilings to the design depth determined by an engineer. Depths may vary from 5 to 20 feet and must be specified based on individual site characteristics.
- On long curves, anchor jack rows at intermediate points along the curve to isolate damages to the jack row. Two 3/8-inch diameter wire cables tied to timber or steel pilings provide adequate anchors. Place anchors up the streambank rather than in the streambed.
- Consider pilings if streambed anchors are required. Space pilings 75 to 125 feet apart along the jack row, with closer spacing on shorter curves.
- Attach an anchored 3/8-inch diameter wire cable to one leg of each jack to prevent rotation and improve stability.
- Place jack rows perpendicular to the bank at regular intervals where jack rows are not close to existing banks. This prevents local scour. Extend bank protection far enough to prevent flanking action. Ensure the jack row is anchored to a hardpoint at the upstream end.
- Supplement the jack string or field with vegetative plantings. Dormant posts offer a compatible component in the system.

Figure 16–31 Concrete jack system several years after installation

(vii) Rock riprap—Rock riprap, properly designed and placed, is an effective method of streambank protection (figs.16–32 and 16–33). The cost of quarrying, transporting, and placing the stone and the large quantity of stone that may be needed must be considered. Gabion baskets, concrete cellular blocks, or similar systems (figs. 16–34, 16–35a, 16–35b; and 16–42, 16–43) can be an alternative to rock riprap under many circumstances.

Applications and effectiveness

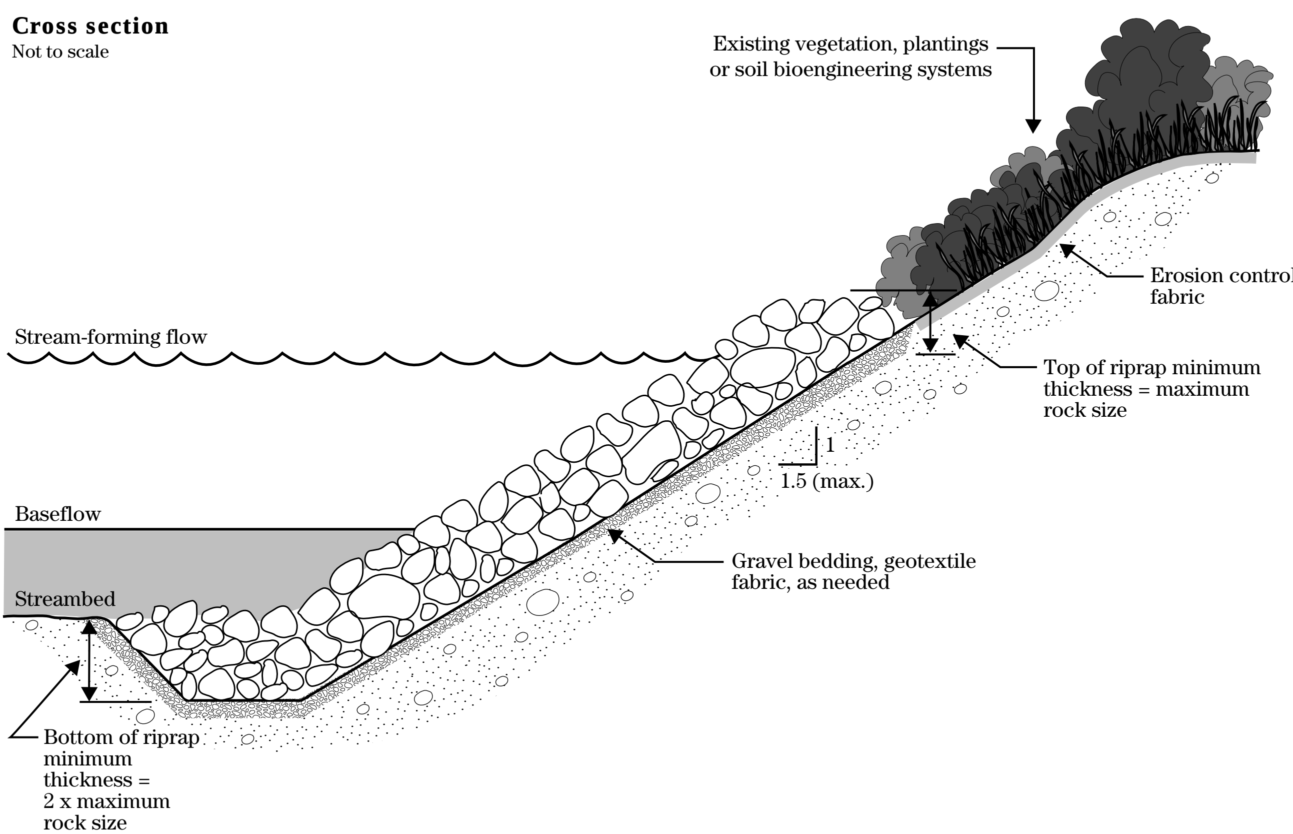
- Provides long-term stability.
- Has structural flexibility. It can be designed to self-adjust to eroding foundations.
- Has a long life and seldom needs replacement.
- Is inert so does not depend on specific environmental or climatic conditions for success.
- May be designed for high velocity flow conditions.

Construction guidelines

Inert materials—Cobbles and gravel obtained from the stream bed should not be used to armor streambanks unless the material is so abundant that its removal will not reduce habitat for benthic organisms and fish. Material forming an armor layer that protects the bed from erosion should not be removed. Use of stream cobble and gravel may require permission from state and local agencies.

Removing streambed materials tends to destroy the diversity of physical habitat necessary for optimum fish production, not only in the project area, but upstream and downstream as well. Construction activities often create channels of uniform depth and width in which water velocities increase. Following disruption of the existing streamflow by alteration of the stream channel, further damage results as the stream seeks to reestablish its original meander pattern.

Figure 16–32 Rock riprap details



Upstream, the stream may seek to adjust to the new gradient by actively eroding or grading its banks and bed. The eroded material may be deposited in the channel downstream from the alteration causing additional changes in flow pattern. The downstream channel will then also adjust to the new gradient and increased streamflow velocity by scour and bank erosion or further deposition.

Rock riprap on streambanks is affected by the hydrodynamic drag and lift forces created by the velocity of flow past the rock. Resisting the hydrodynamic effects are the force components resulting from the submerged weight of the rock and its geometry. These forces must be considered in any analytical procedure for determining a stable rock size. Channel alignment, surface roughness, debris and ice impact, rock gradation, angularity, and placement are other factors that must be considered when designing for given site conditions.

Numerous methods have been developed for designing rock riprap. Nearly all use either an allowable velocity or tractive stress methodology as the basis for determining a stable rock size. Table 16–2 lists several accepted procedures currently used in the NRCS. The table provides summary information and references where appropriate. Two of the more direct methods of obtaining a rock size are included in appendix 16A. All four methods listed in the table provide the user with a design rock size for a given set of input parameters. The first time user is advised to use more than one method in determining rock size. Availability of rock and experience of the designer continue to play important roles in determining the appropriate size rock for any given job.

Figure 16–33 Rock riprap revetment system

A well graded rock provides the greatest assurance of stability and long-term protection. Poorly graded rock results in weak areas where individual stones are subject to movement and subsequent revetment failure. Satisfactory gradation limits and thickness of the rock riprap can be determined from the basic stone size. Figure 16A–3 in appendix 16A can help determine rock gradation limits for any calculated basic rock size (D_{50}, D_{75}, and so forth).

The void space between rocks in riprap is generally many times greater than the void space in existing bank materials. A transition zone serves two purposes:

- Distributes the weight of rock to the underlying soil.
- Prevents movement and loss of fine grained soil into the large void spaces of the riprap.

The transition zone can be designed as a filter, bedding, or geotextile. The bank soils, bank seepage, and rock gradation and thickness are factors to consider when determining the transition material.

Bedding material is generally a pit run sand-gravel mixture. Bedding is suitable for those sites where bank materials are plastic and forces can be considered external, that is, forces acting on the bedding result only from the action of flow past or over the rock riprap. Bedding is not recommended for conditions where flow occurs through the rock (as on steep slopes), where subject to wave action, or where flow velocity exceeds 10 feet per second.

Table 16–2 Methods for rock riprap protection

Method (reference)	Basis for rock size	Procedure	Comments
Isbash Curve Appendix 16A (reprint from SCS Engineering Field Manual, chapter 16, 1969).	Allowable velocity— Curve developed from Isbash work.	Use design velocity and curve to determine basic rock size (D_{100}).	Use judgment to factor in site conditions. The basic stone weight is often doubled to account for debris.
FWS-Lane Appendix 16A (reprint from SCS Engineering Design Standards—Far West States, 1970).	Tractive stress— Monograph developed from Lane's work.	Enter monograph with channel hydraulic and physical data to solve for basic rock size (D_{75}).	Easy to use procedure. Generally results in a conservative rock size.
COE Method Corps of Engineers, EM 1110-2-1601, 7/91, Hydraulic Design of Flood Control Channels.	Allowable velocity— Basic equation developed by COE from study of models and comparison to field data.	Use equation or graphs and site physical and hydraulic data to determine basic rock size (D_{30}).	Detailed procedure can be used on natural or prismatic channels.
Federal Highway Administration Hydraulic Engineering Circular No. 11, Design of Riprap Revetment (1989).	Tractive Force Theory— Uses velocity as a primary design parameter.	Use equation with known site data and user determined stability factor to solve for basic rock size (D_{50}).	Stability factor requires user judgment of site conditions.

A filter is a graded granular material designed to prevent movement of the bank soil. A filter is recommended where bank materials are nonplastic, seepage forces exist, or where bedding is not adequate protection for the external forces as noted above. The site should be evaluated for potential seepage pressures from existing or seasonal water table, rapid fluctuations in streamflow (rapid drawdown), surface runoff, or other factors. In critical applications or where experience indicates problems with the loss of bank material under riprap, use chapter 26, part 633 of the NRCS National Engineering Handbook, January 1994, for guidance in designing granular filters.

Nonwoven geotextiles are widely used as a substitute for bedding and filter material. Availability, cost, and ease of placement are contributing factors. For guidance in selection of the proper geotextile, refer to NRCS Design Note 24, *Guide to Use of Geotextile.*

Installation

- Minimum thickness of the riprap should at least equal the maximum rock size at the top of the revetment. The thickness is often increased at the base of the revetment to two or more times the maximum rock size.
- The toe for rock riprap must be firmly established. This is important where the stream bottom is unstable or subject to scour during flood flows.
- Banks on which riprap is to be placed should be sloped so that the pressure of the stone is mainly against the bank rather than against the stone in the lower courses and toe. This slope should not be steeper than 1.5:1. The riprap should extend up the bank to an elevation at which vegetation will provide adequate protection.
- A filter or bedding must be placed between the riprap and the bank except in those cases where the material in the bank to be protected is determined to be a suitable bedding or filter material. The filter or bedding material should be at least 6 inches thick.
- A nonwoven geotextile may be used in lieu of a bedding or filter layer under the rock riprap. The geotextile material must maintain intimate contact with the subsurface. Geotextile that can move with changes in seepage pressure or external forces permits soil particle movement and can result in plugging of the geotextile. A 3-inch layer of bedding material over the geotextile prevents this movement.
- Hand-placing all rock in a revetment should seldom, if ever, be necessary. While the revetment may have a somewhat less finished look, it is adequate to dump the rock and rearrange it with a minimum of hand labor. However, the rock must be dumped in a manner that will not separate small and large stones or cause damage to the filter fabrics. The finished surface should not have pockets of finer materials that would flush out and weaken the revetment. Sufficient hand placing and chinking should be done to provide a well-keyed surface.

The Engineering Field Handbook, Chapter 17, Construction and Construction Materials, has additional information on riprap construction and materials.

Manufacturers have developed design recommendations for various flow and soil conditions. Their recommendations are good references in use of gabions, cellular blocks, and similar systems.

Figure 16–34 Concrete cellular block details

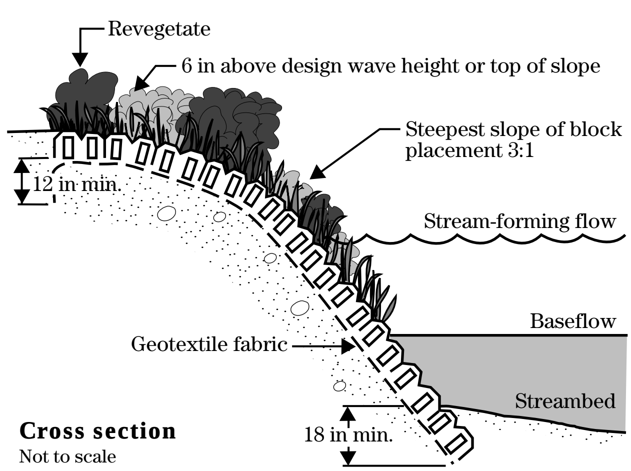


Figure 16–35a Concrete cellular block system before backfilling

Figure 16–35b Concrete cellular block system several years after installation

(viii) Coconut fiber rolls—Coconut fiber rolls are cylindrical structures composed of coconut husk fibers bound together with twine woven from coconut (figs. 16–36, 16–37a, and 16–37b). This material is most commonly manufactured in 12-inch diameters and lengths of 20 feet. It is staked in place at the toe of the slope, generally at the stream-forming flow stage.

Applications and effectiveness

- Protect slopes from shallow slides or undermining while trapping sediment that encourages plant growth within the fiber roll.
- Flexible, product can mold to existing curvature of streambank.
- Produce a well-reinforced streambank without much site disturbance.
- Prefabricated materials can be expensive.
- Manufacturers estimate the product has an effective life of 6 to 10 years.

Construction guidelines

- Excavate a shallow trench at the toe of the slope to a depth slightly below channel grade.
- Place the coconut fiber roll in the trench.
- Drive 2 inch x 2 inch x 36 inch stakes between the binding twine and coconut fiber. Stakes should be placed on both sides of the roll on 2 to 4 feet centers depending upon anticipated velocities. Tops of stakes should not extend above the top of the fiber roll.
- In areas that experience ice or wave action, notch outside of stakes on either side of fiber roll and secure with 16-gauge wire.

Figure 16–36 Coconut fiber roll details

Cross section
Not to scale

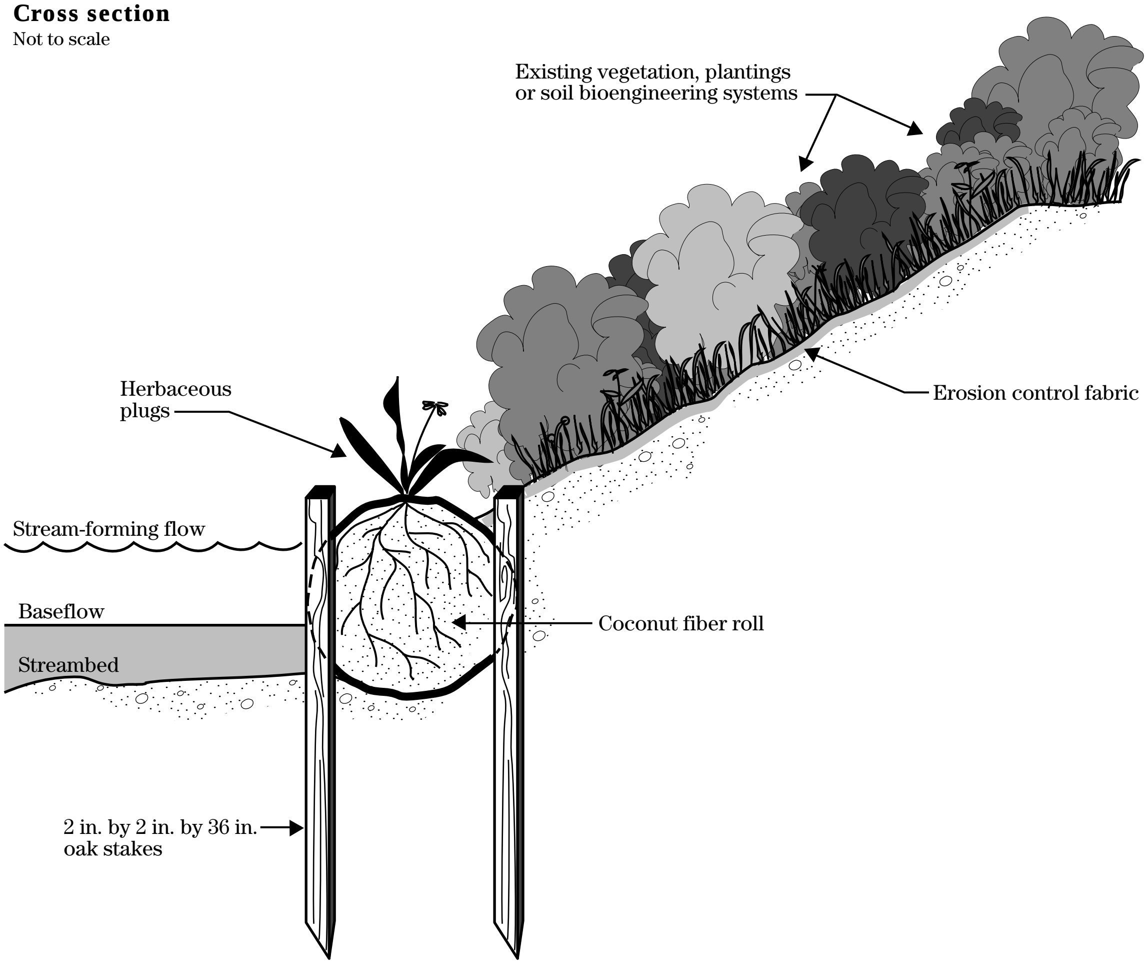


Figure 16–37a Coconut fiber roll

Figure 16–37b Coconut fiber roll system

- Backfill soil behind the fiber roll.
- If conditions permit, rooted herbaceous plants may be installed in the coconut fiber.
- Install appropriate vegetation or soil bioengineering systems upslope from fiber roll.

(ix) Stream jetties—Jetties are short dike-like structures that project from a streambank into a stream channel. They may consist of one or more structures placed at intervals along the bank to be protected. Most are constructed to the top of the bank and can be oriented either upstream, downstream, or perpendicular to the bank (figs. 16–38 and 16–39).

Jetties deflect or maintain the direction of flow through and beyond the reach of stream being protected. In function and design, jetties change the direction of flow by obstructing and redirecting the streamflow. Their design and construction require specialized skills. A fluvial geomorphologist, engineer, or other qualified discipline with knowledge of open channel hydraulics should be consulted for specific considerations and guidelines.

