United States Department of Agriculture
Natural Resources Conservation Service

Part 650 Engineering Field Handbook
National Engineering Handbook

Chapter 18 Soil Bioengineering for Upland Slope Protection and Erosion Reduction

(210-650-H, 2nd Ed., Feb 2021)

Issued February 2021

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Chapter 18 – Soil Bioengineering for Upland Slope Protection and Erosion Reduction

650.1800 Introduction

A. **Purpose and Scope**

(1) Chapter 18 provides field personnel with a guide for soil bioengineering intended primarily for upland slope protection and erosion reduction. It describes characteristics, principles, design, and construction techniques of soil bioengineering. Two approaches to soil bioengineering techniques are presented: woody vegetative systems and woody vegetative systems combined with simple structures. Woody vegetative systems are emphasized. Vegetative plantings and vegetated structures are discussed cursorily to help distinguish them from soil bioengineering techniques.

(2) This chapter is national in scope and should be supplemented with regional and local information. Soil bioengineering measures, such as live cribwalls and brushlayering, are relatively complex and must be tailored carefully to specific soil and site conditions. The contents of this chapter are not directly applicable to massive erosion problems or complex shallow slope failure problems. Additional background on specific designs and sample calculations are available in other sources (Title 210, National Engineering Handbook, Part 654, "Stream Restoration Design" (210-NEH-654), Gray, et.al. 1982).

(3) Planning and design of soil bioengineering systems generally require a team of experts. Therefore, the scope of this chapter reflects the interdisciplinary nature of soil bioengineering.

B. **Background**

(1) Soil bioengineering, in the context of upland slope protection and erosion reduction, combines mechanical, biological, and ecological concepts to arrest and prevent shallow slope failures and erosion. Basic approaches to upland slope protection and erosion control can be divided into two general categories: living or plant based and nonliving or structural based (Fripp, 2008). These are outlined in figure 18–1. Frequently, living and nonliving measures are combined to form a system.

(2) The living approach, which uses live plant materials, can be further divided into two specific categories: vegetative plantings and soil bioengineering. Vegetative plantings are conventional plantings of grasses, forbs, and shrubs used to prevent surface erosion. Soil bioengineering utilizes live plant parts to provide soil reinforcement and prevent surface erosion (fig. 18–2). In soil bioengineering systems, the installation may play the major structural roles immediately or may become the major structural component over time.

(3) Live staking, live fascines, brushlayers, branchpacking, and live gully repair are soil bioengineering techniques that use stems or branch parts of living plants as initial and primary soil reinforcing and stabilizing material. When these vegetative cuttings are placed in the ground, roots develop and foliage sprouts. The resulting vegetation becomes a major structural component of the soil bioengineering system.

(4) Live cribwalls, vegetated rock gabions, vegetated rock walls, and joint plantings are soil bioengineering techniques that use porous structures with openings through which vegetative cuttings are inserted and established. The inert structural elements provide immediate resistance to sliding, erosion, and washout. As vegetation becomes established, roots invade and permeate the slope, binding it together into a unified, coherent mass. Over time, the structural elements diminish in importance as the vegetation increases in strength and functionality.

(5) Nonliving approaches use rigid constructions, such as surface armoring, gravity retaining walls, and rock buttresses. Vegetation can be used in conjunction with nonliving structures to create vegetated structures. Vegetation enhances the structures and helps reduce surface erosion, but usually does not provide any major reinforcement benefits.

C. **Integrated Planning and Design Requirements**

Soil bioengineering combines biological elements with engineering design principles. The requirements for both must be considered when planning and designing the measures presented in figure 18–1. For example, engineering requirements may dictate highly compacted soil for fill slopes, while plants prefer relatively loose soil. Using a sheep's foot roller for compaction is a possible solution for some soil types that would integrate biological and engineering requirements because it compacts the soil, but also allows plant establishment in resulting depressions in the slope. Differing needs can generally be integrated through creative approaches and occasional compromises in planning and design.

D. **Applications**

(1) The soil bioengineering techniques in this document are generally appropriate for immediate protection of slopes against surface erosion, shallow mass wasting, cut and fill slope stabilization, earth embankment protection, and small gully repair treatment. Appropriate application of specific measures is discussed in detail in Section 650.1803, Construction techniques and materials.

(2) Other situations where soil bioengineering measures can be employed are not discussed in this chapter. These situations include dune stabilization, wetland buffers, reservoir drawdown areas where plants can be submerged for extended periods, and areas with highly toxic soils. Properly designed and constructed soil bioengineering measures have also been employed with considerable success in stabilizing shorelines and streambanks. This topic is addressed in 210-NEH-650-16, "Streambank and Shoreline Protection".

Figure 18-1: Approaches to Upland Slope Protection and Erosion Control

Category	Examples	Appropriate Uses	Role of Vegetation
Living - Vegetative plantings			
Conventional plantings	Grass seedlings Transplants Forbs	Control water and wind erosion. Minimize frost effects	Control weeds. Blind and restrain soil. Filter soil from runoff. Intercept raindrops. Maintain infiltration. Moderate ground temperature.
Living - Plant Based Soil Bioengineering			
Woody plants used as reinforcement, as barriers to soil movements and in the frontal openings or interstices of retaining structures.	Live stacking Live fascine Brushlayer Branchpacking Live cribwall Live gully repair Vegetated rock gabion Vegetated rock wall Joint planting	Control of rills and gullies. Control of shallow (translational) mass movement. Filter sediment. Improved resistance to low to moderate earth forces.	Same as above, but also reinforces soil, transpire excess water and minimize downslope movement of earth masses. Reinforce fill info monolithic masses. Improve appearance and performance of structure.
Non Living - Structural Based Soil Bioengineering			
Inert structures with vegetative treatments.	Wall or revetment with slope face planting. Tiered structures with bench planting Vegetated Log Crib Walls	Control erosion on cut and fill slopes subject to scour and undermining.	Stop or prevent erosion and shallow sloughing on or at the slope face above the toe.
Non Living - Inert Structures			
Rigid construction	See 210-NEH-650-6, “Structures”.		

Figure 18-2: Soil Bioengineering Provides Soil Reinforcement and Reduces Surface Erosion

Left photo at installation and right photo was taken 1 year after installation (Robbin B. Sotir & Associates photos)

650.1801 Characteristics of Soil Bioengineering Systems

A. **General**

Soil bioengineering uses characteristics of vegetative components and integrates specific characteristics of structures with vegetation. The resulting systems and their components have benefits and limitations that need to be considered prior to selecting them for use.

B. **Vegetative Components**

(1) **Herbaceous Species**

(i) Herbaceous vegetation, especially grasses and forbs, offers long-term protection against surface (water and wind) erosion on slopes. It provides only minor protection against shallow mass movement. Vegetation helps to prevent surface erosion by:

- Binding and restraining soil particles in place
- Reducing sediment transport
- Intercepting raindrops
- Retarding velocity of runoff
- Enhancing and maintaining infiltration capacity
- Minimizing freeze-thaw cycles of soils susceptible to frost

(ii) Herbaceous species are almost always used in conjunction with soil bioengineering projects to add protection against surface erosion.

(2) **Woody Species**

(i) More deeply rooted woody vegetation provides greater protection against shallow mass movement by:

- Mechanically reinforcing the soil with roots
- Depleting soil-water through transpiration and interception
- Buttressing and soil arching action from embedded stems

(ii) Live fascines, for example, provide many of these protective functions. They are fabricated from woody species, such as shrub willow or shrub dogwood, into sausage-like bundles, which are placed with the stems oriented generally parallel to the slope contour. This method of placement and orientation would not be used in slope reinforcement. Live fascines serve to dissipate the energy of downward moving water by trapping debris and providing a series of benches on which grasses, seedlings, and transplants establish more easily. Portions of the live fascines also root and become part of the stabilizing cover. Live fascines provide an immediate increase in surface stability and can further improve soil stability to depths of 2 to 3 feet as roots develop.

(iii) In the case of brushlayering, live branches or shoots of such woody species as shrub willow, dogwood, or privet are placed in successive layers with the stems generally oriented perpendicular to the slope contour, as shown in figure 18–2. This orientation is the optimal direction for maximum reinforcing effect in a slope. Brushlayering can improve soil stability to depths of 4 to 5 feet.

