Technical Supplement 14I

Streambank Soil Bioengineering

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Cover photo: Earth materials, live and inert plant materials, and manmade materials can be used to form soil bioengineering solutions to streambank erosion problems.

Advisory Note

Techniques and approaches contained in this handbook are not all-inclusive, nor universally applicable. Designing stream restorations requires appropriate training and experience, especially to identify conditions where various approaches, tools, and techniques are most applicable, as well as their limitations for design. Note also that product names are included only to show type and availability and do not constitute endorsement for their specific use.

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Purpose

Streambank soil bioengineering is defined as the use of living and nonliving plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction, and vegetative establishment. As a result of increased public understanding and greater appreciation of the environment, many Federal, state, and local governments, as well as grassroots organizations, are actively engaged in implementing soil bioengineering treatments to stabilize streambanks. Stabilizing streambanks through the integration of natural vegetation has many advantages over using hard armor linings alone. When compared to streams with little or no vegetation on their banks, streams with well-established perennial vegetation on their banks typically have higher economic value, better water quality, and better fish and wildlife habitats. A variety of vegetative techniques are in widespread use. Many of these include soil bioengineering practices. The value of vegetation in civil engineering and the role of woody vegetation in stabilizing streambanks have gained considerable recognition in recent years (Greenway 1987; Coppin and Richards 1990; Gray and Sotir 1996). However, streambank soil bioengineering is not universally applicable. There are important considerations to take into account for their successful application and long-term sustainability. This technical supplement provides guidance for the analysis, design, installation, and maintenance of some of the most effective and commonly used soil bioengineering techniques.

Introduction

Soil bioengineering is an integrated watershed-based technology that uses sound engineering practices in conjunction with integrated ecological principles to assess, design, construct, and maintain living vegetative systems. This technology can be applied to repair damage caused by erosion and failures in the land and protect or enhance already healthy, functioning systems (Gray and Sotir 1996). Streambank soil bioengineering uses plants as structural components to stabilize and reduce erosion on streambanks. When selecting the best-suited soil bioengineering techniques, it is important to have a clear understanding of the ecological systems of the adjacent areas. Plant selection and the techniques used will play an initial role in site stabilization and, ultimately, serve as the foundation for the ecological restoration of the site. The successful establishment and long-term sustainability of herbaceous and woody plants are extremely important to the physical and biological functions of the streams and the connected watershed system.

Streambank soil bioengineering has a long history with many milestones.

- Tapestries have been found in Chinese emperor's tombs that depict Chinese peasants using willow bundles for streambank stabilization along the Yellow River in the year 28 B.C.
- In Europe, soil bioengineering techniques were used by Celtic villagers to create walls and fences.
- Romans used wattles and poles for hydro construction.
- The first written record of soil bioengineering was documented by Leonardo Da Vinci (1452–1519), where he recommended using rootable, living willow branches to stabilize agricultural irrigation channels, thus creating living streambanks. In the 16th century, streambank soil bioengineering treatments were used throughout Europe.
- In 1791, Woltmann published a soil bioengineering manual illustrating live stake techniques (Stiles 1991). In about 1800, soil bioengineers in Austria were using brush trenches to trap silt and reshape channels.
- In the 1900s, European soil bioengineers were using many of the treatments in use today (Stiles 1988).
- In 1934, Charles J. Kraebel, U.S. Forest Service, installed willow wattles above a road near Berkeley, California (Kraebel and Pillsbury 1934).
- In the late 1930s, the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS), now the Natural Resource Conservation Service (NRCS), began working on the Winooski River Watershed in Vermont after a succession of extremely damaging storm events. They used a series of soil bioengineering techniques

such as fascines, brush dams, brush mattresses, and live stakes along the Winooski River streambanks. In 1995, a detailed study of the project was completed. More than 50 out of 92 demonstration sites are still functioning today. The study found that the most successful measures generally included a mix of vegetation and mechanical treatments at each site (USDA NRCS 1999a).

After World War II, the availability of cheap energy; surplus bulldozers and dump trucks; the high cost of labor; and the advent of cheap, well-designed steel and concrete structures caused hard, inflexible structures to take over from the soil-bioengineered structures as the preferred methods for treating streambank erosion. Over the past few decades, it has become apparent that these hard structures have inherent problems that have caused a breakdown of the riparian ecosystem because of their overuse and, often, inappropriate use. A movement back to flexible and more natural streambank soil bioengineering treatments offering broader functions has come from this realization, and so has begun the modern age of soil bioengineering.

Benefits of streambank soil bioengineering

Streambank soil bioengineering has aesthetic benefits. Streambank soil bioengineering provides improved landscape and habitat values (Lewis 2000). However, most designers are interested in the specific structural benefits provided by the vegetation. Gray (1977), Bailey and Copeland (1961), and Allen (1978) describe five mechanisms through which vegetation can aid erosion control:

- reinforce the soil through the plant roots
- dampen waves or dissipate wave energy
- intercept high-water velocities
- enhance water infiltration
- deplete water in the soil profile by uptake and transpiration

Klingeman and Bradley (1976) point out four specific ways vegetation can protect streambanks.

- The root system helps hold the soil together and increases the overall bank stability by its binding network structure, that is, the ability of roots to hold soil particles together.
- The exposed vegetation (stalks, stems, branches, and foliage) increases roughness, which can increase the resistance to flow and reduce the local flow velocities, causing the flow to dissipate energy against the deforming plant, rather than the soil.
- The vegetation acts as a buffer against the abrasive effect of transported materials.
- Close-growing vegetation can induce sediment deposition by causing zones of slow velocity and low shear stress near the bank, allowing coarse sediments to deposit. Vegetation is also often less expensive than most structural methods; it improves the conditions for fisheries and wildlife, improves water quality, and can protect cultural/archeological resources.

Streambank soil bioengineering can be cost effective on local problems if applied early. Erosion areas often begin small and eventually expand to a size requiring costly traditional engineering solutions. Installation of streambank soil-bioengineered systems while the site problem is small will provide greater economic savings, minimize potential construction impacts to adjoining resources, and provide a better project. Landowners and volunteers can install many of the smaller, less complex soil bioengineering projects. The use of native, locally available plant materials and seed may provide additional savings. Costs for the vegetative materials are generally limited to labor for locating the harvesting sites, harvesting, handling and transporting to the project site, as well as the purchase of supplies (erosion control fabrics, twine, wood, and rock). Indigenous plant species are usually readily available as cuttings or rooted plants and well adapted to local climate and soil conditions. In addition, the use of indigenous materials can often have major aquatic and terrestrial habitat value. For example, plant materials can be selected to boost the habitat value by providing food and cover for birds and mammals or by providing overhanging shade to improve instream conditions for fish, waterfowl, and other aquatic life.

Streambank soil bioengineering work is often useful on sensitive or steep sites, in areas with limited access, or where working space for heavy machinery is not feasible. Years of monitoring have demonstrated that streambank soil bioengineering systems are strong initially and grow stronger with time as vegetation becomes established.

Streambank soil bioengineering is especially useful as a transition between conventional, inert bank stabilization and the upland zone. Abrupt transitions from conventional projects, such as riprap, to the upland zone are often prone to scour attack. Established soil bioengineering treatments can act to protect and reinforce the transition and reduce the possibility of washouts and flanking.

The structural benefits of soil bioengineering are varied. Initially, the systems offer mechanical support by controlling soil movement. Over time, the root systems from the establishing woody and herbaceous species increase the strength and structure of the soil. They create a strong and dense matrix of large anchor and small feeder roots that resist streambank erosion forces. They are capable of growing when they are broken off or partially uprooted by high water velocities. They capture nutrients, remove nitrogen and phosphorous from the soil, and trap and retain pollutants, thus improving water quality. In addition, if the plant species and measures are appropriately chosen, the entire project becomes self-supporting through the native invasion of the surrounding plant community. Vegetation improves the hydrology and mechanical stability of slopes through root reinforcement and surface protection. The reinforced soil mantle acts as a solid mass, reducing the possibility of slips and displacements (USDA NRCS 1996b). Even if plants die, roots and surface organic litter continue to play an important role during reestablishment of other plants. Once plants are established, root systems reinforce the soil mantle and remove excess moisture from the soil profile. Often, this is the key to long-term soil stability.

Aboveground biomass is also important because it provides roughness along the stream channel that reduces stream velocities and allows sediment to drop out. This aboveground biomass is a buffer along the stream channel that provides numerous benefits. This buffer increases water infiltration by slowing the flow, provides protection to the streambank by lying down as the high water flows past, provides fish and wildlife habitat, and traps sediment (Eubanks and Meadows 2002). The aboveground biomass is flexible and functions to absorb and reduce the energy along the streambank during high flows. By comparison, hard, rigid structures tend to be inflexible and deflect energy.

Riparian areas

Riparian areas are the zones along streams and rivers that serve as interfaces between terrestrial and aquatic ecosystems. The highly saturated soils in these zones are home to many species of water-loving flora and fauna. Riparian areas are important because they:

- provide erosion control by regulating sediment transport and distribution
- enhance water quality
- produce organic matter for aquatic habitats
- provide fish and wildlife habitat
- act as indicators of environmental change
- are among the most diverse, dynamic, complex biological systems on Earth

Riparian areas are shaped by the dynamic forces of water flowing across the landscape. Flooding, for instance, is a natural and necessary component of riparian areas. Many riparian plant species, such as cottonwood, require floods to regenerate by seed. Geomorphological characteristics of the stream valley, such as flood plain level (connectivity), drainage area, stream capacity, channel slope, and soils, are some of the factors that influence the frequency, duration, and intensity of flooding (Leopold, Wolman, and Miller 1964). In turn, flooding and related sediment transport processes influence the size and structure of the stream channel and composition of the riparian vegetation (Hupp and Osterkamp 1996).

Riparian health and streambank stability are simply a reflection of the conditions in the surrounding landscape. Healthy streams and riparian areas are naturally resilient, allowing recovery from natural disturbances such as flooding (Florsheim and Coats 1997). Streambank stability is a function of a healthy riparian and upland watershed area. When stream and riparian systems are degraded, this resiliency to natural disturbances is diminished. Excessive flooding, erosion in the form of downcutting and widening, and associated sedimentation often will increase, creating a loss of physical and biological equilibrium in the stream corridor.

Riparian planting zones

Success of streambank soil bioengineering treatments depends on the initial establishment and long-term development of riparian plant species. The success of the plants, in turn, depends on numerous factors including:

- species selected
- procurement methods
- installation and handling techniques
- time of year
- soil compaction
- soil type
- nutrients
- salinity
- ice
- sediment
- debris load
- flooding
- accessibility to water
- drought
- hydrology
- climate
- location relative to the stream

It is important to note the location and types of existing vegetation in and adjacent to the project area. The elevation and lateral relationships to the stream can be described in terms of riparian planting zones. Proposed streambank soil bioengineering techniques should also be assessed and designed in terms of the location of the plants relative to the stream and water table. These riparian planting zones can be used to determine where riparian species should be planted in relation to the waterline during different periods of flow. Figure TS14I–1 illustrates an idealized depiction of riparian planting zones (Riparian/Wetland Project Information Series No. 16).

Some of these zones identified in figure TS14I–1 may be absent in some stream systems (Hoag and Landis 1999). Sections that have missing zones will be especially prevalent in streams in the American Southwest, as well as areas that have been impacted by development. Before working on a streambank stabilization project, local experts should be consulted to determine which zones are present. Following is a brief description of each zone.

Toe zone—This zone is located below the average water elevation or baseflow. The cross-sectional area at this discharge often defines the limiting biologic condition for aquatic organisms. Typically, this is the zone of highest stress. It is vitally important to the success of any stabilization project that the toe is stabilized. Due to long inundation periods, this zone will rarely have any woody vegetation. Some areas of the Southwest, however, will have woody vegetation. Often riprap or another type of inert protection is required to stabilize this zone.

Bank zone—The bank zone is located between the average water elevation and the bankfull discharge elevation. While it is generally in a less erosive environment than the toe zone, it is potentially exposed to wet and dry cycles, ice scour, debris deposition, and freeze-thaw cycles. The bank zone is generally vegetated with early colonizing herbaceous species and flexible stemmed woody plants such as willow, dogwood, elderberry, and low shrubs. Sediment transport typically becomes an issue for flows in this zone, especially for alluvial channels.

Bankfull channel elevation—Bankfull stage is typically defined at a point where the width-to-depth ratio is at a minimum. Practitioners use other consistent morphological indices to aid in its identification. Often, the flow at the bankfull stage has a recurrence interval of 1.5 years. Due to the high velocities and frequent inundation, some high risk streambank soil bioengineering projects frequently incorporate hard structural elements, such as rock, below this elevation. Where there is a low tolerance for movement, many projects rely on inert or hard elements in this zone.

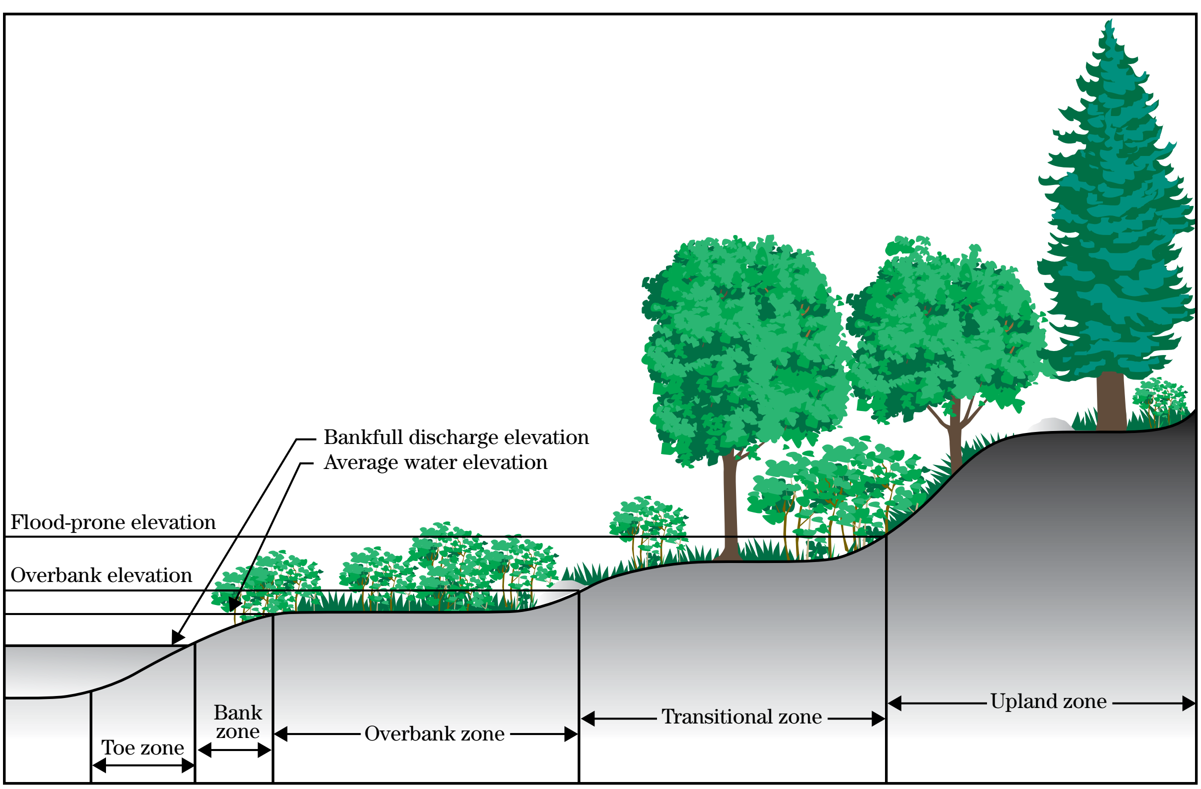
Bankfull flow is often considered to be synonymous with channel-forming discharge in stable channels and is used in some channel classification systems, as well as for an initial determination of main channel dimensions, plan, and profile. In many situations, the channel velocity begins to approach a maximum at bankfull stage. In some cases, on wide, flat flood plains, channel velocity can drop as the stream overtops its bank and the flow spills onto the flood plain. In this situation, it may be appropriate to use the bankfull hydraulic conditions to assess stability and select and design streambank protection. However, when the flood plain is narrower or obstructed, channel velocities may continue to increase with rising stage. As a result, it may also be appropriate to use a discharge greater than bankfull discharge to select and design streambank protection treatments. A further description of bankfull discharge is provided in NEH654.05.

Overbank zone—This zone is located above the bankfull discharge elevation. This typically flat zone may be formed from sediment deposition. It is sporadically flooded, usually about every 2 to 5 years. Vegetation found in this zone is generally flood tolerant and may have a high percentage of hydrophytic plants. Shrubby willow with flexible stems, dogwoods, alder, birch, and others may be found in this zone. Larger willows, cottonwoods, and other trees may be found in the upper end of this zone.

Transitional zone—The transitional zone is located between the overbank elevation and the flood-prone elevation. This zone may only be inundated every 50 years. Therefore, it is not exposed to high velocities except during high-water events. Larger upland species predominate in this zone. Since it is infrequently flooded, the plants in this zone need not be especially flood tolerant.

Upland zone—This zone is found above the flood-prone elevation. Erosion in this zone is typically due to overland water flow, wind erosion, improper farming

Figure TS14I–1 Riparian plant zones indicate where different riparian plant species should be planted



practices, logging, development, overgrazing, and urbanization. Under natural conditions the upland zone is typically vegetated with upland species.

Defining and managing risks

Streambank soil bioengineering offers a broad-based approach to solving many stream problems. However, it is not appropriate for all sites and situations and may offer a higher level of risk than conventional structures such as sheet pile or riprap. While NEH654.02 addresses risk in detail, some particular issues related to streambank soil bioengineering are described in this section.

The use of plants in a project may present problems. Those problems include failure to survive and grow, vulnerability to drought and flooding, timing of the installation, impact of soil nutrient and sunlight deficiencies on establishment success and growth, uprooting by freezing and thawing, damage by ice and debris, impact of undermining currents, damage by wildlife and livestock feeding or trampling, and need for special management measures to ensure long-term project success (modified from Allen and Leech 1997). Many of these problems can be resolved through careful planning and integration of other technologies. If care is taken in planning and design, vegetation often survives well under adverse conditions due to its flexibility and self-repairing capabilities. Some example modifications to features of a streambank soil bioengineering project are shown in table TS14I–1.

Table TS14I–1 Design modifications to account for site conditions

Issue	Concern	Possible action or design modification
Duration of inundation	Some plant species and soils cannot withstand long flooding duration	• Choose plant materials that can withstand long inundation such as willow, dogwood, or elderberry, which can withstand 1 to 6 months of inundation • Use or combine inert or soil reinforcement material in areas of prolonged inundation
Susceptibility of plant materials to disease or insects	Loss of plants could endanger the project	• Use a diversity of species in the plant mix so that the loss of one or two species will not endanger the entire treatment area • Monitor the installation regularly for the first year or two during the establishment period • Apply a fungicide or insecticide as needed to promote healthier growth
Excessive velocity	High velocities could damage or destroy the project	• Compare estimated velocity and/or shear thresholds at site to recommendations for limiting velocity and shear when selecting project type and method of repair
Increased resistance to flood levels	Increased roughness resulting from project may result in more frequent out-of-bank flows	• Choose plant material that remains supple. Avoid plant material that will be tree-like and form an obstruction to the flow • Install the vegetative treatment further up on the bank • Coordinate possible affects with flood plain regulatory authorities • Excavate floodway to account for lost conveyance
Predation by herbivores	Loss of plants could endanger the project	• Fence the project area • Fence planting areas within the project • Surround the area with vegetation that the expected herbivores do not eat • Choose plant material that they typically do not eat—thorny or otherwise unappetizing to the expected herbivores

Projects which are referred to as streambank soil bioengineering can range from those that rely almost solely on plant material to those that primarily rely on inert material to provide bank strength. A project that relies primarily on inert or hard material will be less flexible than a project that relies more on plant material for its strength. Thus, the acceptable level of risk, as well as the tolerance for additional movement at the project areas, will generally steer the project selection. Table TS14I–2 provides a general discussion of streambank stabilization project and tolerance for movement.

Determining appropriateness of treatments

Streambank soil bioengineering offers an excellent approach to solving many stream problems. However, as with any technology, it is not appropriate for all sites and situations. NEH654.03 describes site investigations that can be used to assess site characteristics. The successful application of streambank soil bioengineering presents some additional questions that should be considered before starting to work in the stream (table TS14I–3 (modified from Wells 2002)).

Limiting velocity and shear criterion

The effects of the water current on the stability of any streambank protection treatment must be considered. This evaluation includes the full range of flow conditions that can be expected during the design life of the project. Two approaches that are commonly used to express the tolerances are allowable velocity and allowable shear stress. While these two hydraulic parameters are briefly described in this technical supplement, the reader should also review NEH654.06 for more information.

Flow in a natural channel is governed in part by boundary roughness, gradient, channel shape, obstructions, and downstream water level. If the project represents a sizable investment, it may be appropriate to use a computer model such as the U.S. Army Corps of Engineers (USACE) HEC–RAS computer program (USACE 1995a) to assess the hydraulic conditions. However, if a normal depth approximation is applicable, velocity can be estimated with Manning's equation. It is important to note that this estimate will be an average channel velocity. In some situations, the velocity along the outer bank curves may be considerably larger.