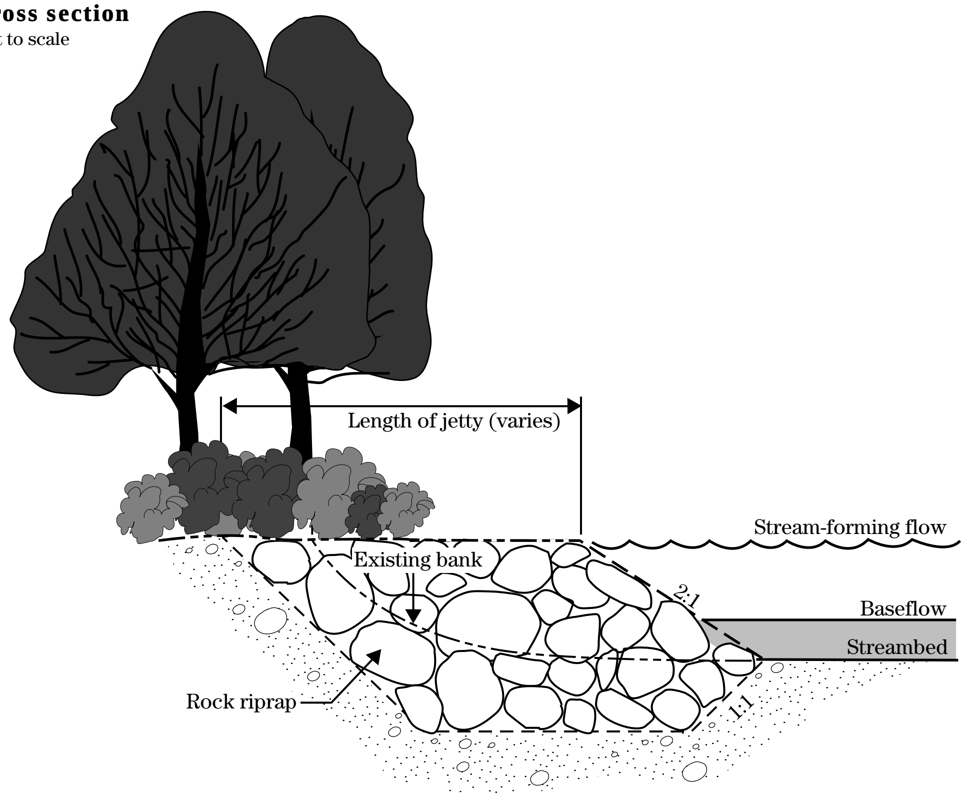
Applications and effectiveness
- Used successfully in a wide variety of applications in all types of rivers and streams.
- Effective in controlling erosion on bends in river and stream systems.
- Can be augmented with vegetation or soil bioengineering systems in some situations; i.e., deposited material upstream of jetties.
- May develop scour holes just downstream and off the end of the jetties.
- Can be complex and expensive.

Construction guidelines
Inert materials—Rock filled jetties are the most common, however, other materials are used including timber, concrete, gabions, and rock protected earth.

Installation
- Use a D_{50} size rock equal to 1.5 to 2 times the d_{50} size determined from rock riprap design methods for bank full flow condition.
- Size and space jetties so that flow passing around and downstream from the outer end will intersect the next jetty before intersecting the eroding bank. The length varies but should not unduly constrict the channel. Rock jetties typically have 2:1 side slopes with an 8 to 12-foot top width and 2:1 end slope.
- Space jetties to account for such characteristics as stream width, stream velocity, and radius of curvature. Typical spacing is 2 to 5 times the jetty length.
- Construct jetties with a level top or a downward slope to the outer end (riverward). The top of the jetty at the bank should be equal to the bank height.
- Orient jetties either perpendicular to the streambank or angled upstream or downstream. Perpendicular and downstream orientation are the most common.
- Tie jetties securely back into the bank and bed to prevent washout along the bank and undercutting. Place rock a short distance on either side of the jetty along the bank to prevent erosion at this critical location. The base of the jetty should be keyed into the bed a minimum depth equal to the D_{100} rock size.

Figure 16–38 Stream jetty details

Cross section
Not to scale



Front elevation
Not to scale

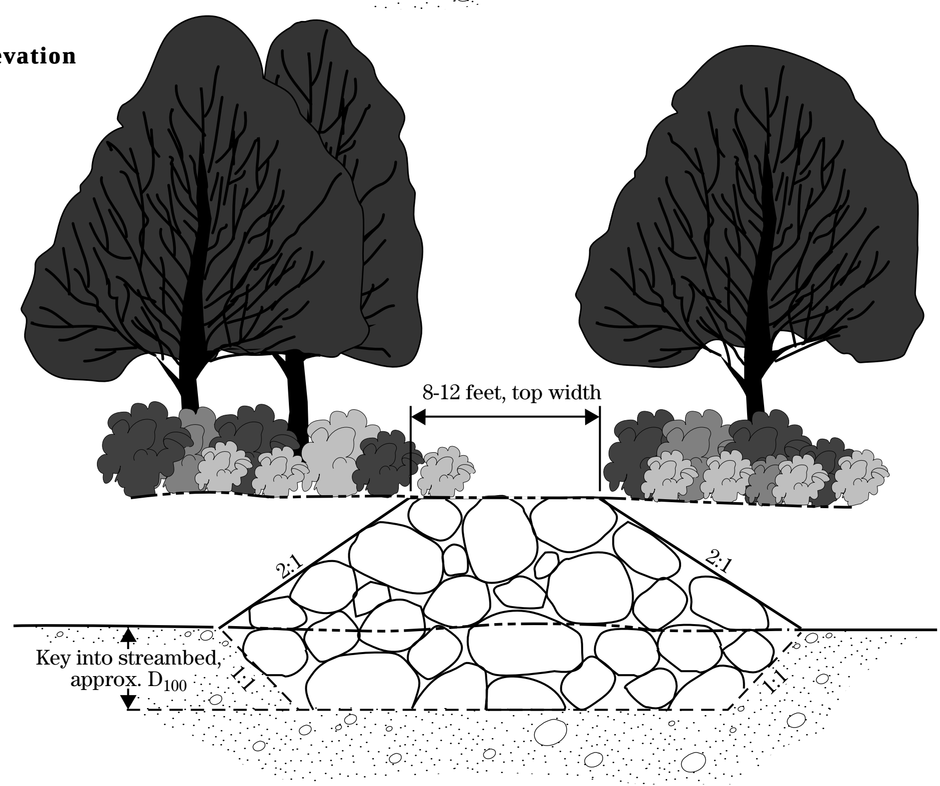


Figure 16–39a Stream jetty placed to protect railroad bridge

Figure 16–39b Long-established vegetated stream jetty, with deposition in foreground

(x) Stream barbs—Stream barbs are low rock sills projecting out from a streambank and across the stream's thalweg to redirect streamflow away from an eroding bank (figs.16–40 and 16–41). Flow passing over the barb is redirected so that the flow leaving the barb is perpendicular to the barb centerline. Stream barbs are always oriented upstream.

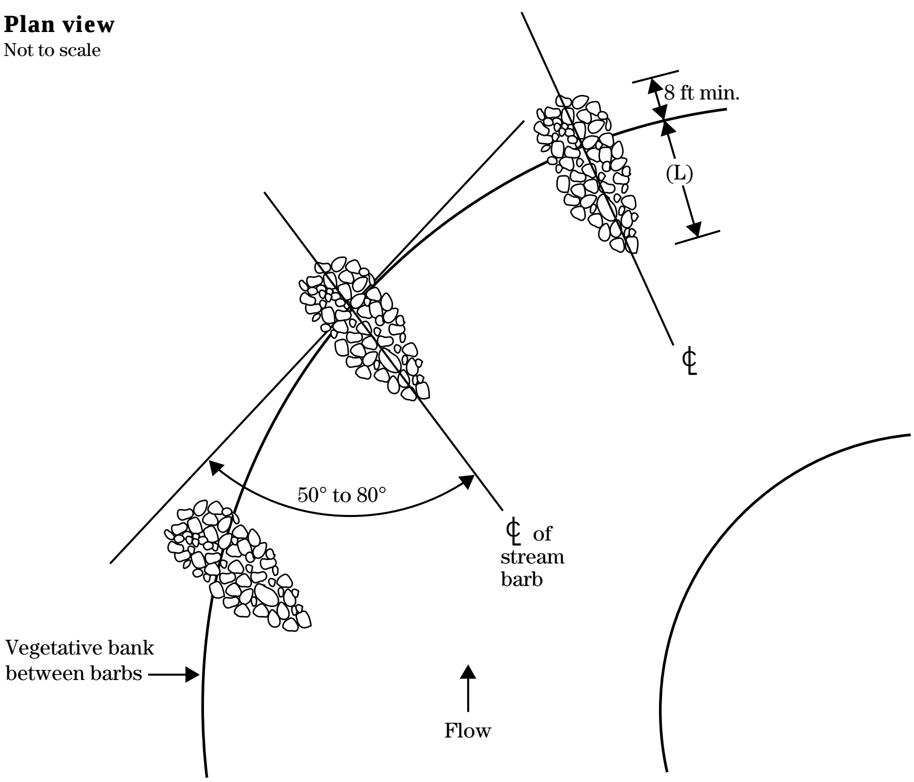
Application and effectiveness
- Used in limited applications and range of applicability is unclear.
- Effective in control of bank erosion on small streams.
- Require less rock and stream disturbance than jetties.
- Improve fish habitat (especially when vegetated).
- Can be combined with soil bioengineering practices.
- Can be complex and expensive.

Construction guidelines
Inert materials—Stream barbs require the use of large rock.

Installation
- Use a D_{50} size rock equal to two times the d_{50} size determined from rock riprap design methods for bank full flow condition. The maximum rock size (D_{100}) should be about 1.5 to 2 times the D_{50} size. The minimum rock size should not be less than $.75D_{50}$.
- Key the barb into the stream bed to a depth approximately D_{100} below the bed.
- Construct the barb above the streambed to a height approximately equal to the D_{100} rock, but generally not over 2 feet. The width should be at least equal to 3 times D_{100}, but not less than a typical construction equipment width of 8 to 10 feet. Construction of barbs can begin at the streambank and proceed streamward using the barb to support construction equipment.
- Align the barb so that the flow off the barb is directed toward the center of the stream or away from the bank. The acute angle between the barb and the upstream bank typically ranges from 50 to 80 degrees.
- Ensure that, at a minimum, the barb is long enough to cross the stream flow low thalweg.
- Space the barbs apart from 4 to 5 times the barb's length. The specific spacing is dependent on finding the point at which the streamflow leaving the barb intersects with the bank.

Figure 16–40 Stream barb details

Plan view
Not to scale



Cross section
Not to scale

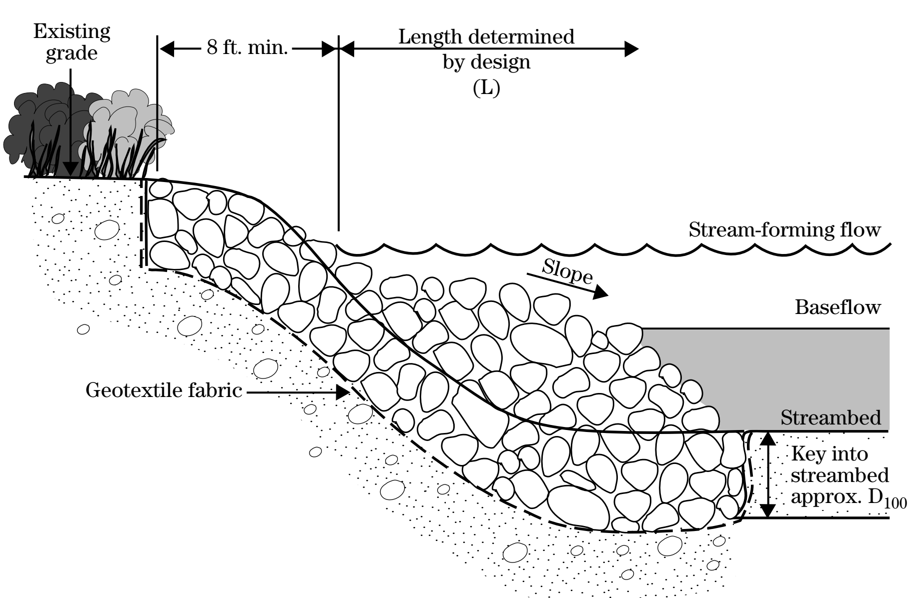


Figure 16–41 Stream barb system

(xi) Rock gabions—Rock gabions begin as rectangular containers fabricated from a triple twisted, hexagonal mesh of heavily galvanized steel wire. Empty gabions are placed in position, wired to adjoining gabions, filled with stones, and then folded shut and wired at the ends and sides. NRCS Construction Specification 64, Wire Gabions, provides detailed information on their installation.

Vegetation can be incorporated into rock gabions, if desired, by placing live branches on each consecutive layer between the rock-filled baskets (fig. 16–42 and 16–43). These gabions take root inside the gabion baskets and in the soil behind the structures. In time the roots consolidate the structure and bind it to the slope.

Applications and effectiveness

- Useful when rock riprap design requires a rock size greater than what is locally available.
- Effective where the bank slope is steep (typically greater than 1.5:1) and requires structural support.
- Appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Can be fabricated on top of the bank and then placed as a unit, below water if necessary.
- Lower initial cost than a concrete structure.
- Tolerate limited foundation movement.
- Have a short service life where installed in streams that have a high bed load. Avoid use where streambed material might abrade and cause rapid failure of gabion wire mesh.
- Not designed for or intended to resist large, lateral earth stresses. Should be constructed to a maximum of 5 feet in overall height, including the excavation required for a stable foundation.
- Useful where space is limited and a more vertical structure is required.
- Where gabions are designed as a structural unit, the effects of uplift, overturning, and sliding must be analyzed in a manner similar to that for gravity type structures.
- Can be placed as a continuous mattress for slope protection. Slopes steeper than 2:1 should be analyzed for slope stability.
- Gabions used as mattresses should be a minimum of 9 inches thick for stream velocities of up to 9 feet per second. Increase the thickness to a minimum of 1.5 feet for velocities of 10 to 14 feet per second.

Construction guidelines

Live material sizes—When constructing vegetated rock gabions, branches should range from 0.5 to 2.5 inches in diameter and must be long enough to reach beyond the back of the rock basket structure into the backfill or undisturbed bank.

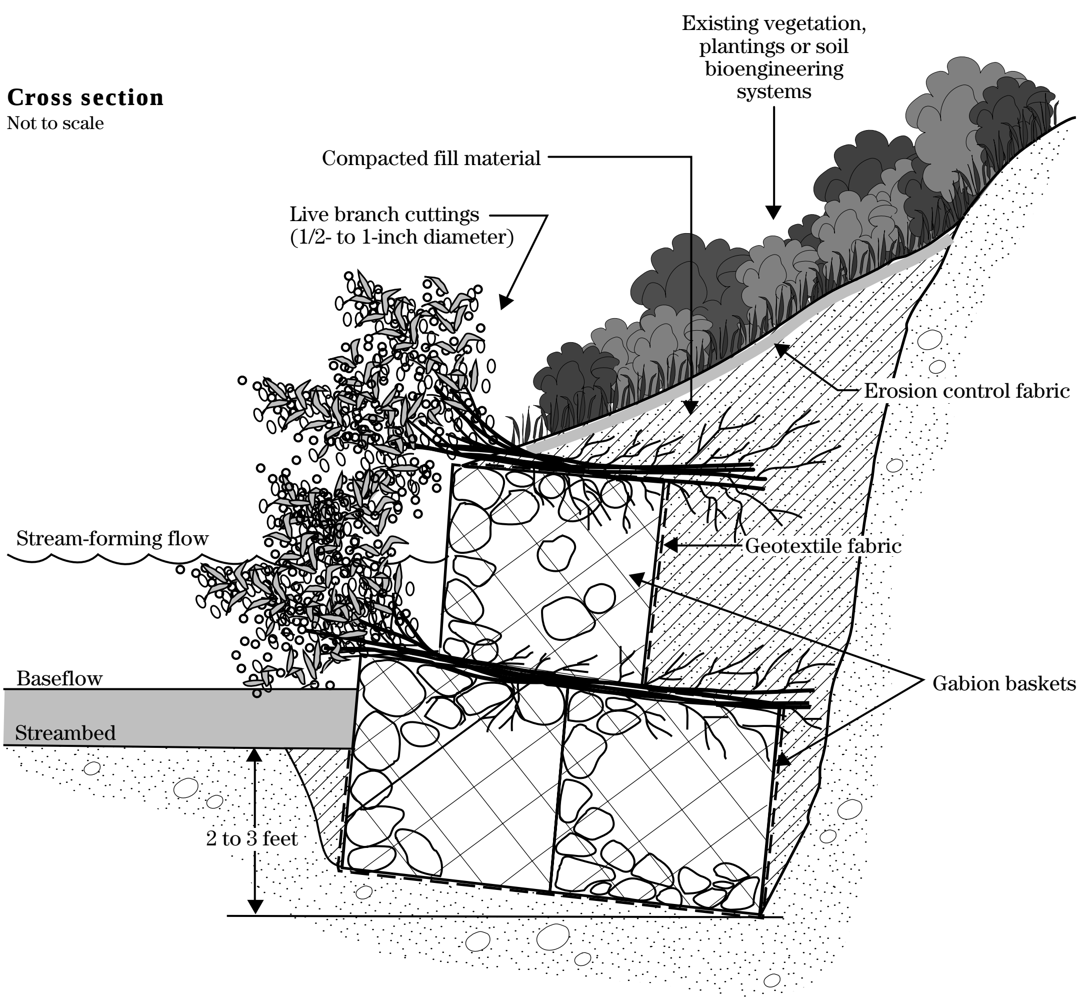
Inert materials—Galvanized woven wire mesh or galvanized welded wire mesh baskets or mattresses may be used. The baskets or mattresses are filled with sound durable rock that has a minimum size of 4 inches and a maximum of 9 inches. Gabions can be coated with polyvinyl chloride to improve their service life where subject to aggressive water or soil conditions.

Installation

- Remove loose material from the foundation area and cut or fill with compacted material to provide a uniform foundation.
- Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure. This provides additional stability to the structure and ensures that the living branches root well for vegetated rock gabions.
- Place bedding or filter material in a uniformly graded surface. Compaction of materials is not usually required. Install geotextiles so that they lie smoothly on the prepared foundation.
- Assemble, place, and fill the gabions with rock. Be certain that all stiffeners and fasteners are properly secured.
- Place the gabions so that the vertical joints are staggered between the gabions of adjacent rows and layers by at least one-half of a cell length.
- Place backfill between and behind the wire baskets.
- For vegetated rock gabions, place live branch cuttings on the wire baskets perpendicular to the slope with the growing tips oriented away from the slope and extending slightly beyond the gabions. The live cuttings must extend beyond the backs of the wire baskets into the fill material. Place soil over the cuttings and compact it.
- Repeat the construction sequence until the structure reaches the required height.