C. **Structural Components**—Properly designed and installed structures help to stabilize a slope against shallow mass movement and protect the slope against rill and gully formation. Structures also play a critical role in the establishment of vegetation on steep slopes or in areas subject to severe erosion. They may make it possible to establish plants on slopes steeper than would normally be possible. Structures stabilize slopes during the critical time for seed germination and root growth. Without this stabilization, vegetative plantings would fail during their most vulnerable time.

(1) **Materials**

(i) Structures can be built from natural or manufactured materials. Natural materials, such as earth, rock, stone, and timber, usually cost less, are environmentally more compatible, and are better suited to vegetative treatment or slight modifications than are manufactured materials. Natural materials may also be available onsite at no cost.

(ii) Some structures are comprised of both natural and manufactured materials. Examples include concrete cribwalls, steel bin walls, gabion walls or revetments, welded wire or polymeric geogrid walls, and reinforced earth. In these cases steel and concrete mostly provide rigidity, strength, and reinforcement, whereas stone, rock, and soil provide mass. These types of structures have spaces that are often planted with herbaceous or woody vegetation.

(2) **Retaining Structures**—A retaining structure of some type is usually required to protect and stabilize steep slopes. Low retaining structures at the toe of a slope make it possible to grade the slope back to a more stable angle that can be successfully revegetated without loss of land at the crest. Structures are generally capable of resisting much higher lateral earth pressures and shear stresses than vegetation.

(3) **Grade Stabilization Structures**

(i) Grade stabilization structures are used to control and prevent gully erosion. A grade stabilization structure reduces the grade above it and dissipates the excess energy of flowing water within the structure itself. Debris and sediment tend to be deposited and trapped upstream of the structure. This, in turn, permits establishment of vegetation behind the structure, which further stabilizes the ground. Grade stabilization structures may range from a series of simple timber check dams to complex concrete overfall structures and earth embankments with pipe spillways.

(ii) Gully control provides a good example of the integration of structures and vegetation. Structural measures may be required in the short term to stabilize critical locations. The long-term goal is to establish and maintain a vegetative cover that prevents further erosion. This goal is seldom realized unless the severe gully conditions can be altered immediately. Vegetation alone, for example, will rarely stabilize gully headcuts because of the concentrated water flow, overfalls, and pervasive forces that promote gully enlargement in an unstable channel system. Initially, the vegetation and the structure work together in an integrated fashion. The ultimate function of these structures, however, is to help establish vegetation which will provide long-term protection.

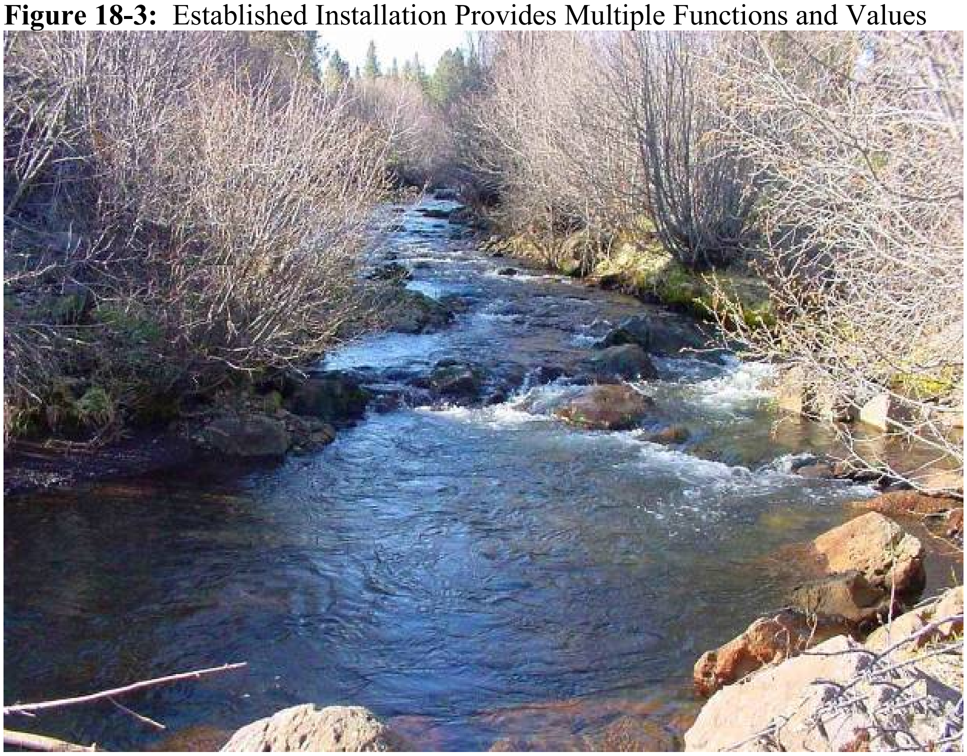
D. **Attributes and Limitations**

(1) Soil bioengineering measures should not be viewed as a panacea or solution for all slope failure and surface erosion problems. Soil bioengineering has unique attributes, but it is not appropriate for all sites and situations. In certain cases, a conventional vegetative treatment (e.g., grass seeding and hydro mulching) works satisfactorily at less cost. In other cases, the more appropriate and most effective solution is a structural retaining system alone or in combination with soil bioengineering.

(2) The following specific attributes and limitations should be considered before applying a soil bioengineering technique:

(i) **Environmental Compatibility** - Soil bioengineering systems generally require minimal access for equipment and workers and cause relatively minor site disturbance during installation. These are generally priority considerations in environmentally sensitive areas, such as parks, woodlands, riparian areas, and scenic corridors where aesthetic quality, wildlife habitat, and similar values may be critical (fig. 18–3).

Figure 18-3: Established Installation Provides Multiple Functions and Values



(ii) **Cost Effectiveness**

- Field studies have shown instances where combined slope protection systems have proven more cost effective than the use of either comparative vegetative treatments or structural solutions alone. Where construction methods are labor intensive and labor costs are reasonable, the combined systems may be especially cost effective. Where labor is either scarce or extremely expensive, however, soil bioengineering systems may be less practical than structural measures. This can be offset by the time of year (fall and winter) when other construction work is slow.
- Using indigenous materials accounts for some of the cost effectiveness because plant costs are limited to labor for harvesting, handling, and direct costs for transporting the plants to the site.

(iii) **Planting Times**

- Soil bioengineering systems are generally most effective when the live portions are installed during the dormant season, usually the late fall, winter, and early spring.
- Constraints on planting times or the availability of the required quantities of suitable plant materials during allowable planting times may limit the usefulness of soil bioengineering methods.

(iv) **Difficult Sites**

- Soil bioengineering is often a useful alternative for small, highly sensitive, or steep sites where the use of machinery is not feasible and hand labor is a necessity. However, rapid vegetative establishment may be difficult on extremely steep slopes.
- The usefulness of soil bioengineering methods may be limited by the available medium for plant growth, such as rocky or gravelly slopes that lack sufficient fines or moisture to support the required plant growth. In addition, soil-restrictive layers, such as hardpans, may prevent required root growth.
- The biotechnical usefulness of vegetation would be limited on slopes that are exposed to high velocity water flow or constant inundation.

(v) **Harvesting Local Plant Material—**Appropriate vegetation is often obtained from local stands of willows and other suitable species. This stock is already well suited to the climate, soil conditions, and available moisture and is a good candidate for survival. While harvesting may often help a beneficial species proliferate, reliance on the use of local plant materials and gathering in the wild could result in short supplies or unacceptable depletion of site vegetation. Some localities may have prohibitions against gathering native plants, and materials must be purchased from commercial sources.

(vi) **Biotechnical Strengths**—Soil bioengineering systems are strong initially and grow stronger with time as vegetation becomes established. In some instances, the primary role of the structural component is to give the vegetation a better chance to become established. It has been shown in slope reconstruction projects that soil bioengineering systems can withstand heavy rainfalls immediately after installation. Even if established vegetation dies, the plant roots and surface residue may continue to play an important protective role during reestablishment.

(vii) **Maintenance Requirements**—Once vegetation is well established on a soil bioengineering project, usually within one growing season, it generally becomes self-repairing by regeneration and growth and requires little maintenance. However, a newly installed soil bioengineering project will require careful periodic inspections until it is established. Established vegetation is vulnerable to trampling, drought, grazing, nutrient deficiencies, toxins, and pests, and may require special management measures at times.