Table TS14I–2 Relationships between type of streambank stabilization project and type of site

Site description	Tolerance for movement	Type of project
Eroding streambank threatening a home or municipal sewage treatment plant	None—streambank must be made static	Relies primarily on hard or inert structures, but may include a vegetative component for adjunctive support, environmental, and aesthetic benefits
Eroding streambank adjacent to a secondary road	Slight—road must be protected for moderate storms, but some movement is allowed	Rely on streambank soil bioengineering measures that incorporate hard or inert components
Eroding streambank threatening hiking trails in a park	Moderate—a natural system is desired, but movement should be slowed	May rely entirely on vegetative protection, but more likely on streambank soil bioengineering measures that incorporate some hard or inert components
Eroding streambank in rangeland	Relatively high—but erosion should be reduced	Rely on fencing, plantings, or streambank soil bioengineering measures—perhaps ones that incorporate some hard or inert components in areas that have suffered significant damage
Erosion on a wild and scenic stream system	High—but erosion should be reduced	Do nothing or rely on plantings and vegetative streambank soil bioengineering measures

Table TS14I–3 Questions to ask before starting a streambank soil bioengineering project

Question	Issue
What is the land use conversion trend for the drainage area?	Past and future land use conversion significantly alters hydrology. Streambank protection measures of any kind may not be successful because of high stresses created by changing hydrologic conditions. The watershed, as well as the site, should be investigated. Designs should consider the effects of potentially new or altered flow, as well as sediment conditions in the watershed
Is a management plan in place and being maintained?	Locally, determine the land use in the immediate area of the site and whether the landowner has a working management plan in place. In some cases, changing the management plan (livestock grazing plan, proper farming techniques, buffer width, conservation logging techniques) may be all that is needed to allow the stream to recover on its own. This is the least expensive alternative and may have less overall impact on the stream. However, if the impact is from upstream development, this approach may have a negative impact because the erosion will continue
Is the purpose of the streambank soil bioengineering project to protect critical structures such as a home, business, or manufacturing site?	In an emergency situation, select soil bioengineering treatments that incorporate sound engineering design components into the overall design. In this case, hard or inert structures (rock, geogrid) are necessary. The use of a soil bioengineering solution can significantly improve surface protection, internal reinforcement strength, aesthetics, habitat, and water quality benefits (table TS14I–2)
Are both sides of channel unstable?	This condition may indicate that the channel is incised or that a large-scale adjustment is occurring in the stream channel, possibly from a systemwide source. These conditions can generate flash flooding, excessive velocity, and shear stress, making it difficult to establish any solution until the correct cross-sectional area and planform has been established. For more information, refer to the channel evolution model (Simon 1989) and NEH654.03
Is the channel grade stable?	If the channel bed is downcutting, any bank treatment may be ineffective without some measure taken to stabilize the grade. Headcuts, overfalls, and nickpoints are indicators of unstable channel grades (NEH654 TS14G)
Is local scour on the bends an issue?	Any bank treatment may be ineffective unless toe and bed protection can be provided below the anticipated scour depth. Depending on the event (1-, 2-, 5-, 10-year event), a general rule of thumb is to add 2 to 5 feet to the deepest depth of water at the eroding outside meander bends. This will be a rough indication of potential scour depth. Specialists need to be involved in the assessment, design, and installation (NEH654 TS14B)
What is the bank height?	When the bank is high, slope stability factors typically add complexity to the design and need to be analyzed, designed, and installed by specialists such as geotechnical engineers. The bank height generally becomes an issue above 6 feet
What is the velocity of the stream at design flows?	The ability of soil bioengineering measures to protect a streambank in part depends on the force that the water exerts on the boundary during the design event. When velocity (or shear) forces exceed a threshold for the type of treatment being considered, other measures or materials may be required in conjunction with the treatment to ensure stability. More details on this important issue are presented later in this document
What is the depth of the water?	Most woody plant species do not grow in standing water. The level and durations of frequent flooding (every 1 to 2 years) will help determine the elevation needed for toe protection and vegetative components

Table TS14I–3 Questions to ask before starting a streambank soil bioengineering project—Continued

Question	Issue
Is a noncohesive soil layer present in the slope?	Noncohesive soil layers may require special design measures. The lower in the slope the weak layer occurs, the more comprehensive the design will need to be to stabilize the bank (NEH654 TS14A)
Is bank instability due to piping or ground water sapping?	Soil bioengineering measures can assist in controlling piping and sapping. An intensive investigation into the reason for the streambank erosion is important to ensure that the actual cause is treated, instead of a symptom (NEH654 TS14A)
Will mature vegetation adversely affect the stream hydraulics?	Changes in flood elevations due to flow resistance on vegetative banks may not be allowable in some settings. This is especially true in urban areas where the stream channel is narrow and flood plains are limited
Is there a stable bank to tie into at each end of the treatment area?	Any streambank protection measure is susceptible to flanking if it is not properly tied into stable points. It is important that both the upstream and downstream ends of the treatment are well keyed-in and protected
What site conditions may inhibit plant growth?	Soil tests are recommended to determine the presence of plant establishment opportunities. Soil texture, restrictive layers, and limiting factors (pH, salts, calcic soils, alkalinity) should be evaluated. The amount and seasonal availability of water, regional extremes in temperature, wind (affects growth and survival, desiccation), and microclimate (cold pockets, solar radiation pockets, wind turbulence, and aspect) are also significant factors to be considered. In many situations, these issues may be overcome by installing native plant materials that grow in or near the area
Is there anything in the stream water or surface runoff that will inhibit plant growth?	Adverse water quality can inhibit plant growth. Check any stream monitoring records for possible problems, and investigate the watershed for sources of potential contaminants. In some cases, the use of plant materials will improve water quality
Will the site be shaded during the growing season?	If the site will be shaded, choose plant species that tolerate and thrive in shade conditions
Is there significant surface runoff from above the streambank?	Identify sources of surface runoff during the site inventory. In some cases, a diversion or waterway may need to be installed to control runoff and erosion. In other cases, vegetated soil bioengineering filter strips or constructed wetland systems can be designed to intercept and treat the water before it enters the stream
Are beaver, muskrats, moose, elk, or deer present in the area?	Browsing animals can damage the vegetation used in soil bioengineering treatments. If these animals are in the area, special precautions may be required to ensure the installations are able to establish. This is especially important during the first growing season. If established during the first year, they will continue to grow and survive. Typically, temporary plant protection measures are all that is needed
Are adequate plant materials available from the natural surrounding area or from local nurseries?	Soil bioengineering techniques require large quantities of plant materials. Locating an adequate nursery or harvesting source of plant material is essential to the success of the project. This source should be as close as possible to the site to ensure that adapted plants are used. Plants can be harvested at higher elevations and brought down to lower elevations, but do not take materials from low elevations and move them to higher elevations (Hoag 1997)
Are invasive species present in the area?	Aggressive invasive species may out-compete the soil bioengineering species and make it difficult for them to get established. It is necessary to eradicate the invasive species prior to the soil bioengineering installation

The average shear stress exerted on a channel boundary can be estimated with the equation provided below, assuming the flow is steady, uniform, and two-dimensional.

$$\tau_0 = \gamma R S_f \qquad \text{(eq. TS14I–1)}$$

where:
τ_0 = average boundary shear (lb/ft^2)
γ = specific weight of water (62.4 lb/ft^3)
R = hydraulic radius (A/P, but can be approximated as depth in wide channels)
S_f = friction slope (can be approximated as bed slope)

The local maximum shear can be up to 50 percent greater than the average shear in straight channels and larger along the outer banks of sinuous channels. Temporal maximums may also be 10 to 20 percent larger, as well. More information on the calculation of this hydraulic parameter is presented in NEH654.08.

Recommendations for limiting velocity and shear vary widely (table TS14I–4). Not all techniques presented in this technical supplement are noted in this table. However, the designer can compare techniques with similar attributes to those listed in the table to estimate the limiting shear.

The designer should proceed cautiously and not rely too heavily on these values. Judgment and experience should be weighed with the use of this information. The recommendations in table TS14I–4 were empirically determined and, therefore, are most applicable to the conditions in which they were derived. The recom-

Table TS14I–4 Compiled permissible shear stress levels for streambank soil bioengineering practices

Practice	Permissible shear stress (lb/ft^2)*	Permissible velocity (ft/s)*
Live poles (Depends on the length of the poles and nature of the soil)	Initial: 0.5 to 2 Established: 2 to 5+	Initial: 1 to 2.5 Established: 3 to 10
Live poles in woven coir TRM (Depends on installation and anchoring of coir)	Initial: 2 to 2.5 Established: 3 to 5+	Initial: 3 to 5 Established: 3 to 10
Live poles in riprap (joint planting) (Depends on riprap stability)	Initial: 3+ Established: 6 to 8+	Initial: 5 to 10+ Established: 12+
Live brush sills with rock (Depends on riprap stability)	Initial: 3+ Established: 6+	Initial: 5 to 10+ Established: 12+
Brush mattress (Depends on soil conditions and anchoring)	Initial: 0.4 to 4.2 Established: 2.8 to 8+	Initial: 3 to 4 Established: 10+
Live fascine (Very dependent on anchoring)	Initial: 1.2 to 3.1 Established: 1.4 to 3+	Initial: 5 to 8 Established: 8 to 10+
Brush layer/branch packing (Depends on soil conditions)	Initial: 0.2 to 1 Established: 2.9 to 6+	Initial: 2 to 4 Established: 10+
Live cribwall (Depends on nature of the fill (rock or earth), compaction and anchoring)	Initial: 2 to 4+ Established: 5 to 6+	Initial: 3 to 6 Established: 10 to 12
Vegetated reinforced soil slopes (VRSS) (Depends on soil conditions and anchoring)	Initial: 3 to 5 Established: 7+	Initial: 4 to 9 Established: 10+
Grass turf—bermudagrass, excellent stand (Depends on vegetation type and condition)	Established: 3.2	Established: 3 to 8
Live brush wattle fence (Depends on soil conditions and depth of stakes)	Initial: 0.2 to 2 Established: 1.0 to 5+	Initial: 1 to 2.5 Established: 3 to 10
Vertical bundles (Depends on bank conditions, anchoring, and vegetation)	Initial: 1.2 to 3 Established: 1.4 to 3+	Initial: 5 to 8 Established: 6 to 10+

* (USDA NRCS 1996b; Hoag and Fripp 2002; Fischenich 2001; Gerstgrasser 1999; Nunnally and Sotir 1997; Gray and Sotir 1996; Schiechtl and Stern 1994; USACE 1997; Florineth 1982; Schoklitsch 1937)

mendations must be scrutinized and modified according to site-specific conditions such as duration of flow, soils, temperature, debris and ice load in the stream, plant species, as well as channel shape, slope and planform. Specific cautions are also noted in the table. However, there are anecdotal reports that mature and established practices can withstand larger forces than those indicated in table TS14I–4.

Plants for soil bioengineering

Consult local expertise and guidelines when selecting the appropriate plant material. Where possible, it is best to procure harvested cuttings from areas that are similar in their location, relative to the stream. Installation will be most successful where the soil, site, and species match a nearby stable site. Harvest three or more species from three to five different locations.

Woody plants

Adventitiously rooting woody riparian plant species are used in streambank soil bioengineering treatments because they have root primordia or root buds along the entire stem. When the stems are placed in contact with soil, they sprout roots. When the stem is in contact with the air, they sprout stems and leaves. This ability to root, independent of the orientation of a stem, is a reproductive strategy of riparian plants that has developed over time in response to flooding, high stream velocities, and streambank erosion.

Many woody riparian plant species root easily from dormant live cuttings. They establish quickly and are fast-growing plants with extensive fibrous root systems. These plants are typically hardy pioneer species that can tolerate both inundation and drought conditions. The keystone species that meet these criteria are willows, cottonwoods, and shrub dogwoods. These traits allow their use in treatments such as fascines, brush mattress, brush layer, and pole cuttings. Typically, the most consistently successful rooting plants are the willow (*Salix* spp.). Data from projects nationwide indicate that shrub willows root successfully on average 40 to 100 percent of the time. Shrub dogwoods (*Cornus* spp.), on the other hand, are more variable in their rooting success, ranging from 10 to 90 percent, but more typically averaging in the 30 to 60 percent range. Rooting success of both willows and dogwoods can be affected by the timing of planting, age of the material used, handling and storage, installation procedures, and placement in the proper hydrologic regime on the streambank.

Cottonwoods and poplars (*Populus* spp.) have also been used successfully in streambank soil bioengineering. However, typical riparian species such as birches (*Betula* spp.) and alders (*Alnus* spp.) do not root well from unrooted hardwood cuttings; therefore, they are not suitable for certain soil bioengineering techniques such as poles or live stakes. They are, however, useful as rooted plant stock for many soil bioengineering measures including hedgelayers, branch packing, cribwalls, vegetated reinforced soil slopes, and live siltation construction. Additionally, these and other species can be included in a riparian seed mix or installed as rooted plants as part of the stream and riparian restoration. In some cases, a pilot study will allow wise selection of some nonstandard plant materials by testing how effectively locally available genotypes are adapted to soil and hydrologic conditions on site. Table TS14I–5 lists a number of woody species which are applicable to many of the techniques described.

Willow (*Salix* spp.)—Willows used in soil bioengineering systems are analogous to annual or short-lived perennial grasses in a seed mixture (nurse or companion crop) (figs. TS14I–2 and 14I–3). They provide a quick pioneer plant cover for soil protection. Their longevity depends on the region of the country and specific site conditions. In sunnier, more open sites or in more arid climates, willows may persist for decades. In the Northeast, willows are generally an early successional pioneer species and will decline and yield to the natural invasion of other species as shade (5 hours or less per day) develops on the site. In all cases, they prefer damp soils.

Some species develop roots from many locations along the stem, known as suckering, but some do not sucker at all. Plants are either male or female and are easily propagated asexually, thus allowing for the use of male, nonsuckering plants to avoid spreading if desired.

Dogwood (*Cornus* spp.)—Species include gray, redosier, roughleaf, alternate leafed, and silky (fig. TS14I–4). All are multistemmed shrubs that are valu-

Table TS14I–5 Woody plants with very good to excellent ability to root from dormant, unrooted cuttings and their soil bioengineering applications

Scientific name	Common name and cultivars*	Procure from	Region of adaptation**	Rooting ability	Soil bioengineering technique
Species with very good to excellent rooting ability from live hardwood material					
Populus balsamifera	Balsam poplar	Local collections	1,2,3,4,5,8,9,0,A	Very good	Live cuttings, poles
Populus deltoids	Eastern cottonwood	Local collections	1,2,3,4,5,6,7	Very good	Poles, live cuttings
Populus balsamifera ssp *trichocarpa*	Black cottonwood	Local collections	4,8,9,0,A	Very good	Poles, live cuttings
Salix alaxensis	Feltleaf willow	Local collections	A	Very good	Poles, live cuttings
Salix amygdaloides	Peachleaf willow	Local collections	1,2,3,4,5,6,7,8,9	Very good	Poles, posts, live cuttings
Salix barclayi	Barclay's willow	Local collections	A	Very good	Poles, posts, live cuttings
Salix brachycarpa	Barren Ground willow	Local collections	A	Very good	Poles, posts, live cuttings
Salix boothii	Booth's willow	Local collections	7,8,9,0	Excellent	Fascines, poles, brush mattress, brush layering, live cuttings
Salix cottetii	Bankers' Dwarf willow (cultivar)	Nursery	Introduced 1,2,3	Very good	Fascines, brush mattress, brush layering, live cuttings
Salix discolor	Pussy willow	Local collections	1,2,3,4,9	Very good	Fascines, poles, brush layering, live cuttings
Salix drummondiana	Drummond's willow	Local collections	7,8,9,0	Very good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix interior	'Greenbank' Sandbar willow (cultivar)	Nursery	1,3,4,5	Excellent	Fascines, poles, brush mattress, brush layering, live cuttings
Salix interior	Sandbar willow	Local collections	1,3,4,5	Very good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix melanopsis	Coyote willow (green stem)	Local collections	8,9,0	Excellent	Fascines, poles, brush mattress, brush layering, live cuttings
Salix eriocephala	Missouri River willow	Local collections	7,8,9,0	Very good	Fascines, poles, brush layering, live cuttings
Salix fluviatilis	'Multnomah' River willow (cultivar)	Nursery	9 (Coast only)	Excellent	Fascines, poles, brush mattress, brush layering, live cuttings
Salix fluviatilis	River willow	Local collections	9	Very good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix geyeriana	Geyer willow	Local collections	7,8,9,0	Very good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix gooddingii	'Goodding's willow	Local collections	6,7,8,0	Very good	Poles, posts, live cuttings
Salix hookeriana	Clatsop' Hooker willow (cultivar)	Nursery	9, 0 (Coast only)	Excellent	Fascines, poles, brush mattress, brush layering, live cuttings

Table TS14I–5 Woody plants with very good to excellent ability to root from dormant, unrooted cuttings and their soil bioengineering applications—Continued

Scientific name	Common name and cultivars*	Procure from	Region of adaptation**	Rooting ability	Soil bioengineering technique
Salix hookeriana	Hooker willow	Local collections	9,0	Very good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix laevigata	Red willow	Local collections	7,8,9,0	Very good	Poles, live cuttings
Salix lasiolepis	‘Rogue’ Arroyo willow (cultivar)	Nursery	9,0	Excellent	Fascines, poles, brush mattress, brush layering, live cuttings
Salix lasiolepis	Arroyo willow	Local collections	6,7,8,9,0	Very good	Poles, live cuttings
Salix lemmonii	‘Palouse’ Lemmon’s willow (cultivar)	Nursery	8,9,0	Very good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix lemmonii	Lemmon’s willow	Local collections	8,9,0	Very good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix eriocephala spp. *ligulifolia*	‘Placer’ Erect willow (cultivar)	Nursery	9,0 (Coast only)	Excellent	Fascines, poles, brush mattress, brush layering, live cuttings
Salix ligulifolia	Strapleaf willow	Local collections	8,9,0	Very good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix lucida ssp. *lasiandra*	‘Nehalem’ Pacific willow (cultivar)	Nursery	9 (Coast only)	Very good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix lucida ssp. *lasiandra*	Pacific willow	Local collections	7,8,9,0,A	Excellent	Poles, live cuttings
Salix pentandra	‘Aberdeen Selection’ Laurel willow (cultivar)	Nursery	Introduced 8,9,0	Excellent	Poles, live cuttings
Salix purpurea	‘Streamco’ Purpleosier willow (cultivar)	Nursery	Introduced 1,2,3	Excellent	Fascines, brush mattress, brush layering, live cuttings
Salix sericea	‘Riverbend Germplasm’ Silky willow (cultivar)	Nursery	1,2,3	Excellent	Fascines, poles, brush mattress, brush layering, live cuttings
Salix sericea	Silky willow	Local collections	1,2,3	Very good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix sitchensis	‘Plumas’ Sitka willow (cultivar)	Nursery	9,0 (Coast only)	Very good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix sitchensis	Sitka willow	Local collections	9,0,A	Very good	Fascines, brush mattress, brush layer
Sambucus nigra ssp. *anadensis*	Common elderberry	Local collections	1,2,3,4,5,6,8,0,A	Very good	Fascines, brush mattress, brush layering, live cuttings

Table TS14I–5 Woody plants with fair to good ability to root from dormant, unrooted cuttings and their soil bioengineering applications—Continued

Scientific name	Common name and cultivars*	Procure from	Region of adaptation**	Rooting ability	Soil bioengineering technique
Species with fair to good rooting ability from live hardwood material					
Baccharis pilularis	'Coyote' brush	Local collections	7,9,0	Fair	Fascines, brush mattress, brush layering, live cuttings
Baccharis salicifolia	Mule's Fat	Local collections	6,7,8,0	Fair	Fascines, brush mattress, brush layering, live cuttings
Cephalanthus occidentalis	'Keystone' Common Button-bush (cultivar)	Nursery	1,2,3,5,6,7,0	Good	brush mattress, brush layering, Fascines
Cephalanthus occidentalis	Common buttonbush	Local collections	1,2,3,5,6,7,0	Fair	brush mattress, brush layering, Fascines
Cornus amomum	'Indigo' Silky dogwood (cultivar)	Nursery	1,2,3,4,5,6	Good	Fascines, brush mattress, brush layering, live cuttings
Cornus amomum	Silky dogwood	Local collections	1,2,3,4,5,6	Fair	Fascines, brush mattress, brush layering, live cuttings
Cornus sericea	'Ruby' Redosier dogwood (cultivar)	Nursery	1,3,4,5,7,8,9,0,A	Good	Fascines, brush mattress, brush layering, live cuttings
Cornus sericea	Redosier dogwood	Local collections	1,3,4,5,7,8,9,0,A	Fair	Fascines, brush mattress, brush layering, live cuttings
Cornus sericea ssp. *occidentalis*	'Mason' Western Redosier dogwood (cultivar)	Nursery	9,0 (Coast only)	Good	Fascines, brush mattress, brush layering, live cuttings
Cornus sericea ssp. *occidentalis*	Western Redosier dogwood	Local collections	9,0,A	Good	Fascines, brush mattress, brush layering, live cuttings
Lonicera involucrate	Black Twinberry	Local collections	3,7,8,9,0,A	Fair	Fascines, brush layering, live cuttings
Philadelphus lewisii	'Lewis' Mock-orange	Local collections	9,0	Fair	Fascines, live cuttings
Physocarpus capitatus	Pacific ninebark	Local collections	9 (Coast only)	Fair	Fascines, brush layering, live cuttings
Physocarpus opulifolius	Common ninebark	Local collections	1,2,3,4,5	Fair	Fascines, brush mattress, brush layering, live cuttings
Populus angustifolia	Narrowleaf cottonwood	Local collections	4,5,6,7,8,9,0	Fair	Poles, live cuttings
Populus fremontii	Fremont cottonwood	Local collections	6,7,8,0	Fair	Poles, live cuttings
Rubus spectabilis	Salmonberry	Local collections	8,9,0	Fair	Fascines, live cuttings
Salix alba	White willow	Local collections	introduced 1,2,3,4	Fair	Poles, posts, live cuttings
Salix bebbiana	Bebb willow	Local collections	1,3,4,5,7,8,9,0,A	Fair	Poles, live cuttings