- Where abrasive bedloads or debris can snag or tear the gabion wire, a concrete cap should be used to protect those surfaces subject to attack. A concrete cap 6 inches thick with 3 inches penetration into the basket is usually sufficient. The concrete for the cap should be placed after initial settlement has occurred.
- A filter is nearly always needed between the gabions and the foundation or backfill to prevent soil movement through the baskets. Geosynthetics can be used in lieu of granular filters for many applications, however, when drainage is critical, the fabric must maintain intimate contact with the foundation soils. A 3-inch layer of sand-gravel between the gabions and the filter material assures that contact is maintained.
- At the toe and up and downstream ends of gabion revetments, a tieback into the bank and bed should be provided to protect the revetment from undermining or scour.

Figure 16–42 Vegetated rock gabion details



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

Figure 16–43 Vegetated rock gabion system (H.M. Schiechtl photo)

650.1602 Shoreline protection

(a) General

Shoreline erosion results primarily from erosive forces in the form of waves generally perpendicular to the shoreline. As a wave moves toward shore, it begins to drag on the bottom, dissipating energy. This eventually causes it to break or collapse. This major turbulence stirs up material from the shore bottom or erodes it from banks and bluffs. Fluctuating tides, freezing and thawing, floating ice, and surface runoff from adjacent uplands may also cause shorelines to erode.

(1) Types of shoreline protection

Systems for shoreline protection can be living or nonliving. They consist of vegetation, soil bioengineering, structures, or a combination of these.

(2) Planning for shoreline protection measures

The following items need to be considered for shoreline protection in addition to the items listed earlier in this chapter for planning streambank protection measures:

- Mean high and low water levels or tides.
- Potential wave parameters.
- Slope configuration above and below waterline.
- Nature of the soil material above and below water level.
- Evidence of littoral drift and transport.
- Causes of erosion.
- Adjacent land use.
- Maintenance requirements.

(b) Design considerations for shoreline protection

(1) Beach slope

Slopes should be determined above and below the waterline. The slope below waterline should be representative of the slope for a distance of at least 50 feet.

(2) Offshore depth and wave height

Offshore depth is a critical factor in designing shoreline protection measures. Structures that must be constructed in deep water, or in water that may become deep, are beyond the scope of this chapter. Other important considerations are the dynamic wave height acting in deep water (roughly, the total height of the wave is three times that visible) and the decreased wave action caused by shallow water. Effective fetch length also needs to be considered in determining wave height. Methods for computing wave height using fetch length are in NRCS Technical Releases 56 and 69.

(3) Water surface

The design water surface is the mean high tide or, in nontidal areas, the mean high water. This information may be obtained from tidal tables, records of lake levels, or from topographic maps of the reservoir site in conjunction with observed high and normal water lines along the shore.

(4) Littoral transport

The material being moved parallel to the shoreline in the littoral zone, under the influence of waves and currents should be addressed in groin design. It is important to determine that the supply of transport material is not coming from the bank being protected and the predominant direction of littoral transport. This information is used to locate structures properly with respect to adjacent properties and so that groins can fill most quickly and effectively. Another factor to be considered is that littoral transport often reverses directions with a change in season.

The rate of littoral transport and the supply are as important as the direction of movement. No simple ways to measure the supply are available. For the scope of this chapter, supply may be determined by observation of existing structures, sand beaches, auger samples of the sand above the parent material on the beach, and the presence of sandbars offshore. Other considerations are existing barriers, shoreline configuration, and inlets that tend to push the supply offshore and away from the area in question. The net direction of transport is an important and complex consideration.

(5) Bank soil type

Determining the nature of bank soil material aids in estimating the rate of erosion. A very dense, heavy clay can offer more resistance to wave action than noncohesive materials, such as sand. A thin sand lens can result in erosion problems since it may be washed out when subjected to high tides or wave action for extended periods of time. The resulting void will no longer support the bank above it, causing it to break away.

(6) Foundation material

The type of existing foundation may govern the type of protection selected. For example, a rock bottom will not permit the use of sheet piling. If the use of riprap is being considered on a highly erodible foundation, a filter will be needed to prevent fine material from washing through the voids. A soft foundation, such as dredge spoil, may result in excessive flotation or movement of the structure in any direction.

(7) Adjacent shoreline and structures

Structures that might have an effect on adjacent shoreline or other structures must be examined carefully. End sections need to be adequately anchored to existing measures or terminated in stable areas.

(8) Existing vegetation

The installation of erosion control structures can have a detrimental effect upon existing vegetation unless steps are taken to prevent what is often avoidable site disturbance. Existing vegetation should be saved as an integral part of the erosion control system being installed.

(c) Protective measures for shorelines

The analysis and design of shoreline protection measures are often complex and require special expertise. For this reason the following discussion is limited to revetments, bulkheads, and groins no higher than 3 feet above mean high water, as well as soil bioengineering and other vegetative systems used alone or in combination with structural measures. Consideration must be given to the possible effects that erosion control measures can have on adjacent areas, especially estuarine wetlands.

(1) Groins

Groins are somewhat permeable to impermeable finger-like structures that are installed perpendicular to the shore. They generally are constructed in groups called groin fields, and their primary purpose is to trap littoral drift. The entrapped sand between the groins acts as a buffer between the incoming waves and shoreline by causing the waves to break on the newly deposited sand and expend most of their energy there (figs. 16–44 and 16–45).

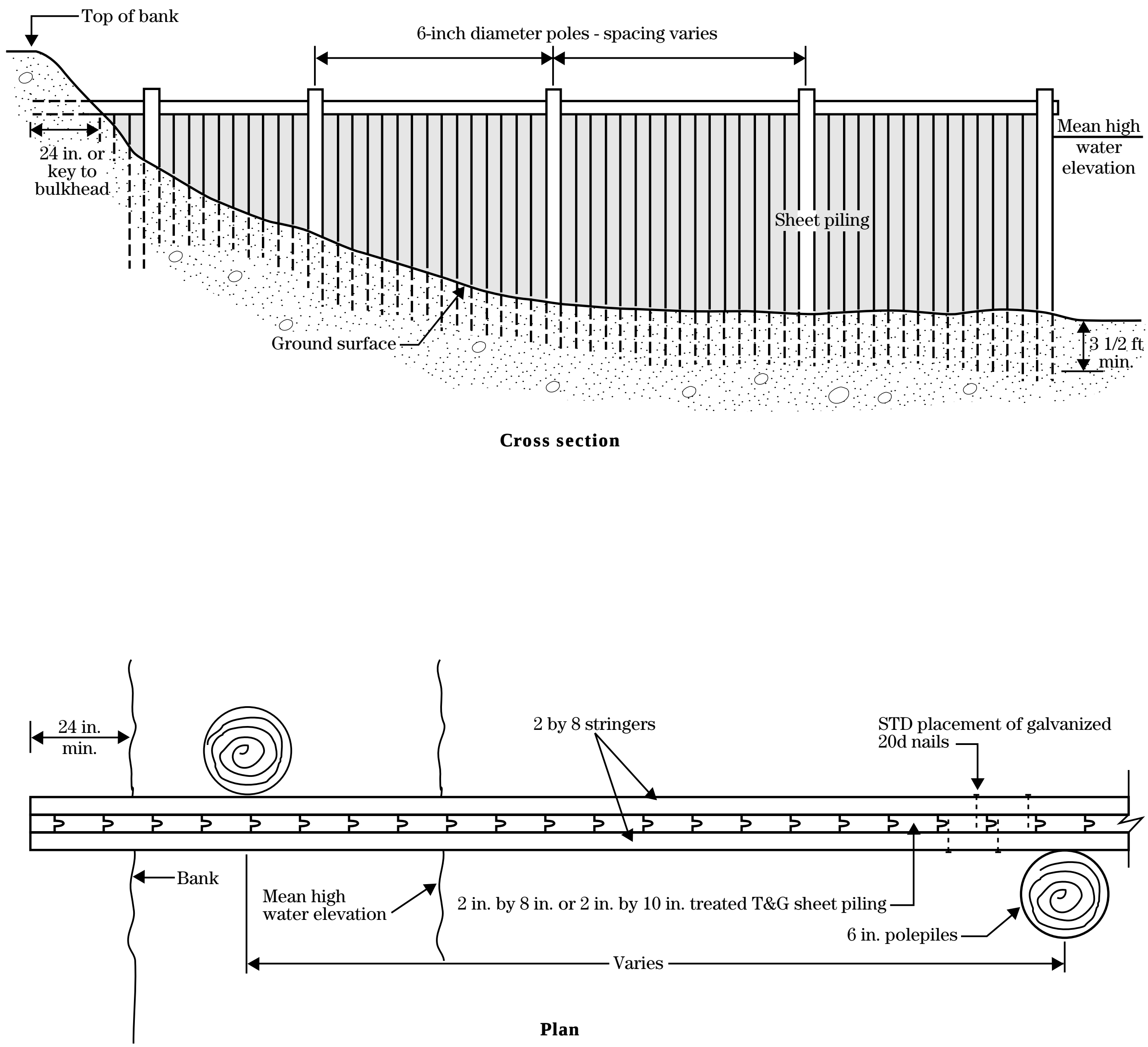
Applications and effectiveness

- Particularly dependent on site conditions. Groins are most effective in trapping sand when littoral drift is transported in a single direction.
- Filling the groin field with borrowed sand may be necessary, if the littoral transport is clay or silt rather than sand.
- Will not fill until all preceding updrift groins have been filled.

Construction guidelines

Inert materials—The most common type of structural groin is built of preservative-treated tongue and groove sheet piling.

Figure 16–44 Timber groin details



Installation

- Groins must extend far enough into the water to retain desired amounts of sand. The distance between groins generally ranges from one to three times the length of the groin. When used in conjunction with bulkheads, the groins are usually shorter.
- Groins are particularly vulnerable to storm damage before they fill, so initially only the first three or four at the downdrift end of the system should be constructed.
- Install the second group of groins after the first has filled and the material passing around or over the groins has again stabilized the downdrift shoreline. This provides the means to verify or adjust the design spacing.
- Key the shoreward end of the groins into the shoreline bank for at least 2 feet or extend them to a bulkhead.
- Measure the groin height on the shoreline so that it will generally be at high tide or mean high water elevation plus 2 or 3 feet for wave surge height. Decrease the height seaward at a gradual rate to mean high water elevation.

Figure 16–45 Timber groin system

(3) Bulkheads

Bulkheads are vertical structures of timber, concrete, steel, or aluminum sheet piling installed parallel to the shoreline.

Applications and effectiveness

- Generally constructed where wave action will not cause excessive overtopping of the structure, which causes bank erosion to continue as though the bulkhead were not there.
- Scour at the base of the bulkhead also causes failure. The vertical face of the bulkhead re-directs wave action to cause excessive scour at the toe of the structure unless it is protected.

Construction guidelines

Inert materials—The most common materials used for bulkhead construction are timber (figs. 16–46 and 16–47), concrete (figs. 16–48 and 16–49), and masonry.

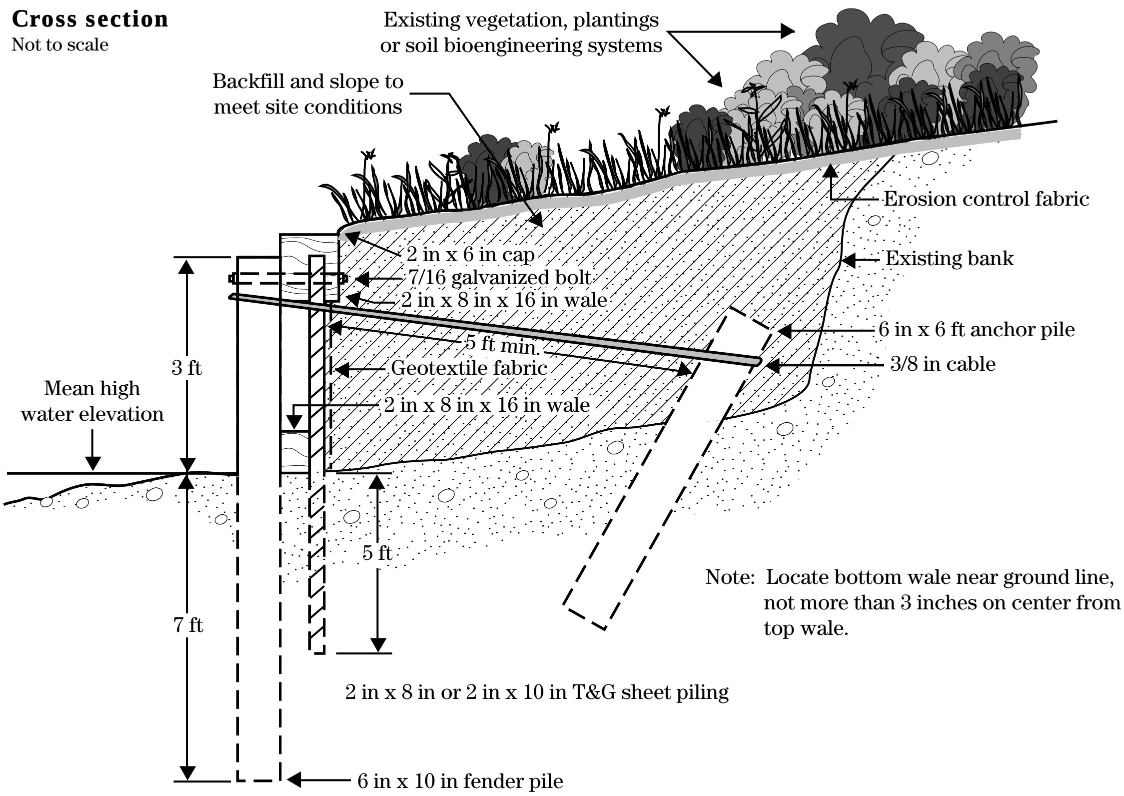
Installation

- Use environmentally compatible treated timber.
- Thickness and spacing of pilings, supports, cross member, and face boards must be engineered on a site-by-site basis.
- Pilings can be drilled, driven, or jetted depending on the foundation materials. Depth of piling must be at least equal to the exposed height below the point of maximum anticipated scour.
- Place stones or other appropriate materials at the base of the bulkhead to absorb wave energy.
- In salt water environments, use noncorrosive materials to the greatest extent possible.

Figure 16–46 Timber bulkhead system

Figure 16–47 Timber bulkhead details

Cross section
Not to scale



Cross section
Not to scale

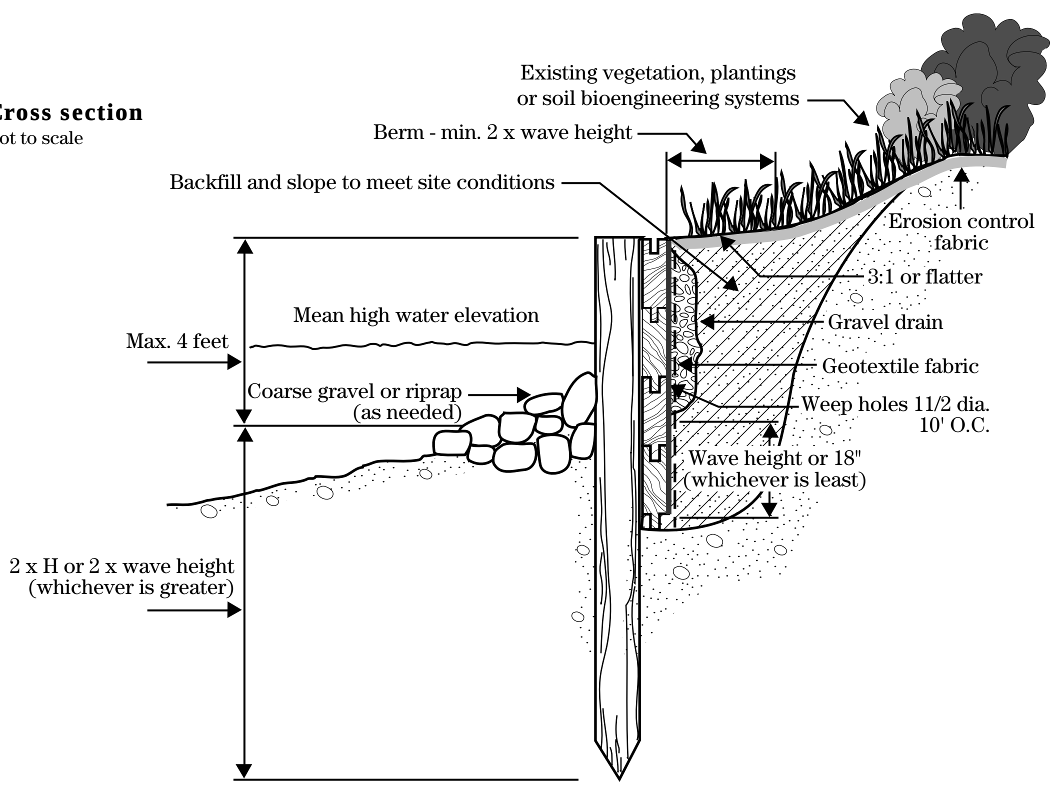
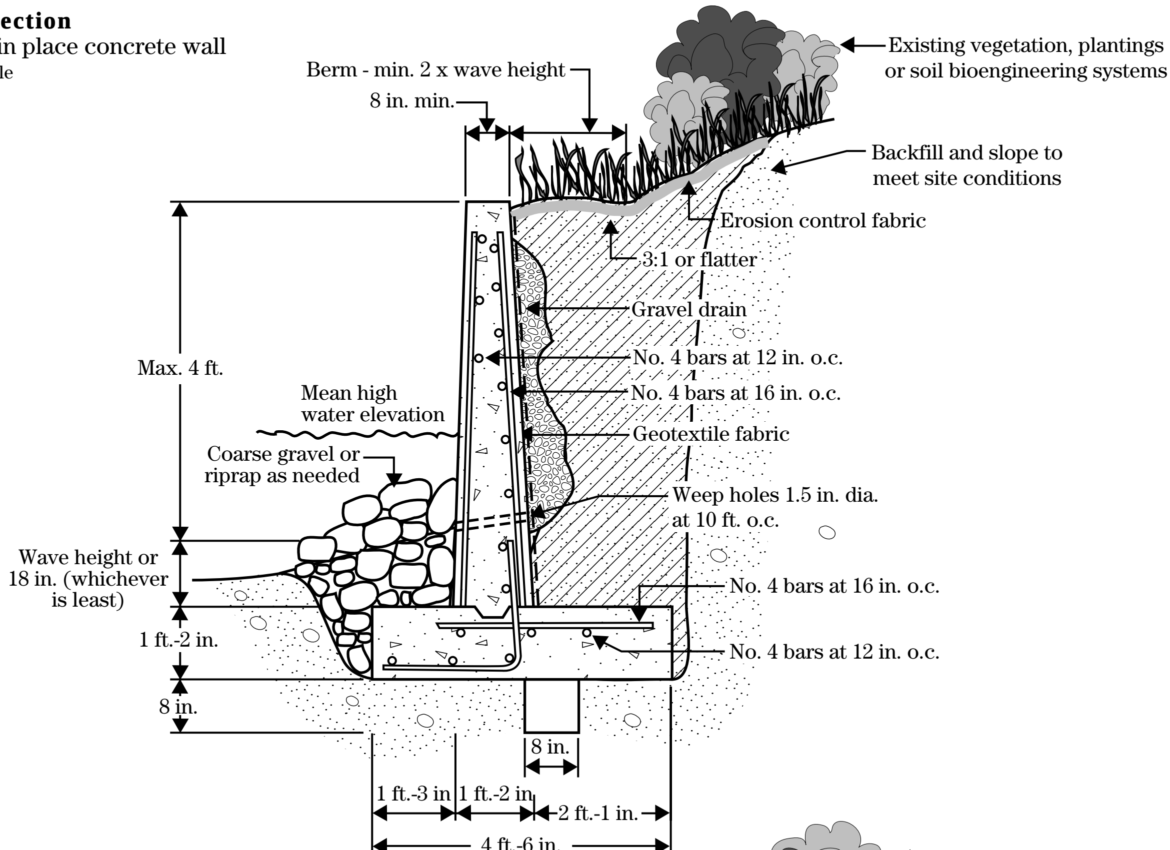