650.1802 Basic Principles and Design Considerations

A. **Basic Principles of Soil Bioengineering**—The basic principles that apply to conventional soil erosion control also apply in general to soil bioengineering. These principles are mostly common-sense guidelines that involve planning, timing, and minimizing site disturbance as well as the design of individual measures themselves. Applicable principles can be summarized as follows:

(1) **Fit the Soil Bioengineering System to the Site**—This means considering site topography, geology, soils, vegetation, and hydrology. Avoid extensive grading and earthwork in critical areas and perform soil tests to determine if vigorous plant growth can be supported. At a minimum, collect the following information:

(i) **Topography and Exposure**

- Note the degree of slope in stable and unstable areas. Also note the presence or lack of moisture. The likely success of soil bioengineering treatments can best be determined by observing existing stable slopes in the vicinity of the project site.
- Note the type and density of existing vegetation in areas with and without moisture and on slopes facing different directions. Certain plants grow well on east-facing slopes, but will not survive on south-facing slopes.
- Look for areas of vegetation that may be growing more vigorously than other site vegetation. This is generally a good indicator of excess moisture, such as seeps and a perched water table, or it may reflect a change in soils.

(ii) **Geology and Soils**

- Consult NRCS geologists about geologic history and types of deposits (colluvium, glacial, alluvium, other).
- Note evidence of past sliding. If site evidence exists, determine whether the slide occurred along a deep or shallow failure surface. Leaning or deformed trees may indicate previous slope movement or downhill creep. In addition to site evidence, check aerial photos, which can reveal features that may not be apparent from a site visit.
- Determine soil type and depth. Use the soil survey report, if available, or consult NRCS soil scientists.

(iii) **Hydrology and Hydraulics**
- Determine the drainage area associated with the problem area. Note whether water can be diverted away from the problem area.
- Determine the annual precipitation. Are there concentrated discharges?
- Calculate peak flows or mean discharge through the project area.
- If a seep area was noted, locate the source of the water. Determine whether the water can be intercepted and diverted away from the slope face.
- Retain existing vegetation whenever possible
- Vegetation provides excellent protection against surface erosion and shallow slope failures. Soil bioengineering measures are designed to aid or enhance the reestablishment of vegetation.

(2) **Limit Removal of Vegetation**
(i) Limit cleared area to the smallest practical size
(ii) Limit duration of disturbance to the shortest practical time
(iii) Remove and store existing woody vegetation that may be used later in the project
(iv) Schedule land clearing during periods of low precipitation whenever possible

(3) **Stockpile and Protect Topsoil**
(i) Topsoil removed during clearing and grading operations can be reused during planting operations.
(ii) Protect areas exposed during construction
(iii) Temporary erosion and sediment control measures can be used.

(4) **Divert, Drain, or Store Excess Water**
(i) Install a suitable system to handle increased and/or concentrated runoff caused by changed soil and surface conditions during and after construction.
(ii) Install permanent erosion and sediment control measures in the project before construction is started if possible.

B. **Design Considerations**

(1) **Earthwork**—Typically, sites require some earthwork prior to the installation of soil bioengineering systems. A steep undercut or slumping bank, for example, requires grading to flatten the slope for stability. The degree of flattening depends on the soil type, hydrologic conditions, geology, and other site factors.

(2) **Scheduling and Timing**—Planning and coordination are needed to achieve optimal timing and scheduling. The seasonal availability of plants or the best time of year to install them may not coincide with the construction season or with tight construction schedules. In some cases, rooted stock may be used as an alternative to unrooted dormant season cuttings.

(3) **Vegetative Damage to Inert Structures**—Vegetative damage to inert structures may occur when inappropriate species or plant materials that exceed the size of openings in the face of structures are used. Vegetative damage does not generally occur from roots. Plant roots tend to avoid porous, open-faced retaining structures because of excessive sunlight, moisture deficiencies, and the lack of a growing medium.

(4) **Moisture Requirements and Effects**—The backfill behind a stable retaining structure has certain specified mechanical and hydraulic properties. Ideally, the fill is coarse-grained, free-draining, granular material. Excessive amounts of clay, silt, and organic matter are not desirable. Free drainage is essential to the mechanical integrity of an earth retaining structure and important to vegetation, which cannot tolerate waterlogged soil conditions. The establishment and maintenance of vegetation, however, usually requires the presence of some fines and organic matter in the soil to provide adequate moisture and nutrient retention. In many instances, these biological requirements can be satisfied without compromising engineering performance of the structure. With cribwalls, for example, adequate amounts of fines or other amendments can be incorporated into the backfill. Gabions can be filled with rock and soil drifted into them to facilitate growth of vegetation. Woody vegetative cuttings can be placed between the baskets during filling and into the soil or backfill beyond the baskets. The needs of plants and the requirements of structures must be taken into account when designing a system.

650.1803 Construction Techniques and Materials

A. **General Considerations**

(1) Soil bioengineering measures have certain requirements and capabilities. Plant species must be suitable for the intended use and adapted to the site's climate and soil conditions. Consult a plant materials specialist about available cultivars to ensure that appropriate species are used. Species that root easily, such as willow, are required for such measures as live fascines, brushlayer, and live staking or where unrooted stems are used with structural measures. Figure 18-4 is a general listing of plant species used in soil bioengineering. A more complete list of plant species is an appendix to 210-NEH-650-16, "Streambank and Shoreline Protection".

(2) Rooted plants and vegetative cuttings are living materials and must be handled properly to avoid excess stress, such as drying or exposure to heat. They must be installed in moist soil and be adequately covered. The soil must be compacted to eliminate or minimize air pockets around the buried stems. If soils are not at or near moisture capacity, the installation must be delayed unless deep and regular irrigation can be provided during and following installation.

(3) Installation of soil bioengineering systems is best accomplished in the late fall at the onset of plant dormancy, in the winter as long as the ground is not frozen, or in early spring before growth begins. In some cases installation after may require maintenance and/or replacement throughout their life. Where the main function of structural elements is to allow vegetation to become established and take over the role of slope stabilization, the eventual deterioration of the structures is not a cause for concern. initial spring growth may be successful if extreme care is used, but the risks of failure are high. Summer installation is not recommended. Rooted plants can be used, but they are sometimes less effective and more expensive.

(4) All installations should be inspected regularly and provisions made for prompt repair if needed. Initial failure of a small portion of a system normally can be repaired easily and inexpensively. Neglect of small failures, however, can result in the failure of large portions of a system.

(5) Properly designed and installed vegetative portions of systems will become self-repairing to a large extent. Periodic pruning and replanting may be required to maintain healthy and vigorous vegetation. Structural elements, such as cribwalls, rock walls, and gabions.

Figure 18-4: Soil Bioengineering Plant Species

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Acer negundo Boxelder	N, NE	Common	Excellent	Tree	Fibrous, mod. deep, spreading, suckering	Poor to fair
Alnus rubra Red alder	NW	Very common	Excellent	Medium tree	Shallow, spreading, suckering	Poor to fair
Baccharis glutinosa Water wally	W	Common	Very good	Medium shrub	Fibrous	Good
Baccharis halimifolia Eastern baccharis	S, SE	Common	Very poor	Medium shrub	Fibrous	Good
Baccharis pilularis Coyotebrush	W	Very common	Good	Medium shrub	Fibrous	Good
Baccharis viminea Mule fat	W	Very common	Very good	Medium shrub	Fibrous	Good
Betula papyrifera Paper birch	N, E, and W	Common	Good	Tree	Fibrous shallows	Poor
Betula pumila Low birch	N, E, and W	Common	Very good	Medium shrub	Fibrous	Poor
Cornus amomum Silky dogwood	N, SE	Very common	Very good	Small shrub	Shallow fibroud	Very good
Cornus racemose Gray dogwood	NE	Common	Very good	Med-small shrub	Shallow fibroud	Good
Cornus rugosa Roundleaf dogwood	NE	Common	Very good	Med-small shrub	Shallow fibroud	Fair-good
Cornus sericea ssp. Stolonifera Red osier dogwood	N, NE, and NW	Very common	Very good	Med-small shrub	Shallow fibroud	Very good
Crataegus Sp Hawthorn	SE	Uncommon	Good	Small dense tree	Tap root	Fair
Elaeagnus commutate Silverberry	N. Cent.	Very Common	Poor	Small tree	Shallow fibrous	Fair-good
Ligustrum sinense Chinese privet	S, SE	Common	Fair-good	Medium shrub	Shallow spreading	Good