Table TS14I–5 Woody plants with fair to good ability to root from dormant, unrooted cuttings and their soil bioengineering applications—Continued

Scientific name	Common name and cultivars*	Procure from	Region of adaptation**	Rooting ability	Soil bioengineering technique
Salix humilis	Prairie willow	Local collections	1,2,3,4,5,6	Fair	Fascines, poles, brush mattress, brush layering, live cuttings
Salix drummondiana	'Curlew' Drummond's willow (cultivar)	Nursery	7,8,9,0	Good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix drummondiana	Drummond's willow	Local collections	7,8,9,0	Fair	Fascines, poles, brush mattress, brush layering, live cuttings
Salix exigua	'Silvar' Coyote willow (cultivar)	Nursery	6,7,8,9,0,A	Good	Fascines, poles, brush mattress, brush layering, live cuttings
Salix exigua sp interior	Sandbar willow (grey stem)	Local collections	6,7,8,9	Fair	Fascines, live cuttings, poles, brush mattress, brush layering
Salix lucida	Shining willow	Local collections	1,3,4,5,7,8,9,0,A	Fair	Fascines, poles, brush mattress, brush layering, live cuttings
Salix lutea	Yellow willow	Local collections	4,5,7,8,9,0	Fair	Fascines, poles, brush mattress, brush layering, live cuttings
Salix nigra	Black willow	Local collections	1,2,3,5,6	Fair	Fascines, poles, brush mattress, brush layering, live cuttings
Salix planifolia	Plainleaf willow	Local collections	1,3,4,5,7,8,9,0,A	Fair	Fascines, poles, brush mattress, brush layering, live cuttings
Salix prolixa	'Rivar' Mackenzie's willow (cultivar)	Nursery	8,9,0,A	Good	Poles, live cuttings
Salix prolixa	Mackenzie's willow	Local collections	8,9,0,A	Fair	Poles, live cuttings
Salix scouleriana	Scouler's willow	Local collections	9,0 (Coast only)	Fair	Fascines, poles, brush mattress, brush layering, live cuttings
Sambucus racemosa	Red elderberry	Local collections	9	Fair	Brush layering, live cuttings
Spiraea douglasii	'Bashaw' Douglas Spirea (cultivar)	Nursery	9 (Coast only)	Fair	Fascines, brush mattress, brush layering, live cuttings
Spiraea douglasii	Douglas Spirea	Local collections	0,9	Fair	Fascines, brush mattress, brush layering, live cuttings
Symphoricarpos albus	Common snowberry	Local collections	9 (Coast only)	Fair	Fascines, brush mattress, brush layering, live cuttings

Table TS14I–5 Woody plants with fair to good ability to root from dormant, unrooted cuttings and their soil bioengineering applications—Continued

Scientific name	Common name and cultivars*	Procure from	Region of adaptation**	Rooting ability	Soil bioengineering technique
Caribbean area					
Batis maritima	Barilla, Saltwort	Local collections	C,H	Good	Brush mattress, brush layering, live cuttings
Bucida buceras	úcar, gregre	Local collections	C	Fair	Poles, live cuttings
Bursera simaruba	almácigo, turpentine tree	Local collections	C	Good	Poles, live cuttings
Clusia rosea	Cupey	Local collections	C,H	Good	Pole, live cuttings
Commelina ssp.	Cihítre	Local collections	C	Good	Brush mattress, brush layering, live cuttings
Cordia sebestenea	Vomitel, geiger tree	Local collections	C,H	Fair	Poles, live cuttings
Erythrina poeppigiana	Bucayo, bucare, mountain immortale	Local collections	C,H	Good	Poles, live cuttings
Glyricidia sepium	Mata ratón, Glyricidia	Local collections	C,H	Good	Poles, live cuttings
Hibiscus spp.	Hibiscos	Local collections	C,H	Good	Fascines, poles, brush mattress, brush layering, live cuttings
Hymenocallis caribaea	Lirio blanco, Spyder lilly	Local collections	C	Fair	Brush mattress, brush layering, live cuttings
Lagerstroemia indica	Astromelia	Local collections	C	Good	Fascines, poles, brush mattress, brush layering, live cuttings
Mangrove species	(Rhizophora, Avicenia, Conocarpus)	Local collections	C,H	Good	Pole, live cuttings
Nicolaia elatior	Flor de cera, Torch ginger	Local collections	C	Fair	Brush mattress, brush layering, live cuttings
Pictetia aculeata	Fustic	Local collections	C	Fair	Fascines, poles, brush mattress, brush layering, live cuttings
Rhoeo spathacea	Sanguinaria	Local collections	C,H	Good	Brush mattress, brush layering, live cuttings
Sansevieria hyacinthoides	Lengua de chucho, sweet Sansevieria	Local collections	C	Good	Brush mattress, brush layering, live cuttings
Sphagneticola trilobata	Margarita, Bay Biscayne creeping oxeye	Local collections	C	Fair	Brush mattress, brush layering, live cuttings
Zingiber spp.	Jengibre, Ginger	Local collections	C, H	Fair	Fascines, poles, brush mattress, brush layering, live cuttings
Cordyline terminalis	Ti	Local collections	H	Good	Live cuttings, poles
Polyscias guifoylei	Panax	Local collections	H	Good	Live cuttings, poles

Table TS14I–5 Woody plants with fair to good ability to root from dormant, unrooted cuttings and their soil bioengineering applications—Continued

Scientific name	Common name and cultivars*	Procure from	Region of adaptation**	Rooting ability	Soil bioengineering technique
Erythrina variegate	Tropic Coral' Tall Erythrina (cultivar)	Nursery	H	Good	Live cuttings, poles

**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

A–Alaska
C–Caribbean
H–Hawaii

*Cultivar
The NRCS Plant Materials Program is responsible to locating native species to address conservation problems

Once a species is identified, the Plant Material Centers make multiple collections of this species, plant them out, compare them against each other, select the best ones, and release them to the public market.

The release notice describes where the cultivar was collected and how and where it was tested. This release notice, or pedigree, also explains how the cultivar performed in various soil series, precipitation zones, and provides other information regarding its growing requirements

Figure TS14I–2 *Salix exigua* ssp. *exigua* (Coyote willow)

Figure TS14I–3 *Salix amygdaloides* (Peachtree willow)

Figure TS14I–4 *Cornus sericea* (Redosier dogwood)

able to wildlife as fruit producers and are adapted to most soil conditions including wetter sites. Gray dogwoods prefer drier sites. The shrubs spread through bird activity, branch layering, wounding, and root suckering. Dogwoods generally persist longer than willows because of their shade tolerance. Some practitioners apply rooting hormone to stimulate development from cuttings of dogwood and some other species, while others find that this is not cost-effective, and may be counterproductive to long-term, successful survival.

Redosier and silky dogwoods both perform excellent when used in soil bioengineering techniques. Gray dogwood, while excellent for wildlife, is a multistemmed clone and does not always perform well when used in soil bioengineering techniques. Roughleaf and alternated leafed dogwood also do not perform well in soil bioengineering techniques.

Cottonwoods and poplars (*Populus* spp.)—Numerous native cottonwoods exist and are suitable to a range of settings. Species include black, narrowleaf, Fremont and Eastern cottonwoods, and balsam poplar. All are trees that typically inhabit coarse-textured soils that are periodically flooded such as flood plains and streambanks. Unlike willows, cottonwoods may require periodic phases of dry soils. Black cottonwood (fig. TS14I–5) occurs with whiplash and yellow willow on coarse, well-drained soils that flood periodically. Narrowleaf cottonwood (fig. TS14I–6) is found at slightly higher elevations with redosier dogwood and alder and prefers coarse-textured, wet sites that drain quickly. Hardwood cuttings should be taken from sections with smooth bark, rather than older, deeper furrowed branches, as these stem tissues generate more roots and shoots from active nodes. The live cuttings should be generally tapered from the bottom to the top. If a tree form is needed, do not cut the top apical bud off; strip off all but the top five to six buds from the pole. Cutting the top off will cause the resulting cottonwood to be more shrub-like than tree-like.

Size and form

Hardwood propagation is defined as a cutting taken from a mature woody stem for the purpose of propagation. Hardwood cuttings are made from branches, stems, or trunks. They are collected when the plants are dormant. Dormant hardwood cuttings can be divided into four general categories.

- whips
- bundles
- poles or live stakes
- post cuttings

Whips are typically the current year's growth or 1-year-old materials. Because of their small size, they should generally not be used in drier areas or areas without consistent deep watering. Pole cuttings or live stakes can be fabricated from shrub and tree species and usually range in diameter from 3/4 to 2 inches. All leaves are removed from pole cuttings and live stakes. Essentially, pole cuttings and live stakes are the same materials. Post cuttings are much larger and are taken from large shrub and tree species and range in diameter from 3 to 6 inches. Bundles are packages of smaller diameter cuttings from various species with the branches left intact.

Collection and preparation

Field identification of plant species for collection can be difficult during the dormant season, and willows, in particular, are notoriously challenging. Most field guides for trees and shrubs rely mainly on characteristics such as leaves and flowers that are observable during the growing season. A fruit and twig key can supplement a field guide in attempting to make a determination. Alternatively, source material can be located and identified in advance, preferably when leaves and other readily distinguishing features are visible. However, for most projects, precise species identification is unnecessary. Usually determining what the general plant group is (willow vs. alder), where it is growing, what the soils are, and what the water regime is will be sufficient to allow for collection of suitable materials.

Most species should be harvested when the plants are dormant or entering dormancy. This is typically in the late fall to early spring, after leaves fall and before the buds swell. Choose and harvest healthy material that is free of splits, rot, disease, and insect infestation. While it is often appropriate to include material that ranges in age up to 7 years, material should be harvested from plants that are at least 2 years old. In drier areas, current year's growth to 1-year-old stock should not be used. This younger material is often too small and does not have enough stored energy for good root establishment, and its small diameter makes it prone to drying. Harvesting of live materials should leave at

Figure TS14I–5 *Populus balsamifera* ssp. *trichrocarpa* (Black cottonwood)

Figure TS14I–6 *Populus angustifolia* (Narrowleaf cottonwood)

least a third of the parent plant intact. The equipment should be sharp to make clean cuts.

The amount of time required for cutting, bundling, transporting, and handling woody branch materials is highly dependent on a number of variables. With reasonably good access, one person can collect over 200 stems per hour. Frequently, finding the targeted plants, locating suitably sized materials, and carrying them in tied bundles back to the vehicle is a complicated and slow process, in which case, the production rate can be a mere 10 stems per hour. Finding and collecting large-sized materials typically requires more time per stem than does smaller diameter brush cuttings. Many willows grow in large stands, while most other species will be spread out and be mixed in with other species, reducing production rates. If the people performing the cutting work cannot correctly identify plant materials, a skilled botanist or forester must be supplied for that process.

Soaking the material is desirable. Soaking hydrates the stem and starts swelling the root primordia. The roots will start to emerge from the bark in 15 to 30 days depending on the species and temperature. The optimum time for soaking is 14 days. Alternatively, live cuttings can be installed the same day they are harvested. If it is necessary to harvest material significantly before installation, the live cuttings should be stored dry, but in 50 to 90 percent humidity at approximately 33 to 40 degrees Fahrenheit. Hardwood cuttings can last up to 4 months if refrigerated under continuous, cold conditions. Material that has been stored cold and dry should be rehydrated by soaking before planting. Limited mold growth may occur and is usually tolerated without compromising the viability of the cuttings. If the harvested material is stored under wet conditions for longer than 10 days, the rooting process may start. These initial roots are typically tender, making it difficult to use the material without breaking or damaging them.

Table TS14I–5 provides information about plant species associated with soil bioengineering techniques. The information is based on the expertise of soil bioengineering practitioners. Table TS14I–5 lists plant species and their performance as dormant, unrooted, hardwood cuttings. The performance of a species in any given technique may vary from that listed in the chart based on many factors. When selecting the soil bioengineering techniques, it is important to have a clear understanding of ecological influences of the area. Plant selection and the soil bioengineering techniques used will play a role in site stabilization and will create the foundation for the ecological restoration of the site. When planning a project, the practitioner should consider using plant species that could be planted as seeds or seedlings, in addition to dormant, unrooted hardwood cuttings to enhance the restoration process. There are many soil bioengineering techniques not listed in table TS14I–5 due to their consideration as an adaptation to the basic techniques.

Herbaceous plants

Soil bioengineering also uses grasses, legumes, and forbs for streambank stabilization. These plants are typically applied in a seed mix under erosion control fabric. With adequate moisture they sprout quickly and put out root systems that hold soil in place. Table TS14I–6 lists a number of grass, legumes, and forbs species that are useful in soil bioengineering projects.

USDA NRCS Plant Materials Program: Plant development for streambank stabilization

The USDA NRCS Plant Materials Program is a nationwide network of 26 Plant Materials Centers (PMC). The PMCs service area boundaries are ecologically distinct. The PMCs evaluate plants for specific conservation traits, select top performers, and make these materials available to the public as conservation plant releases. The PMCs also develop innovative ways for land managers to use and manage a variety of conservation plants. Specialists relay information about new plant releases and offer on-the-ground assistance with conservation plantings. The Plant Materials Program evaluates streambank stabilization species based primarily on the following criteria:

- rooting/layering ability
- growth rate
- branching density
- disease resistance

Table TS14I–6 Grasses, legumes, and forbs for soil bioengineering systems

Scientific name	Common name	Region/ wetland status	Soil	Shade tolerance	Drought tolerance	Flood tolerance
Ammophila breviligulata	American beachgrass	1, facu 2, upl 3, upl*	Sands	Poor	Fair	Poor
Andropogon gerardii	Big bluestem	1, fac 2, fac 3, fac- 4, facu 5, fac- 6, facu 7, fac- 8, facu 9, facu	Loams	Poor	Good	Fair
Beckmannia Syzigachne	Sloughgrass	1, obl 3, obl 4, obl 5, obl 7, obl	Silt	Poor	Poor	Good
Calamagrostis canadensis	Blue-joint reedgrass	1, facw+ 2, obl 3, obl 4, facw+ 5, obl 7, obl 8, obl 9, facw+ 0, facw+	Silt	Poor	Poor	Good
Carex aquatilis	Water sedge	1, obl 3, obl 4, obl 5, obl 7, obl 8, obl 9, obl 0, obl	Silt	Poor	Poor	Good
Carex nebrascensis	Nebraska sedge	3, obl 4, obl 5, obl 7, obl 8, obl 9, obl 0, obl	Silt	Poor	Poor	Good
Carex utriculata	Beaked sedge	A, obl	Silt	Poor	Poor	Good

Table TS14I–6 Grasses, legumes, and forbs for soil bioengineering systems—Continued

Scientific name	Common name	Region/ wetland status	Soil	Shade tolerance	Drought tolerance	Flood tolerance
Deschampsia caespitosa	Tufted hairgrass	1, facw 2, facw 3, facw+ 4, facw 7, facw- 8, facw 9, facw 0, facw A, fac	Loam	Poor	Poor	Good
Distichlis spicata var.*stricta*	Inland saltgrass	8, fac+* 9, fac+ 0, facw*	Loam	Good	Good	Good
Eleocharis palustris	Creeping spikerush	1, obl 2, obl 3, obl 4, obl 5, obl 6, obl 7, obl 8, obl 9, obl 0, obl A, obl	Silt	Poor	Poor	Good
Elymus lanceolatus	Streambank wheatgrass	3, facu- 4, fac 5, fac 7, fac 8, upl 9, facu- A, upl	Loam	Fair	Fair	Fair
Elymus virginicus	Wildrye	1, facw- 2, fac 3, facw- 4, fac 5, fac 6, fac 7, facw 8, facw 9, facw	Loams	Good	Fair	Good
Elytrigia elongate	Tall wheatgrass	3, fac 4, fac 5, fac 8, fac	Loam	Fair	Fair	Good

Table TS14I–6 Grasses, legumes, and forbs for soil bioengineering systems—Continued

Scientific name	Common name	Region/ wetland status	Soil	Shade tolerance	Drought tolerance	Flood tolerance
Elytrigia intermedia	Intermediate wheatgrass	2, facu 3, facu	Loam	Fair	Fair	Fair
Eragrostis trichodes	Sand lovegrass		Sands	Poor	Good	Poor
Festuca rubra	Red fescue	1, facu 2, facu+ 3, fac- 5, fac 6, fac* 7, facw- 8, fac 9, fac 0, fac A, fac	Loams	Good	Good	Fair
Hemarthria altissima	Limpograss	6, facw	Sandy	Poor	Poor	Good
Glyceria striata	Mannagrass	1-9, obl 0,A, obl	Silt	Fair	Fair	Good
Juncus balticus	Baltic rush	1, facw+ 3, obl 4, obl 5, obl 6, obl 7, obl 8, facw 9, obl 0, obl A, obl	Silt	Good	Good	Good
Juncus mertensianus	Merten's rush	7, obl 8, obl* 9, obl 0, obl A, obl	Silt	Fair	Fair	Good

Table TS14I–6 Grasses, legumes, and forbs for soil bioengineering systems—Continued

Scientific name	Common name	Region/ wetland status	Soil	Shade tolerance	Drought tolerance	Flood tolerance
Juncus tenuis	Poverty rush	1, fac- 2, fac 3, fac 4, fac 5, fac 6, fac 7, facw- 8, fac 9, fac 0, fac A, facw C, obl H, fac+	Silt	Fair	Fair	Fair
Panicum	Coastal	1, facu- 2, fac	Sands to	Poor	Good	Good
Amarulum	Panicgrass	6, facu-	loams			
Panicum virgatum	Switchgrass	1, fac 2, fac+ 3, fac+ 4, fac 5, fac 6, facw 7, fac+ 8, fac 9, fac+ H, upl	Loams to sands	Poor	Good	Good
Pascopyrum smithii	Western wheatgrass	1, upl 2, facu 3, facu+ 4, facu 5, facu 6, fac- 7, fac- 8, facu 9, facu 0, fac- A, upl	Loam	Good	Good	Good
Paspalum vaginatum	Seashore paspalum	2, obl 6, facw* C, obl H, facw+	Sandy	Poor	Good	

Table TS14I–6 Grasses, legumes, and forbs for soil bioengineering systems—Continued

Scientific name	Common name	Region/ wetland status	Soil	Shade tolerance	Drought tolerance	Flood tolerance
Puccinellia nuttalliana	Alkaligrass	1, fac 3, obl 4, obl 5, obl 7, obl 8, obl 9, obl 0, obl A, facw	Loam	Good	Good	Good
Schizachyrium scoparium	Little bluestem	1, facu- 2, facu 3, facu- 4, facu 5, facu 6, facu+ 7, facu 8, facu 9, facu	Sands to loams	Poor	Good	Poor
Scirpus acutus	Hard-stem bulrush	1, obl 2, obl 3, obl 4, obl 5, obl 6, obl 7, obl 8, obl 9, obl 0, obl	Silt	Poor	Poor	Good
Scirpus maritimus	Cosmopolitan bulrush	1, obl 9, obl 0, obl H, obl	Silt	Good	Good	Good
Scirpus pungens	Common three-square	1, facw+ 2, obl 4, obl 5, obl 6, obl 7, obl 8, obl 9, obl 0, obl	Silt	Fair	Fair	Good
Sorghastrum nutans	Indiangrass	1, upl 2, facu 3, facu+ 4, facu 5, facu 6, facu 7, upl 8, facw	Sands to loam	Fair	Fair	Poor

Table TS14I–6 Grasses, legumes, and forbs for soil bioengineering systems—Continued

Scientific name	Common name	Region/ wetland status	Soil	Shade tolerance	Drought tolerance	Flood tolerance
Spartina pectinata	Prairie cordgrass	1, obl 2, obl 3, facw+ 4, facw 5, facw 6, facw+ 7, facw 8, obl 9, obl	Silt	Fair	Fair	Good
Verbena hastate	Blue vervain Swamp verbena	1, facw+ 2, fac 3, facw+ 4, facw 5, facw 8, facw 9, fac+ 0, facw	Loam	Fair	Fair	Fair
Zizaniopsis miliacea	Giant cutgrass	1, obl 2, obl 3, obl 6, obl	Loam	Poor	Poor	Good

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
H–Hawaii

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 natural conditions in wetlands
upl Obligate upland—Occur almost always (99%) under natural conditions in nonwetlands

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 indicator status

Purchasing plant materials

Collection of plant materials in the wild typically results in a good match of locally adapted plants that are available at modest cost. However, this is not always possible, and if local materials are in short supply or are not available or are unsuitable, nursery-grown material can be used instead. An increasing number of nurseries grow cultivars specifically developed for streambank stabilization/soil bioengineering by the NRCS Plant Materials Program. Some nurseries have blocks of plants available on their site, and the customer cuts it themselves and pays by the pound or per stem for the cuttings. Other nurseries offer cuttings suitable for use as pole cuttings, fascines, brush layers, or other applications, and these are priced and sold by the unit. The practitioner should coordinate with the nursery in advance so that these plants match the desired specifications for the project. It is frequently necessary to reserve plant materials in advance by placing a deposit or by arranging to contract-grow or cut the desired materials, including both woody and herbaceous plants. Species selected from nursery-grown stock should be appropriate for the plant hardiness zone (fig. TS14I–7) in which the project occurs. Nurseries sell materials that are grown elsewhere in the country, so it is important to know the provenance of the plant materials or seed that are being purchased.