Figure 16–48 Concrete bulkhead details

Cross section
Poured in place concrete wall
Not to scale



Cross section
Concrete block wall
Not to scale

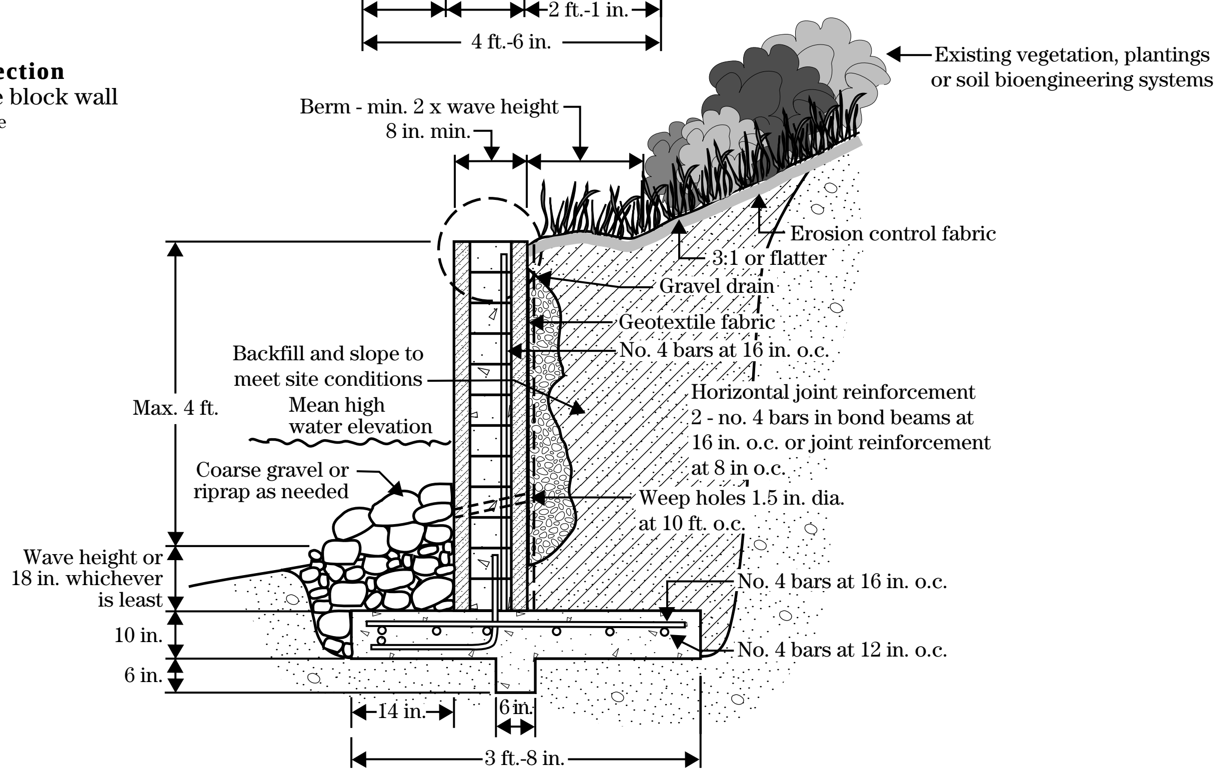


Figure 16–49 Concrete bulkhead system

(4) Revetments

Revetments are protective structures of rock, concrete, cellular blocks, or other material installed to fit the slope and shape of the shoreline (figs. 16–50 and 16–51).

Applications and effectiveness

- Flexible and not impaired by slight movement caused by settlement or other adjustments.
- Preferred to bulkheads where the possibility of extreme wave action exists.
- Local damage or loss of rock easily repaired.
- No special equipment required for construction.
- Subject to scour at the toe and flanking, thus filters are important and should always be considered.
- Complex and expensive.

Construction guidelines

- The size and thickness of rock revetments must be determined to resist wave action. NRCS Technical Release 69, *Rock Riprap for Slope Protection Against Wave Action*, provides guidance for size, thickness, and gradation.
- The base of the revetment must be founded below the scour depth or placed on nonerosive material.
- Angular stone is preferred for revetments. If rounded stone is used, increase the layer thickness by a factor of 1.5.
- Use a minimum thickness of 6-inch filter material under rock.
- If geotextile is used in place of granular filter, cover the geotextile with a minimum of 3inches of sand-gravel before placement of rock.

Figure 16–50 Concrete revetment (poured in place)

Figure 16–51 Rock riprap revetment

(5) Vegetative measures

If some vegetation exists on the shoreline, the shoreline problem may be solved with more vegetation. Determine if the vegetation disappeared because of a single, infrequent storm, or if plants are being shaded out by developing overstory trees and shrubs. In either case revegetation is a viable alternative. Consult local technical guides and plant material specialists for appropriate plant species and planting specifications. NRCS Technical Release 56, *Vegetative Control of Wave Action on Earth Dams*, provides additional guidance.

(6) Patching

A shoreline problem is often isolated and requires only a simple patch repair. Site characteristics that would indicate a patch solution may be appropriate include good overall protection from wave action, slight undercutting in spots with an occasional slide on the bank, and fairly good vegetative growth on the shoreline. The problems are often caused by boat wake or excessive upland runoff. Fill undercut areas with stone sandbags or grout-filled bags and repair with a grass transplant, reed clumps, branchpacking, vegetated geogrid, or vegetated riprap.

Slides that occur because of a saturated soil condition are best alleviated by providing subsurface drainage or a diversion. Leaning or slipping trees in the immediate slide area may need to be removed initially because of their weight and the forces they exert on the soil; however, once the saturated condition is remedied, disturbed areas should be revegetated with native trees, shrubs, grasses, and forbs to establish cover.

(7) Soil bioengineering systems

Soil bioengineering systems that are best suited to reducing erosion along shorelines are live stakes, live fascines, brushmattresses, live siltation, and reed clump constructions.

***(i) Live stake*—**Live stakes offer no stability until they root into the shoreline area, but over time they provide excellent soil reinforcement. To reduce failure until root establishment occurs, installations may be enhanced with a layer of long straw mulch covered with jute mesh or, in more critical areas, a natural geotextile fabric.

Refer to streambank protection section of this chapter for appropriate applications and construction guidelines.

***(ii) Live fascine*—**The live fascines previously described in this chapter work best in shoreline applications where the ground between them is also protected. Natural geotextiles, such as those manufactured from coconut husks, are strong, durable, and work well to protect the ground.

Construction guidelines
Live materials—Live cuttings as previously described for fabrication of live fascine bundles. Fabricate live fascine bundles approximately 8 inches in diameter. Live stakes should be about 3 feet long.

Inert materials—Dead stout stakes approximately 3 feet long to anchor well in loose sand. Jute mesh with long straw for low energy shorelines. Natural geotextile with long straw for higher energy shorelines.

Installation
The installation methods are similar to those discussed for live fascines, with the following variations:

- Excavate a trench approximately 10 inches wide and deep, beginning at one end of and parallel to the shoreline section to be repaired and extending to the other end.
- Spread jute mesh or geotextile fabric across the excavated trench and temporarily leave the remainder on the slope immediately above the trench.
- Place a live fascine bundle in the trench on top of the fabric and anchor with live and dead stout stakes.
- Spread long straw on the slope above the trench to the approximate location of the next trench to be constructed upslope.
- Pull the fabric upslope over the long straw and spread in the next excavated trench. Trenches should be spaced 3 to 5 feet apart and parallel to each other.
- Repeat the process until the system is in place over the treatment area.

(iii) Brushmattress—Brushmattresses for shorelines perform a similar function as those for streambanks. Therefore, effectiveness and construction guidelines are similar to those given earlier in this chapter, with the following additions.

Applications and effectiveness

- May be effective in lake areas that have fluctuating water levels since they are able to protect the shoreline and continue to grow.
- Able to filter incoming water because they also establish a dense, healthy shoreline vegetation.

Installation

- After the trench at the bottom has been dug and the mattress branches placed, the trench should be lined with geotextile fabric.
- Secure the live fascine, press down the mattress brush, and place the fabric on top of the brush.
- At this point, install the live and dead stout stakes to hold the brush in place. A few dead stout stakes may be used in the mattress branch and partly wired down before covering the fabric. This helps in the final steps of covering and securing the brush and the fabric.

(iv) Live siltation construction—Live siltation construction is similar to brushlayering except that the orientation of the branches are more vertical. Ideally live siltation systems are approximately perpendicular to the prevailing winds. The branch tips should slope upwards at 45 to 60 degrees. Installation is similar to brushlayering (see Engineering Field Handbook, chapter 18 for a more complete discussion of a brushlayer).

Live siltation branches that have been installed in the trenches serve as tensile inclusions or reinforcing units. The part of the brush that protrudes from the ground assists in retarding runoff and surface erosion from wave action and wind (figs. 16–52 and 16–53).

Applications and effectiveness

Live siltation systems provide immediate erosion control and earth reinforcement functions, including:

- Providing surface stability for the planting or establishment of vegetation.
- Trapping debris, seed, and vegetation at the shoreline.
- Reducing wind erosion and surface particle movement.
- Drying excessively wet sites through transpiration.
- Promoting seed germination for natural colonization.
- Reinforcing the soil with unrooted branch cuttings.
- Reinforcing the soil as deep, strong roots develop and adding resistance to sliding and shear displacement.

Construction guidelines

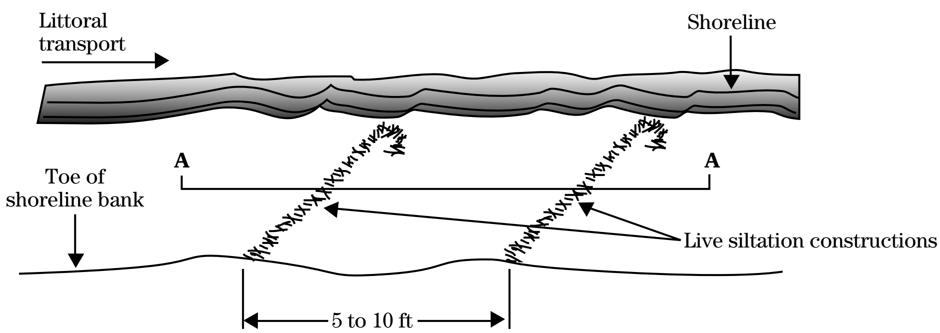
Live material—Live branch cuttings 0.5 to 1 inch in diameter and 4 to 5 feet long with side branches intact.

Installation

- Beginning at the toe of the shoreline bank to be treated, excavate a trench 2 to 3 feet deep and 1 to 2 feet wide, with one vertical side and the other angled toward the shoreline.
- Parallel live siltation rows should vary from 5 to 10 feet apart, depending upon shoreline conditions and stability required. Steep, unstable and high energy sites require closer spacing.

Figure 16–52 Live siltation construction details

Plan
Not to scale



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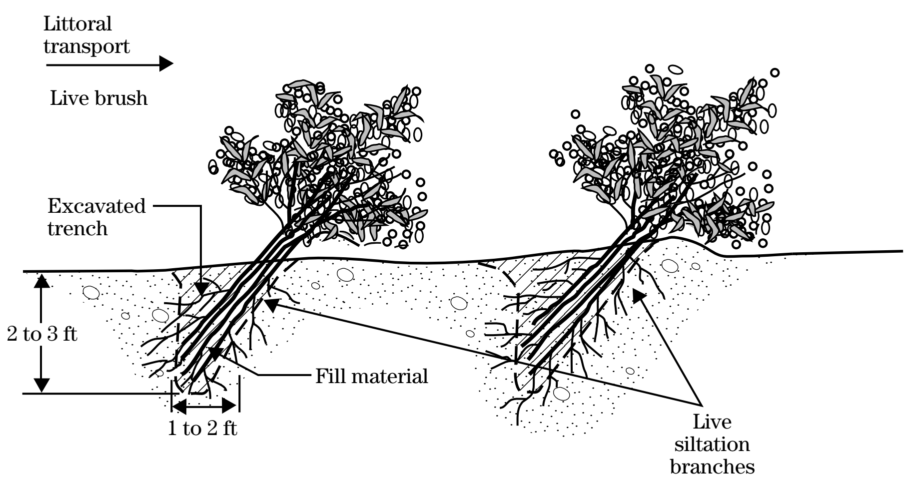


Note: Rooted/leafed condition of the living plant material is not respresentative of the time of installation.

Figure 16–53 Live siltation construction system (Robbin B. Sotir & Associates photo)

(v) Reed clump—Reed clump installations consist of root divisions wrapped in natural geotextile fabric, placed in trenches, and staked down. The resulting root mat reinforces soil particles and extracts excess moisture through transpiration. Reed clump systems are typically installed at the water's edge or on shelves in the littoral zone (fig. 16–54 and 16–55).

Applications and effectiveness

- Reduces toe erosion and creates a dense energy-dissipating reed bank area.
- Offers relatively inexpensive and immediate protection from erosion.
- Useful on shore sites where rapid repair of spot damage is required.
- Retains soil and transported sediment at the shoreline.
- Reduces a long beach wash into a series of shorter sections capable of retaining surface soils.
- Enhances conditions for natural colonization and establishment of vegetation from the surrounding plant community.
- Grows in water and survives fluctuating water levels.

Construction guidelines

Live materials—The reed clumps should be 4 to 8 inches in diameter and taken from healthy water-dependent species, such as arrowhead, cattail, or water iris. They may be selectively harvested from existing natural sites or purchased from a nursery.

Wrap reed clumps in natural geotextile fabric and bind together with twine. These clumps can be fabricated several days before installation if they are kept moist and shaded.

Inert materials—Natural geotextile fabric, twine, and 3- to 3.5-foot-long dead stout stakes are required.

Installation

- Reed root clumps are either placed directly into fabric-lined trenches or prefabricated into rolls 5 to 30 feet long. With the growing tips pointing up, space clumps every 12 inches on a 2- to 3-foot-wide strip of geotextile fabric to fabricate the rolls. The growing buds should all be oriented in the same upright direction for correct placement into the trench.
- Wrap the fabric from both sides to overlap the top, leaving the reed clumps exposed and bound with twine between each plant.
- Beginning at and parallel to the water's edge, excavate a trench 2 inches wider and deeper than the size of the prefabricated reed roll or reed clumps.
- To place reed clumps directly into trenches, first line the trench with a 2- to 3-foot-wide strip of geotextile fabric before spreading a 1-inch layer of highly organic topsoil over it at the bottom of the trench. Next, center the reed clumps on 12-inch spacing in the bottom of the trench. Fill the remainder of the trench between and around reed clumps with highly organic topsoil, and compact. Wrap geotextile fabric from each side to overlap at the top and leave the reed clumps exposed before securing with dead stout stakes spaced between the clumps. Complete the installation by spreading previously excavated soil around the exposed reed clumps to cover this staked fabric.
- To use the prefabricated reed clump roll, place it in the excavated trench, secure it with dead stout stakes, and backfill as described above.
- Repeat the above procedure by excavating additional parallel trenches spaced 3 to 6 feet apart toward the shoreline. Place the reed clumps from one row to the next to produce a staggered spacing pattern.