Figure 18-4: Soil Bioengineering Plant Species - continued

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Lonicera involucrate Black twinberry	E	Common	Poor-fair	Large shrub	Shallow fibrous	Good
Physocarpus capitatus Pacific ninebark	NW, W	Common	Fair	Large shrub	Fibrous	Good
Physocarpus opulifolius Common ninebark	NE	Common	Good	Medium shrub	Shallow lateral	Fair-good
Populus angustifolia Narrowleaf cottonwood	W	Common	Good	Tree	Shallow	Very good
Populus balsamifera ssp. trichocarpa Black cottonwood	NW	Common	Good	Tree	Shallow fibrous	Very good
Populus deltoides Eastern cottonwood	MW, E	Very common	Good	Large tree	Shallow fibrous suckering	Very good
Populus fremontii Fremont cottonwood	SW	Very common	Good	Tree	Shallow fibrous	Very good
Populus tremuloides Quaking aspen	NW	Very common	Good	Large tree	Shallow suckering	Fair
Robinia pseudoacacia Black locust	NE	Common	Very poor	Tree	Shallow	Good
Rubus allegheniensis Allegheny blackberry	NE	Very common	Very good	Small shrub	Fibrous	Good
Rubus spectabilis Salmonberry	SW	Very common	Good	Small shrub	Fibrous	Good
Rubus strigosus Red raspberry	N, NE, and W	Very common	Very good	Small shrub	Fibrous	Good
Salix amygdaloides Peachleaf willow	N, S	Common	Good	Very large shrub	Shallow to deep	Very good

Figure 18-4: Soil Bioengineering Plant Species - continued

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Salix bonplandiana Pussy willow	W and MW	Very common	Good	Medium shrub	Fibrous	Very good
Salix eriocephala ssp. Ligulifolia Erect willow	NW	Common	Good	Large shrub	Fibrous	Very good
Salix exigua Coyote willow	NW	Fairly common	Good	Medium shrub	Shallow suckering	Good
Salix gooddingii Goodding willow	SW	Very common	Good	Large shrub Small tree	Shallow to dep	Excellent
Salix hookeriana Hooker willow	NW	Common	Good	Large shrub small tree	Fibrous dense	Very good
Salix humilis Prairie willow	N, NE	Very common	Good	Medium shrub	Fibrous spreading	Good
Salix interior Sandbar willow	N, SE	Common	Good	Large shrub	Shallow to deep	Very good
Salix lasiolepis Arroya willow	W	Common	Good	Large shrub	Fibrous	Very good
Salix lemmonii Lemmon willow	W	Common	Good	Medium shrub	Fibrous	Very good
Salix lucida Shining willow	N, NE	Very common	Good	Medium large shrub	Fibrous spreading	Very good
Salix lucida ssp. lasiandra Pacific willow	NW	Very common	Good	Large shrub small tree	Fibrous	Very good
Salix lutea Yellow willow	W	Very common	Good	Medium large shrub	Fibrous	Very good
Salix nigra Black willow	N, SE	Very common	Good	Large shrub small tree	Shallow to deep	Excellent
Salix purpurea Purpleosier willow	N, S, E, and W	Very common	Very good	Medium shrub	Shallow	Very good
Salix scouleriana Scouler's willow	NE	Very common	Good	Large shrub small tree	Shallow	Very good
Salix sitchensis Sitka willow	NW	Common	Good	Very large shrub		Very good

Figure 18-4: Soil Bioengineering Plant Species - continued

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Salix discolor Pussy willow	N, NE	Very common	Good	Large shrub	Shallow fibrous spreading	Very good
Sambucus canadensis American elderberry	NE, SE	Very common	Very good	Medium shrub	Fibrous	Good
Sambucus cerulea Blue elderberry	W	Common	Very good	Medium shrub	Fibrous	Poor
Sambucus racemose Red elderberry	NW	Common	Good	Medium shrub		Good
Sambucus racemose ssp. pubens Scarlet elder	NE	Common	Very good	Medium shrub	Deep laterals	Fair-good
Spiraea alba Meadowsweet spirea	N, E	Common	Good	Small dense tree	Dense shallow lateral	Fair-good
Spiraea douglasii Douglas spirea	NW	Common	Fair	Dense shrub	Fibrous suckering	Good
Spiraea tomentosa Hardhack spirea	NE	Common	Good	Small shrub	Sense shallow	Fair
Symphoricarpos albus Snowberry	N, NW, and E	Common	Good	Small shrub	Dense shallow	Good
Viburnum alnifolium Hubbiebush viburnum	NE	Fairly common	Good	Large shrub	Shallow fibrous	Good
Viburnum dentatum Arrowwood viburnum	E	Common	Good	Medium shrub	Shallow fibrous	Good
Viburnum lentago Nannyberry viburnum	S, SE	Fairly common	Good	Large shrub	Shallow	Fair-good

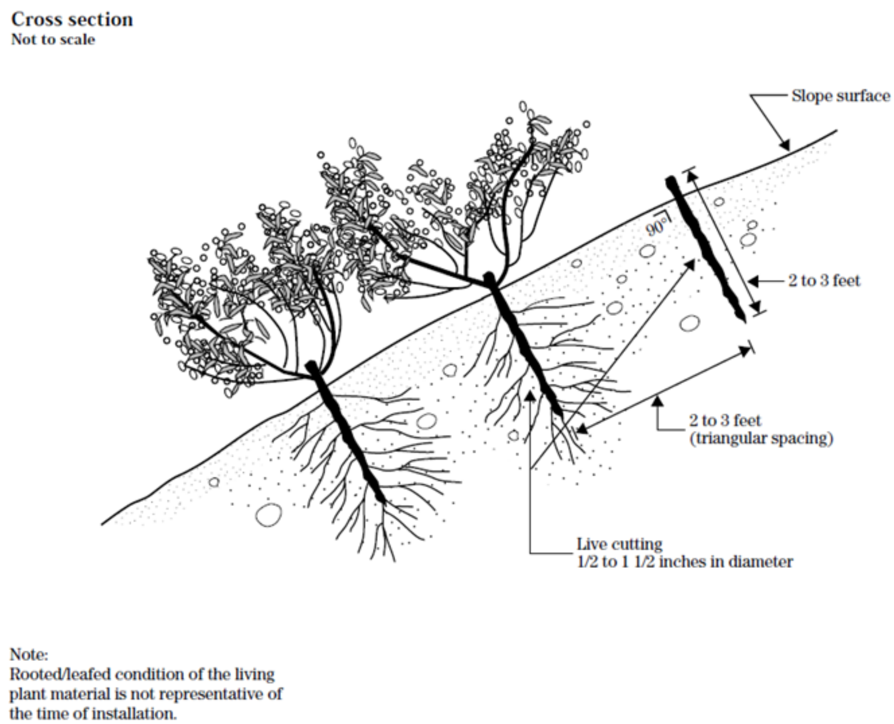
B. **Soil Bioengineering Techniques**

The following describes soil bioengineering techniques. Their applications, effectiveness, and construction guidelines are also presented.

(1) **Live Cutting/Pole Planting**

(i) **Description**—Cuttings of live woody plant material inserted into the ground. The poles provide some limited immediate reinforcement of soil layers if they extend beyond a failure plane. The live cuttings are intended to root and provide reinforcing and subsurface protection, as well as providing roughness to the stream bank and some control of internal seepage (fig 18-5). Most willow species root rapidly and begin to dry out a slope soon after installation. This is an appropriate technique for repair of small earth slips and slumps that frequently are wet.

Figure 18-5: Live Cutting



(ii) **Applications and Effectiveness**

- A technique for relatively uncomplicated site conditions when construction time is limited, and an inexpensive method is necessary.
- May be used for pegging down surface erosion control materials.
- Enhances conditions for natural invasion and the establishment of other plants from the surrounding plant community.
- Can be used to stabilize intervening area between other soil bioengineering techniques, such as live fascines.

(iii) **Materials**

- Live Cuttings/Poles - adventitiously rootable, 3/4 to 3-inch in diameter, 2 to 5 feet long (fig 18-6). May use up to 10 feet long with use of augers in installation.

- Tools: Machete, clippers, hammer, punch bar, saw. May also include chainsaw, loppers, power auger, hand auger, waterjet.