Bareroot plants

Bareroot trees and shrubs are commonly grown by native-plant nurseries. This form of plant is useful both as direct plantings and when used in selected soil bioengineering measures. Bareroot materials are economical and easy to store, transport, and install. When purchasing bareroot plants, select good quality seedlings with a height of at least 18 inches and a root collar of 3/8 inch. Plants should be firm, and the growing layer underneath the bark should be green. This is tested by scratching off a small area of the bark. The plants should have a substantial root mass about equal in size to the rest of the plant.

Proper storage and handling of bareroot materials is critical to ensure viability. Bareroot plants can be stored for months prior to planting as long as the roots do not dry out, or freeze, and the plant does not leaf out. Store bareroot plants in a cool, damp, dark location. Moist materials such as sawdust, shredded newspaper, long straw or soil can be placed around the plants to prevent the roots from drying out.

Dehydration of the roots is one of the main causes for poor performance. In addition to keeping the roots moist during storage and handling, it is important to ensure good soil-to-root contact, once installed. The use of root gels and absorbent polymers, such as Terra-Sorb®, increase survival rates in drier, coarser textured soils.

Containerized plants

Containerized plants are the most expensive and cumbersome restoration materials, but they have the highest survival rate. Seedlings are grown in containers that vary in size and shape. Each container holds a seedling, soil, and nutrients. These containerized seedlings are planted whenever the soil is unfrozen. Spring and fall are generally the best times. Containerized seedlings have not experienced the root trauma of bareroot stock when they are harvested. Generally, containerized plants have a higher survival rate than bareroot and a lower cost per surviving seedling. They are easier to hand-plant, and they store better and for longer periods than bareroot plants. The use of container stock extends the season for soil bioengineering.

The practitioner should carefully inspect containerized plants prior to accepting delivery. Remove several plants from their pots, and check the roots to be sure they are white and fibrous and conform to the shape of the container. Plants with large, thick, circling roots indicate that the plant has outgrown its container. These need to be rejected and removed from the job site. Conversely, if a significant amount of soil spills out from the pot, revealing a root system that does not conform to the shape of the container, then the plant is too small for the container and should be rejected and removed from the job site.

Plants should be vigorous, healthy, and free of damage to the roots and branches. Containerized plants should also be free of insect infestation, disease, sun-scald, disfigurement, and abrasion. Healthy plant materials are most able to tolerate less than ideal conditions and survive on a restoration site.

Figure TS14I–7 USDA plant hardiness zone map and key

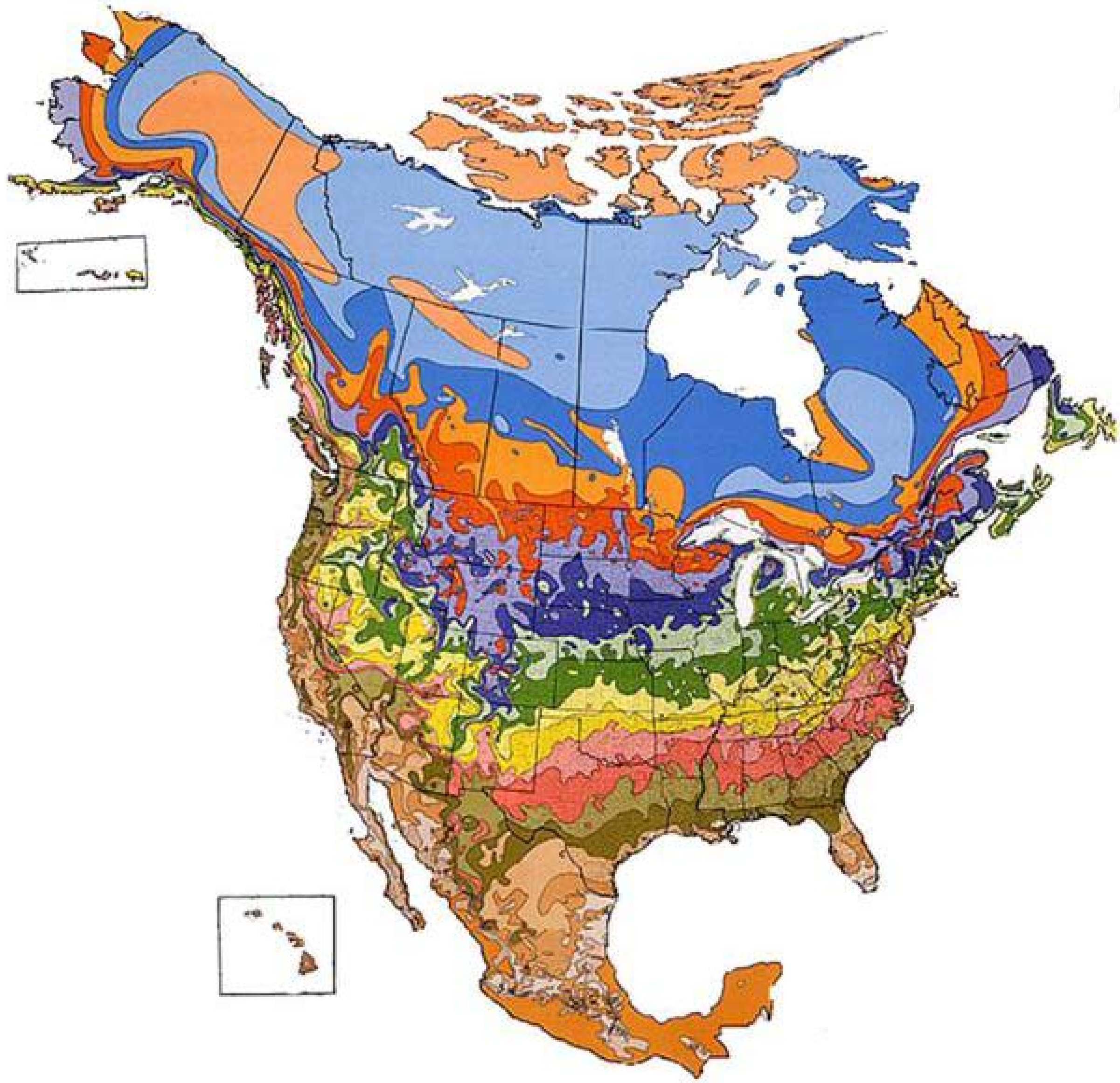


Figure TS14I–7 USDA plant hardiness zone map and key—Continued

USDA zone	Temperature range	Example cities
1	Below -50 F (-45.6 C)	Fairbanks, Alaska Resolute, Northwest Territories (Canada)
2a	-50 to -45 F (-42.8 to -45.5 C)	Prudhoe Bay, Alaska Flin Flon, Manitoba (Canada)
2b	-45 to -40 F (-40.0 to -42.7 C)	Unalakleet, Alaska Pinecreek, Minnesota
3a	-40 to -35 F (-37.3 to -39.9 C)	International Falls, Minnesota St. Michael, Alaska
3b	-35 to -30 F (-34.5 to -37.2 C)	Tomahawk, Wisconsin Sidney, Montana
4a	-30 to -25 F (-31.7 to -34.4 C)	Minneapolis/St.Paul, Minnesota Lewistown, Montana
4b	-25 to -20 F (-28.9 to -31.6 C)	Northwood, Iowa Nebraska
5a	-20 to -15 F (-26.2 to -28.8 C)	Des Moines, Iowa Illinois
5b	-15 to -10 F (-23.4 to -26.1 C)	Columbia, Missouri Mansfield, Pennsylvania
6a	-10 to -5 F (-20.6 to -23.3 C)	St. Louis, Missouri Lebanon, Pennsylvania
6b	-5 to 0 F (-17.8 to -20.5 C)	McMinnville, Tennessee Branson, Missouri
7a	0 to 5 F (-15.0 to -17.7 C)	Oklahoma City, Oklahoma South Boston, Virginia
7b	5 to 10 F (-12.3 to -14.9 C)	Little Rock, Arkansas Griffin, Georgia
8a	10 to 15 F (-9.5 to -12.2 C)	Tifton, Georgia Dallas, Texas
8b	15 to 20 F (-6.7 to -9.4 C)	Austin, Texas Gainesville, Florida
9a	20 to 25 F (-3.9 to -6.6 C)	Houston, Texas St. Augustine, Florida
9b	25 to 30 F (-1.2 to -3.8 C)	Brownsville, Texas Fort Pierce, Florida
10a	30 to 35 F (1.6 to -1.1 C)	Naples, Florida Barstow, California
10b	35 to 40 F (4.4 to 1.7 C)	Miami, Florida Coral Gables, Florida
11	above 40 F (4.5 C)	Honolulu, Hawaii Mazatlan, Mexico

The 1998 Web version of the 1990 USDA Plant Hardiness Zone Map

Balled and burlapped material

Balled and burlapped (B&B) plants can be expensive and cumbersome to establish. However, they provide a larger, more robust plant that is big enough to give some structure to a new planting. B&B trees can provide immediate cover for wildlife, and they moderate hydrology, and protect streambanks. They are used on eroding salmonid streams to reestablish the habitat functions more rapidly.

B&B plants are dug, and the root mass is wrapped in burlap to keep the soil on the roots. They should have solid root balls with enough of the root systems present to support the top growth of the plants. Ensure that the grower has harvested sufficient root mass to support the aboveground biomass.

Before B&B plants are set in the planting hole, it is recommended that the burlap be totally removed to ensure that the roots are allowed to grow uninhibited. B&B plants will need to be braced with supports for the first season until the root system has grown and spread enough to support the tree on its own.

Streambank soil bioengineering techniques

Many types of streambank soil bioengineering treatments have been used throughout the country. A collection of techniques that are broadly applicable have been divided into sections that address the different bank zones.

It is appropriate to modify these treatments to account for site-specific conditions, cost of materials, and material availability. Many variations of these techniques exist. Many of the techniques listed are often combined with other streambank soil bioengineering techniques or with harder, inert structures.

Toe treatments

Coir fascines

This is a manufactured product also known as coir logs or coconut fiber rolls (figs. TS14I–8 and TS14I–9). Coir fascines consist of coconut husk fibers bound together in a cylindrical bundle by natural or synthetic netting and are manufactured in a variety of standard lengths, diameters, and fill densities for different energy environments. Coir fascines are flexible and can be fitted to the existing curvature of a streambank. They provide immediate toe protection and bank stabilization, while trapping sediment within the coir fascine, which encourages plant growth. Coir fascines are well suited for establishing herbaceous materials, and they can be prevegetated prior to installation. A key advantage of this method is the modularization and standardization of the materials that result in relatively predictable and reliable performance. A disadvantage of coir fascines is that they are expensive to purchase and ship. They require additional anchoring systems, which increases the initial costs and installation time.

Materials

- Fascines fabricated from and filled with 100 percent coir (coconut husk) are preferred for streambank stabilization work because they serve as a stable growing medium on which seeds and young plants can become established. This material provides some resistance to damage from ice flows, floating debris, and other impacts, and provides a reinforcing framework for vegetation until the coir filling decays, at which point the plants should be able to protect the banks.
- For most settings, high tensile strength (minimum 200 lb tensile strength) synthetic mesh is desirable for the knotted or braided mesh exterior of the coir fascine. Although coir mesh versions are available, the mesh frequently loses its strength before vegetation can become fully established, making the material vulnerable to failure. Therefore, coir mesh versions are typically used on sites with low stress levels.
- The most sturdy and resistant coir fascines are manufactured with a density of 9 pounds per cubic foot. Where ice, debris, steep banks, and other stress factors are not a problem, lower density materials may offer a more cost-effective alternative.
- The most commonly used size is 12-inch diameter, although they are available in both larger and smaller sizes.
- Coir fascines are typically anchored with wooden stakes or earth anchors with cable assemblies. Soil anchor design and installation are addressed in more detail in NEH654 TS14E.

Figure TS14I–8 Installation of coir fascines: (a) Anchoring; (b) Tying of the coir fascines together (*Photos courtesy of Robbin B. Sotir & Associates, Inc.*)

(a) (b)

Figure TS14I–9 Stacked coir fascines using woody vegetation (*Photo courtesy of Hollis Allen*)

Installation

- Coir fascines may be installed during any season, provided that the ground can be worked adequately for placement and anchoring. Planting into the coir fascine may be planned for later in a more desirable season, as needed.
- Coir fascines can either be placed so that they help position the toe of a bank, where it was located prior to an erosion event, or in direct contact with the current bank profile. Typically, they are positioned so that the top of the coir fascine is located at the mean water level during the summer growing season. In most cases, this zone best supports herbaceous vegetation. Due to the distance from the plant to the soil, it is imperative that the coir fascine remain wet.
- Coir fascines are frequently planted with 2-inch-diameter plugs of herbaceous species which, preferably, have been rooted in a coir fiber matrix to provide good frictional contact.
- Coir fascines require protection against scouring and flanking that should be addressed in the design.
- The anchoring system must be adequate to seat the coir fascine securely in contact with the adjacent soil. Normally, this means a pair of stakes placed every 2 feet along the coir fascine, one on each side. In cold climates, earth anchors or rope tie-downs are necessary to prevent lifting of the coir fascine as ice forms. Always place wooden stakes between the cable or rope and the coir to keep the cable or rope from cutting clear through the coir fascine. Piercing a high-density coir fascine with stakes should be avoided. The stakes should be driven alongside the coir fascine. The coir fascine is secured by either tightly sandwiching the coir fascine between the stakes or by using ropes or cables to tie around the coir fascine.
- To form a continuous unit, coir fascines must be tied together end to end. This is most convenient to do while the coir fascines are still on dry land, laid out along the top of bank. Strong synthetic rope is used to stitch the ends together, with knots tied at frequent intervals to ensure a reliable connection.
- When coir fascines are stacked to provide coverage of a wider strip of bank, they must be laced together on the edges where they touch. One row of lacing is typically adequate to hold two tiers together, although two rows of lacing will result in a tighter contact between the tiers, which is useful at holding back noncohesive soils. All tiers require appropriate staking or anchoring.
- After anchoring is complete, coir fascines may be planted (fig. TS14I–9). Either live cuttings may be inserted through the coir fascine itself, or 2-inch-diameter plugs may be inserted 6 inches on center along the length of the coir fascine.
- When the coir fascines are stacked, live poles, live cuttings, or rooted plants may be placed on the first (lower) coir fascine, prior to placing the next one above it.

Brush and tree revetments

Brush and tree revetments are nonsprouting shrubs or trees installed along the toe of the streambank (fig. TS14I–10). They slow the stream velocity adjacent to an eroding bank and promote sediment deposition at the toe. This treatment is sometimes referred to as Christmas tree revetments or juniper revetments. The revetment material does not need to sprout and most

Figure TS14I–10 Brush/tree revetment over poles and a brush mattress

species used will not. It is generally recommended that live willows or other quickly sprouting species be planted behind the revetment to assist in capturing sediment and to provide a permanent living cover.

Materials

- Dead/live brush or trees such as junipers, spruce, fir, or hawthorn. Pine trees do not typically have dense and durable enough needles and branches to provide ideal shielding.
- Ties—10- to 2-gauge, galvanized smooth wire, 1/8- to 1/4-inch cable, clamps, gripples, and anchors.
- Anchors—5-foot metal T-posts or 2-inch oak posts are often used. Soil anchors and rock bolsters may also be used. Soil anchor design and installation are described in more detail in NEH654 TS14E.
- Tools—wire cutters, hammer, post pounder, chain saw for cutting brush.

Installation

- Brush and tree revetments can usually be installed throughout the year. However, for safety reasons, it is generally best to avoid high water periods.
- Harvest the trees for the revetment and stage near the site. Use trees with dense branches, such as junipers, because they will collect more sediment. Collect trees or brush and stage at the treatment area.
- Place the first tree one tree length below the downstream end of the treatment area. The stump of the tree should point upstream. Push firmly into the channel bank.
- Install an anchor post on the streamside of the tree adjacent to the trunk at the stump end where it overlaps with the next tree. Secure the tree to the post with three wraps of cable or wire, then clamp. In some situations, it may be easier to install the anchor posts before placing the trees.
- Overlap the next downstream tree trunk into the main branches of the first one by a third of the length of the tree. The stump end of the second tree should lie between the top end of the first tree and the bank. The result is a shingle-like arrangement.
- Wire the two trunks together, leaving the branches loose. Use a minimum of two wraps of cable or wire in two different places on the overlap.
- Install a second anchor post in the middle of the overlap portion of the two trees. Secure the two trees to the post with a minimum of two wraps of cable or wire in two different places on the overlap.
- Continue this process until a continuous row of brush protects the length of the treatment area.
- The trunks of the revetment should be placed at the toe where the bank meets the bed. They should be of a large enough diameter to reach to the average water elevation. In areas of fluctuating water levels, it may be necessary to place a second row of revetment at the high water line to prevent scouring behind the revetment during flood events.
- Fill in the space between the bank and the revetment with live cuttings or fascines to create a dense matrix. This material should be high enough so that they will not be rapidly covered by sediment trapped by the revetments.
- It is important that the revetment extend upstream and downstream past the area being treated to prevent flows from getting behind the revetment. It is advisable to key the upstream and downstream ends of the revetment into the bank and reinforce the key with additional brush or rock.
- To enhance recovery of the treated area, grade or knock down the sloughing streambank on the revetment to create a gentler slope as shown below. Make sure the revetment has enough brush material to catch the soil. If not, add additional brush before shaping the bank. Willow cuttings or other quickly sprouting species should then be installed on the new slope, using treatments such as fascines, brush mattress, vertical bundles, or willow post or pole plantings. This option may damage any existing vegetation.

Rootwad revetments

Rootwads are not soil bioengineering measures themselves, but are useful in supporting soil bioengineering measures installed higher up the slope of the bank. Rootwad revetments (figs. TS14I–11 and TS14I–12) make use of locally available logs and root fans to add physical habitat to streams in the form of coarse woody debris and deep scour pockets (root fan is the root mass which includes large and small roots attached to the main root mass). When placed correctly, rootwads and logs used as footers and headers around the rootwads can form an effective armor along the bank that shields soils, deflects flows away from the near-bank area, and provides roughness to reduce velocities in the near-bank zone. The use of large woody debris is addressed in more detail in NEH654 TS14J. Normally, earth, large rock or cables, and earth anchors are used to stabilize the woody elements. Various shrub and tree plantings are incorporated into the bank and flood plain areas. Since rootwads themselves will not last indefinitely, this treatment depends on a complementary strategy to replant the bank or to allow a healthy riparian corridor plant community to develop in the overbank zone. A key advantage of this method is that most materials are frequently available at low cost on or near the project site. When existing rootwad materials are not available, however, this system may be expensive due to construction collection and transportation costs and may damage the forest environment.

Figure TS14I–11 Rootwads being installed over rock toe and with soil anchors (*Photo courtesy of Mike Martyn*)

Materials

- Rootwad revetments are best created from hardwood tree species in sound condition, free from extensive decay.
- Preferably, log and root fan materials will not be collected from the bank and flood plain areas where they can provide bank stability if left intact.
- To harvest the rootwads, trees are typically pushed down with a bulldozer so that the root fan pops out of the soil attached to the tree trunk. Some cutting of larger surface roots may be required. Root fans of 5 to 12 feet in diameter are most valuable for application in typical streambank treatments, although smaller root fans may be used where they provide adequate coverage to a smaller streambank. A length of bole (or trunk) 10 to 15 feet in length is left

Figure TS14I–12 Rootwad being pushed into the bank

attached to the root fan, creating the rootwad. Remaining trunk of 12 inches or greater diameter is cut into lengths of 10 to 20 feet to form header or footer logs, as needed. The length of the logs is set, based on the desired spacing between rootwads.

- Large rock, cables, and earth anchors are often used to anchor rootwads and header/footer logs into position, and they must be sized to be stable during extreme storm events. Soil anchor design and installation are addressed in more detail in NEH654 TS14E. Rootwads may also be installed over a stone toe, footer logs, or by themselves. The choice of the toe protection depends on site-specific conditions and project purpose.

Installation

- The first step for installing rootwads is to install the toe protection. If soil anchors are to be used, they must be installed and proofed as described in NEH654 TS14E. If a rock toe is to be used, the necessary excavation and placement should be accomplished (fig. TS14I–11). If footer logs are used, they are placed along the toe of the bank with their ends overlapping. Boulders or earth anchors are used to secure them into position. Soil backfill is added to fill any gaps behind the logs.
- Rootwads are positioned in an overlapping, shingle-type arrangement with the trench almost parallel to the direction of flow. The rootwad is angled so that the root fan fits snugly into the bank at the upstream side, and may angle away from the bank on the downstream side. This requires that the bole of the rootwad be embedded into the bank pointing downstream, not perpendicular to the bank (fig. TS14I–12). Typically, the bole is pointing 30 degrees away from the tangent of the curve of the bank in plan view.
- The tip of the bole may be sharpened and forced into the bank, or it may be laid into an excavated trench. The bole is eventually buried so that it can serve as a deadman to stabilize the revetment. Boulders can be placed as needed to securely wedge the rootwad in place. Since the root fans jut into the flow path and are subject to extreme tractive forces, it is essential to secure the bole of the rootwad through careful soil packing, boulder wedging, clumps, or anchoring; otherwise, the rootwads will loosen and eventually fail.
- The header logs are placed above the footer logs, likewise with the joints located behind the root fan. Boulders or earth anchors can be used to secure the header logs in place. Soil fill is packed behind and between the header log.
- Ideally, this treatment will provide coverage up to the bankfull height; although, in some cases, it is necessary to add other additional treatments above the rootwad revetment.
- Any exposed soil above and between the header and footer logs is vulnerable to loss during extreme flow events. Normally, transplanted riparian sod or live staking is used to provide coverage and to establish vegetation for these areas.