Figure 16–54 Reed clump details

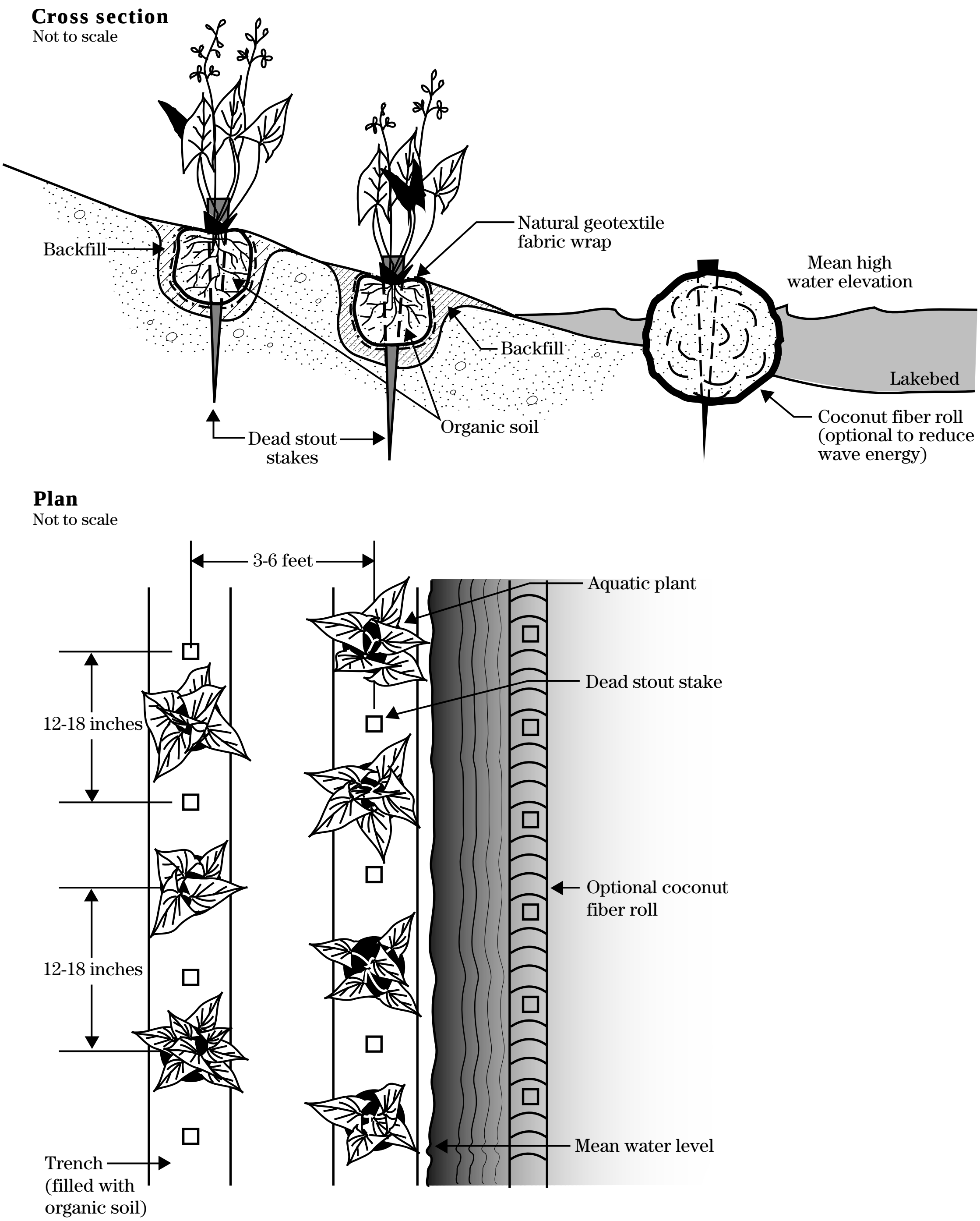


Figure 16–55a Installing dead stout stakes in reed clump system (Robbin B. Sotir & Associates photo)

Figure 16–55b Completing installation of reed clump system (Robbin B. Sotir & Associates photo)

Figure 16–55c Established reed clump system (Robbin B. Sotir & Associates photo)

(8) Coconut fiber roll

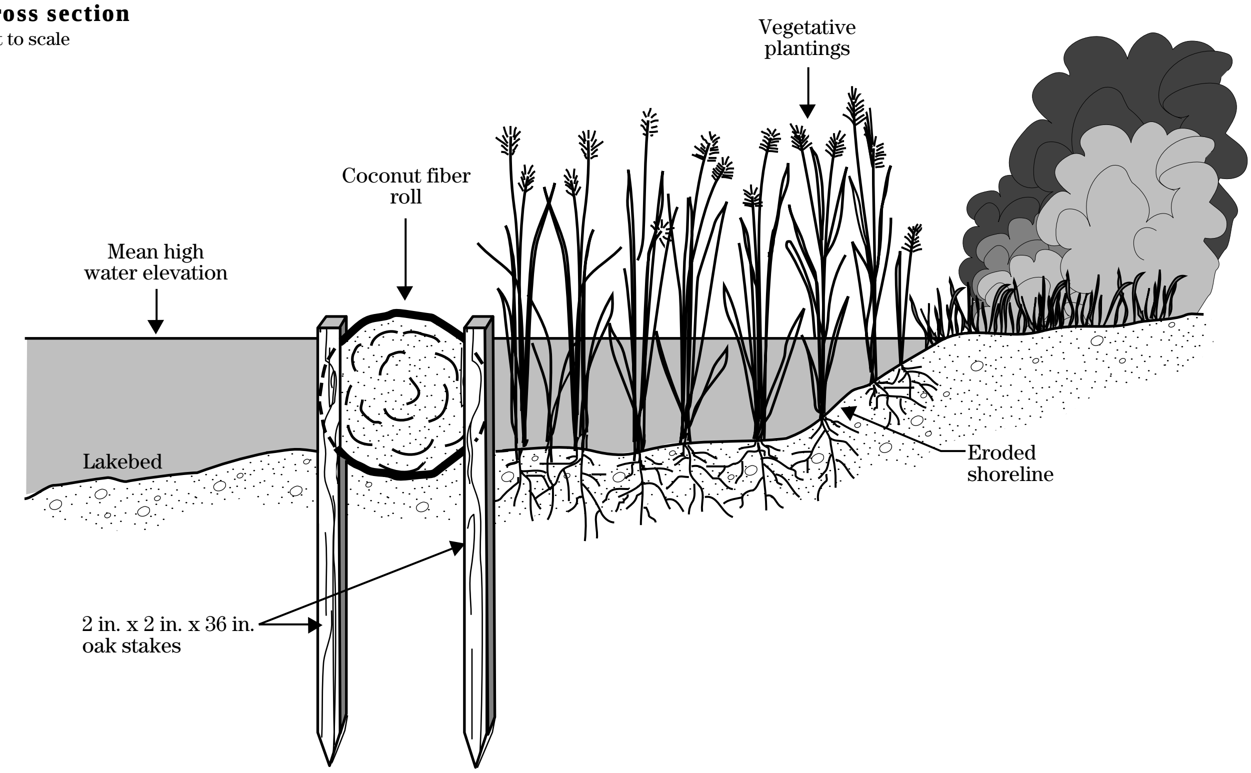
Coconut fiber rolls are cylindrical structures composed of coconut fibers bound together with twine woven from coconut (figs. 16–56 and 16–57). This material is most commonly manufactured in 12-inch diameters and lengths of 20 feet. The fiber rolls function as breakwaters along the shores of lakes and embayments. In addition to reducing wave energy, this product can help contain substrate and encourage development of wetland communities.

Applications and effectiveness

- Effective in lake areas where the water level fluctuates because it is able to protect the shoreline and encourage new vegetation.
- Flexible, can be molded to the curvature of the shoreline.
- Prefabricated materials can be expensive.
- Manufacturers estimate the product has an effective life of 6 to 10 years.

Figure 16–56 Coconut fiber roll details

Cross section
Not to scale



Installation

- Fiber roll should be located off shore at a distance where the top of the fiber roll is exposed at low tide. In nontidal areas, the fiber roll should be placed where it will not be overtopped by wave action.
- Drive 2 inch x 2 inch stakes between the binding twine and the coconut fiber. Stakes should be placed on 4-foot centers and should not extend above the fiber roll.
- If desired, rooted cuttings can be installed between the coconut fiber roll and the shoreline.

Figure 16–57 Coconut fiber roll system

650.1603 References

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Glossary

Bankfull discharge — Natural streams—The discharge that fills the channel without overflowing onto the flood plain.

Modified or entrenched streams—The streamflow volume and depth that is the 1- to 3-year frequency flow event.

The discharge that determines the stream's geomorphic planform dimensions.

Bar — A streambed deposit of sand or gravel, often exposed during low-water periods.

Baseflow — The ground water contribution of streamflow.

Bole — Trunk of a tree.

Branchpacking — Live, woody, branch cuttings and compacted soil used to repair slumped areas of streambanks.

Brushmattress — A combination of live stakes, fascines, and branch cuttings installed to cover and protect streambanks and shorelines.

Bulkhead — Generally vertical structures of timber, concrete, steel, or aluminum sheet piling used to protect shorelines from wave action.

Channel — A natural or manmade waterway that continuously or intermittently carries water.

Cohesive soil — A soil that, when unconfined, has considerable strength when air dried and significant strength when wet.

Current — The flow of water through a stream channel.

Dead blow hammer — A hammer filled with lead shot or sand.

Deadman — A log or concrete block buried in a streambank to anchor revetments.

Deposition — The accumulation of soil particles on the channel bed, banks, and flood plain.

Discharge — The volume of water passing through a channel during a given time, usually measured in cubic feet per second.

Dormant season — The time of year when plants are not growing and deciduous plants shed their leaves.

Duration of flow — Length of time a stream floods.

Erosion control fabric — Woven or spun material made from natural or synthetic fibers and placed to prevent surface erosion.

Erosion The wearing away of the land by the natural forces of wind, water, or gravity.

Erosive (erodible) A soil whose particles are easily detached and entrained in a fluid, either air or water, passing over or through the soil. The most erodible soils tend to be silts and/or fine sands with little or no cohesion.

Failure Collapse or slippage of a large mass of streambank material.

Filter A layer of fabric, sand, gravel, or graded rock placed between the bank revetment or channel lining and soil to prevent the movement of fine grained sizes or to prevent revetment work from sinking into the soil.

Fines Silt and clay particles.

Flanking Streamflow between a structure and the bank that creates an area of scour.

Flow rate Volume of flow per unit of time; usually expressed as cubic feet per second.

Footer log A log placed below the expected scour depth of a stream. Foundation for a rootwad and boulders.

Gabion A wire mesh basket filled with rock that can be used in multiples as a structural unit.

Geotextile Any permeable textile used with foundation soil, rock, or earth as an integral part of a product, structure, or system usually to provide separation, reinforcement, filtration, or drainage.

Groin A structure built perpendicular to the shoreline to trap littoral drift and retard erosion.

Ground water Water contained in the voids of the saturated zone of geologic strata.

Headcutting The development and upstream movement of a vertical or near vertical change in bed slope, generally evident as falls or rapids. Headcuts are often an indication of major disturbances in a stream system or watershed.

Joint planting The insertion of live branch cuttings in openings or interstices of rocks, blocks, or other inert revetment units and into the underlying soil.

Littoral drift The movement of littoral drift either transport parallel (long shore transport) or perpendicular (on-shore transport) to the shoreline.

Littoral The sedimentary material of shorelines moved by waves and currents.

Littoral zone An indefinite zone extending seaward from the shoreline to just beyond the breaker zone.

Live branch cuttings Living, freshly cut branches from woody shrub and tree species that readily propagate when embedded in soil.

Live cribwall A rectangular framework of logs or timbers filled with soil and containing live woody cuttings that are capable of rooting.

Live fascine Bound, elongated, cylindrical bundles of live branch cuttings that are placed in shallow trenches, partly covered with soil, and staked in place.

Live siltation construction Live branch cuttings that are placed in trenches at an angle from shoreline to trap sediment and protect them against wave action.

Live stake Live branch cuttings that are tamped or inserted into the earth to take root and produce vegetative growth.

Noncohesive soil Soil, such as sand, that lacks significant internal strength and has little resistance to erosion.

Piling (sheet) Strips or sheets of metal or other material connected with meshed or interlocking members to form an impermeable diaphragm or wall.

Piling A long, heavy timber, concrete, or metal support driven or jetted into the earth.

Piping The progressive removal of soil particles from a soil mass by percolating water, leading to the development of flow channels or tunnels.

Reach A section of a stream's length.

Reed clump A combination of root divisions from aquatic plants and natural geotextile fabric to protect shorelines from wave action.

Revetment (armoring) A facing of stone, interlocking pavers, or other armoring material shaped to conform to and protect streambanks or shorelines.

Riprap A layer, facing, or protective mound of rubble or stones randomly placed to prevent erosion, scour, or sloughing of a structure of embankment; also, the stone used for this purpose.

Rootwad A short length of tree trunk and root mass.

Scour Removal of underwater material by waves or currents, especially at the base or toe of a streambank or shoreline.

Sediment deposition The accumulation of sediment.

Sediment load The amount of sediment in transport.

Sediment Soil particles transported from their natural location by wind or water.

Seepage The movement of water through the ground, or water emerging on the face of a bank.

Slumping (sloughing) Shallow mass movement of soil as a result of gravity and seepage.

Stream-forming flow The discharge that determines a stream's geomorphic planform dimensions. Equivalent to the 1- to 3-year frequency flow event (see Bankfull discharge).

Streambank The side slopes within which streamflow is confined.

Streambed (bed) The bottom of a channel.

Streamflow The movement of water within a channel.

Submerged vanes Precast concrete or wooden elements placed in streambeds to deflect secondary currents away from the streambank.

Thalweg The deepest part of a stream channel where the fastest current is usually found.

Toe The break in slope at the foot of a bank where it meets the streambed.

Vegetated geogrid Live branch cuttings placed in layers with natural or synthetic geotextile fabric wrapped around each soil lift.

Vegetated structural revetments Porous revetments, such as riprap or interlocking pavers, into which live plants or cuttings can be placed.

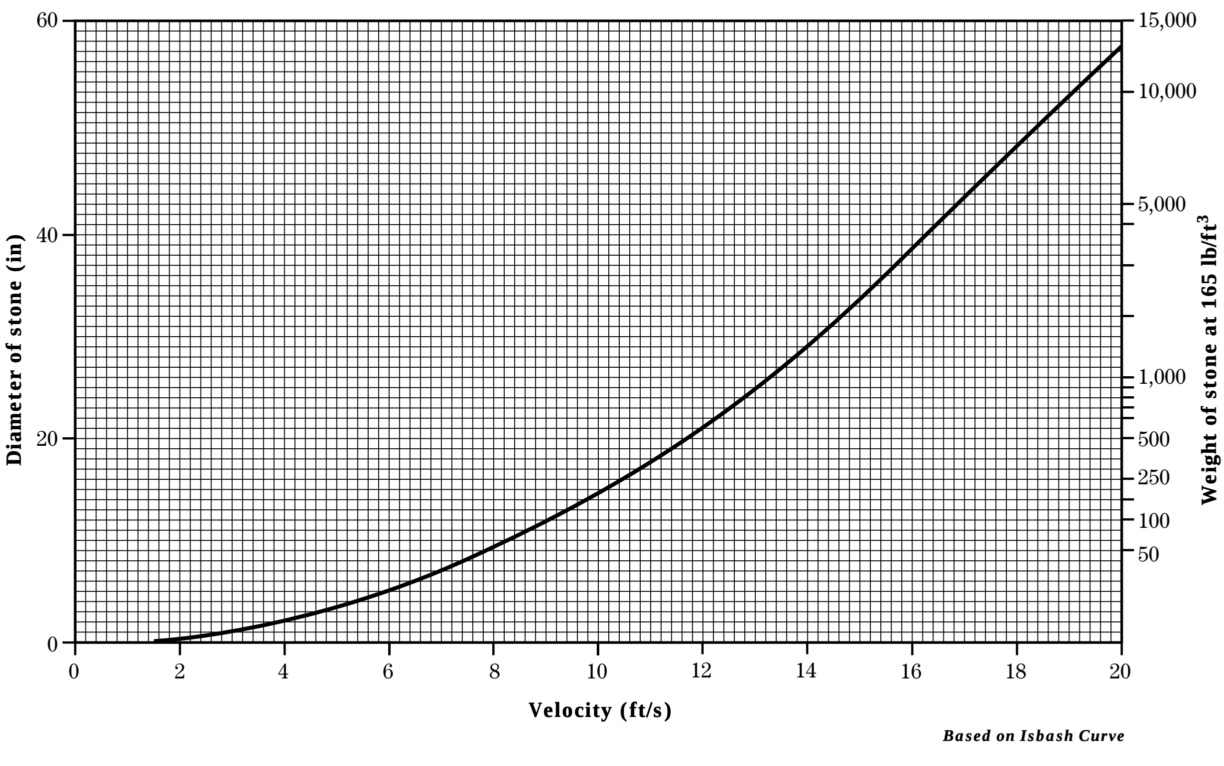
Vegetated structures A retaining structure in which live plants or cuttings have been integrated.

Appendix 16A Size Determination for Rock Riprap

Isbash Curve

The Isbash Curve, because of its widespread acceptance and ease of use, is a direct reprint from the previous chapter 16, Engineering Field Manual. The curve was developed from empirical data to determine a rock size for a given velocity. See figure 16A–1. The user can read the D_{100} rock size (100 percent of riprap ≤ this size) directly from the graph in terms of weight (pounds) or dimension (inches). Less experienced users should use this method for quick estimates or comparison with other methods before determining a final design.

Figure 16A–1 Rock size based on Isbash Curve



Procedure
1. Determine the design velocity.
2. Use velocity and fig. 16A-1 (Isbash Curve) to determine basic rock size.
3. Basic rock size is the D_{100} size.

Figure 16A–2 Rock size based on Far West States (FWS)-Lane method

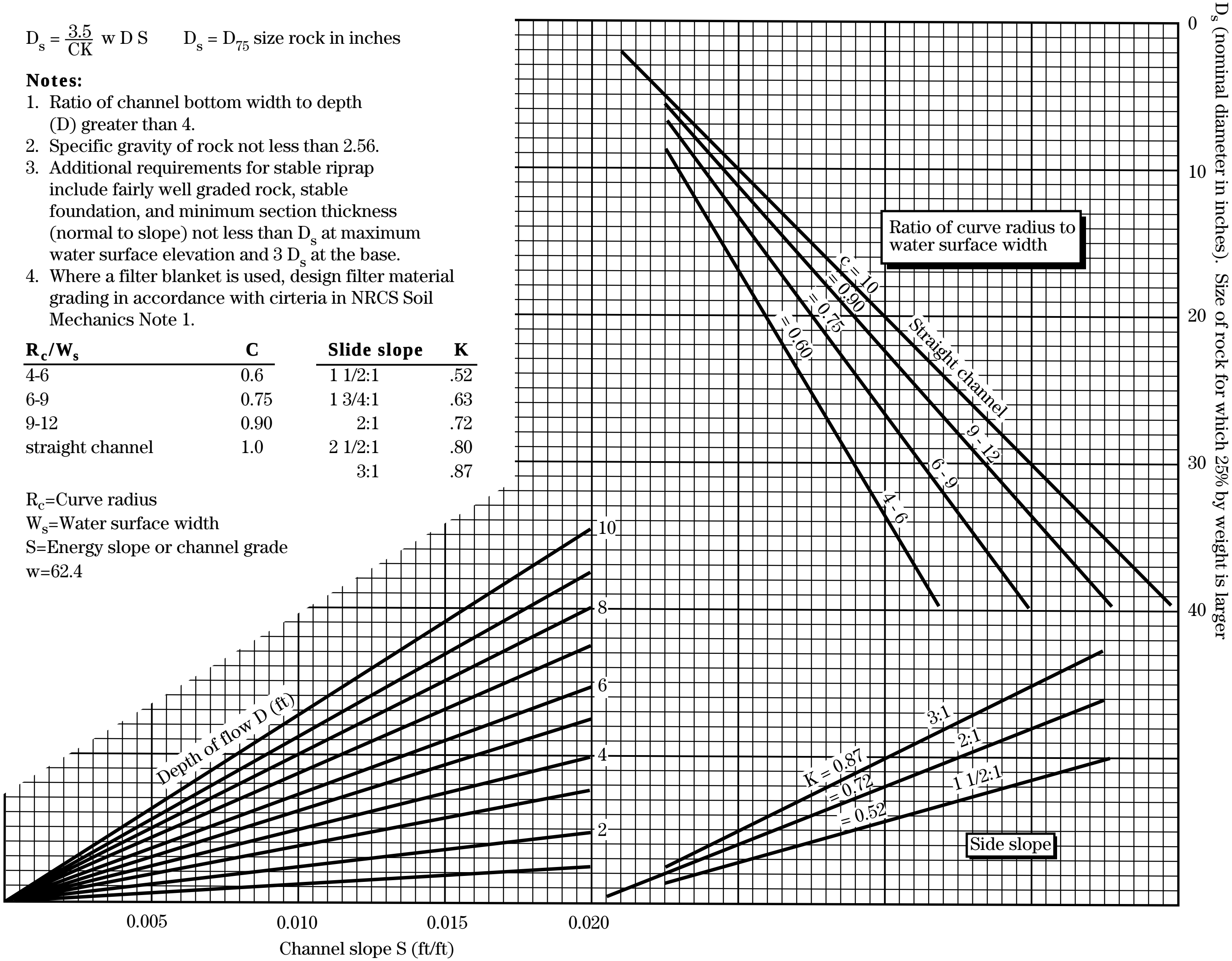
$D_s = \frac{3.5}{CK}$ w D S $D_s = D_{75}$ size rock in inches

Notes:

1. Ratio of channel bottom width to depth (D) greater than 4.
2. Specific gravity of rock not less than 2.56.
3. Additional requirements for stable riprap include fairly well graded rock, stable foundation, and minimum section thickness (normal to slope) not less than D_s at maximum water surface elevation and 3 D_s at the base.
4. Where a filter blanket is used, design filter material grading in accordance with cirteria in NRCS Soil Mechanics Note 1.