Figure 18-6: Top Growth and Root Development of a Live Cutting (<1 year)

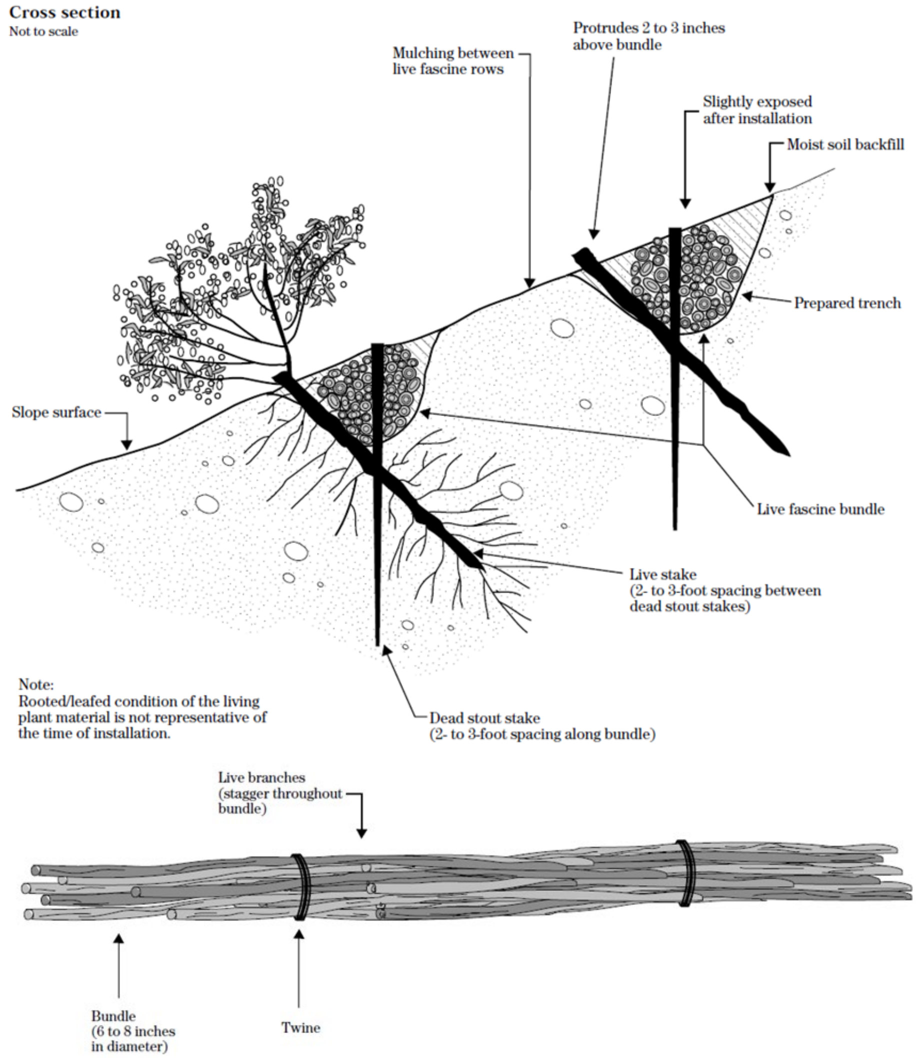
(iv) **Installation**

- Cleanly remove all side branches and the top foot. Sharpen the basal (bottom) end. At least 2 buds or bud scars should be present above the ground.
- Collect and soak cuttings.
- Use a punch bar or auger to create a pilot hole that is perpendicular to the slope. The hole should be 2/3 to ¾ the length of the stake. Make the hole diameter as close to the cutting diameter size as possible. Hole should be deep enough to intercept the lowest water table of the year or a minimum of 2 feet.
- Push or lightly tap the stake into the ground such that the sharpened basal end is inserted first.
- To achieve good soil to stem contact, fill the hole around the pole with a mixture of water and soil slurry. Tamp the ground around the stake and water the hole.
- Do not split the cuttings during installation. Cuttings that split should be cut one inch below the split or removed and replaced.
- Place stakes on 1 to 3 foot spacing in a random pattern for most shrub species. Spacing is species dependent.

(2) **Live Fascine**

(i) **Description**—A fascine is a long bundle of live branch cuttings bound together into rope or sausage-like bundles. They should be placed in shallow contour trenches on dry slopes and at an angle on wet slopes (fig 18-7). The structure provides immediate protection against surface erosion and shallow face sliding. The structures can change overland flow by breaking up long slopes. The live cuttings eventually root and provide permanent reinforcement.

Figure 18-7: Fascine Details



(ii) **Applications and Effectiveness**

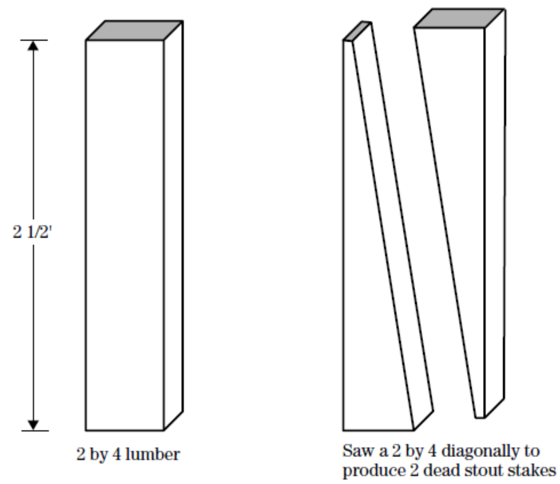
- An effective stabilization technique for slopes.
- Protects slopes from shallow slides (1 to 2-foot depth).
- Immediately reduces surface erosion or rilling.
- Suited to steep, rocky slopes, where digging is difficult.
- Capable of trapping and holding soil on the face of the slope, thus reducing a long slope into a series of shorter slopes.
- Enhances vegetative establishment by creating a microclimate conducive to plant growth.
- Since this is a surface treatment, it is important to avoid sites that will be too wet or too dry.

(iii) **Materials**

- Live Branches/Live Cuttings – adventitiously rootable, ¾ to 2 inch in diameter, 5 to 8 feet long. Cuttings should be from species, such as young willows or shrub dogwoods, that root easily and have long, straight branches.
- Cord or non-galvanized wire

- Dead stout stakes - wedge shaped, 2 to 3 feet long depending on soil. Dead stout stakes used to secure the live fascines should be untreated, 2 by 4 lumber. Each length should be cut again diagonally across the 4-inch face to make two stakes from each length (fig 18-8). Only new, sound, unused lumber should be used, and any stakes that shatter upon installation should be discarded
- Tools: Machete, shovels, clippers, hammer, sledgehammer, saw

Figure 18-8: A Dead Stout Stake



(iv) **Installation**

- Collect and soak cuttings.
- Stagger cuttings in a uniform line 5 to 20 feet long depending on site conditions and handling capabilities. Vary the orientation of the cuttings.
- Tie bundles with string or wire at approximate 1.5 to 2-foot increments. The bundle should be 6 to 12 inch in diameter (fig 18-9).
- Start installation from the toe of the slope.
- Remove loose, failed or failing soil from face of the slope.
- Align the fascine along the contour for dry slopes. Place at a slight angle along wet slopes to facilitate drainage. On upper banks adjacent to a stream, it may also be advisable to align the fascines at a slight angle to reduce the likelihood of rilling during high flows.
- Excavate a trench approximately 2/3rds the diameter of the bundle.
- Place bundle in trench and stake (use wedge shaped dead stakes) through the bundle at approximately 2 to 4-foot centers. Allow stake to protrude 3 inches above top of bundle.
- Cover the brush with soil, then wash in to assure good soil to stem contact. Some of the stems should remain exposed to sunlight to promote sprouting. Use material from next, upslope trench. It may be desirable to use erosion control fabric to hold the adjacent soil. Installation is shown in figure 18-10.
- Long straw or similar mulching material should be placed between rows on 2.5:1 or flatter slopes, while slopes steeper than 2.5:1 should have jute mesh or similar material placed in addition to the mulch.

- At intervals on contour or at an angle up the face of the bank, repeat the preceding steps to the top of the slope (fig 18-11).

Figure 18-9: Fabrication of a Live Fascine Bundle

Figure 18-10: Example Live Fascine System Installation and 3 Months After Installation

(Robbin B. Sotir & Associates photos)

Figure 18-11: Live Fascine Installation Guidelines

Slope H:V	Slope distance between trenches (ft)	Maximum Slope length (ft)
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

(3) **Brush Layering**

(i) **Description**—Brush layering is alternating layers of live branches and earth placed on benches that are excavated into the slope. The cuttings are oriented in layers that are perpendicular to the slope contour with ends that protrude beyond the face of the slope. The brush stems provide frictional resistance to shallow slides similar to conventional geotextile reinforcement. The stems that protrude from the slope face serve to break long slopes into shorter slopes and retard runoff and reduce surface erosion. The live cuttings eventually root and provide a permanent reinforcement.