Brush spurs

A brush spur is a long, box-like structure of brush that extends from within the bank into the streambed (figs. TS14I–13 and TS14I–14). They function very similarly to stone stream barbs as described in NEH654 TS14H. Brush spurs are sometimes referred to as brush box spurs or deflectors. The purpose of brush spurs is to promote sediment deposition along the toe of the bank. This helps with rebuilding and strengthening an eroding bank, absorbing energy, deflecting flows away from the bank, and habitat enhancement. Brush spurs are low structures and are completely overtopped during channel-forming flow events. They typically project into the channel less than a fifth of the channel width. This treatment requires a moderate to high sediment load of fine material and may not be suitable for areas with high velocities, prolonged inundation, or high debris loads.

Materials

- Brush spurs—live cuttings 3/4 to 2 inches in diameter, 6 to 20 feet long with the branches left intact
- Ties—braided manila, sisal, or prestretched cotton twine, 10- to 12-gauge, galvanized wire, 1/8- to 1/4-inch cable, clamps, or Gripples®

- Anchor posts—6 to 12 feet long and 6 inches in diameter oak posts (use longer posts in areas of looser bed material)
- Soil anchors design and installation are described in NEH654 TS14E.
- Tools—wire cutters, knives, shovels, hammers, post pounder, and chain saws

Installation

- Collect and soak live cuttings as described earlier in this technical supplement. Leave side branches intact.
- Determine alignment and spacing of brush spurs. Spurs are typically installed at an angle of 30 to 45 degrees to the bank facing upstream and act together as a system.
- The top of the spurs should be between the annual low and high water levels and slope down towards the stream channel bed. The rooted end should not extend above the top of the bank.
- Excavate a 2- to 4-foot-wide key or root trench a fifth of the spur length into the bank at the root of each spur as shown in figure TS14I–13(a). Keep this excavation as narrow as possible. The bottom of the trench should be below the bottom of the channel bed at the toe of the bank.
- Install at least two pairs of anchor posts to frame the spur (fig. TS14I–13(b)). One pair should be positioned at approximately one-third of the length of the spur, and the second pair at the approximate two-thirds distance location. The maximum distance between the posts in a pair should be 5 feet. The posts should be spaced apart at the expected width of the spur (2 to 4 feet). The final set of anchor posts should be 3 to 5 feet from the end or nose of the spur. The top of the anchor posts should extend above that of the planned spur by 6 to 12 inches.

Figure TS14I–14 Brush spur after one growing season

Figure TS14I–13 Brush spur being installed

(a)

(b)

- Install soil anchors adjacent to the posts. Soil anchor design and installation are addressed in more detail in NEH654 TS14E.
- Pack live cuttings tightly into the gap between the anchor posts. The butt or basal end of the live cuttings should be placed in the key trench, touching the undisturbed soil at the back of the trench. In areas where a longer spur is needed, overlap a mixture of live and dead material by a minimum of one-half the length of the brush. Secure the material together with two wraps of twine, wire, or cable at approximate 3- to 5-foot centers along the length of the bundle.
- Secure the brush between the posts with a minimum of two wraps of twine, wire, or cable.
- Install poles around the outside edge of the key trench.
- Cover the brush in the key trench with soil, ensuring good soil-to-stem contact. In higher stress areas, stone can be used to reinforce the area where the spur is keyed in. The installation procedure is the same as without stone with the exception of the following.
  - — Excavate a wider trench where the invert of the key trench is 1 to 2 feet below the toe of the bank.
  - — Fill the invert of the trench to the elevation of the bank toe with appropriately sized stone material.
  - — Install the brush spur as described, but fill around the key trench with additional stone.

Live siltation construction or live brush sills
Live siltation construction or live brush sills (figs. TS14I–15 and TS14I–16) are rows of live cuttings inserted into an excavated trench. Siltation in this context means the encouragement of sediment deposition of all particle sizes, not just silt sized. The live cuttings are expected to root and provide additional structural support. Live siltation construction or live brush sills are often used to supplement other treatments to assist with final infilling of scoured areas. Since this is a treatment that is intended to promote sediment deposition, it requires a moderate to high sediment load of fine materials. Live siltation construction is generally not suitable for areas with high velocities or prolonged inundation. Live siltation construction can also function as erosion stops in dry channel beds to resist the formation of rills and gullies, or in bends to resist meander cutoffs. They can also be placed parallel to the stream adjacent to the toe.

Figure TS14I–15 Live siltation construction or live brush sills

Figure TS14I–16 Live siltation construction or live brush sills with rock

Materials

- Live cuttings—3/4 to 3 inches in diameter, 2.5 to 5 feet long
- Tools—machete, clippers, shovel, saw, hammer, backhoe
- Fertilizer and other soil amendments

Installation

- Collect and soak live cuttings for 14 days, or install them the day they are harvested. Leave side branches intact. It is important to use or harvest low-growing species that will remain supple.
- Excavate a trench that is approximately 1 to 3 feet deep. The trench should have a trapezoidal shape when excavation is complete. If the trench is located along a channel, it should be oriented at about a 20- to 30-degree angle against the direction of the flow. The trench should be keyed into the bank 3 to 5 feet.
- Trenches should be approximately 3 to 15 feet apart, depending on the erodibility of the soil, gradient of the channel, and nature of the treatment they are being used to supplement.
- Orienting the growing tips downstream, pack the branches tightly with the basal ends in the excavated trench forming a dense layer of branches. The branches are placed on the downstream 45-degree angle side, with layers of soil in between. Approximately 15 to 25 live cuttings per foot of trench should be used. Be sure the branches are thick and continuous with no gaps. The ends of the branches should protrude beyond the top of the trench by 12 to 36 inches.
- Cover the downstream side of the trench with the live cuttings and soil. Wash in the soil to assure good soil-to-stem contact, then compact the soils by foot.
- Rock may be added on the upstream side of the installation to provide additional strength and protection.
- Consider seeding between the traverses. Use species that will not create competition with the woody vegetation.
- Trim the terminal end or bud to promote root growth. After installation, the area should be watered. Supplemental irrigation may also be required.

Cribwall

A cribwall is a hollow, boxlike structure of interlocking logs or timbers (fig. TS14I–17). The structure is filled with rock, soil, and live cuttings, or rooted plants. The live cuttings or rooted plants are intended to develop roots and top growth and take over some or all of the structural functions of the logs. The maximum height is typically less than 6 feet for untreated timber. Treated timber can be used to construct larger structures. The structures may not be able to resist large lateral earth pressures, and may provide a false sense of security. If used adjacent to a stream, the impact if the structure fails and washes downstream must be considered. It is critical that the toe be set securely below the estimated maximum scour. Excavations over three feet may require shoring.

Materials

- Front and rear long beams—4- to 8-inch-diameter logs or square wooden timbers, approximately 20 feet long. Peeled logs are typically more resistant to rot than logs with bark.
- Cross beams—4- to 8-inch-diameter logs, length equal to anticipated height of the structure
- Live cuttings—3/4 to 3 inches in diameter, 5 to 7 feet long, and/or bareroot plants 18 to 24 inches in length or 1 gallon container stock
- Rebar or spikes—3/8 to 1/2 inch in diameter to secure logs
- 2- to 6-inch rock for the toe foundation
- Fill material—The permeability of soil in cribbing must be less than that of the undisturbed back slope to prevent back pressure, unless a back slope drainage system is installed. Heights of over 5 feet typically require an engineered fill.
- Soil anchors may also be used. Soil anchor design and installation are addressed in more detail in NEH654 TS14E.
- Tools—machete, shovels, clippers, axe, hammer, sledge hammer, saw, and excavator

- Filter fabric to wrap the rock in the toe foundation and back slope drains
- Fertilizer and other soil amendments

Installation

- Collect and soak live cuttings for 14 days or install them the day they are harvested. Leave side branches intact. Remove loose, failed, or failing soil from the face of the slope.
- Excavate loose material to reach a stable foundation. Tilt the excavated toe so that the structure is battered (sloped into the embankment) by approximately 6 inches to 1 foot, or more. A stone toe should be set below the depth of anticipated scour and be placed in front and under the structure.
- Place front and rear long beams approximately 3 to 5 feet apart and parallel to the streambank and each other. The rear beam should be approximately 6 inches to 1 foot below the front beam.
- Place crossbeams perpendicular to the front and long rear beams on 3- to 5-foot centers.
- Allow crossbeams to overlap the front and long rear long beams by 6 inches to 1 foot. Secure with spikes or rebar.
- Fill inside of structure with rock approximately 1 to 3 feet above the channel baseflow. In a small stream system, the rock should only be used in the face of the cribwall to a height of 1 to 2 feet above baseflow. Confine and separate the rock with filter fabric if necessary.
- The next layer or two is typically filled with a 50/50 mix (by volume) of rock and soil. The soil used is typically native soil, but it must be able to drain sufficiently to prevent pressure from building up in the bank. In rare cases, amended soil (native material that has been improved with fertilizers and other nutrients that will improve plant establishment) may be used, especially if the native soil is infertile. However, this can increase the cost and may have negative ecological impacts on the stream.
- Step back succeeding layers so that the cribwall is inclined 10 to 30 degrees from the vertical (1H:4V to 1H:6V).

Figure TS14I–17 (a) Live cribwall under construction; (b) After first growing season

(a)

(b)

- Once logs or timbers are stacked above the existing rock fill, place live cuttings with the basal ends towards the slope and the growing tips towards the stream, or use bareroot or container stock. When live cuttings are used, allow the bud tips to extend 6 to 18 inches beyond the front of the long beams, and ensure that at least 40 percent of the basal ends of the branches extend 6 to 12 inches beyond the long rear cross beams.
- Align the live cuttings so they extend on top of the front long beam and below the long rear beam for a given course.
- Trim the terminal bud so that stem energy will be routed to the lateral buds for more rapid sprouting.
- Typical density is 6 to 12 live cuttings per linear foot, or 3 to 6 bareroot plants per linear foot, or one container plant every 12 to 18 inches.

Fascines

A fascine is a long bundle of live cuttings bound together into a rope or sausage-like bundles (figs. TS14I–18 and TS14I–19). The structure provides immediate protection for the toe. Since this is a surface treatment, it is important to avoid sites that will be too wet or too dry.

The live cuttings eventually root and provide permanent reinforcement. Fascines may be placed farther up the bank to assist in controlling overland flow by breaking long banks into a series of shorter banks. This is described later in contour fascines.

Figure TS14I–19 Installation of live fascines combined with erosion control fabric (*Photo courtesy of Robbin B. Sotir & Associates, Inc.*)

Figure TS14I–18 Assembling fascines

Materials

- Live cuttings—3/4 to 2 inches in diameter, 5 to 15 feet long
- Cord, braided manila, sisal or prestretched cotton twine, or small-gauge, nongalvanized wire
- Dead stout stakes—wedge-shaped wooden stakes, 2 to 3 feet long depending on soil conditions
- Tools—machete, shovels, clippers, hammer, sledge hammer, saw, and chain saw
- Fertilizer and other soil amendments

Installation

- Collect and soak live cuttings for 14 days, or install them the day they are harvested and fabricated. Leave side branches intact.
- Stagger the live cuttings in a uniform bundle built to a length of about 8 feet. Vary the orientation of the cuttings. Use 8- to 10-foot bundles for ease of handling, and transport in a pickup bed. They can also be easily spliced together to create a fascine long enough to fit the particular project site.
- Tie bundles with twine at approximately 2-foot intervals. The bundles should be 6 to 24 inches in diameter, depending on their application.
- Start installation from a stable point at the upstream end of the eroding bank.
- Excavate a trench into the bed of the stream, where the bank meets the bed. The trench should be about a half to three-quarters the diameter of the bundle.
- Align the fascine along the toe of the bank of the eroding section.
- Place the bundle in the trench and stake (use wedge shaped dead stout stakes) directly through the bundle 3 feet on center. Allow the stake to protrude 2 inches above the top of the bundle. To improve depth of reinforcement and rooting, install live stakes (2 to 3 ft in length) just below (downslope) and in between the previously installed dead stout stakes, leaving 3 inches protruding from the finished ground elevation.
- Cover the fascine with soil, ensuring good soil-to-stem contact. Wash it in with water to get around the inner stems of the bundle. Some of the bundle should remain exposed to sunlight to promote sprouting. Use material from the next upbank trench. It may be desirable to use erosion control fabric to hold the soil adjacent to and in between the fascine bundles, especially in wet climates. When using erosion control fabric between the fascine bundles, the fabric is first placed in the bottom of the trench, an inch of soil is placed on top and up the sides of the trench and erosion control fabric, and the fascine bundle is then placed in the trench and staked down (fig. TS14I–19).

Note: Fascines can be oriented perpendicular to the streambank contours. This practice is often called the vertical bundle method. The primary difference between the construction of a vertical bundle and a fascine is that all of the cuttings in a vertical bundle are oriented so the cut ends are in the water. It is particularly applicable in arid and semiarid areas where there is uncertainty in determining the water table.

Bank treatments

Live pole cuttings or live stakes

Live pole cuttings are dormant stems, branches, or trunks of live, woody plant material inserted into the ground with the purpose of getting them to grow (figs. TS14I–20 through TS14I–22). Live stakes are generally shorter material that are also used as stakes to secure other soil bioengineering treatments such as fascines, brush mattresses, erosion control fabric, and coir fascines. However, the terms live stakes and live pole cuttings are often used interchangeably. Both live poles and live cuttings can be used as anchoring stakes. They are live material so they will also root and sprout. Live pole cuttings are 3 to 10 feet long, and 3/4 to 3 inches in diameter. These cuttings typically do not provide immediate reinforcement of soil layers, as they normally do not extend beyond a failure plane. Over time, they provide reinforcement to the soil mantle, as well as surface protection and roughness to the streambank and some control of internal seepage. They assist in quickly reestablishing riparian vegetation and cause sediment deposition in the treated area.

Figure TS14I–20 Preparation of pole cuttings

Figure TS14I–21 Iron punch bar being used to create pilot hole

Figure TS14I–22 Live pole cuttings after one season

Materials

- Live cuttings—3/4 to 3 inches in diameter, 3 to 20 feet long
- Tools—machete, clippers, dead blow hammer, saw, chain saw, loppers, and rebar

Installation

- Cleanly remove all side branches and the top growth. Cut the basal (bottom) end to a 45-degree angle, or sharpen into a pointed end. The top end should be cut flat. At least two buds or bud scars should be present above the ground in the final installation, depending on the surrounding vegetation height. The live cuttings should be taller than the surrounding vegetation to ensure that they are not shaded.
- Collect and soak the live cuttings for 14 days, or install them the day that they are harvested and fabricated.
- Use a punch bar or hand auger to create a pilot hole that is perpendicular to the slope. The depth of the hole should be 2/3 to 3/4 the length of the live cutting. Make the hole diameter as close to the cutting's diameter as possible to obtain the best soil-to-stem contact. The hole should be deep enough to intercept the lowest water table of the year or a minimum of 2 feet.
- To achieve good soil-to-stem contact, fill the hole around the pole with a water-and-soil slurry mixture. Add soil around the cutting as the water percolates into the ground and the soil in suspension settles around the cutting. Another method is to tamp soil around the cutting with a rod. Throw a small amount of soil in the hole around the cutting and tamp it down to remove all air pockets. This is similar to installing a wooden fence post.
- Install the pole into the ground at a right angle to the slope face. Use a dead blow hammer to tap the cutting into the ground. Insert the cutting at a 90-degree angle to the face of the slope. Ensure that the sharpened basal end is installed first.
- Place stakes on 2- to 4-foot spacing in either a random pattern or triangular grid for most shrub species. Spacing depends on species, moisture, aspect, and soil.

Dormant post planting

Dormant post plantings are large cuttings of live, woody plant material inserted into the ground (fig. TS14I–23). Typically, these are 5 to 20 feet long and have diameters ranging in size from 3 to 8 inches. These dormant live post cuttings provide some immediate, but limited, reinforcement of soil layers if they extend beyond a failure plane. The live post cuttings are intended to root and provide soil reinforcement and subsurface protection, as well as supply roughness to the streambank and offer some control of internal seepage. They assist in quickly reestablishing riparian vegetation and cause sediment deposition in the treated area.

Materials

- Dormant live post cuttings—3 to 8 inches in diameter, 3 to 20 feet long. May use posts up to 10 feet long with auger installation, depending on auger length
- Tools—machete, clippers, hammer, punch bar, and saw. May also include chain saw, loppers, power auger, hand auger, waterjet, and mechanized stingers (fig. TS14I–23).
- Fertilizer and other soil amendments

Installation

- Cleanly remove all side branches and the top growth. Cut the basal end to a 45-degree angle or sharpen to a point. The top end should be cut flat. At least two buds or bud scars should be present above the ground, depending on the surrounding vegetation height. The live post cuttings should be taller than the surrounding vegetation to ensure that they are not shaded.
- Collect and soak live post cuttings for 14 days, or install them the day they are harvested.
- Use a punch bar, hand, or power auger to create a pilot hole that is perpendicular to the slope. The depth of the hole should be two-thirds to three-fourths the length of the stake. Make the hole diameter as close to the cutting's diameter as possible to obtain the best soil-to-stem contact. The hole should be deep enough to intercept the lowest water table of the year or a minimum of 2 feet.

Figure TS14I–23 Installation of dormant posts with stinger

- Push or lightly tap the post into the ground perpendicular to the slope, so that the sharpened basal end is inserted first.
- To achieve good soil-to-stem contact, fill the hole around the post with a water and soil slurry mixture. Add soil around the cutting as the water percolates into the ground and the soil in suspension settles around the cutting. Another method is to tamp soil around the cutting with a rod. To use this approach, throw a small amount of soil in the hole around the cutting and tamp it down to remove all air pockets. Repeat this in layers. This is similar to installing a wooden fence post.
- Place the dormant post on 2- to 4-foot spacing in a random pattern or triangular grid. Spacing is dependent on species, moisture, aspect, and soil characteristics.

Contour fascines

Contour fascines are another use of fascines to assist in controlling overland flow by breaking long banks into a series of shorter banks (fig. TS14I–24). (See fascine description under the section entitled Toe treatments). They may be placed on the bank along the contour, or on an angle to facilitate (capture and direct) drainage. The structure provides immediate protection against surface erosion, due to its orientation (approximately perpendicular, even at an angle) to the slope face and its porous barrier-like installation. This treatment may provide immediate protection against shallow-seated slope failure, as both live cuttings and dead stout stakes are incorporated into the measure. The live cuttings are intended to root and provide additional reinforcement to the soil mantle.

Materials

- Live cuttings—3/4 to 2 inches in diameter, 5 to 15 feet long
- Ties—cord, braided manila, sisal or pre-stretched cotton twine, or small-gauge, nongalvanized wire
- Dead stout stakes—wedge shaped, 2 to 3 feet long, depending on soil conditions
- Tools—machete, shovels, clippers, hammer, sledge hammer, saw, and chain saw
- Fertilizer and other soil amendments

Installation

- Collect and soak cuttings 14 days, or install them the day they are harvested and fabricated. Leave the side branches intact.
- Stagger the live cuttings in a uniform bundle built to a length of about 8 feet. Vary the orientation of the cuttings. Use 8- to 10-foot bundles for easy to handling, and transport in a pickup bed. They can also be easily spliced together to create a fascine long enough to fit the particular project site.
- Tie bundles with twine at approximately 1- to 2-foot intervals. The bundles should be 6 to 24 inches in diameter, depending on their application. Typically, smaller diameter bundles are used.
- The installation process begins at the toe of the bank and proceeds towards the top of bank.
- Remove loose, failed, or failing soil from face of the bank, and generally smooth the face to facilitate installation procedures.
- Align the fascine along the contour for dry banks. Place the fascine bundle at an angle ranging from 30 to 60 degrees along wet slopes to facilitate (capture and direct) drainage. On upper banks adjacent to a stream and along outside meanders, it may be useful to align the fascines at an angle to reduce the likelihood of scour and rilling around installed bundles.

Figure TS14I–24 Fascines installed at an angle over a riprap toe

- Excavate a trench approximately three-quarters the diameter of the bundle. In rare cases, it may be desirable to place 1 inch of amended soil (native material that has been improved with fertilizers or other nutrients that will improve establishment) in the bottom and up the sides of the trench. However, this can increase project costs and may have negative ecological impacts on the stream.
- Place the bundle in the trench and hammer in the wedge shaped (dead stout) stakes directly through the bundle 3 feet on center. The top of the stakes should protrude 2 inches above the top of the bundle. To improve depth of reinforcement and rooting, install live cuttings (2 to 3 ft in length) just below (downslope) and in between the previously installed dead stout stakes, leaving 3 inches protruding from the finished ground elevation.
- Cover the brush with soil, ensuring good soil-to-stem contact. Some of the bundle should remain exposed to sunlight to promote sprouting. Use material from the next upbank trench. It may be desirable to use erosion control fabric to hold the soil adjacent to and in between the fascine bundles especially in wet climates. When using erosion control fabric between the fascine bundles, the fabric is first placed in the bottom of the trench, an inch of soil is placed on top and up the sides of the trench and erosion control fabric, and the fascine bundle is then placed in the trench and staked down as previously described. Since this is a surface treatment, it is important to avoid sites that will be too wet or too dry. Table TS14I–7 (NRCS 1996b) provides information on how to install the trenches based on the slope of the bank along the stream.

Fascines can be oriented perpendicular or at an angle to the streambank contours to provide an immediately roughened surface for erosion control. The fascines can also be arranged in a chevron pattern to create a pole drainage system for wet slopes and intercept ground water seepage (Gray and Sotir 1996).