R_c/W_s	C	Slide slope	K
4-6	0.6	1 1/2:1	.52
6-9	0.75	1 3/4:1	.63
9-12	0.90	2:1	.72
straight channel	1.0	2 1/2:1	.80
		3:1	.87

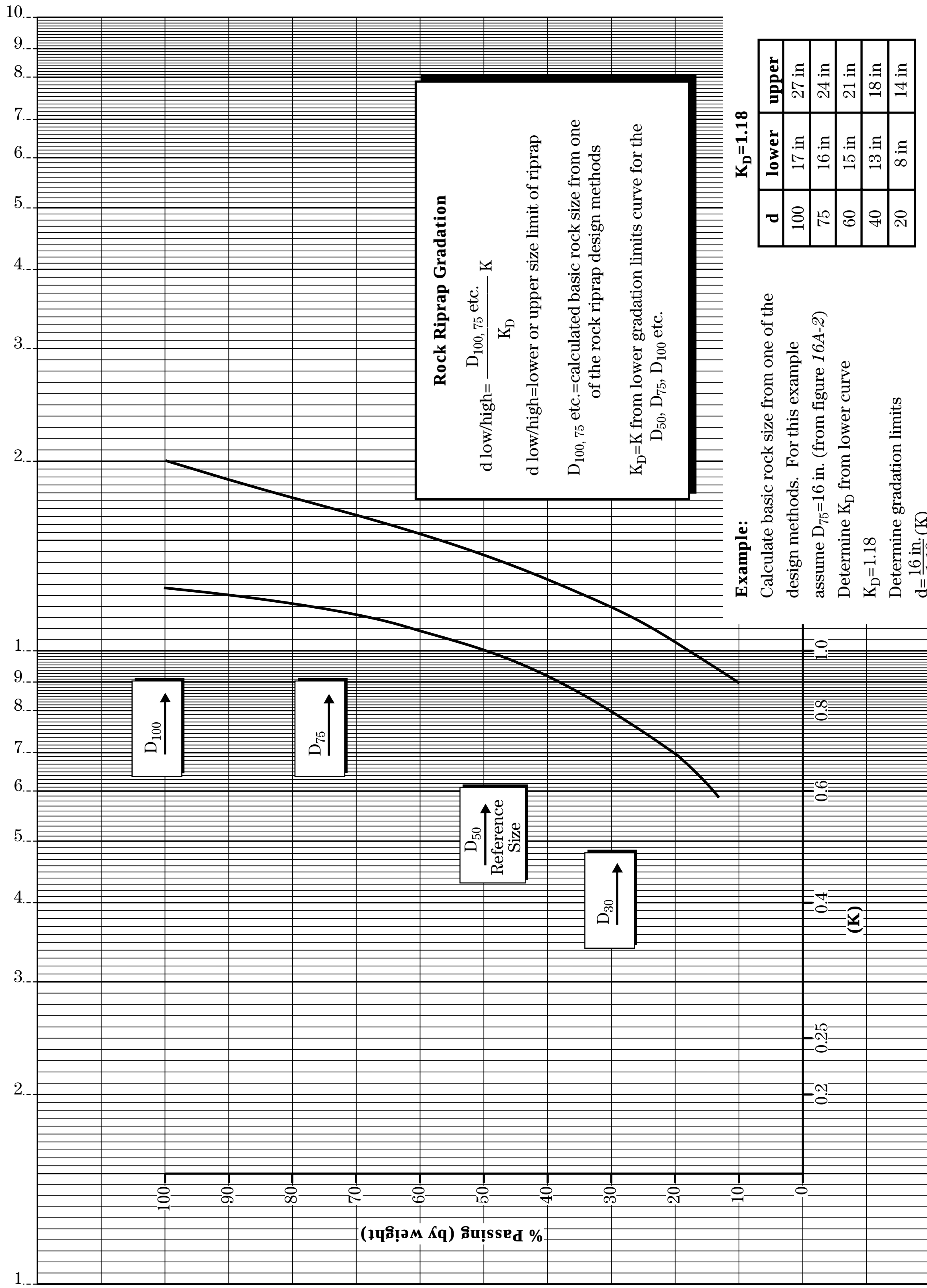
R_c=Curve radius
W_s=Water surface width
S=Energy slope or channel grade
w=62.4



Procedure

1. Determine the average channel grade or energy slope.
2. Enter fig. 16A-2 with energy slope, flow depth, and site physical characteristics to determine basic rock size.
3. Basic rock size is the D_{75} size.

Figure 16A–3 Gradation limits curve for determining suitable rock gradation



Example:
Calculate basic rock size from one of the design methods. For this example assume D_{75}=16 in. (from figure *16A-2*)
Determine K_D from lower curve
K_D=1.18
Determine gradation limits
$d=\frac{16 \text{ in.}}{1.18}$ (K)

K_D=1.18

d	lower	upper
100	17 in	27 in
75	16 in	24 in
60	15 in	21 in
40	13 in	18 in
20	8 in	14 in

Appendix 16B Plants for Soil Bioengineering and Associated Systems

The information in appendix 16B is from the Natural Resources Conservation Service's data base for Soil Bioengineering Plant Materials (biotype). The plants are listed in alphabetical order by scientific name. Further subdivision of the listing should be considered to account for local conditions and identify species suitable only for soil bioengineering systems.

Table header definitions (in the order they occur on the tables):

Scientific name—Genus and species name of the plant.

Common name—Common name of the plant.

Region of occurrence—Region(s) of occurrence using the regions of distribution in PLANTS (Plant List of Attributes, Nomenclature, Taxonomy, and Symbols, 1994). Region code number or letter:

1 Northeast—ME, NH, VT, MA, CT, RI, WV, KY, NY, PA, NJ, MD, DE, VA, OH
2 Southeast—NC, SC, GA, FL, TN, AL, MS, LA, AR
3 North Central—MO, IA, MN, MI, WI, IL, IN
4 North Plains—ND, SD, MT (eastern) WY (eastern)
5 Central Plains—NE, KS, CO (eastern)
6 South Plains—TX, OK
7 Southwest—AZ, NM
8 Intermountain—NV, UT, CO (western)
9 Northwest—WA, OR, ID, MT (western) WY (western)
0 California—Ca
A Alaska—AK
C Caribbean—PR, VI, CZ, SQ
H Hawaii—HI, AQ, GU, IQ, MQ, TQ, WQ, YQ

Commercial availability—Answers whether the plant is available from commercial plant vendors.

Plant type—Short description of the type of plant: tree, shrub, grass, forb, legume, etc.

Root type—Description of the root of the plant: tap, fibrous, suckering, etc.

Rooting ability from cutting—Subjective rating of cut stems of the plant to root without special hormone and/or environmental surroundings provided.

Growth rate—Subjective rating of the speed of growth of the plant: slow, medium, fast, etc.

Establishment speed—Subjective rating of the speed of establishment of the plant.

Spread potential—Subjective rating of the potential for the plant to spread: low, good, etc.

Plant materials—The type of vegetation plant parts that can be used to establish a new colony of the species.

Notes—Other important or interesting characteristics about the plant.

Soil preference—Indication of the type of soil the plant prefers: sand, loam, clay, etc.

pH preference—Lists the pH preference(s) of the plant.

Drought tolerance—Subjective rating of the ability of the plant to survive dry soil conditions.

Shade tolerance—Subjective rating of the ability of the plant to tolerate shaded sites.

Deposition tolerance—Subjective rating of the ability of the plant to tolerate deposition of soil or organic debris around or over the roots and stems.

Flood tolerance—Selective rating of the ability of the plant to tolerate flooding events.

Flood season—Time of the year that the plant can tolerate flooding events.

Minimum water depth—The minimum water depth required by the plant for optimal growth.

Maximum water depth—The maximum water depth the plant can tolerate and not succumb to drowning.

Wetland indicator—A national indicator from National List of Plant Species that Occur in Wetlands: 1988 National Summary.