(ii) **Applications and Effectiveness**—A brushlayer installation performs several immediate functions in erosion control, earth reinforcement, and mass stability of slopes:

- Breaking up the slope length into a series of shorter slopes separated by rows of brushlayer.
- Reinforcing the soil with the unrooted branch stems.
- Reinforcing the soil as roots develop, adding significant resistance to sliding or shear displacement.
- Providing slope stability and allowing vegetative cover to become established.
- Trapping debris on the slope.
- Aiding infiltration on dry sites.
- Drying excessively wet sites.
- Adjusting the site's microclimate, thus aiding seed germination and natural regeneration.
- Redirecting and mitigating adverse slope seepage by acting as horizontal drains.

(iii) **Materials**

- Live Branches/Live Cuttings – adventitiously rootable, ½ to 3 inch in diamter, length so that the cut end of the branches can touch the undisturbed soil at the back of the void or bench and the growing end can protrude 6 to 24 inches from the face of the slope
- Tools: Machete, shovels, clippers, saw, hammer

(iv) **Installation**

- Collect and soak cuttings. Leave side branches intact.
- Remove loose, failed or failing soil from face of the slope.
- Start installation from the toe of the slope.
- For cut slopes: Excavate benches on contour, 2 to 5 feet wide.
- For fill slopes: Construct benches on contour, 5 to 20 feet wide.
- Benches should be sloped at about 10 degrees (6H: 1V) so that the bench tilts back and into the slope.
- Place branches in over-lapping and crisscross configuration. Typically, 12 to 24 stems per foot of bench (measured on the contour) depending upon the size of material.
- Orient the stems such that the basal ends touch the back of the undisturbed slope. Approximately ¼ of the branch stem should extend beyond the completed slope.

- Place 3 to 6-inches of soil on the layer of cuttings and tamp to remove air pockets. Place additional soil in 6 to 8-inch lifts and compact. Repeat until desired thickness is reached. Use material from next, upslope terrace to fill the bench if working on a cut slope. Installation is shown in figure 18-12.
- Trim the terminal bud so that stem energy will be routed to the lateral buds for more rapid root and stem sprouting.
- Long straw or similar mulching material with seeding should be placed between rows on 3:1 or flatter slopes, while slopes steeper than 3:1 should have jute mesh or similar material placed in addition to the mulch.
- The brushlayer rows should vary from 3 to 5 feet apart, depending upon the slope angle and stability (table 18–13).

Figure 18-12: Example Brushlayer System Installation (left) and 2 Years After Installation (right)

(Robbin B. Sotir & Associates photos)

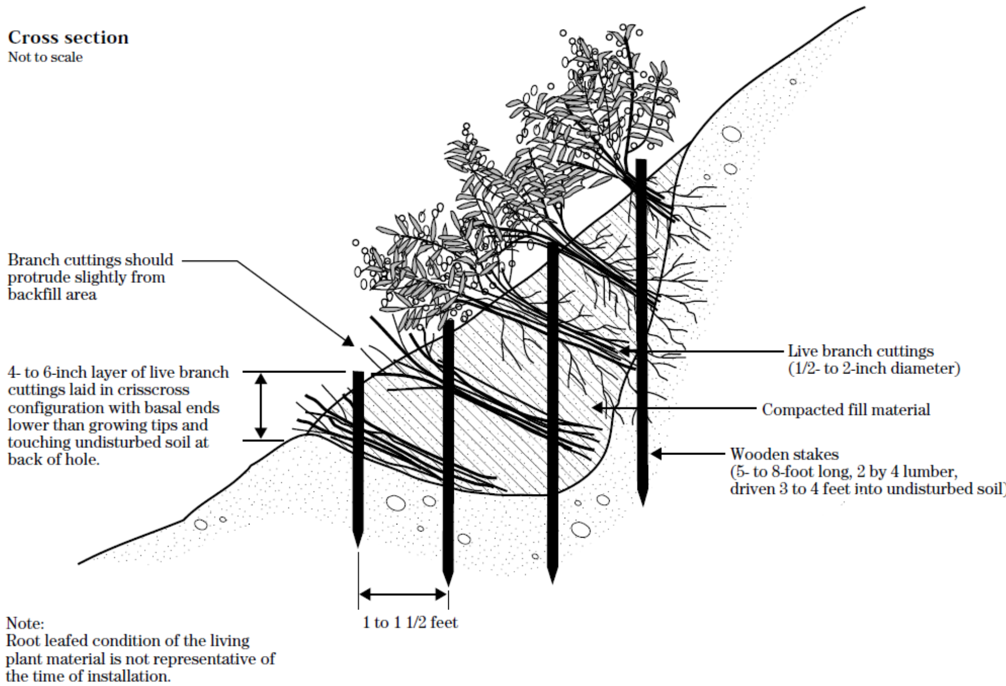
Figure 18-13: Brushlayer Installation Guidelines

Slope H:V	Slope distance (ft) between benches for wet slope	Slope distance (ft) between benches for dry slope	Maximum Slope 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

(4) **Branch Packing**

(i) **Description**—Branch or Brush Packing is alternating layers of live branches and earth used to fill localized slumps and holes in slopes. The branches protrude beyond the face of the slope. The brush stems reinforce the earth similar to conventional geotextile reinforcement. The stems provide frictional resistance to shallow slides. Wood stakes are used to anchor the material. The live cuttings eventually root and provide a permanent reinforcement (fig 18-14).

Figure 18-14: Branch Packing Details



(ii) **Applications and Effectiveness**—Branch Packing perform several immediate functions in erosion control, earth reinforcement, and mass stability of slopes:

- Effective in earth reinforcement and mass stability of small earthen fill sites.
- Produces a filter barrier, reducing erosion and scouring conditions.
- Repairs holes in earthen embankments other than dams where water retention is a function.
- Provides immediate soil reinforcement.
- Reinforcing the soil with the unrooted branch stems.
- Reinforcing the soil as roots develop, adding significant resistance to sliding or shear displacement.
- Providing slope stability and allowing vegetative cover to become established.
- Trapping debris on the slope.
- Branchpacking is not effective in slump areas greater than 4 feet deep or 5 feet wide.

(iii) **Materials**

- Live Branches/Live Cuttings – adventitiously rootable, ½ to 3 inch, length so that the cut end of the branches can touch the undisturbed soil at the back of the void or bench and the growing end can protrude 6 to 24 inches from the face of the slope
- Stakes –Live or dead, 2 to 3-inch in diameter, 5 to 8 feet long
- Tools: Machete, shovels, clippers, saw, hammer

(iv) **Installation**

- Collect and soak cuttings. Leave side branches intact.
- Remove loose, failed or failing soil from the face of the slope.
- Start installation from the toe of the slope.
- Construct a bench on contour, 4 to 6 feet deep into the slope.
- Benches should be sloped at about 10 degrees (6H: 1V) so that it slopes down and into the slope.
- Drive stakes 3 to 5 feet into the ground. The tops of the stakes should extend to the projected surface of the completed slope. Space stakes 1 to 2 feet apart.
- Place a 3 to 6-inch layer of branches between the stakes in over lapping configuration. Typically, 20 to 25 stems per yard of bench.
- Orient the stems such that the basal end touches the back of the undisturbed slope. Approximately ¼ of the branch stem should extend beyond the completed slope.
- Backfill 3 inches of soil on the layer and tamp to remove air pockets.
- Place additional soil in 6 to 8-inch lifts. Repeat until 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 is filled.
- The final installation should match the existing slope. Installation is shown in figure 18-15.
- The soil should be moist or moistened to ensure that live branches do not dry out.
- Trim the terminal bud so that stem energy will be routed to the lateral buds for more rapid root and stem sprouting.