Joint plantings

Joint plantings or vegetated riprap are cuttings of live, woody plant material inserted between the joints or voids of riprap and into the ground below the rock (fig. TS14I–25). Joint planting cuttings are 30 to 48 inches long, and from 3/4 to 2 inches in diameter. These live cuttings typically do not provide immediate reinforcement of soil layers, as they normally do not extend beyond the failure plane. The live cuttings are intended to root and develop top growth providing several adjunctive benefits to the riprap. Over time, these installations provide reinforcement to the soil on which the riprap has been placed, as well as providing roughness (top growth) that typically causes sediment deposition in the treated area. Some control of internal seepage is also provided. These joint planting installations assist in quickly reestablishing riparian vegetation. Joint plantings are frequently used on the lower part of the bank.

Materials

- Joint plantings—live cuttings 3/4 to 2 inches in diameter and 2.5 to 4 feet long. They should be long enough so that at least 1 foot of the cutting will extend into the ground below the riprap.
- Tools—machete, clippers, dead blow hammers, sledge hammer, rebar, saw, chain saw, loppers, and rebar

Table TS14I–7 Recommended spacing of fascines

Bank H:V	Bank distance between trenches in feet	Maximum bank length in feet
1:1 to 1.5:1	3–4	15
1.5:1 to 2:1	4–5	20
2:1 to 2.5:1	5–6	30
2.5:1 to 3:1	6–8	40
3:1 to 4:1	8–9	50
4:1 to 5:1	9–10	60

Installation

- Cleanly remove all side branches and the top growth from the cuttings. Cut the basal end to a 45-degree angle, or sharpen to a point. The top end should be cut flat. At least two buds or bud scars should be present above the ground in the final installation, depending on the surrounding vegetation height. The live cuttings should be taller than the surrounding vegetation to ensure that they are not shaded.
- Collect and soak the live cuttings for 14 days, or install them the day they are harvested and fabricated.
- Make a pilot hole by hammering in a piece of rebar between the rock. A steel stinger can also be used. Carefully extrude the rebar and tamp in the joint planting stem. Insert the basal end first.
- To achieve good soil to stem contact, fill the hole around the cutting with a water and soil slurry mixture.
- Plant live cuttings on 1.5- to 2-foot spacing in a random pattern or triangular grid. Spacing depends on species, moisture, aspect, and soil characteristics.

Brush layering

Brush layering consists of alternating layers of live cuttings and soil (figs. TS14I–26 and TS14I–27). The cuttings protrude beyond the face of the slope approximately 6 to 18 inches. The installed live cuttings provide immediate frictional resistance to shallow slides, similar to conventional geotextile/geogrid reinforcement. The protruding stems serve to break long slopes into a series of shorter slopes to decrease runoff erosion. The cuttings are intended to root and provide additional reinforcement to the soil. This treatment provides immediate protection against surface erosion and shallow-seated slope failure. This measure is limited to shallow-cut bank excavations, and needs to be started above a stable foundation.

Materials

- Live cuttings—3/4 to 3 inches in diameter and 3 to 6 feet long. The branches must be long enough so that the cut basal ends of the branches touch the back of the excavation, and the growing tips protrude 6 to 18 inches from the face of the slope.
- Tools—machete, shovels, mattock, clippers, saw, and hammer
- Fertilizer and other soil amendments

Figure TS14I–25 (a) Completed installation of joint planting; (b) Early in first growing season (*Photo courtesy of Robbin B. Sotir & Associates, Inc.*)

(a)

(b)

Figure TS14I–26 (a) Excavation of the brush layer bench; (b) Cutting placement (*Photo courtesy of Robbin B. Sotir & Associates, Inc.*)

(a)

(b)

Figure TS14I–27 (a) Completed installation of brush layers; (b) Results after two growing seasons (*Photo courtesy of Robbin B. Sotir & Associates, Inc.*)

(a)

(b)

Installation

- Collect and soak the live cuttings for 14 days, or install them the day they are harvested. Leave the side branches intact. Collect brushy material for this technique.
- Remove loose, failed, or failing soil from face of the bank.
- Begin excavation and installation above a stable toe structure. Like riprap, this measure requires a stable foundation.
- Excavate benches along the contour, 2 to 3 feet wide.
- Benches should be sloped 15 to 25 degrees down from the front outer edge to the back of the excavation.
- Place branches in an overlapping, crisscross configuration. Typically 12 to 24 stems per linear foot of constructed bench (measured on the contour), depending on the size of material and branching.
- Orient the stems so that the basal ends touch the back of the undisturbed, excavated bank. Approximately a fourth of the branch stem should extend beyond the completed bank face.
- Install the brush layer in three courses: layer 1, cuttings oriented to the left; layer 2, cuttings oriented to the right; and the cuttings in the final layer point straight out towards the stream. Place a few inches of soil between each layer of branches. The soil layers should be compacted by foot or with a manually directed tamper to remove air pockets. In some circumstances, amended soil (soil that has been nutrient tested and fertilized, lime has been added to enhance growth) may be used in these layers. Each course has 5 to 15 live cuttings. The completed brush layer measure is made up of 15 to 45 branches per foot. The determination of density is by the amount of available sunlight, soils, steepness, moisture, and cutting material available. Repeat until desired thickness is reached. Use the soil material from the next upbank terrace to fill the one beneath.
- Trim the terminal bud so that stem energy will be routed to the lateral buds for more rapid sprouting of roots and stems.

Construct according to the spacing shown in the table TS14I–8 (USDA NRCS 1996b).

Brush mattress

A brush mattress is a layer of live cuttings placed flat against the sloped face of the bank (fig. TS14I–28). Dead stout stakes and string are used to anchor the cutting material to the bank. This measure is often constructed using a fascine, joint planting, or riprap at the toe, with live cuttings in the upper mattress area. The branches provide immediate protection from parallel streamflow. The cuttings are expected to root into the entire bank face and provide surface reinforcement to the soil.

Materials

- Live cuttings—3/4 to 1 inch in diameter. The cuttings should be approximately 2 feet taller than the bank face. This will allow the basal ends to be placed in or at the edge of the water. Up to 20 percent of the cuttings can be dead material to add bulk.
- Dead stout stakes—wedge shaped, 1.5 to 4 feet long, depending on soil texture
- Ties—string, braided manila, sisal or prestretched cotton twine, or galvanized wire
- Tools—machete, shovels, clippers, hammer, sledge hammer, punch bar, saw, and machine to shape the bank
- Fertilizer and other soil amendments

Installation

- Collect and soak the live cuttings for 14 days, or install them the day they are harvested. Leave side branches intact.
- Cut a 2- by 4-inch board diagonally and at desired length to create the dead stout stakes.
- Excavate the bank to a slope of 1V:2H or flatter. The distance from the top of the slope to the bottom of the slope is typically 4 to 20 feet. Excavate a 1-foot-wide and 8- to 12-inch-deep trench along the toe.
- Drive the dead stout stakes 1 to 3 feet into the ground up the face of the prepared bank. Space the installation of the dead stout stakes on a grid that is 1.5 to 3 foot square. Start the lowest

Table TS14I–8 Spacing for brush layers

Bank H:V	Bank distance (ft) between benches for wet slopes	Bank distance (ft) between benches for dry slopes	Maximum bank length (ft)
2:1 to 2.5:1	3	3	15
2.5:1 to 3.5:1	3	4	15
3.5:1 to 4:1	4	5	20

Figure TS14I–28 (a) Brush mattress being installed; (b) Brush mattress after one growing season

(a)

(b)

row of dead stout stakes below bankfull width or a fourth of the height of the bank. The tops of the dead stout stakes should extend above the ground 6 to 9 inches. Live cuttings may also be mixed with the dead stout stakes, and tamped in between to add deeper initial rooting. However, the live cuttings cannot generally be driven-in as securely as the dead stout stakes and should not be relied upon solely for anchoring the brush mattress.

- Lay the live cuttings up against the face of the bank. The basal ends of the cuttings are installed into the trench with the growing tips oriented upbank. The live cuttings' side branches should be retained and should overlap in a slight crisscross pattern. Depending on the size of the branches, approximately 8 to 15 branches are installed per linear foot of bank.
- Use a fascine or some form of anchoring along the bottom portion of the brush mattress to ensure the basal ends of the live cuttings are pressed against the bank.
- Stand on the live cuttings and secure them by tying string, cord, wire, braided manila, sisal, or prestretched cotton twine in a diamond pattern between the dead stout stakes. Short lengths of tying material are preferred over long lengths. In the event of a failure, only a small portion of the treatment would be compromised if short lengths are used. Otherwise, there are risks of losing larger portions of the project if long lengths of tying material are used to anchor the cuttings to the dead stout stakes.
- After tying the string to the stakes, drive the dead stout stakes 2 to 3 inches further into the bank to firmly secure the live cuttings to the bank face. This improves the soil-to-stem contact.
- Wash loose soil into the mattress between and around the live cuttings so that the bottom half of the cuttings is covered with a 3- to 4-inch layer of soil.
- Backfill the trench with soil or a suitable toe protection such as rock.
- Trim the terminal bud at the top of bank so that stem energy will be routed to the lateral buds for more rapid root and stem sprouting.

Branch packing

Branch packing consists of alternating layers of live cuttings and soil to fill localized slumps or gullies (fig. TS14I–29). The branches protrude beyond the face of the bank. The live cuttings reinforce the soil similar to conventional geotextile/geogrid reinforcements. The stems provide immediate frictional resistance to shallow slides. Dead stout stakes are used to anchor the live cuttings or the rooted plants and provide initial support to the soil. The cuttings or rooted plants are intended to provide additional soil reinforcement within the fill area and into the surrounding gully sides and bank.

Materials

- Live cuttings—3/4 to 3 inches in diameter, cut to a length so that the cut end of the branches touch the undisturbed soil at the back of the void, and the growing tips protrude 6 to 18 inches from the face of the bank. Alternatively, or together with the cuttings, 24- to 36-inch-long bareroot plants may be used.
- Dead stout stakes—2 by 4 inches by 5- to 8-foot-long board, cut diagonally
- Tools—machete, shovels, clippers, saw, and sledge hammer
- Fertilizer and other soil amendments

Installation

- Collect and soak the live cuttings for 14 days, or install them the day they are harvested. Leave the side branches intact.
- Remove loose, failed, or failing soil from the face of the bank slump or gully.
- The installation should begin at the toe of the bank and proceed to the top of the bank.
- Construct a bench on contour. The width of the bench should approximate the depth of the gully, or the bench can be excavated so that it tilts back into the bank.
- The constructed bench should slope down into the bank at a 15- to 25-degree angle.
- Drive the dead stout stakes 3 to 5 feet into the ground in a square configuration over the formed base bench. The tops of the wooden

stakes should extend to the projected surface of the completed bank. Space the wooden stakes 1 to 2 feet apart. Alternately, live poles can be used.

- In wet areas, install a layer of rock 6 to 9 inches deep, which has been wrapped in filter fabric prior to installing the live cuttings.
- Scarify the sides of the gully or slump surface.
- Place 6 to 12 brushy live cuttings between the wooden stakes in an overlapping, fan-like configuration. Typically, 30 to 50 stems will be required per linear yard of bench.
- Orient the stems so that the basal ends touch the back and sides of the gully or slump. Approximately a fourth of the branch stem should extend beyond the completed bank.
- Backfill with a few inches of amended soil in between the installed branches and tamp by foot to ensure good soil-to-stem contact.
- Add another 6 to 8 inches of amended soil. Repeat until the desired thickness is reached. Once the soil layer is 6 to 12 inches deep, place another layer of branches over the terrace and repeat until the slump or gully is filled.
- Trim off the terminal bud so that the available stem energy will be routed to the remaining lateral buds and encourage more rapid sprouting of roots and stems.

Vegetated reinforced soil slope or vegetated soil lifts with geogrids

A vegetated reinforced soil slope (VRSS) system is made up of layers of soil wrapped in synthetic geogrid or geotextile with live cuttings or rooted plants installed in between the wrapped soil layers (figs. TS14I–30 through TS14I–33). As with brush layering or branch packing, the branches or rooted plants protrude beyond the face of the bank. The live cuttings contribute to soil reinforcement along with the geogrid. VRSS can be used to stabilize steep banks (1H:1V or greater). While this technique is not as structurally sound as a retaining wall, it is a good soil bioengineering alternative to hard engineered structures for steep sites.

Figure TS14I–29 (a) Branch packing (using live poles) under construction; (b) One growing season later

(a)

(b)

Figure TS14I–30 Fill placement within VRSS (*Photo courtesy of Robbin B. Sotir & Associates, Inc.*)

Figure TS14I–31 Geogrid wrapping of soil lift (*Photo courtesy of Robbin B. Sotir & Associates, Inc.*)

Figure TS14I–32 Completed VRSS (*Photo courtesy of Robbin B. Sotir & Associates, Inc.*)

Figure TS14I–33 VRSS development after 4 years (*Photo courtesy of Robbin B. Sotir & Associates, Inc.*)

Materials

- Live cuttings—3/4 to 3 inches in diameter, 3 to 15 feet in length, so that the basal end of the live branches touch the undisturbed soil at the back of the excavation and the growing tips protrude from the face of the bank by 6 to 18 inches
- The selection of synthetic geogrid or geotextile is based on the required parameters for stability against rapid drawdown, wedge failures, and circular failures.
- Dead stout stakes or rebar to anchor the geogrid in place
- Gravel drainage materials or in-place drainage systems, if needed
- Burlap or geosynthetic filter fabric to retain the fines
- Wood for temporary batter boards
- Fertilizer and other soil amendments
- Plastic ties, hog rings, or string

Installation

- Collect and soak the live cuttings for 14 days, or install them the day they are harvested. Leave the side branches intact.
- Start the excavation below the channel bed. Install a foundation below the anticipated scour elevation. This foundation may be composed of materials such as rock or wrapped-rock layers.
- Install a temporary batter board along the front edge of the previously constructed bench. Its location will determine the steepness and shape of the finished bank face.
- Starting on a bench of amended soil (soil that has been nutrient tested and fertilizer, lime has been added to enhance growth) above the installed foundation toe protection, ensure that the constructed bench slopes back into the bank, making the back of the constructed bench at least 6 to 12 inches lower than the front edge.
- In poorly drained soils, a drainage layer of gravel, manufactured in-place drainage systems, or a gravel, sand, or soil mix may be included to promote and improve internal drainage of the bank.
- Install the geogrid according to the manufacturer's instructions. Position the geogrid from the back of the constructed bench excavation, across the bench, and up the temporary batter board, with the remainder draping down the bank towards the stream. Securely anchor the geogrid in place at the back of the bench and along the front with rebar or dead stout stakes.
- Install burlap or geosynthetic fabric inside the geogrid at the temporary batter board. This may be held in place with plastic ties, hog rings, or string. The purpose of this fabric is to hold the fine soils until the live cuttings or rooted plants are established.
- Place fill soils on the geogrid layer to the specified depth, compacting in 6-inch lifts to 80 to 85 percent Standard Proctor Density. When the soil has been placed to a lift height of 12 to 18 inches, pull the loose geogrid back over the front and top of the soil lift. Use a lever bar or the knuckle of an excavator to drag the geogrid towards the back edge of the bench to achieve adequate tension. Anchor the geogrid using dead stout stakes. It is important that this newly created bench and the ones to follow above it also slope to the back into the bank.
- Lay live cuttings on the constructed bench with the cut basal ends in the back of the trench and the growing tips oriented and protruding over the front edge. The tips of the branches should protrude 6 to 18 inches beyond the front edge of the bench. Lay the live cuttings in three layers with a few inches of soil in between each. Lay the first layer so that tips point to the left, tips in the second layer point to the right and the third layer points out towards the stream. Typically, 5 to 15 cuttings per linear foot of bank are used, depending on the species, growing conditions, and physical parameters of the site. Container plants may also be used in place of live cuttings.
- Repeat these steps to add successive lifts of live cuttings or rooted plants, geogrid, and soil.
- The top bench is finished off so that the geogrid is buried under a soil layer with erosion control

fabric, long straw mulch and seed, or other materials used, as needed, to finish the final grade.

Brush wattle fence

Treatments are intended to promote sediment deposition and protect the bed from erosion (fig TS14I–34). They are typically installed in multiple rows along flood plains and areas adjacent to banks. Wattle fences are rows of live stakes or poles with live wattling materials woven in a basket-like fashion. The cuttings eventually root and provide a permanent living structure.

Materials

- Live cuttings—2 to 4 inches in diameter, 3 to 4 feet long
- Wattling materials—flexible branches that are 3/4 to 1 inch in diameter and 4 to 10 feet long
- Tools—machete, shovels, hammer, punch bar, clippers, and saw

Installation

- Collect and soak the live cuttings. Collect and soak wattling as described earlier. Leave side branches intact. It is important to use low-growing species that will remain supple.
- Excavate a trench that is 1 to 2 feet deep. If the treatment is located along a channel, it should be oriented at a 20- to 30-degree angle against the direction of the flow and be keyed into the bank.
- Trenches should be 10 to 50 feet apart, depending on the erodibility of the soil and gradient of the channel.
- Use a punch bar or stake to create a pilot hole at the base of the trench. The pilot hole should have a minimum depth of 1 foot below the invert of the trench.
- Tap the stake into the ground so that the sharpened basal end is inserted first. Leave about 12 inches of the live cutting exposed above the top of the trench.
- To achieve good soil-to-stem contact, fill the hole around the cutting with a water and soil slurry mixture. Add soil around the cutting. As the water percolates into the ground, the soil in suspension will settle around the cutting. Another method is to tamp soil around the cutting with a rod. To do this, throw a small amount of soil into the hole around the cutting and tamp it down with a rod to remove all air pockets. This procedure is similar to installing a wooden fence post.

Figure TS14I–34 (a) Wattle fence immediately after construction; (b) 1 year later

(a)

(b)

- Install additional live cuttings at 1- to 2-foot intervals along the proposed location of the wattle wall. If the wattling materials available do not flex easily, the distance between the live cuttings can be adjusted accordingly.
- Weave the flexible wattling material between the live cuttings in a basket-like fashion. To begin, take a length of wattling material and weave it horizontally to the left of the first live cutting, then to the right of the second live cutting, then to the left of the next. Do this over the entire length of the wattle wall. Gently compress, so this layer makes contact with the ground. Begin the next layer by weaving the wattling material in the opposite direction; begin by weaving the material to the right of the first live cutting, then to the left of the second, and so on. Once the second layer is woven, gently compress so it touches the first layer, ensuring a tight weave. Continue weaving in this manner up to the top of the wattle wall.
- Backfill the trench and tamp the soil. After installation, the area should be watered. Supplemental irrigation may also be required as the plants become established.

Top of bank/flood plain treatments

Brush trench

A brush trench is a row of live cuttings that is inserted into a trench along the top of an eroding streambank parallel to the stream (figs. TS14I–35). The live cuttings form a fence that filters runoff and reduces the likelihood of rilling. The live cuttings eventually root and provide a permanent living structure. Brush trenches are often used to supplement other soil bioengineering treatments.

Materials

- Live cuttings—3/4 to 3 inches in diameter, 2.5 to 5 feet long
- Tools—machete, clippers, shovel, saw, hammer, and excavator
- Fertilizer and other soil amendments

Installation

- Collect and soak the live cuttings for 14 days or install them the day they are harvested. Leave the side branches intact. It is important to select low-growing species that will remain supple.

Figure TS14I–35 (a) Brush trench after installation; (b) 1 year later

(a)

(b)

- Install appropriate bank and toe protection prior to excavating the brush trench.
- If a moderate amount of runoff currently flows over the bank, consider using a low berm along the top of the bank and directing the flow to a stable outfall away from the bank.
- Excavate a trench that is 10 to 12 inches wide and 1 to 2 feet deep. The trench should be no less than 1 foot back from the top of the bank so that it does not weaken the bank.
- Pack the branches tightly with the basal ends down, forming an intertwined mat. Make sure that the basal ends touch the bottom of the trench. Install 8 to 15 live cuttings per linear foot of trench. The branches protruding from the top of the trench should be taller than the height of competing vegetation.
- Avoid gaps in the vegetation.
- Fill in around the live cuttings with soil, then wash in to assure good soil-to-stem contact. All gaps between the plant materials within the trench should be filled with soil.
- Cut off the terminal end or buds to promote root growth. After the installation is completed, water the entire area. Supplemental irrigation may also be required as the vegetation becomes established.

Other techniques

Wattle fence as an erosion stop

A wattle fence can be used to deter erosion in ditches or small dry channel beds to resist the formation of rills and gullies (fig. TS14I–36). Wattle fences are rows of live stakes or poles with live cuttings woven in a basket-like fashion. The live cuttings eventually root and provide a permanent living structure. During planning and selection of wattling material, consider the potential for excessive growth clogging the channel. The planted material should be of a species that will remain supple. This treatment is not typically suitable for areas with high velocities, prolonged inundation, or significant headcuts.

Materials

- Live cuttings—2 to 4 inches in diameter and 2 to 3 feet long
- Wattling materials—flexible branches that are 3/4 to 1 inch in diameter and 4 to 10 feet long
- Tools—machete, shovels, hammer, punch bar, clippers, and saw
- Fertilizer and other soil amendments

Installation

- Collect and soak the live cuttings for 14 days, or install them the day they are harvested. Leave the side branches intact.
- Excavate a trench 1 to 2 feet deep across the dry channel or ditch.
- The trench should be keyed-in or extended 1 to 3 feet into the sides of the channel or ditch and should curve upslope.
- Use a punch bar or stake to create a pilot hole at the base of the trench. The pilot hole should have a minimum depth of 1 foot below the invert of the trench.
- Tap the live cutting into the ground so that the sharpened basal end is inserted first. Approximately two-thirds to three-fourths of the live cutting should be below the top of the trench. In addition, the top of the stakes should not be higher than one-third of the channel depth.