Table 16B–1 Woody plants for soil bioengineering and associated systems

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Acer circinatum	vine maple	9,0	yes, but in limited quant-ities	shrub to small tree	fibrous, rooting at nodes	fair to good	slow	slow	good	plants	Branches often touch& root at ground level. Often occurs with conifer overstory. Occurs British Columbia to CA.
Acer glabrum	dwarf maple	4,5,7, 8,9,0, A	yes	small tree		poor				plants	usually dioecious, grows in poor soils.
Acer negundo	boxelder	1,2,3, 4,5,6, 7,8,9, 0	yes	small to medium tree	fibrous, moderate-ly deep, spreading, suckering	poor	fast	fast	fair	plants, rooted cuttings	Use in sun & part shade. Survived deep flooding for one season in Pacific NW.
Acer rubrum	red maple	1,2,3, 6	yes	medium tree	shallow	poor	fast when young	medium	good	plants	Not tolerant of high pH sites. Occurs on and prefers sites with a high water table and/or an annual flooding event.
Acer saccharinum	silver maple	1,2,3, 4,5,6, 8	yes	medium tree	shallow, fibrous	poor	fast when young	medium	fair	plants	Plants occur mostly east of the 95th parallel. Survived 2 years of flooding in MS.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Alnus pacifica	pacific alder			tree		poor	most alders are fast			plants	A species for forested wetland sites in the Pacific northwest. Plant on 10- to 12-foot spacing.
Alnus rubra	red alder	9,0,A	yes	medium tree	shallow, spreading, suckering	poor to fair	fast	fast	good	plants	Usually grows west of the Cascade Mtns, within 125 milesof the ocean & below 2,400 feet elevation. A nitrogen source. Short lived species. May be seedable. Susceptible to caterpillers.
Alnus serrulata	smooth alder	1,2,3, 5,6	yes	large shrub	shallow, spreading	poor	slow	medium	fair	plants	Thicket forming. Survived 2 years of flooding in MS. Roots have relation with nitrogen-fixing actinomycetes, susceptible to ice damage, needs full sun.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Alnus viridis ssp.sinuata	sitka alder	9,0,A	yes, but very limited quan-tities	shrub to small tree	shallow	poor	rapid first year, moderate thereafter	medium	fair to good	plants	A nitrogen source. Occurs AK to CA.
Amelanchier alnifolia var cusickii	cusick's serviceberry	9	yes	shrub		poor	medium	medium	medium	plants	Usually seed propagated. Occurs in eastern WA, northern ID, & eastern OR. A different variety is Pacific serviceberry A. alnifolia var semiintegrifolia. Host to several insect & disease pests.
Amelanchier utahensis	utah serviceberry	9		small to large shrub						plants	Occurs in southeast OR, south ID, NV, & UT.
Amorpha fruitcosa	false indigo	1,2,3, 4,5,6, 7,8,0	yes	shrub		poor	medium	fast	poor	plants, seed	Supposedly root suckers. Has been seeded directly on roadside cut and fill sites in MD.
Aronia arbutifolia	red chokeberry	1,2,3, 6	yes	shrub		poor	fast	fast		plants, seed	Rhizomatous. May produce fruit in second year.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Asimina triloba	pawpaw	1,2,3, 5,6	yes	small tree	tap and root suckers	poor to fair	fast		poor	root cuttings, plants	Does produce thickets where native & can be propagated by layering & root cuttings. Occurs NY to FL & TX.
Baccharis glutinosa	seepwillow	6,7,8, 0	yes	medium shrub	deep & wide-spreading, fibrous	good				plants	Thicket forming.
Baccharis halimifolia	eastern baccharis	1,2,6	yes	medium shrub	fibrous	good	fair	fast	fair	fascines, cuttings, plants,	Resistant to salt spray; unisexual plants. Occurs MA to FL & TX.
Baccharis pilularis	coyotebush	9,0		medium evergreen shrub	fibrous	good			fair	fascines, stakes, brush mats, layering, cuttings	Pioneer in gullies, many forms prostrate & spread-ing. May be seed-able. Colony-forming to 1 foot high in CA coastal bluffs.
Baccharis salicifolia	water wally	6,7,8, 0		medium ever-green shrub	fibrous, deep, wide-spreading	good			fair	fascines, brush mats, stakes, layering, cuttings	Was B. glutinosa. Thicket forming, unisexual plants.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Baccharis viminea	mulefat baccharis	6,7,8, 0		medium ever-green shrub	fibrous	good				fascines, stakes, brush mats, layering, cuttings	May be B. salicifolia.
Betula nigra	river birch	1,2,3, 5,6	yes	medium to large tree		poor	fast when young	fast	poor	plants	Plants coppice when cut. Survived 1 year of flooding in MS. Hybridizes with B papyrifera.
Betula occidentalis	water birch	4,5,7, 8,9,0, A	yes	medium tree	fibrous, spreadin g					plants	Occurs on the Pacific Coast to CO.
Betula papyrifera	paper birch	1,3,4, 5,9,A	yes	medium tree	shallow, fibrous	poor	fast when young	fast	poor	plants	Not tolerant of more than a few days inundation in a New England trial. Short lived but the most resistant to borers of all birches.
Betula pumila	low birch	1,3,4, 8,9		small to large shrub	fibrous	poor				plants	Occurs Newfound-land to NJ & MN.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Carpinis caroliniana	american hornbeam	1,2,3, 6	yes, limited sources	small tree		poor	slow	slow	poor	plants	Not tolerant of flooding in TN Valley trial. Occurs MD to FL & west to southern IL & east TX. A northern form occurs from New England to NC & west to MN & AR.
Carya aquatica	water hickory	1,2,3, 6	yes	tall tree	tap to shallow lateral	poor	slow	fast	poor	plants	A species for forested wetland sites.
Carya cordiformis	bitternut hickory	1,2,3, 5,6	yes	tree	tap & dense laterals	poor	slow		poor	plants	Roots & stumps coppice. Not tolerate flooding in a MO trial. Occurs Quebec to FL & LA. Transplants with difficulty.
Carya ovata	shagbark hickory	1,2,3, 4,5,6	yes	medium tree	tap	poor	slow	slow	poor	plants	Hard to transplant. Occurs Quebec to FL & TX.
Catalpa bignonioides	southern catalpa	1,2,3, 5,6,7	yes	tree		poor	fair	fair	poor	plants	Occurs in SW GA to LA; naturalized in New England, OH, MI, & TX.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Celtis laevigata	sugarberry	1,2,3, 5,6,7, 9,0	yes	medium tree	relatively shallow	poor	medium	slow	low	plants	Very resistant to witches-broom. Occurs FL, west to TX & southern IN. Also in Mexico. Leaf fall allelopathic.
Celtis occidentalis	hackberry	1,2,3, 4,5,6, 8	yes	medium tree	medium to deep fibrous	poor	medium to fast	slow	low	plants	Survived 2 years of flooding in MS. Not tolerate more than a few days inundation in a MO trial. Susceptible to witches-broom. Occurs Quebec to NC & AL.
Cephalanthus occidentalis	buttonbush	1,2,3, 5,6,7, 8,0	yes	large shrub		fair to good	slow	medium	poor	brush mats, layering, plants	Survived 3 years of flooding in MS. Will grow in sun or shade.
Cercis canadensis	redbud	1,2,3, 5,6,7, 8	yes	small tree	tap	poor	slow	slow	poor	plants	Juvenile wood & roots will root.
Chilopsis linearis	desert willow	6,7,8, 0	yes	shrub	fibrous		medium	medium	low	plants	Occurs TX to southern CA & into Mexico. 'Barranco,' 'Hope,' & 'Regal' cultivars were releasedin New Mexico.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Chionanthus virginicus	fringetree	1,2,3, 6	yes	small tree		poor	slow		poor	plants	Susceptible to severe browsing & scale. Occurs PA to FL & west to TX.
Clematis ligusticifolia	western clematis	1,2,4, 5,6,7, 8,9,0	yes	vine	shallow & fibrous	poor	fast	fast	good	plants	Produces new plants from layering in sandy soils at 7- to 8-inch precip & 1,000-foot elevation.
Clethera alnifolia	sweet pepperbush	1,2,6	yes	shrub		poor	slow			plants	Has rhizomes; salt tolerant on coastal sites. Occurs ME to FL.
Cornus amomum	silky dogwood	1,2,3, 4,5,6	yes	small shrub	shallow, fibrous	fair	fast	medium	poor	fascines, stakes, brush mats, layering, cuttings, plants	Pith brown, tolerates partial shade. 'Indigo' cultivar was released by MI PMC.
Cornus drummondii	roughleaf dogwood	1,2,3, 4,5,6	yes	large shrub	root suckering, spreading	fair			fair	fascines, stakes, layering, brush mats, cuttings, plants	Root suckers too. Pith usually brown. Occurs Saskatche-wan to KS & NE, south to MS, LA, & TX.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Cornus florida	flowering dogwood	1,2,3, 5,6	yes	small tree	shallow, fibrous	poor	fair	fair	poor	plants	Hard to transplant as bare root; coppices freely. Not tolerant of flooding in TN Valley trial.
Cornus foemina	stiff dogwood	1,2,3, 4,5,6		medium shrub		fair	fast			fascines, plants	Formerly C. racemosa Occurs VA to FL & west to TX. Pith white.
Cornus racemosa	gray dogwood	1,2,3, 4,5,6	yes	medium to small shrub	shallow, fibrous	fair	medium		fair	fascines, stakes, brush mats, layering, cuttings, plants	Forms dense thickets. Pith usually brown, tolerates city smoke. Occurs ME & MN to NC & OK.
Cornus rugosa	roundleaf dogwood	1,3		medium to small shrub	shallow, fibrous	fair to good				fascines, cuttings, plants	Pith white. Use in combination with species with root_abil = good to excellent. Occurs Nova Scotia to VA & ND.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Cornus sericea ssp sericea	red-osier dogwood	1,3,4, 5,7,8, 9,0,A	yes	medium shrub	shallow	good	fast	medium	fair	fascines, stakes, brush mats, layering, cuttings, plants	Forms thickets by rootstocks & rooting of branches. Survived 6 years of flooding in MS. Pith white, tolerates partial shade. Formerly C. stolonifera. 'Ruby' cultivar was released by NY PMC.
Cornus stricta	swamp dogwood			shrub		poor				plants	May be same as C. foemina.
Crataegus douglasii	douglas hawthorn	3,8,9, 0,A	yes	small tree	tap to fibrous	poor to fair	slow		poor	cuttings, plants	Forms dense thickets on moist sites. Grown from seed or grafted. Occurs British Columbia to CA & MN.
Crataegus mollis	downy hawthorn	1,2,3, 4,5,6	yes	tree	tap	poor to fair				plants	Occurs Ontario & MN to AL, AR & MS. 'Homestead' cultivar was released by ND PMC.
Cyrilla racemiflora	titi	1,2,6, C		small tree		poor				plants	Semievergreen, a good honey plant. Occurs VA to FL & on to South America. Prefers organic sites.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Diospyros virginiana	persimmon	1,2,3, 5,6	yes	medium tree	tap	poor	slow	fair	poor	plants	Forms dense thickets on dry sites. Stoloniferous & tap rooted. Occurs CT toFL & TX.
Elaeagnus commutata	silverberry	1,3,4, 8,9,A	yes	small tree	shallow, fibrous	poor to fair	fast	fast	fair	plants	Grows well in limestone & alkaline soils.
Forestiera acuminata	swamp privet	1,2,3, 6	yes	large shrub to small tree		fair	slow		poor	plants	Thicket forming. Survived 3 years of flooding in MS.
Fraxinus caroliniana	carolina ash	1,2,6		large tree	fibrous	poor	fast	fast		plants	Easily transplanted. Occurs in swamps VA to TX.
Fraxinus latifolia	oregon ash	9,0	yes	medium tree	moderately shallow, fibrous	poor	fast when young	medium	fair	plants	May be grown from seed but usually grafted. Usually occurs west of the Cascade Mtns.
Fraxinus pennsylvanica	green ash	1,2,3, 4,5,6, 8,9	yes	medium tree	shallow, fibrous	poor	fast	fast	good	plants	Survived 3 years of flooding in MS. 'Cardan' cultivar was released by ND PMC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Gleditsia triacanthos	honeylocust	1,2,3, 4,5,6, 7,8,9	yes	medium tree	deep & wide-spread	poor to fair	fast	fast	medium	plants	Survived deep flooding for 100 days 3 consecutive years. Has been used in reg_occ 7,8,9. Native ecotypes have thorns!
Hibiscus aculeatus	hibiscus	2,6	yes	shrub		poor				plants	
Hibiscus laevis	halberd-leaf marshmallow		yes	shrub		poor				plants	Was H. militaris.
Hibiscus moscheutos	common rose mallow	1,2,3, 5,6,7, 0	yes	shrub		poor				plants	
Hibiscus moscheutos ssp.lasiocarpos	hibiscus		yes	shrub		poor				plants	
Holodiscus discolor	oceanspray	9,0	yes, from contract growers.	shrub		poor to fair	medium to rapid	fast	poor	plants	Often pioneers on burned areas. Occurs from British Columbia to CA to ID. Usually grown from seed or cuttings.
Ilex coriacea	sweet gallberry	1,2,6, C	yes	small to large shrub		poor				plants	Evergreen.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Ilex decidua	possomhaw	1,2,3, 5,6	yes	large shrub to small tree		poor	slow			plants	Survived 3 years of flooding in MS.
Ilex glabra	bitter gallberrry	1,2,6	yes	small shrub		poor	slow			plants	Evergreen, sprouts after fire. Stoloniferous! Occurs eastern US & Canada.
Ilex opaca	american holly	1,2,3, 6	yes	small tree	tap root & prolific laterals	poor	slow	medium	poor	plants	Easy to transplant when young.
Ilex verticillata	winterberry	1,2,3, 6	yes	small to large shrub		poor	slow			plants	Prefers seasonally flooded sites. Plants dioecious.
Ilex vomitoria	yaupon	1,2,6	yes	large shrub		poor				plants	Root suckers.
Juglans nigra	black walnut	1,2,3, 4,5,6	yes	medium tree	tap & deep & wide-spread laterals	poor	fair	fair	poor	plants	Though drought tolerant, will not grow on poor or dry soil sites. Not tolerate flooding in TN Valley trial.
Juniperus virginiana	eastern redcedar	1,2,3, 4,5,6	yes	large tree	tap & dense fibrous laterals	poor	slow	medium	good	plants	Not tolerate flooding in TN Valley trial.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Leucothoe axillaris	leucothoe	1,2	yes	small to large shrub		poor	slow			plants	Evergreen.
Lindera benzoin	spicebush	1,2,3, 5,6	yes	shrub		poor	slow			plants	Prefers acid soils. Dioecious.
Liquidambar styraciflua	sweetgum	1,2,3, 6	yes	large tree	tap to fibrous	poor	slow		fair	plants	A species for forested wetland sites.
Liriodendron tulipifera	tulip poplar	1,2,3, 5,6	yes	large tree	deep & wide-spreading	poor	fast	fast		plants	Hard to transplant.
Lonicera involucrata	black twinberry	3,7,8, 9,0,A	yes	small to large shrub	fibrous & shallow	good	fast	fast	poor to fair	fascines, stakes, cuttings, plants	
Lyonia lucida	fetterbush	1,2		small to large shrub		poor				plants	Evergreen.
Magnolia virginiana	sweetbay	1,2,6	yes	small tree		poor	slow			plants	Occurs in swamps from MA to FL and west to east TX.
Myrica cerifera	southern waxmyrtle	1,2,6, c	yes	small shrub	fibrous	poor	medium	slow	slow	plants	Evergreen. Occurs east TX & OK, east to FL & north to NJ.
Nyssa aquatica	swamp tupelo	1,2,3, 6	yes	large tree	shallow, fibrous	poor		slow		plants	Trees from the wild do not transplant well.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Nyssa ogeeche	ogeeche lime	2		large shrub to small tree	sparse, fibrous	poor	slow	medium	poor	plants	Largest fruit of all Nyssa. Vegetative reproduction not noted. Only grows close to perennial wetland sites.
Nyssa sylvatica	blackgum	1,2,3, 6	yes	tall tree	sparse, fibrous, very long, decending	poor	medium	slow	fair	plants	A species for forested wetland sites. Difficult to transplant but plant in sun or shade on 10- to 12-foot spacing.
Ostrya virginiana	hophorn-beam	1,2,3, 4,5,6	yes	small tree		poor	slow	slow		plants	Difficult to transplant. Tolerated flooding for up to 30 days during 1 growing season.
Persea borbonia	redbay	1,2,6	yes	small to large evergreen tree		poor	slow	slow		plants	
Philadelphus lewesii	lewis mockorange	9,0	yes	large shrub	fibrous	poor	fast	medium to fast	medium	plants	Usually grown from seed.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Physocarpus capitatus	pacific ninebark	8,9,0, A	yes	large shrub	fibrous	good				fascines, brush mats, layering, cuttings, plants	Usually occurs west of the Cascade Mtns.
Physocarpus malvaceus	mallow ninebark	8,9	yes	small shrub	shallow but with rhizomes	fair				cuttings, plants	Propagated by seed or cuttings. Usually occurs east of the Cascade Mtns.
Physocarpus opulifolius	common ninebark	1,2,3, 4,5,6, 8,9	yes	medium shrub	shallow, lateral	fair	slow	slow	poor	fascines, brush mats, layering, cuttings, plants	Use in combination with other species with rooting ability good to excellent.
Pinus taeda	loblolly pine	1,2,3, 6	yes	medium tree	short tap changes to shallow spreading laterals	poor	fast	fast	poor	plants	
Planera aquatica	water elm	1,2,3, 5,6		small tree		poor	fairly fast			plants	Occurs KY to FL, west to IL & TX.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Platanus occidentalis	sycamore	1,2,3, 5,6	yes	large tree	fibrous, wide-spreading	poor	fast	fast	medium	plants	A species for forested wetland sites. Tolerates city smoke & alkali sites. Plant on 10- to12-foot spacing. Trans-plants well.
Platanus racemosa	California sycamore	0		tall tree						plants	A species for forested wetlands sites in CA.
Populus angustifolia	narrowleaf cottonwood	4,5,6, 7,8,9, 0		large tree	shallow	v good				fascines, stakes, poles, brush mats, layering, cuttings, plants	Under development in ID for riparian sites.
Populus balsamifera	balsam poplar	1,2,3, 4,5,8, 9,O,A	yes	tall tree	deep, fibrous	v good	fast	fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Populus deltoides	eastern cottonwood	1,2,3, 4,5,6, 7,8,9	yes	tall tree	shallow, fibrous, suckering	v good	fast	fast	poor	fascines, stakes, poles, brush mats, layering, cuttings, root suckers, plants	Short lived. Endures heat & sunny sites. Survived over 1 year of flooding in MS. Hybridizes with several other poplars. Plant roots may be invasive. May be sensitive to aluminum in the soil.
Populus fremontii	fremont cottonwood	6,7,8, 0		tree	shallow, fibrous	v good	fast			fascines, stakes, poles, brush mats, layering, cuttings, plants	Tolerates saline soils. Dirty tree.
Populus tremuloides	quaking aspen	1,2,3, 4,5,7, 8,9,0, A	yes	medium tree	shallow, profuse suckers, vigorous under-ground runners	poor to fair	fast	fast	fair	layering, root cuttings, plants	Short lived. A pioneer species on sunny sites. Normal propagation is by root cuttings. Not tolerant of more than a few days inundation in a New England trial. Use rooted plant materials.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Populus trichocarpa	black cottonwood	4,7,8, 9,0,A	yes	large tree	deep & wide-spread, fibrous	v good	fast	fast	good	fascines, stakes, poles, brush mats, layering, cuttings, plants	A species for forested wetland sites. Was P. trichophora. Usually grown from cuttings. Under development in ID for riparian sites. Plant on 10- to 12-foot spacing. May be P. balsimifera
Prunus angustifolia	wild plum	1,2,3, 5,6	yes	small shrub	fibrous, spreading, suckering	poor	medium	fast	good	plants, root cuttings	Thicket forming. 'Rainbow' cultivar released by Knox City, TX, PMC.
Prunus virginiana	common chokecherry	1,2,3, 4,5,6, 7,8,9, 0,A	yes	large shrub	shallow, suckering	poor	medium	medium	fair	plants	A species for forested wetland sites. Has hydrocyanic acid in most parts, especially the seeds. Usually grown from seed. Thicket forming. Plant on 5- to 8-foot spacing. Reportedly poisonous to cattle.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Quercus alba	white oak	1,2,3, 5,6	yes	large tree	tap to deep, well-developed fibrous	poor	slow	slow	slow	plants	Did not survive more than a few days flooding in a trial in New England. Difficult to transplant larger specimens.
Quercus bicolor	swamp white oak	1,2,3, 5,6	yes	medium tree	somewhat shallow	poor	fast	medium	fair	plants	Survived 2 years of flooding in MS.
Quercus garryana	oregon white oak	9,0	yes	shrub to large tree	deep tap & well-developed laterals	poor	slow	slow	fair	plants	Usually grows west of the Cascade Mtns, in the Columbia River Gorge to the Dalles & to Yakima, WA. Propagated from seed sown in fall.
Quercus laurifolia	swamp laurel oak	1,2,6		tree	tap	poor	fast	fast		plants	Often used as a street tree in the southeast US.
Quercus lyrata	overcup oak	1,2,3, 6	yes	medium tree	tap deteriorates to dense shallow laterals	poor	slow	slow	slow	plants	Often worthless as a lumber species.
Quercus macrocarpa	bur oak	1,2,3, 4,5,6, 9	yes	large tree	deep tap & well-developed laterals	poor	medium	fast	poor	plants	Survived 2 years of flooding in MS. 'Boomer' cultivar released by TX PMC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Quercus michauxii	swamp chestnut oak	1,2,3, 6		medium tree	tap & deep laterals	poor	fair	fair	poor	plants	
Quercus nigra	water oak	1,2,3, 6		medium tree	shallow & spreading	poor	fast on good sites	slow	poor	plants	Easily transplanted.
Quercus pagoda	cherrybark oak			tree		poor				plants	
Quercus palustris	pin oak	1,2,3, 5,6	yes	large tree	well-developed fibrous laterals after taproot disinte-grates	poor	fast	fast	fair	plants	A species for forested wetland sites. Survived 2 years of flooding in MS. Plant on 10- to 12-foot spacing.
Quercus phellos	willow oak	1,2,3, 6	yes	medium to large tree	shallow, fibrous	poor	fast	medium	fair	plants	Easily transplanted.
Quercus shumardii	shumard oak	1,2,3, 5,6	yes	large tree	shallow	poor	medium	slow	low	plants	
Rhododendron atlanticum	coast azalea	1,2		small shrub		poor	fast		good by stolons	plants	Mat forming from suckers & stolons. Occurs from DE to SC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Rhododendron viscosum	swamp azalea	1,2		shrub		poor	slow			plants	Has stoloniferous forms. Occurs from ME to SC. Highly susceptible to insects & diseases.
Rhus copallina	flameleaf sumac	1,2,3, 4,5,6	yes	medium shrub	fibrous, suckering	poor to fair	fast	fast	fair	root cuttings, root suckers, plants	Thicket forming.
Rhus glabra	smooth sumac	1,2,3, 4,5,6, 7,8,9	yes	large shrub	fibrous, suckering	poor to fair	fast	fast	fair to good	root cuttings, root suckers, plants	Thicket forming.
Robinia pseudoacacia	black locust	1,2,3, 4,5,6, 7,8,9, 0	yes	medium tree	shallow	poor	medium to fast	fast	good	root cuttings, plants	Normal propagation is by root cuttings or seed. Not tolerant of flooding in TN Valley trial. Escaped in regions 5,7,8,9,0. Reported toxic to livestock.
Rosa gymnocarpa	baldhip rose	9,0		shrub		fair to good				cuttings, plants	A browsed species.
Rosa nutkana	nootka rose	7,8,9, 0,A		shrub		fair to good				cuttings, plants	A browsed species.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Rosa palustris	swamp rose	1,2,3, 5		small shrub	shallow	good				fascines, plants	
Rosa virginiana	virginia rose	1,2,3	yes	small shrub	rhizomat-ous & fibrous	good	fair	fast	fair	plants	
Rosa woodsii	woods rose	3,4,5, 6,7,8, 9,0,A		shrub		fair to good				cuttings, plants	A browsed species.
Rubus alleghenensis	allegheny blackberry	1,2,3, 5,6,0		small shrub	fibrous	good				plants	Normal propagation is by root cuttings.
Rubus idaeus ssp. strigosus	red raspberry	1,2,3, 4,5,6, 7,8,9, A		small shrub	fibrous	good				plants	Was R. strigosus. Normal propagation is by root cuttings.
Rubus spectabilis	salmonberry	9,0,A		small shrub	fibrous	good				plants	Normal propagation is by root cuttings. Use in combination with other species. Rooting ability is good to excellent.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Salix X cottetii	dwarf willow	not native	yes	small shrub	shallow	v good	medium	fast	poor	fascines, stakes, brush mats, layering, cuttings, plants	Not a native species. Plant plants on 2' to 6' spacing. 'Bankers' cultivar released by Kentucky PMC.
Salix amygdaloides	peachleaf willow	1,2,3, 4,5,6, 7,8,9	yes	large shrub to small tree	shallow to deep	v good	fast	fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	Often roots only at callus cut. May be short-lived. Under development in ID for riparian sites. Not tolerant of shade. Hybridized with several other willow species.
Salix bebbiana	bebb's willow	1,3,4, 5,7,8, 9,A		small shrub to large tree	fibrous					cuttings, plants	Does not form suckers. Usually east of the Cascade Mtns & in ID & MT.
Salix bonplandiana	pussy willow	7	yes	medium shrub to large tree	fibrous	v good				fascines, stakes, poles, brush mats, layering, cuttings, plants	Eaten by livestock when young.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix boothii	booth willow	8,9		shrub							Under development in Idaho for riparian sites.
Salix discolor	pussy willow	1,2,3, 4,9	yes	large shrub	shallow, fibrous, spreading	v good	rapid			fascines, stakes, poles, layering, cuttings, plants	Use on sunny to partial shade sites.
Salix drummondiana	drummond's willow	7,8,9, 0	yes	shrub		good				fascines, cuttings, plants	Usually east of the Cascade Mtns. Under development in ID for riparian sites. 'Curlew' cultivar released by WA PMC.
Salix eriocephala	erect willow	7,8,9, 0	yes	large shrub	fibrous	v good		fast		fascines, stakes, poles, layering, cuttings, plants	A botanic discrepancy in the name, it may be S. ligulifolia! 'Placer' cultivar released by OR PMC.
Salix exigua	coyote willow	1,2,3, 4,5,6, 7,8,9, 0,A	yes	medium shrub	shallow, suckering, rhizomatous	good	fast			fascines, stakes, poles, brush mats, layering, cuttings, plants	Relished by livestock. Under development in ID for riparian sites. 'Silvar' cultivar released by WA PMC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Salix geyeriana	geyer's willow	7,8,9, 0		small to large shrub						cuttings, plants	Occurs east of the Cascade Mtns at higher elevations. Relished by livestock. Under development in ID for riparian sites.
Salix goodingii	goodding willow	6,7,8, 0		small shrub to large tree	shallow to deep	good to excel	fast	fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	Not tolerate alkaline sites. Some say this is western black willow.
Salix hookeriana	hooker willow	9,0	yes	large shrub to small tree	fibrous, dense	v good	rapid when young, medium there-after	medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	May have salt tolerance. Can compete well with grasses. 'Clatsop' cultivar was released by OR PMC.
Salix humilis	prairie willow	1,2,3, 4,5,6		medium shrub	fibrous, spreading	good		medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	Thicket forming.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Salix interior	sandbar willow	1,3,4, 5,7,8, 9,A	yes	large shrub	shallow to deep	exce	medium	medium	fair	fascines, stakes, poles, brush mats, layering, cuttings, plants	Thicket forming. This species has been changed to S. exigua. Use in combination with species with rooting ability good to excellent.
Salix lasiolepis	arroyo willow	6,7,8, 9,0	yes	tall shrub to small tree	fibrous	v good	rapid when young, medium there-after	medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	Roots only on lower 1/3 of cutting or at callus. 'Rogue' cultivar released by OR PMC.
Salix lemmonii	lemmon's willow	8,9,0	yes	medium shrub	fibrous	v good		fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	Occurs at high elevations, east of the Cascade Mtns. Under development in ID for riparian sites. 'Palouse' cultivar released by WA PMC.
Salix lucida	shining willow	1,3,4, 5,7,8, 9,0		medium to tall shrub	fibrous, spreading	v good	rapid			fascines, stakes, poles, brush mats, layering, cuttings, plants	