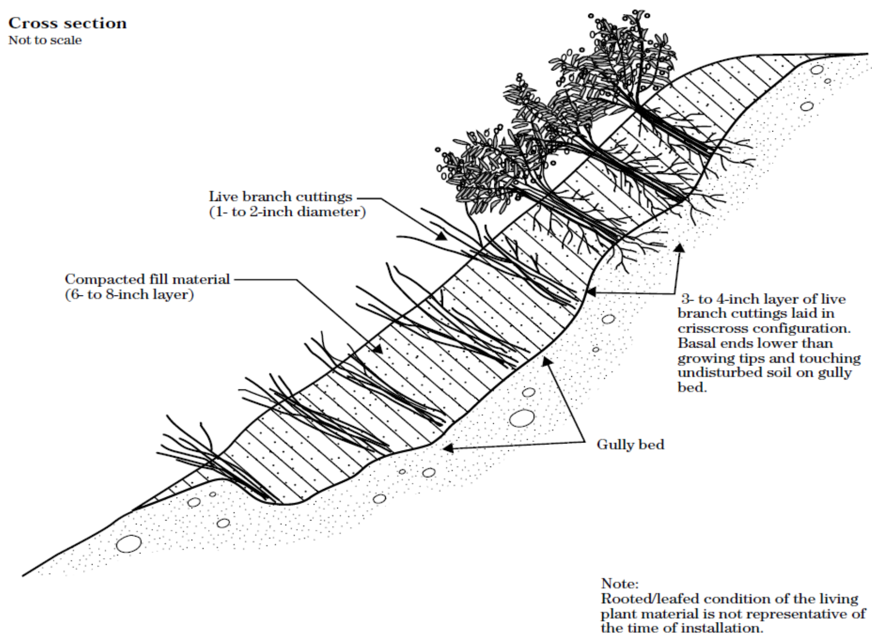
Figure 18-15: Examples of Branchpacking Systems Being Installed

Photo on left uses timber poles. Photo on right uses live poles

(5) **Live Gully Repair**

(i) **Description**—A live gully repair utilizes alternating layers of live branch cuttings and compacted soil to repair small rills and gullies. Similar to branchpacking, this method is more appropriate for the repair of rills and gullies (fig 18-16).

Figure 18-16: Live Gully Repair Detail



(iv) **Installation**

(ii) **Applications and Effectiveness**

- The installed branches offer immediate reinforcement to the compacted soil and reduce the velocity of concentrated flow of water.
- Provides a filter barrier that reduces rill and gully erosion.
- Limited to rills or gullies which are a maximum of 2 feet wide, 1 foot deep, and 15 feet long.

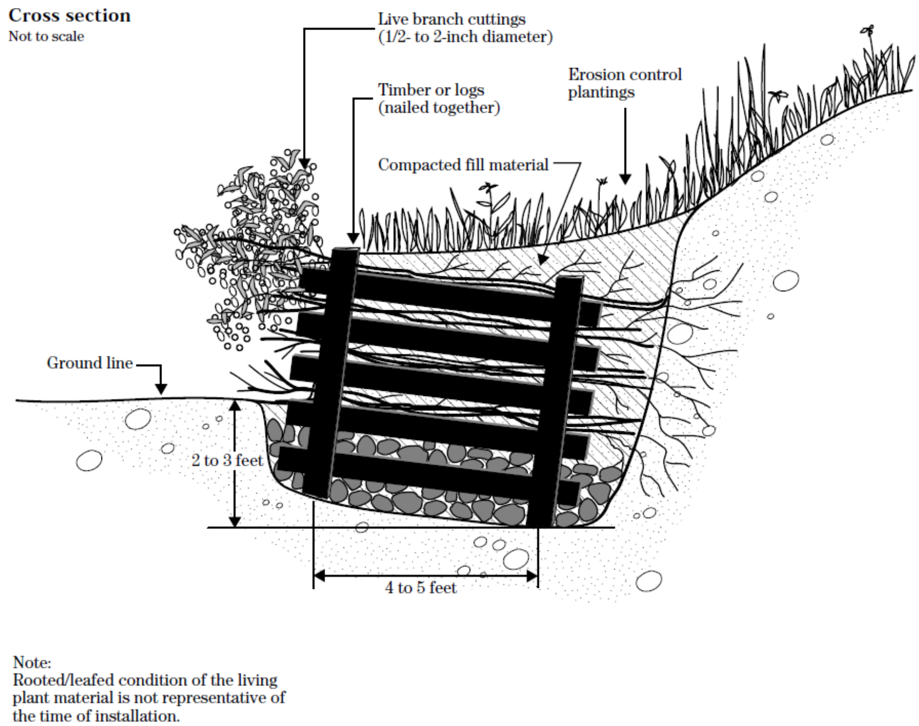
(iii) **Materials**

- Live Branches/Live Cuttings – adventitiously rootable, ½ to 3 inch in diameter, length so that the cut end of the branches can touch the undisturbed soil at the back of the void or bench and the growing end can protrude 6 to 24 inches from the face of the slope
- Stakes –Live or dead, 2 to 3-inch diameter, 5 to 8 feet long
- Tools: Machete, shovels, clippers, saw, hammer
- Collect and soak cuttings. Leave side branches intact.
- Remove loose, failed or failing soil from the face of the slope.
- Starting at the lowest point of the slope, place a 3- to 4-inch layer of branches at lowest end of the rill or gully and perpendicular to the slope.
- Cover with a 6- to 8-inch layer of fill soil.
- Install the live branches in a crisscross fashion. Orient the growing tips toward the slope face with basal ends lower than the growing tips.
- Follow each layer of branches with a layer of compacted soil to ensure soil contact with the live branch cuttings.

(6) **Live Cribwall**

(i) Description—A live cribwall consists of a hollow, box-like interlocking arrangement of untreated log or timber members. The structure is filled with suitable backfill material and layers of live branch cuttings which root inside the crib structure and extend into the slope. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members (fig. 18–17).

Figure 18-17: Live Cribwall Details



(ii) **Applications and Effectiveness**

- This technique is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Not designed for or intended to resist large, lateral earth stresses. It should be constructed to a maximum of 6 feet in overall height, including the excavation required for a stable foundation.
- Useful where space is limited and a vertical structure is required.
- Provides immediate protection from erosion, while established vegetation provides longterm stability.
- Should be tilted back or battered if the system is built on a smooth, evenly sloped surface.
- May also be constructed in a stair-step fashion, with each successive course of timbers set back 6 to 9 inches toward the slope face from the previously installed course.

(iii) **Materials**

- Front and rear beams - 4 to 12-inch diameter logs, approximately 20 feet long. Peeled logs are typically more resistant to rot than logs with bark.

- Cross Beams – 4 to 12 inch diameter logs, length equal to anticipated height of the structure.
- Live Branches/Live Cuttings – adventitiously rootable, ½ to 3 inch in diameter, 5 to 8 feet long cut so that the cut end of the branches can touch the undisturbed soil at the back of the crib and the growing end can protrude 6 to 24 inches from the face of the crib
- Stakes –Live or dead, 2 to 3-inch diameter, 5 to 8 feet long