Figure TS14I–36 Brush wattle fence to deter erosion in a gully

- Fill the hole with water and soil slurry. Tamp the ground around the live cutting.
- Install additional live cuttings at 1- to 2-foot intervals along the proposed location of the wattle wall. If the wattling materials available do not flex easily, the distance between the live cuttings can be adjusted accordingly.
- Weave the flexible wattling material between the live cuttings in a basket-like fashion. To begin, take a length of wattling material and weave it horizontally to the left of the first live cutting, then to the right of the second live cutting, then to the left of the next. Do this over the entire length of the wattle wall. Gently compress so this layer makes contact with the ground. Begin the next layer by weaving the wattling material in the opposite direction. Begin by weaving the material to the right of the first live cutting, then to the left of the second, and so on. Once the second layer is woven, gently compress so it touches the first layer, ensuring a tight weave. Continue weaving in this manner up to the top of the wattle wall.
- The center of the wattle should be lower than the sides to reduce the likelihood of bank erosion. The sides of the wattling should be keyed-in 1 to 3 feet into the sides of the ditch or channel.
- Backfill the trench and tamp the soil. After the installation is completed, water the entire area. Supplemental irrigation may also be required as the vegetation becomes established.
- Key stones into the bed of the channel below the wattle structure for a minimum length of two times the height of the structure.

Crimping and seeding

Crimping is a surface roughening treatment that secures straw to the surface (fig. TS14I–37). It is a temporary surface treatment that protects and promotes the establishment of permanent grasses and vegetation. It can be accomplished with heavy equipment or by hand.

Materials

- Straw—avoid moldy or compacted straw
- Seeds
- Tools—shovels

Installation

- Determine approximate contour lines for installation along the slope. The contour lines should be separated by 2 to 3 feet.
- Push the shovel into the ground along the contour lines to a depth of approximately 8 inches. With the shovel still in the ground, push the shovel forward then pull it backwards to make a V-shaped indentation in the soil.
- Distribute straw along the tops of the V-shaped indentations.
- Using the shovel, push the straw into the V-shaped indentations leaving 1 to 3 inches of straw protruding above the ground surface.
- Tamp the ground by foot to close the indentation around the straw.
- Seed the area and water it.
- Place a 2- to 4-inch layer of straw between the contours. Supplemental irrigation may be required.

Figure TS14I–37 Crimped straw

Adjunctive measures

Erosion control fabric

Detailed presentation of the full range of erosion control fabrics that are available is beyond the scope of this document. However, many of these materials can help to augment or complement soil bioengineering measures for bank protection (figs. TS14I–38, TS14I–39, and TS14I–40). Various erosion control fabrics are produced from natural and synthetic materials such as erosion control blankets made of straw, wood excelsior, woven coir, or combinations of these and turf reinforcement mats produced from nondegradable, synthetic, three-dimensional fibers. Jute mesh and coir mesh are most always used on projects where wildlife habitat is a consideration because snakes, birds, and other small animals do not become entangled in these meshes as they would in nylon netting used to bind erosion control blankets. Although none of these erosion control products are designed to withstand the stress of concentrated water flow, they are useful along the upper sections of tall banks, overbank areas, or spots where overbank drainage is called for. Sometimes they can be combined with other materials, such as live cuttings or fascines, to achieve effective bank stabilization.

Materials

- Erosion control fabric—Select a product based on the manufacturer's recommendations and on shear-stress values and velocities: metal pins, plastic pegs, biodegradable polymer stakes, dead stout stakes, or live cuttings.
- Seed
- Fertilizer (use minimally where needed)

Installation

- Distribute seed and fertilize before installing erosion control blanket or turf reinforcement mat.
- Erosion control fabrics may be oriented in either direction related to the bank. However, it is important to follow the manufacturer's recommendations.
- Follow the manufacturer's recommendations for securing the edges of the fabric and suggested percent of overlap. Typically, this is accomplished with a trench and backfilling. However, other techniques such as fascines and revetments have been used to secure the edges.
- Use a quantity, pattern, and style of stakes, pins, or pegs in accordance with manufacturer's recommendations.

Integrating soil bioengineering and structural treatments

Rock is often used as a component of streambank stabilization projects. It is often used where:

- long-term durability is needed
- water velocities are high
- long periods of inundation are present
- there is a significant threat to life and property

The sizing of rock for riprap should be approached with caution, as it can be expensive and can give a false sense of security if not applied appropriately. Techniques for stone sizing are provided in NEH654 TS14C. Additional issues to consider include, but are not limited to:

- filter layer
- bank slope
- height
- thickness
- length
- tiebacks
- scour

For more information on these issues, refer to NEH654 TS14K.

Figure TS14I–38 Cutting coir fabric (*Photo courtesy of Sonia Jacobson, NRCS*)

Figure TS14I–39 Live cuttings installed in fabric

Figure TS14I–40 Combining fascines and fabric

Soil bioengineering techniques for specific climate conditions

Hot climate issues

The southern regions of the United States have warm winters which reduce the dormancy periods of plants. Furthermore, these areas have rainy winters, which produce frequent flowing water in many intermittent streams. Warmer temperatures and short dormant periods, coupled with the limitations imposed by rain, make constructing streambanks in the winter difficult and increase costs if flow diversion is necessary (fig. TS14I–41).

Plant dormancy is critical to the success of soil bioengineering techniques when live cuttings are used because materials must be harvested and installed while they are dormant. A plant becomes dormant because of changes in environments (Lang et al. 1985), normally decreasing temperature and day length (Wareing 1969). The dormancy period begins when the plant has lost its leaves and ends when new leaf buds appear along branches and stems. In general, plants in the USDA plant hardiness zones 8, 9 and 10 (fig. TS14I–7) become dormant in December and break dormancy from March to early March, depending on the latitude. This short dormancy period restricts the installation for live cuttings to a 2- to 3-month installation timeframe.

To extend the dormancy period of live cuttings, Li et al. (2004) published a study using a cold storage to extend the dormancy of live cuttings. The research was conducted in Bryan, Texas, which is in USDA Plant Hardiness zone 8b. The average annual minimum temperature ranges between 15 and 20 degrees Fahrenheit (−6.7 and −9.4 °C). Black willow (*Salix nigra*) cuttings measuring 1/2 to 1 1/2 inches in diameter were used for the study. The cuttings were harvested in March and stored in a refrigerator, maintaining a temperature range from 34 to 40 degrees Fahrenheit. While in storage, the basal ends of the cuttings were submerged in water to maintain vitality. Opaque plastic was used to block light. The cuttings were soaked prior to planting. The trial plots were planted in three separate installations during the months of March, April, and May. A single layer of cuttings was used employing the brush layering technique.

Li et al. (2004) reported survival rates of 81 percent for the cuttings installed in March, and 44 percent for materials planted in both April and May. These findings ranked as satisfactory when compared with survival rates of 40 to 70 percent reported by Gray and Sotir (1996). In conclusion, the cold storage method described appears to extend *Salix nigra's* dormancy period. The cold storage method could be considered viable in areas where warm, wet winters might otherwise rule out the use of soil bioengineering practices.

Cold climate issues

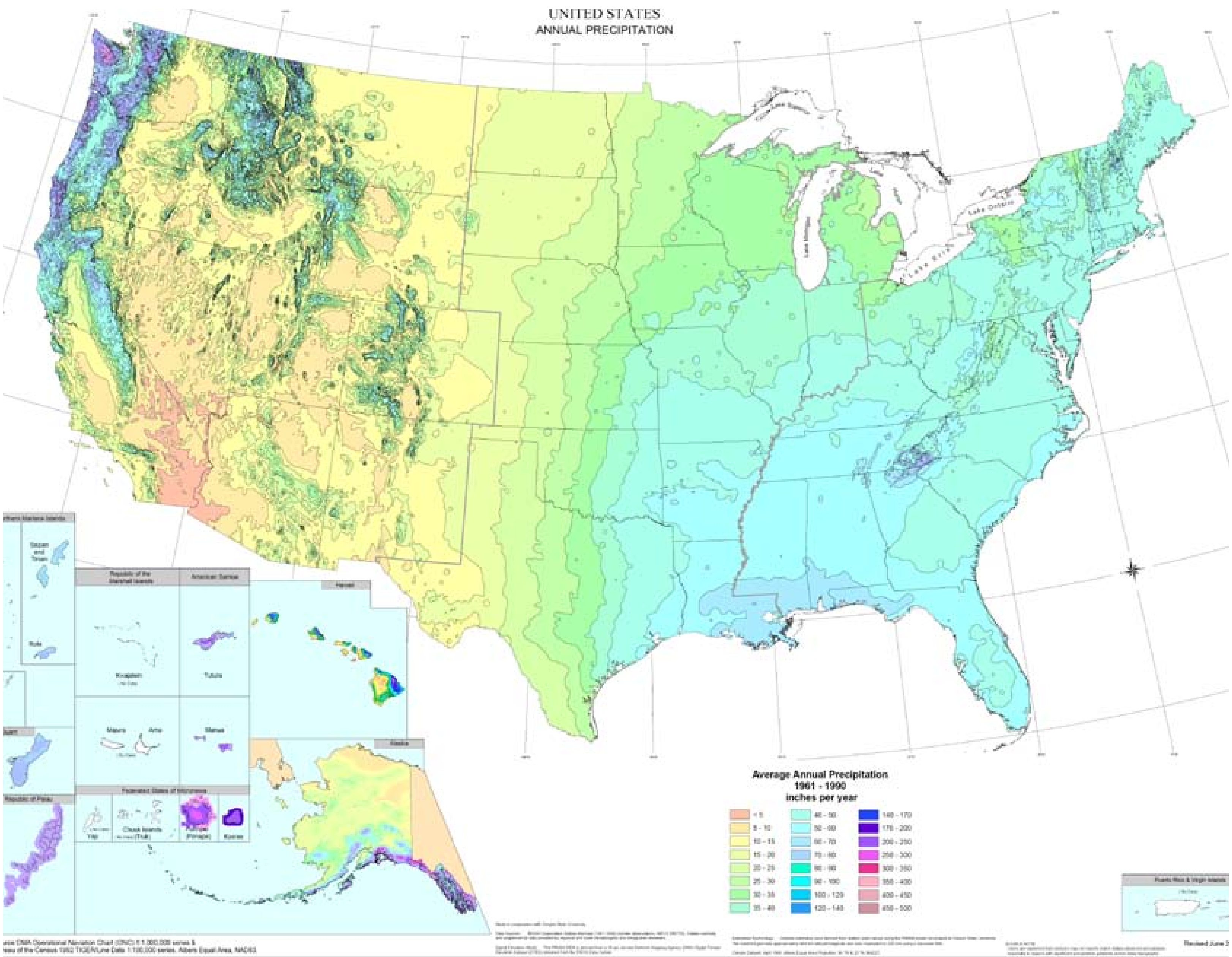
Cold climates place few constraints on the use of soil bioengineering treatments, which have been used widely in alpine areas and northern regions of Europe for hundreds of years. Many willows and other readily sprouting species are well adapted to cold conditions, and they perform excellently.

One of the main problems in cold climates is the impacts of ice flows on new installations and on developing plant stands. Many willows, dogwoods, and alders, for instance, can be sheared off by rafts of ice. This impact normally does not damage the vitality of the bank plantings, which easily resprout, but it can seriously dislodge other elements used in treating the banks.

Where ice is a factor, typically in USDA plant hardiness zone 4 or colder, it is important to use rigorous bank stabilization measures. A key to selecting streambank stabilization treatments that can withstand ice impacts is to provide full initial coverage of the bank with a durable treatment system. It is also critical to install greater quantities of well-adapted plants. They will be able to self-repair after being sheared off by ice. Live cuttings, live siltation constructions, tree revetments, and brush mattresses have been known to withstand ice impact in the toe and bank zones better than rootwad revetments, log cribs, and coir fascines. However, on poorly cohesive soils, freeze-thaw action can dislodge surface treatments, and measures that are more deeply embedded below the frost line may prove more stable.

Although planting season in cold climates is longer than in hot climates, there are some limitations that

Figure TS14I–41 U.S. annual precipitation map



affect how they are used. In warm areas, plantings can be installed throughout the winter season. This work comes to a halt in cold climates as soon as the ground freezes to the point that it is no longer workable. A shallow frost that can be broken by excavation equipment does not interfere with construction of streambank stabilization treatments or the placement of plant materials.

In winter conditions, plants face a risk of drought. Although water may be present in the soil, it is normally frozen and inaccessible to plants. The air is typically dry, and windy conditions easily lead to desiccation of plants. The best method to combat problems of cold weather desiccation is to bury up to 95 percent of the length of dormant cuttings, prune excess growth from other woody plant species, and apply a thick layer of mulch.

The structural elements of a bank stabilization treatment are typically placed first, and the plantings are added in late spring once the ground has thawed and the highest flow period, including ice break-up, has passed.

In the most extreme ranges of cold regions, conditions may not be suitable for treatments that use plant materials. This can be checked by locating healthy reference plant communities to serve as proof that the species present are able to grow under the same conditions on a nearby site. These sites often may be suitable as donor sites for collection of woody or herbaceous species for use in plantings.

One of the easiest mistakes to make is to obtain plant materials from a commercial nursery source or convenient wild collection source, then attempt to install them at higher elevations or in a more northern locale. Without proper hardening off, these plantings will often succumb to frost, dessication, diseases, and pests. It is usually acceptable to procure plants from a cold area and use them in a warmer location, but not the reverse.

High precipitation issues

It is important to have a detailed understanding of the rainfall, soils, and stream hydrology and hydraulics. Generally, the plant materials are similar to the average temperate areas. Some of the biggest differences involve how the overbank area and upper bank must be managed to properly accommodate concentrated flow from intensive runoff events. It is practical to plan on adding a berm at the top of the bank, with a swale parallel to the bank to carry water to a chosen armored point, where it can safely be carried over the bank to the stream.

Woody plants should be selected to include the widest possible array of species adapted to the region as pests, such as fungi and insects, are most likely to set in when moisture levels in the upper soil horizons remain high, and foliage, bark, and buds rarely dry out fully. Having a diverse planting plan makes it less likely that pests will destroy a planting completely and helps to keep any pest impacts far more localized. Often, seed and mulch must be used to establish vegetation on disturbed areas that would be able to regenerate on their own in drier climates.

At times, erosion control fabrics must be used to secure seed in place long enough to germinate and prevent rill formation on steep banks. Controlling how water flows over the bank is critical, as is construction phase erosion and sediment control, and restoration of all access roads and staging areas that may have been disturbed. Without proper care, these areas may collect water, and concentrated flow may cause new problems. Fortunately, areas with high precipitation tend to develop into lush and prolific revegetation once the plantings are established.

Since soil saturation can occur frequently in high precipitation areas, it is important to make sure that streambank stabilization measures address slope failure mechanisms, such as shallow slumping or deeper slides, rather than focusing on surface erosion protection alone.

Low precipitation issues

Areas with low precipitation are regions or climates where moisture clearly limits the production of vegetation (Society of Range Management 1989). In arid climates, the precipitation/potential evapotranspiration (P/PET) ratio is greater than or equal to 0.05 and less than 0.20. These regions receive less than 10 inches of average annual precipitation. In semiarid climates, the P/PET ratio is greater than or equal to 0.20 and less than 0.50. These regions receive between 10 to 20 inches of average annual precipitation (Convention on Biological Diversity 1999). Most rain falls in the spring and fall, with little in the summer months. Flooding will usually occur in the spring or early summer. High water often lasts for about a month (sometimes less in the southwestern parts of the United States), depending on climate, rainfall, snow pack, and elevation. Once the high water has passed, the water level will decrease through the summer. This often leaves the toe zone exposed, particularly on smaller river systems. In arid and semiarid regions, water removal from dams, diversions, or irrigation pumping will often exacerbate the problem.

The main limiting factor in a low-precipitation area is water availability. The amount and seasonal availability of water is important for the long-term survival and plant range of adaptation. Knowing the lowest water table level for the year and ensuring the live cuttings and plants reach that point is crucial to their survival. Plants may require additional moisture during the establishment period. In fact, many plants can survive with much lower precipitation amounts if they are established with supplemental moisture (Hoag and Fripp 2002). In low-precipitation areas, drought tolerance is a major consideration when selecting a plant species.

In some areas of the western United States where irrigation of cropland is important, stream channels are used to convey water from a reservoir to irrigated farmland. This causes the water level to be higher in the middle of the summer when water levels should be low, and establishing vegetation in the bank zone becomes problematic.

Supplemental watering

Supplemental deep watering is typically required if the lowest water table cannot be accessed by the roots of live cuttings. For many streambank stabilization projects, temporary irrigation is a practical way to ensure that plants become established in droughty soils, arid regions, or if there have been delays in the project's schedule that have pushed the planting operations beyond the seasonal beneficial rains. Supplemental watering should be adjusted as the plantings become established. Initially, watering should be frequent and of short duration. As the plants get bigger and more roots have developed, the watering frequency should be less often and of longer duration to encourage deeper rooting.

In some cases, when major construction is part of the design, inexpensive drip tape can be installed in the rocks or layers to water the plantings. This tape can be used until the plants are large enough to survive without supplemental watering, and then the tape can be abandoned. This method will generally reduce the cost of the project, and the soaker tape can be placed directly in the root zone of the plants to provide more efficient watering.

Excessive irrigation can be damaging to a project. Interestingly, some areas with average or low precipitation can experience the problems associated with high precipitation areas due to poor design or management of irrigation. If a temporary irrigation system is not carefully designed, excessive amounts of water can be delivered to the bank. This can cause loss of seed and mulch, gullying of the bank, and may trigger major slumping in saturated soils. If using poorly adapted irrigation equipment, design highly sturdy treatments or perform a detailed evaluation of the pump, piping, and sprinkler equipment that will be used and the frequency and duration of watering to prevent excessive artificial precipitation.

Water-retaining soil amendments

Plant mortality is often around 20 percent under good conditions and as high as 80 percent in arid areas or where drought conditions occur and soil fertility is poor. Because of this, there is growing interest in the use of soil amendments that retain and release water over time.

Water-absorbent polymers are polyacrylamide-based granules designed to absorb up to 400 times their own weight of water and release it slowly back to plant roots over a period of months or even years. The granules are recharged by precipitation, irrigation, or hand watering. Fine and medium-grade consistencies of the product are sold. Fine-grained granules are mixed with water and applied to bareroot seedling roots prior to planting. Medium-grained granules are saturated and then either mixed with backfill or placed directly in the planting hole.

A solid water product made of 98 percent water and 2 percent food-grade cellulose and alum is also available. Soil bacteria degrade the cellulose, releasing the water slowly and continuously. The number of applications needed for plants to become established has not yet been fully documented, but is likely influenced by factors such as depth to ground water, frequency of seasonal rainfall, temperatures, soil type, plant species, elevation, and drying winds. This product is sold under the name DriWater®. The efficacy and cost-effectiveness of water-retaining soil amendments in arid and semiarid regions are being assessed by the Environmental Laboratory at the USACE Engineer Research and Development Center (Fischer 2004).

Installation equipment and tips

Dead blow hammer

When installing poles by pounding them into the ground, it is helpful to use a sand-filled dead blow hammer or a rubber mallet. This simple and readily available tool helps prevent splitting of the cutting, mushrooming of the top end, and other forms of damage to the plant, thereby increasing its odds of survival and growth. If a live cutting is cracked during installation, it should be cut at least a half-inch below the crack to reduce the possibility of insect infestation. If the height of competing vegetation is an issue, it may be necessary to plant additional cuttings in close proximity.

Stinger (metal)

The stinger, a metal tool to plant unrooted hardwood cuttings of willow and cottonwood species for riparian or shoreline erosion control or rehabilitation, was designed and built specifically for planting into rock riprap (figs. TS14I–42). In the past, unrooted, woody vegetation has been planted into rock riprap, but planting methods have concentrated on inserting the cuttings in the ground first and dumping rock on top of them or planting through riprap with a steel bar or waterjet (Schultze and Wilcox 1985). These methods are not very efficient and have not achieved great success. The stinger, however, builds on these methods and utilizes the power of a backhoe to plant larger diameter and longer unrooted cuttings than was possible before. The stinger can plant unrooted cuttings through rock riprap with minimal effort to better stabilize the rock. This method allows the placement of cuttings above the ice layer where they will not be torn out by the force of the ice. The method also improves the aesthetics of riprap.

The stinger fits on the end of a backhoe arm in place of the bucket. It is constructed by welding a long round bar to a support frame. The support frame is attached to the backhoe arm, using the same pins as the bucket, after the bucket is removed. The upper hydraulic ram on the backhoe arm moves the bar forward and backward so the holes can be punched at almost any angle. See the specification sheet and drawing for actual design. The entire attachment weights about 900 to 1,000 pounds and can be transported either attached to the backhoe arm or in a pickup truck. It was designed to be heavy enough to punch a hole down through the spaces between large rock riprap into moist to wet soil underneath. Once the stinger reaches the soil under the rock riprap, it is pushed in deep enough to make a hole that allows the placement of cuttings in moist soil.

The willow or cottonwood pole is inserted part way into the hole. A metal cap is placed over the top of the cutting and the tip of the stinger is placed on the top of the cap. The backhoe operator then pushes the stinger down, pushing the cutting into the hole. Only 1 to 5 feet of the cutting should remain above the rock surface. The majority of the cutting (2/3 to 3/4 of the length) should be in the ground.

The stinger can plant 3 to 6 inches in diameter by 4- to 12-foot-long unrooted willow and cottonwood cuttings directly through riprap. This size cutting has had excellent establishment success when two key planting guidelines are followed: the cuttings should be planted deep enough to be in permanently moist soil; and the cutting tops should extend 1 to 5 feet above the high water level.

For reservoirs used for irrigation purposes, cuttings should be planted 1 vertical foot below the high waterline in the spring of the year for best results. Plant the cuttings when the water level has dropped 2 vertical feet or more below the high waterline. If plantings are planned on reservoirs that are operated differently, care should be taken to ensure that the cuttings are in moist soil during the growing season, but not inundated longer than 1 month. Once established, cuttings can be inundated for longer periods of time.