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix lucida ssp. lasiandra	pacific willow	4,7,8, 9,0,A	yes	large shrub to small tree	fibrous	v good	medium to slow	medium to slow		fascines, stakes, poles, brush mats, layering, cuttings, plants	A species for forested wetlands sites. There are several subspecies of S. lucida. Under development in ID for riparian sites. Susceptible to several diseases and insects. Plant on 10- to 12-foot spacing. 'Nehalem' cultivar released by OR PMC.
Salix lutea	yellow willow	1,4,5, 7,8,9, 0		medium to tall shrub	fibrous	v good				fascines, stakes, poles, brush mats, layering, cuttings, plants	Usually browsed by livestock. Under development in ID for riparian sites.
Salix nigra	black willow	1,2,3, 5,6,7, 8	yes	small to large tree	dense, shallow, sprouts readily	good to excel	fast	fast	good	fascines, stakes, poles, brush mats, layering, cuttings, root cuttings, plants	May be short lived. Survived 3 years of flooding in MS. Needs full sun. Susceptible to several diseases & insects.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Salix pentandra	laural willow	not native	yes	large shrub to small tree	fibrous, spreading	good	fast	medium	poor	fascines, stakes, poles, brush mats, layering, cuttings, plants	From Europe, sparingly escaped in the East. Insects may defoliate it regularly.
Salix purpurea	purpleosier willow	1,2,3, 5	yes	medium tree	shallow	excel	fast	fast	poor	fascines, stakes, poles, brush mats, layering, cuttings, plants	Tolerates partial shade. 'Streamco' cultivar released by NY PMC.
Salix scouleriana	scouler's willow	4,7,8, 9,0,A		large shrub to small tree	shallow	v good	fast			fascines, stakes, poles, brush mats, layering, cuttings, plants	Pioneers on burned sites. Occurs on both sides of the Cascade Mtns in low to high eleva-tions. Often roots only at callus.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix sitchensis	sitka willow	9,0,A	yes	very large shrub		v good	rapid when young, medium thereafter	medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	Occurs on both sides of the Cascade Mtns. Vigorous shoots branch freely; lends itself to bioengineering uses; excellent survival in trials. 'Plumas' cultivar released by OR PMC.
Sambucus canadensis	american elder	1,2,3, 4,5,6, 8,9	yes	medium shrub	fibrous & stoloniferous	good	fast	fast	poor	fascines, cuttings, plants	Softwood cuttings root root easily in spring or summer. Pith white.
Sambucus cerulea	blue elderberry	6,7,8, 9,0	yes	large shrub	fibrous	poor	v fast	v fast	poor	plants	
Sambucus cerulea ssp. mexicana	mexican elder	6,7,8, 0,H		large shrub		good				fascines, plants	Was S. mexicana. Evergreen. Softwood cuttings root easily in spring or summer.
Sambucus racemosa	red elderberry	1,2,3, 4,7,8, 9,0,A	yes	medium shrub		good	medium	slow		fascines, brush mats, layering, cuttings, plants	Softwood cuttings root easily in spring or summer. Pith brown. This may be S. callicarpa.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Sambucus racemosa ssp. pubens	red elder	1,2,3, 4,9,A		medium shrub	deep laterals	fair to good				fascines, plants	Occurs west of the Cascade Mtns, usually within 10 miles of the ocean & on the coastal bays & estuaries. Soft-wood cuttings root easily in spring or summer. Pith brown. Use in com-bination with species with rooting ability good to excellent.
Spiraea alba	meadow-sweet spirea	1,2,3, 4	yes	short dense tree	dense shallow, lateral	fair to good		medium		plants	Propagation by leafy softwood cuttings in mid-summer under mist.
Spiraea betulifolia	shinyleaf spirea	1,2,4, 9		shrub						plants	Usually grown from seed. Occurs east of the Cascade Mtns at medium to high elevations.
Spiraea douglasii	douglas spirea	2,3,9, 0	yes	small dense shrub	fibrous, suckering	good	rapid	fast	excellent	fascines, brush mats, layering, cuttings, division of suckers, plants	Resists fire & pro-lific sprouter (forms thickets). Propaga-tion by leafy soft-wood cuttings in midsummer under mist. 'Bashaw' cul-tivar released by WA PMC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Spiraea tomentosa	hardhack spirea	1,2,3, 5		small shrub	dense, shallow	poor to fair				plants	Propagation by leafy softwood cuttings in mid-summer under mist. A weed in New England pastures. Use rooted materials.
Styrax japonica	Japanese snowbell	1,2,3, 5,6	yes	large shrub		poor				plants	
Symphoricarpos albus	snowberry	1,3,4, 5,7,8, 9,0,A	yes	small shrub, dense colony forming	shallow, fibrous, freely suckering	good	rapid	slow	fair	fascines, brush mats, layering, cuttings, plants	Plant in sun to part shade, especially on wet sites.
Taxodium distichum	baldcypress	1,2,3, 5,6	yes	medium tree	tap with laterals for knees for aeration	poor	medium	fast	poor	plants	Plant on 10- to 12-foot spacing. Tolerates upland sites in region 6 with 32" rainfall.
Tsuga canadensis	eastern hemlock	1,2,3	yes	large tree	shallow fibrous	poor	slow	slow	low	plants	

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Ulmus americana	american elm	1,2,3, 4,5,6, 8	yes	large tree	tap on dry sites to shallow fibrous on moist sites	poor	medium	medium	poor	plants	A species for forested wetland sites. Survived near 2 years of flooding in MS. Plant on 10- to 12-foot spacing; tolerates full shade.
Viburnum dentatum	arrowwood	1,2,3, 6	yes	medium to tall shrub	shallow, fibrous	good	fast	slow		layering, cuttings, plants	Thicket forming; tolerates city smoke. Use rooted plant materials.
Viburnum lantanoides	hubblebush viburnam	1,2,3		medium shrub	shallow, fibrous	good				fascines, stakes, brush mats, layering, cuttings, plants	Was V. alnifolium. Thicket forming. Branch tips root at soil.
Viburnum lentago	nannyberry	1,2,3, 4,5,9	yes	large shrub	shallow	fair to good	fast	fast		fascines, cuttings, stakes, plants	Thicket forming; tolerates city smoke. Tolerates full shade. Older branches often root when they touch soil. Use in combination with species with rooting ability good to excellent.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

cientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Viburnum nudum	swamp haw	1,2,6		large shrub		poor				plants	D. Wymann says it is more adapted to the South than V. cassinoides.
Viburnum trilobum	american cranberry-bush	1,3,4, 5,9	yes	medium shrub		poor	medium	slow		layering, plants	Use rooted plant materials. Fruits are edible.

Table 16B–2 Woody plants with fair to good or better rooting ability from unrooted cuttings

Scientific name	Common name	Scientific name	Common mame
Acer circinatum	vine maple	*Salix bonplandiana*	pussy willow
Baccharis glutinosa	seepwillow	*Salix discolor*	pussy willow
Baccharis halimifolia	eastern baccharis	*Salix drummondiana*	drummond's willow
Baccharis pilularis	coyotebush	*Salix eriocephala*	erect willow
Baccharis salicifolia	water wally	*Salix exigua*	coyote willow
Baccharis viminea	mulefat baccharis	*Salix gooddingii*	goodding willow
Cephalanthus occidentalis	buttonbush	*Salix hookeriana*	hooker willow
Cornus amomum	silky dogwood	*Salix humilis*	prairie willow
Cornus drummondii	roughleaf dogwood	*Salix interior*	sandbar willow
Cornus foemina	stiff dogwood	*Salix lasiolepis*	arroyo willow
Cornus racemosa	gray dogwood	*Salix lemmonii*	lemmon's willow
Cornus rugosa	roundleaf dogwood	*Salix lucida*	shining willow
Cornus sericea ssp sericea	red-osier dogwood	*Salix lucida ssp. lasiandra*	pacific willow
Lonicera involucrata	black twinberry	*Salix lutea*	yellow willow
Physocarpus capitatus	pacific ninebark	*Salix nigra*	black willow
Physocarpus opulifolius	common ninebark	*Salix pentandra*	laural willow
Populus angustifolia	narrowleaf cottonwood	*Salix purpurea*	purpleosier willow
Populus balsamifera	balsam poplar	*Salix scouleriana*	scouler's willow
Populus deltoides	eastern cottonwood	*Salix sitchensis*	sitka willow
Populus fremontii	fremont cottonwood	*Sambucus canadensis*	american elder
Populus trichocarpa	black cottonwood	*Sambucus cerulea ssp. mexicana*	mexican elder
Rosa gymnocarpa	baldhip rose	*Sambucus racemosa*	red elderberry
Rosa nutkana	nootka rose	*Sambucus racemosa ssp. pubens*	red elder
Rosa palustris	swamp rose	*Spiraea alba*	meadowsweet spirea
Rosa virginiana	virginia rose	*Spiraea douglasii*	douglas spirea
Rosa woodsii	woods rose	*Symphoricarpos albus*	snowberry
Rubus allegheniensis	allegheny blackberry	*Viburnum dentatum*	arrowwood
Rubus idaeus ssp.strigosus	red raspberry	*Viburnum lantanoides*	hubblebush viburnam
Rubus spectabilis	salmonberry	*Viburnum lentago*	nannyberry
Salix X cottetii	dwarf willow		
Salix amygdaloides	peachleaf willow		

Table 16B–3 Woody plants with poor or fair rooting ability from unrooted cuttings

Scientific name	Common name	Scientific name	Common mame
Acer glabrum	dwarf maple	*Fraxinus pennsylvanica*	green ash
Acer negundo	boxelder	*Gleditsia triacanthos*	honeylocust
Acer rubrum	red maple	*Hibiscus aculeatus*	hibiscus
Acer saccharinum	silver maple	*Hibiscus laevis*	halberd-leaf marshmallow
Alnus pacifica	pacific alder	*Hibiscus moscheutos*	common rose mallow
Alnus rubra	red alder	*Hibiscus moscheutos ssp. lasiocarpos*	hibiscus
Alnus serrulata	smooth alder	*Holodiscus discolor*	oceanspray
Alnus viridis ssp.sinuata	sitka alder	*Ilex coriacea*	sweet gallberry
Amelanchier alnifolia var cusickii	cusick's serviceberry	*Ilex decidua*	possomhaw
Amorpha fruitcosa	false indigo	*Ilex glabra*	bitter gallberrry
Aronia arbutifolia	red chokeberry	*Ilex opaca*	american holly
Asimina triloba	pawpaw	*Ilex verticillata*	winterberry
Betula nigra	river birch	*Ilex vomitoria*	yaupon
Betula papyrifera	paper birch	*Juglans nigra*	black walnut
Betula pumila	low birch	*Juniperus virginiana*	eastern redcedar
Carpinis caroliniana	american hornbeam	*Leucothoe axillaris*	leucothoe
Carya aquatica	water hickory	*Lindera benzoin*	spicebush
Carya cordiformis	bitternut hickory	*Liquidambar styraciflua*	sweetgum
Carya ovata	shagbark hickory	*Liriodendron tulipifera*	tulip poplar
Catalpa bignonioides	southern catalpa	*Lyonia lucida*	fetterbush
Celtis laevigata	sugarberry	*Magnolia virginiana*	sweetbay
Celtis occidentalis	hackberry	*Myrica cerifera*	southern waxmyrtle
Cercis canadensis	redbud	*Nyssa aquatica*	swamp tupelo
Chionanthus virginicus	fringetree	*Nyssa ogeeche*	ogeeche lime
Clematis ligusticifolia	western clematis	*Nyssa sylvatica*	blackgum
Clethera alnifolia	sweet pepperbush	*Ostrya virginiana*	hophornbeam
Cornus florida	flowering dogwood	*Persea borbonia*	redbay
Cornus stricta	swamp dogwood	*Philadelphus lewesii*	lewis mockorange
Crataegus douglasii	douglas' hawthorn	*Physocarpus malvaceus*	mallow ninebark
Crataegus mollis	downy hawthorn	*Physocarpus opulifolius*	common ninebark
Cyrilla racemiflora	titi	*Pinus taeda*	loblolly pine
Diospyros virginiana	persimmon	*Planera aquatica*	water elm
Dlaeagnus commutata	silverberry	*Platanus occidentalis*	sycamore
Forestiera acuminata	swamp privet	*Populus tremuloides*	quaking aspen
Fraxinus caroliniana	carolina ash	*Prunus angustifolia*	wild plum
Fraxinus latifolia	oregon ash		

Table 16B–3 Woody plants with poor or fair rooting ability from unrooted cuttings—Continued

Scientific name	Common name	Scientific name	Common mame
Prunus virginiana	common chokecherry	*Rhododendron atlanticum*	coast azalea
Quercus alba	white oak	*Rhododendron viscosum*	swamp azalea
Quercus bicolor	swamp white oak	*Rhus copallina*	flameleaf sumac
Quercus garryana	oregon white oak	*Rhus glabra*	smooth sumac
Quercus laurifolia	swamp laurel oak	*Robinia pseuodoacacia*	black locust
Quercus lyrata	overcup oak	*Sambucus cerulea*	blue elderberry
Quercus macrocarpa	bur oak	*Spiraea tomentosa*	hardhack spirea
Quercus michauxii	swamp chestnut oak	*Styrax americanus*	Japanese snowbell
Quercus nigra	water oak	*Taxodium distichum*	bald cypress
Quercus pagoda	cherrybark oak	*Tsuga canadensis*	eastern hemlock
Quercus palustris	pin oak	*Ulmus americana*	american elm
Quercus phellos	willow oak	*Viburnum nudum*	swamp haw
Quercus shumardii	shumard oak	*Viburnum trilobum*	american cranberrybush

Table 16B–4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems

Scientific name	Common name	Warm season or non-competitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h_2o	Max. h_2o	Wetland indicator 1/
Agrostis alba	redtop											
Ammophila breviligulata	American beachgrass		sands	5.5	fair	poor	good			0		1,facu- 2,upl 3,upl*
Andropogon gerardii	big bluestem	yes	loams	6.0	good	poor	poor	fair		0		1,fac 2,fac 3,fac- 4,facu 5,fac- 6,facu 7,fac- 8,facu 9facu
Arundo donax	giant reed		sandy	7.0	good	poor		poor		0	1"	1,facu- 2,facw 3,facw 6,fac+ 7,facw 8,facw 0,facw C,ni H,ni
Elymus virginicus	wildrye	yes noncompetitive	loams	6.0	fair	good	fair	good		0		1,facw-
Eragrostis trichodes	sand lovegrass	yes	sands	6.0	good	poor	poor	poor		0		
Festuca rubra	red fescue	noncompetitive	loams	6.5	good	good	poor	fair		0		1,facu

Table 16B–4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems—Continued

Scientific name	Common name	Warm season or non-competitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h_2o	Max. h_2o	Wetland indicator 1/
Hemarthria altissima	limpograss		sandy		poor	poor	poor	good		0	1'	1,facw 2,facw 6,facw
Panicum amarulum	coastal panicgrass	yes	sands to loams	5.5	good	poor	fair	good		0		1,facu- 2,fac 6,facu-
Panicum clandestinum	deertongue	yes										
Panicum virgatum	switchgrass	yes	loams to sands	6.0	good	poor	fair	good	all	0		1,fac 2,fac+ 3,fac+ 4,fac 5,fac 6,facw 7,fac+ 8,fac 9,fac+ H,ni
Paspalum vaginatum	seashore paspalum		sandy			poor		good		1/2'	1'	2,obl 6,facw* C,ni H,ni
Pennisetum purpureum	elephant-grass					poor				0	2'	2,facu+ C,ni H,ni

Table 16B–4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems—Continued

Scientific name	Common name	Warm season or non-competitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h_2o	Max. h_2o	Wetland indicator 1/
Poa pratensis	Kentucky bluegrass		loam	6.5	poor	poor	poor	fair		0		1,facu
Schizachyrium scoparium	little bluestem	yes	sands to loams	6.5	good	poor	poor	poor		0		1,facu
Sorghastrum nutans	Indiangrass	yes	sands to	6.5	fair	poor	poor	poor		0		1,upl
Spartina pectinata	prairie cordgrass	yes	sands to loams	6.0	good	fair	fair	fair		0	1"	1,obl 2,obl 3,facw+ 4,facw 5,facw 6,facw+ 7,facw 8,obl 9,obl
Zizaniopsis miliacea	giant cutgrass		loam	4.3-6.0	poor	poor		good	all	1/2'	2'	1,obl 2,obl 3,obl 6,obl

Table 16B–4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems—Continued

Scientific name	Common name	Warm season or non-compe-titive	Soil prefer-ence	pH prefer-ence	Drought tolerance	Shade toler-ance	Deposi-tion tol-erance	Flood toler-ance	Flood season	Min. h_2o	Max. h_2o	Wetland indicator 1/

1/ Wetland indicator terms (from USDI Fish and Wildlife Service's National List of Plant Species That Occur in Wetlands, 1988):

Region code number or letter:
- **1** Northeast (ME, NH, VT, MA, CT, RI, WV, KY, NY, PA, NJ, MD, DE, VA, OH)
- **2** Southeast (NC, SC, GA, FL, TN, AL, MS, LA, AR)
- **3** North Central (MO, IA, MN, MI, WI, IL, IN)
- **4** North Plains (ND, SD, MT (eastern), WY (eastern))
- **5** Central Plains (NE, KS, CO (eastern))
- **6** South Plains (TX, OK)
- **7** Southwest (AZ, NM)
- **8** Intermountain (NV, UT, CO (western))
- **9** Northwest (WA, OR, ID, MT (western), WY (western))
- **0** California (Ca)
- **A** Alaska (AK)
- **C** Caribbean (PR, VI, CZ, SQ)
- **H** Hawaii (HI, AQ, GU, IQ, MQ, TQ, WQ, YQ)

Indicator categories (estimated probability):
- **fac** Facultative—Equally likely to occur in wetlands or nonwetlands (34-66%).
- **facu** Facultative upland—Usually occur in nonwetlands (67-99%), but occasionally found in wetlands (1-33%)
- **facw** Facultative wetland—Usually occur in wetlands (67-99%), but occasionally found in nonwetlands.
- **obl** Obligate wetland—Occur almost always (99%) under naturl conditions in wetlands.
- **upl** Obligate upland—Occur in wetlands in another region, but occur almost always (99%) under natural conditions in nonwetlands im¸QæB¸regioK¸QpC Ûh”DGed-¸'e¸` Qpec%Cs BMeQ nMt Mccur %n wetlands in any region, it is not on the National List.

Frequency of occurrence:
- **–** (negative sign) indicates less frequently found in wetlands.
- **+** (positive sign) indicates more frequently found in wetlands.
- ***** (asterisk) indicates wetlands indicators were derived from limited ecological information.
- **ni** (no indicator) indicates insufficient information was available to determine an indiator status.