If shoreline erosion control is the primary purpose of the planting, always plant in layers using different types of willow or cottonwood species. Shrub-type willows should be planted first, and tree-type willows or cottonwoods should be planted farther up the bank. The shrub-type willows intercept the wave first and absorb some of its erosive energy. Shrub-type willows have more flexible stems that will bend and not break. Tree-type willows or cottonwoods have less flexible stems, but have deeper root systems and larger trunk diameters that can withstand more wave energy (Hoag and Ogle 1994).

If the planting site has been riprapped, plant one row of shrub-type willows about 4 to 6 feet apart and one row of tree-type willows or cottonwoods about 5 to 8 feet up the bank on a 10- to 12-foot spacing. The spacing depends on the type of maintenance that is planned for the planting site. Plant at a wider spacing if equipment will be used to pull rock riprap back up the bank as part of a regular maintenance schedule.

If the planting site has not been riprapped and has a vertical slope, common in riparian corridors, plant each layer with a narrower spacing and the cuttings closer together to provide better protection for the exposed soil. Shrub-type willows have been planted as close as 1 to 2 feet apart, while the tree-type willows have been planted as close as 5 to 6 feet apart.

The primary limiting factor for establishing cuttings is moisture. The key to good establishment is placing the cuttings into permanently moist soil where competition from the roots of the surrounding vegetations is significantly decreased (Hoag, Young, and Gibbs 1991).

When planting unrooted cuttings into rock riprap, vertical cutbanks, or eroded streambanks, insert them at a 45-degree angle to the water surface. This will protect the cuttings from damage caused when the bank above the cutting sloughs off and crashes down onto the stem. This sloughing can cause a vertically planted cutting to break off. This technique also reduces the damage the cutting could sustain from heavy wave action, floating debris, or floating ice chunks.

A maintenance schedule is very important for the first 2 years following the planting. Dead cuttings should be replaced as soon as possible to prevent holes in the vegetative armor that could allow excessive wave energy to impact the shoreline. The longer the period between planting and replacement, the higher the potential erosion hazard to the shoreline or streambank (Hoag, Young, and Gibbs 1991).

Waterjet hydrodrill

The waterjet hydrodrill or waterjet stinger was specially designed to use high-pressure water to hydrodrill a hole in the ground to plant unrooted hardwood cuttings into riparian revegetation (figs. TS14I–43 and TS14I–44). Typically, cuttings are installed so that the bottom of the cutting is about 1 foot into the lowest water table. A waterjet hydrodrill is a useful tool for creating a planting hole with adequate depth to the water table. It is especially useful in semiarid regions where the water table may be 3 to 6 feet below the surface. This device has also been used in areas of high precipitation to accelerate the installation of large numbers of cuttings.

This device consists of a stainless steel nozzle welded to the end of a 3/4-inch pipe. A valve is fixed to the top to control flow. A T-handle is welded near the top to aid in the planting operations. The probe is connected by a garden hose to a high-pressure pump. A pressure relief valve is included on the pump for safety. The requirements for the pump include:

- gasoline powered
- small enough to be transported
- minimum 80 pounds per square inch output
- 120 gallons per minute output
- minimum vertical lift of 18 feet

The waterjet is operated by placing the nozzle against the ground and turning on the valve. As the water jets out, the waterjet probe slowly works its way into the ground. If it hits a hard layer, it may slow or stop, but the jet should eventually work through it. If obstructions are encountered, the user will need to wiggle the jet back and forth until the water can find a way around it. Once the desired depth is reached, the user should pull the waterjet out of the hole while continuously rocking it back and forth to create a larger hole.

It is important that the operator not allow significant amounts of sediment to bubble up out of the hole while

Figure TS14I–42 Stinger

Figure TS14I–43 (a) Water jet nozzle; (b) Stinger

(a)

(b)

Figure TS14I–44 (a) Water jet pump; (b) Equipment on trailer

(a)

(b)

drilling. The more sediment that is allowed to bubble out, the more sediment that will have to be replaced after the water moves into the surrounding soil. The cuttings should be pushed into the hole immediately after it has been jetted, to avoid having it collapse or fill with sediment. The waterjet does not work well in large gravels and cobbles. It works best in fine-textured soils. It will work in sands if the cutting is pushed into the ground at the same time as the probe.

Muddying-in

Good soil-to-stem contact is critical for successful establishment of most dormant unrooted cuttings. This can be achieved by muddying them in. Muddying-in the cuttings means pouring a slurry mix of water and soil into the hole around the cutting stem. The slurry mix will flow around the cutting, completely displacing any air pockets and creating good soil-to-stem contact. As the water percolates into the surround soil, the soil that is in the slurry will settle tightly around the stem, improving rooting success. Using the waterjet can accomplish the same thing.

Holding ponds

All dormant cuttings benefit from being soaked prior to installation. Ideally, this will be for 14 days. The soaking process can occur in an existing pond, backwater zone of a river, a small plastic-lined pond, or anything that will hold water. The goal is to fully submerge the dormant cuttings. Soaking the cuttings allows the plant tissues to fully hydrate. It also causes the root buds to start growing. The roots will emerge from the bark in about 14 days. The tender emerged roots will rub off when the cuttings are planted, so remove the cuttings from the water just before the roots emerge. Once planted, the cuttings will root into the soil much faster than they would if they have to absorb water from the surround soil (fig. TS14I–45).

If the entire cutting is soaked in a cold water pond, preferably in shady conditions, it can prolong the dormant period, allowing a project to proceed effectively even when the construction schedule is lagging. The entire cutting should be submerged while soaking especially as the air temperature rises. Lastly, placing the cuttings in a holding pond facilitates inventorying of plant materials to be assembled and safely stored, allowing an efficient and uninterrupted process of collection and installation (NEH654 TS14I–46).

Figure TS14I–45 Cuttings with basal ends submerged in a pond (*Photos courtesy of Robbin B. Sotir & Associates, Inc.*)

Sealing or marking paint

Once dormant cuttings are collected, it is difficult for most people to accurately identify one species of plant from another and keep track of which end is up on a cutting. One of the simplest measures for addressing this need is to have various colors of marking paint available for coding plants and tagging the top (shoot) end of the cuttings (NEH654 TS14I).

Bundle the cuttings, and tap the tops on the ground to ensure the tops are even. Pour about 1 inch of a mix of 50 percent water and 50 percent latex paint into a flat pan or bucket. Dip the top inch of the bundle briefly into the paint/water mix, and stack the bundles to dry. This treatment does not harm the plants. Its purpose is to prevent desiccation and make it easier to identify the species once they are planted. In addition, it reduces the chance that the live cuttings will be planted upside down.

Painting the tops of the cuttings is handy for a construction inspector who can far more readily spot the cuttings, and it helps the crews keep track of where to plant them. It also is indispensable in monitoring to assess how well the plantings have developed.

Figure TS14I–46 Soaking willow cuttings at Fox Creek, Driggs, ID

Construction scheduling

Many of the soil bioengineering treatments outlined here depend on installation of inert elements, as well as plant materials. To accommodate the inevitable delays in construction project scheduling, it is useful to realize that the structural phase can often be done first, during a season that is not amenable to planting, and the planting can be scheduled immediately thereafter or added the following year.

Plant protection

One benefit of soil bioengineering treatments is their ability to provide habitat by serving as a food source, but too much of a good thing can be destructive to the success of the project.

Newly planted shrubs along the riverbank may be grazed by deer and other herbivores. This becomes an issue in harsh climate, such as cold, dry climates, where vegetation is scarce. Although most stands of plants can tolerate being trimmed down to the ground once a year (assuming they have initially rooted and become established onsite), continual grazing pressure may exceed the ability of plants to maintain the health of their root system and regenerate.

There are a number of different options to protect the cuttings until they have rooted or to protect mature riparian woody plants. Often, fencing that surrounds either the entire planting, or sections of it, is the best solution. After 3 to 5 years, the plants no longer require that protection. Similarly, tree plantings in riparian corridors frequently come under pressure from deer or small mammals that eat their bark at the snow level. Wire rabbit mesh or commercially available plant protection sleeves can prevent this damage (fig. TS14I–48).

Particular care and attention should be exercised when using tall plant protection sleeves in very hot areas because they can act as super hot greenhouses that will cook the tender plants inside. In areas that have moose and elk, 6-foot-high horse fence that is tied into 3- to 4-foot circles and placed around the trees will prevent them from putting their heads over the top of the fencing and eating the apical bud. The circle should be wide enough to prevent wildlife from eating any branches that are close to the sides.

Figure TS14I–47 (a) Cottonwood cuttings being dipped into a mixture of paint and water to seal the tops; (b) Cuttings that have been sealed with paint

(a)

(b)

Figure TS14I–48 (a) Tree cage built out of 6-foot-high horse fence; (b) Example of a tree protection sleeve

(a)

(b)

Where beaver are a problem, cover the bottom of the cutting with paint that has sand added to it. When a beaver starts to chew on the bark and gets a mouthful of paint and sand, further browsing is normally deterred.

Where livestock or wildlife are known to be present, fencing to exclude them is the best defense. Livestock fencing works well for horses, sheep, and cattle, but it is normally not high enough to exclude deer. A double row of higher fencing (8 ft or more) can be effective. Chemical repellents that are commercially available work to some degree, but should not be relied upon by themselves. They must also be recharged on a regular basis, especially after heavy rainfall. Muskrat and beaver can be excluded from a site by using heavy-gauge, welded wire or hardware cloth, which can be buried into the ground or used as a covering below the topsoil layer. Metal posts should be used to support the wire, since beavers will gnaw through wood. For beaver exclusion, the fencing should be at least 4 feet high (higher if deep snow is deposited during the winter). Goose fencing must break up the site into small cells, typically no larger than 6 feet by 10 feet in area and must be made of multiple-strand string or wire fencing to prevent them from landing inside the cells. Chicken wire should be placed around the base of the cells to prevent the geese from swimming or walking under the strings. Preventing or responding to problematic levels of herbivory can be costly. Use local knowledge and experience to effectively design and maintain protective measures.

Soil compaction

Few standards exist for determining ideal design parameters for soil compaction when installing vegetation for stabilization and erosion control purposes on slopes and banks. Geotechnical engineers regularly recommend the highest practical soil compaction based on data correlating soil density with increased mechanical strength. Agronomists, on the other hand, recommend minimal soil compaction because compacted soils impede the growth and development of crops, forests, and native plant communities.

Generally, a compaction rate of between 80 and 85 percent of the standard Proctor maximum dry density optimizes slope stability with vegetation development and growth (Goldsmith, Silva, and Fischenich 2001). A soil compacted between 80 and 85 percent Proctor will not provide a significant engineering function to the stability of slopes, but it will provide a suitable environment for roots to grow.

There is usually some delay between the introduction of vegetation and the start of its active growth. If the slope is in a critical condition at this stage, a high degree of compaction may protect the slope against failure, but root growth may be restricted. In this situation, the geotechnical requirements should be addressed using some initial safeguard against failure such as biodegradable and synthetic geotextiles, live or dead wooden stakes, metal pins or spikes, soil nails, or a retaining structure. This provides a temporary engineering function until vegetation takes root and grows.

Planting plans

The restoration of vegetation for the entire riparian zone is essential for improving a range of wildlife and aquatic habitats. Such efforts require that the dynamic processes of establishment, growth, and succession of riparian plant communities be allowed to occur. Overbank, transitional, and upland areas are often restored using a variety of plant stock types. Vegetation experts (plant specialists, landscape architects, agronomists, botanists, and biologists) must inventory the existing vegetation (including noxious species) and gather information about the soils and migratory paths. They combine this data with the project's goals and objectives prior to making decisions about species selection, plant stock types, planting density, and wildlife habitat value. The information gathered should also consider the types and sizes of vegetation on adjacent property and whether these will impact the proposed planting plan. Any existing vegetation that is to remain on the site should be identified and protected during the construction process. Invasive species may also need to be eradicated.

If seedlings for broadleaf species will be used, ensure that they are a minimum of 3/8-inch caliper size, measured 1 inch above the root collar. Coniferous species must have good balance between top and root. Seedlings should be a minimum of 3/8-inch caliper size, measured 1 inch above the root collar, and should be about 2 to 3 years old and at least 18 inches tall. They can be planted manually or mechanically. The hole should be deep enough so that when the plant is in place the root crown (where the root cells meet the stem cells) is level or slightly below the finished grade. Vegetation should be set plumb in relation to surrounding topography.

Over planting with seedlings of shade intolerant pioneer species that grow quickly can close the canopy rapidly and may accelerate succession. Seedlings of shade-tolerant dominants can be introduced to this mix so that with time, they will replace the pioneering species. Over planting with canopy species helps reduce the prevalence of browsers that would otherwise devour the smaller specimen-dominant species. Seedlings vary in price depending on species, source, and whether they are bareroot or containerized ($2.50–$12 per plant for containerized material versus $0.35–$1.50 per plant for bareroot plants).

Container-grown seedlings have better survival rates and greater root mass than their bareroot counterparts, making them better equipped to deal with drought. While they can be shipped most of the year, installation should be done within their prescribed planting times. Controlling herbaceous material after planting operations and during establishment is critical to the overall survival rate of seedlings; therefore, long-term maintenance costs must be factored into the project budget.

Bareroot stock is generally easier to plant, cheaper, and more available than containerized stock. Weed control and initial site preparation are very important for successful establishment of bareroot stock.

Where instantaneous results are desired (high-use recreation sites or projects adjacent to urban areas), large containerized and balled-and-burlapped (B&B) stock should be used. The public's perception of success or failure of a project may be based solely on aesthetic qualities. These stock types are the most expensive. Prices start at $8 per plant (2005). Installation costs vary from $10 to $30 per plant. The most popular planting size is 1 1/2- to 2 1/2-inch caliper, measured 6 inches above the root crown. This size makes them larger, heavier, and more awkward to install on most streambank projects, when compared to bareroot stock. However, they will also speed up the establishment of wildlife and fish habitat, restore missing riparian functions, and improve overall aesthetic appearance. Adding in a few large containerized or B&B plants as specimen plants and concentrating on using smaller containerized plants or bareroot plants around them will give the planner the best of both worlds.

After the planting plan is developed, the next step is to mark plant locations in the field. Plant materials should be arranged randomly unless mowing will be used to control herbaceous material. For large-scale restoration projects, it is not necessary to mark the location of each individual plant, as long as the planting crew has a general understanding of the planting plan. This is not the case for high visibility projects or when working with crews who have little experience in restoration work. Planting season varies depending on species and geographic location. Generally, woody-stemmed materials are planted when the vegetation is dormant, from leaf fall in the late fall, to bud break in the spring. When planted in late fall, the roots of deciduous vegetation continue to grow as long as soil temperature remains above 45 degrees Fahrenheit. Soils must remain moist; otherwise, a severe winter storm will kill the vegetation. Installation generally starts at the toe and progresses up the bank.

All the efforts, knowledge, and resources invested in today's planting plan may not resemble tomorrow's plant community. Stream restoration and improvement requires a long-term perspective. Natural disturbance regimes influence the functions of riparian vegetation until the vegetative communities become stable. Through succession, the landscape becomes more refined by becoming more integrated, diversified, and complex.

Soil bioengineering projects often install a monoculture that consists mainly of the pioneering species. Depending on project details, it may be possible to accelerate the vegetative succession process by selecting a few species that would typically be found in a later successional phase. This is difficult since many late successional-stage plants need early successional-stage plants to create the right conditions like soils, nutrients, microbial populations, and shade for those species to establish. Given the complexities and uncertainties about the use of vegetation, a plant specialist is the most knowledgeable person on the design team to develop a planting plan and decide which plants are best suited to a particular site.

Monitoring and maintenance

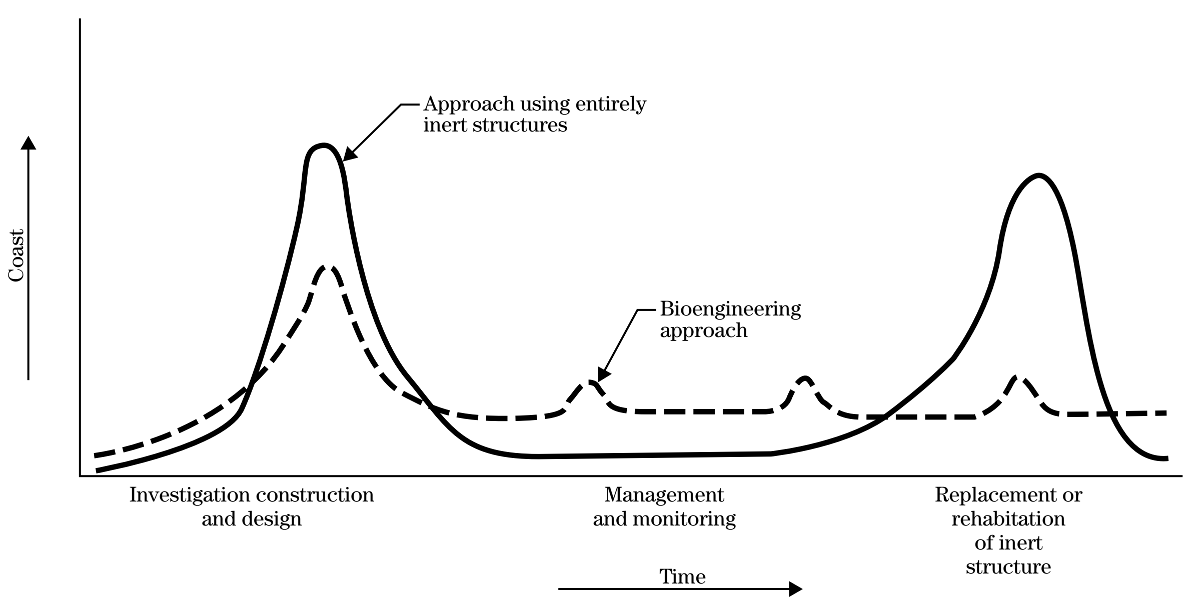
While soil bioengineering projects tend to be self-renewing and grow stronger with time, project areas require periodic monitoring and maintenance, particularly during the establishment stage. Maintenance is especially important on highly erosive sites. Maintenance could include removal of debris and elimination of invasive or undesirable species, as well as replanting vegetation in spot areas. The idealized plot in figure TS14I–49 (Coppin and Richards 1990) compares the cost of traditional inert bank protection to soil bioengineering approach. The plot illustrates that a soil bioengineering approach requires some expenditures for monitoring and maintenance, while an inert structural approach has higher initial costs, minimal or no maintenance, but eventual replacement (Allen and Leach 1997). The plot also illustrates that the reconstruction costs of a soil bioengineering approach are often significantly less than those associated with inert structures.

The success of a soil bioengineering streambank stabilization project obviously depends on the establishment and growth of the vegetative component. Allen and Leach (1997) noted that it is important to monitor soil bioengineering projects after project completion to assure plant survival and development. For example, supplemental irrigation may be necessary for exceptionally dry conditions. A fungicide or insecticide may need to be applied if insects or disease are an issue. Beaver, geese, livestock, moose, elk, and other herbivores may also eat the plants in a streambank soil bioengineering project. The loss of a predetermined percentage of the planting may be used to trigger a requirement for remedial planting.

If a moderate storm occurs before establishment of the vegetative component of a streambank soil bioengineering project, there is a potential for significant damage to the project. In fact, depending on the nature of the stream and the project, this damage may be severe enough that the vegetative component of the project may not recover. Therefore, it is recommended that most soil bioengineering projects be inspected after moderate flows, as well as on a periodic basis. These inspections are often enough to determine if remedial action will be necessary.

One of the most common problems identified with newly installed bioengineered treatments is herbivory, or consumption by plant-eating animals. At times, Canada geese or muskrats may decimate a new her-

Figure TS14I–49 Illustration of expenditure profiles for soil bioengineering and inert structures



baceous planting, or beaver may trim every shrub and tree sprout down to ground level. This comes as a shock and disappointment when it occurs, especially after completing a project or even after a robust initial growing phase. Most woody plantings rebound quickly from such impacts, and therefore, can be considered indications of beneficial habitat use. Many herbaceous plantings also rebound well, but if unrooted or repeatedly grazed down to the ground, the damage can be permanent. If this is a possibility, it may be advisable to provide a measure in the plans for inspection and replacement of lost material.

Conclusion

Streambank soil bioengineering is the use of living and nonliving herbaceous and woody plant materials in combination with natural or synthetic support materials for slope stabilization, erosion reduction, and vegetative establishment. This technique has a rich history and uses plants and sometimes inert material to increase the strength and structure of the soil. The use of streambank soil bioengineering treatments is increasing in popularity for a number of reasons: improved aesthetics, increased scrutiny by regulatory agencies, improved water quality benefits, restored fish and wildlife habitat, and decreased costs.

The long-term goal of many streambank soil bioengineering stabilization projects is to mimic natural conditions within a natural or newly altered regime. Unaltered channels in their natural environments can be expected to move and erode during large storms. Therefore, where the goal is to allow the system to remain natural, the bank will likely not be static, and periodic bank erosion should be expected. This condition can be contrasted to more urban situations where the proposed conditions of the channel typically do not allow for bank erosion. In these cases, the selected streambank soil bioengineering methods incorporate hard or inert elements that can handle higher velocity flows and to limit the flexibility of the protected bank.

Many types of soil bioengineering treatments can be used to stabilize streambanks and can withstand varying shear limits and velocities. Streambank soil bioengineering treatments are a viable alternative to hard structures, as long as the risks are clearly understood and planned for. Understanding the riparian planting zones is particularly important to ensure that the vegetation is planted in the right zone.