(iv) **Tools**—Machete, shovels, clippers, saw, ax, sledge hammer, hammer

(v) **Installation**

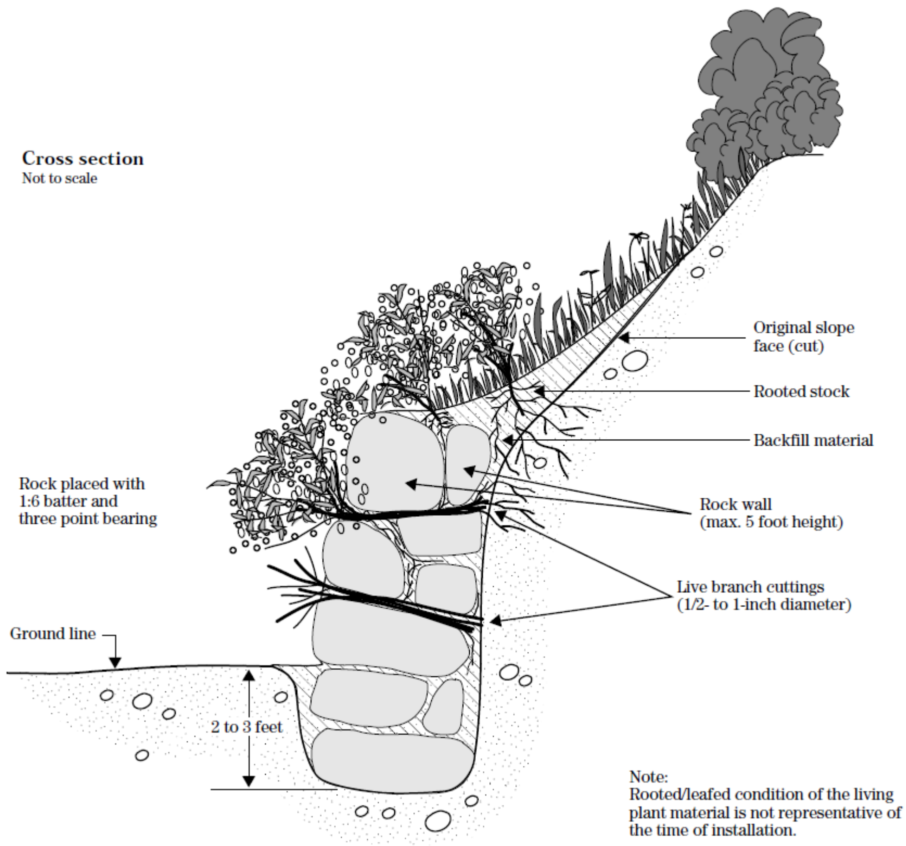
- Collect and soak cuttings. Leave side branches intact.
- Remove loose, failed or failing soil from the face of the slope.
- Excavate loose material to reach a stable foundation. Tilt the excavated toe so that the structure slopes into the embankment by approximately 6 inches to 1 foot. If the structure is to be used adjacent to a stream, it is recommended that a stone toe set below the anticipated scour be placed in front and under the structure.
- Place front and rear beams approximately 4 to 5 feet apart and parallel to slope. Rear beam should be approximately 6 inches to 1 foot below front beam.
- Place cross beams perpendicular to front and rear beams at approximately 5 to 6 foot centers.
- Allow crossbeams to overlap front and rear beams by 6 inches to 1 foot. Secure with spikes or rebar.
- Fill the inside of the first cribs with rock. Fill later portions with soil. If the structure is to be used adjacent to a stream, stone should be used along the face of the cribwall to a height of 1 to 2 foot above baseflow.
- Incline succeeding layers so that the cribwall is inclined approximately 10 to 20 degrees from vertical (1H:6V to 1H:3V).
- Once logs are above the existing ground line, place live branches with basal end towards slope and the growing tips towards the outside. Allow bud ends to extend beyond front and rear cross beams by approximately 1 foot.
- Align live branches so that they extend on top of the front cross beam and below the rear cross beam for a given course. Installation is shown in figure 18-18.
- Trim the terminal bud so that stem energy will be routed to the lateral buds for more rapid root and stem sprouting.

Figure 18-18: Example Live Cribwall Installation

(7) **Vegetated Rock Wall**

(i) **Description**—A vegetated rock wall is a combination of rock and live branch cuttings used to stabilize and protect the toe of steep slopes (fig 18-19). Vegetated rock walls differ from conventional retaining structures in that they are placed against relatively undisturbed earth and are not intended to resist large lateral earth pressures. Vegetated rock walls are considered toe walls that are normally 3 to 5 feet high, with 2 to 3 feet below grade for its footing. Further description for the design requirements is found in 210-NEH-654-14, Technical Supplement (TS) 14M, "Vegetated Rock Walls".

Figure 18-19: Vegetated Rock Wall Details



(ii) **Applications and Effectiveness**

- This technique is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Useful where space is limited and natural rock is available.

(iii) **Materials**

- Live cuttings should have a diameter of 1/2 to 1 inch and be long enough to reach beyond the rock structure into the fill or undisturbed soil behind.
- Inert materials consist of rocks and fill material for the wall construction. Rock used should normally range from 8 to 24 inches in diameter. Rock should be rectangular in shape.

(iv) **Installation**

- Collect and soak cuttings. Leave side branches intact.

- Remove loose, failed or failing soil from the face of the slope.
- Starting at the lowest point of the slope, remove loose soil until a stable base is reached. This usually occurs 2 to 3 feet below ground elevation, but ultimate scour depth should be checked. Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure.
- Excavate the minimum amount from the existing slope to provide a suitable recess for the wall.
- Provide a well-drained base in locations subject to deep frost penetration.
- The vegetated rock wall shall be constructed so that the external wall face has a 6V:1H batter. The rocks should have a slight rearward pitch.
- The rocks should be placed with at least a three-point bearing on the foundation material or underlying rock course. The rock-to-rock contact is maximized.
- The rock should be rectangular or nearly so at the rock-to-rock contact. If not perfectly flat, the thicker end should be placed towards the front of the wall.
- The rock should be placed so that the center of gravity is as low as possible, with the long axis and bedding planes slanting inward toward the slope. As the rocks are placed, fill is laid behind and around the rocks and tamped thoroughly.
- As the wall is built, the layers must be placed in an overlapping pattern, closely adjacent and in a continuous manner to minimize gaps.
- When a rock wall is constructed adjacent to an impervious surface, place a drainage system at the back of the foundation and the outside toe of the wall to provide an appropriate drainage outlet.
- Overall height of the rock wall, including the footing, should not exceed 5 feet.
- A wall can be constructed with a sloping bench behind it to provide a base on which live branch cuttings can be placed during construction.
- Live branch cuttings of shrub-type species of adventitiously rooting material can be placed in the interstices of the rock wall during or after construction. The basal ends of the branches must extend into the backfill or undisturbed soil behind the wall. The live branch cuttings should be oriented perpendicular to the slope contour, with growing tips protruding slightly from the finished rock wall face

(8) **Joint Planting**

Joint planting or vegetated riprap involves tamping live cuttings of rootable plant material into soil between the joints or open spaces in rocks that have previously been placed on a slope (fig 18-20). While this is a technique which provides improved aesthetics and habitat benefits it should be approached cautiously. Woody species can destabilize placed rock. For the vegetation to grow, the ends must extend through not only the rock but any drainage layer or filter material. This may prove to be unacceptable for the design. Alternatively, the bundles of cuttings can be placed and staked behind the rock while rock is being placed on the slope face (fig 18-21). Further guidance on joint planting is found in 210-NEH-654-14, “Treatment Technique Design”.

Figure 18-20: Joint Planting

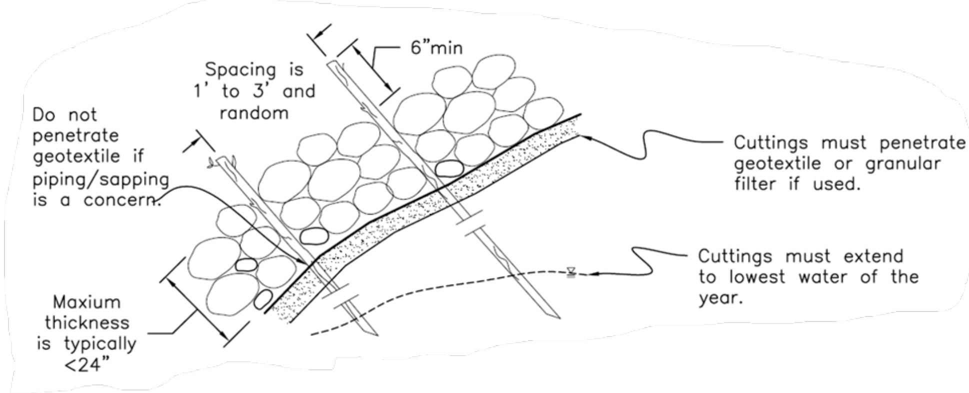
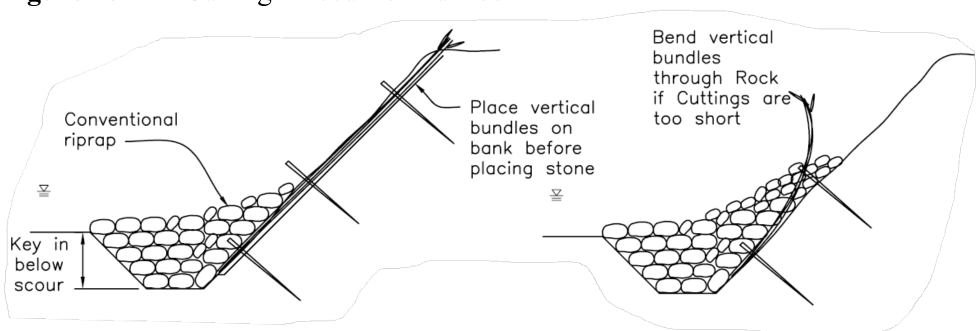
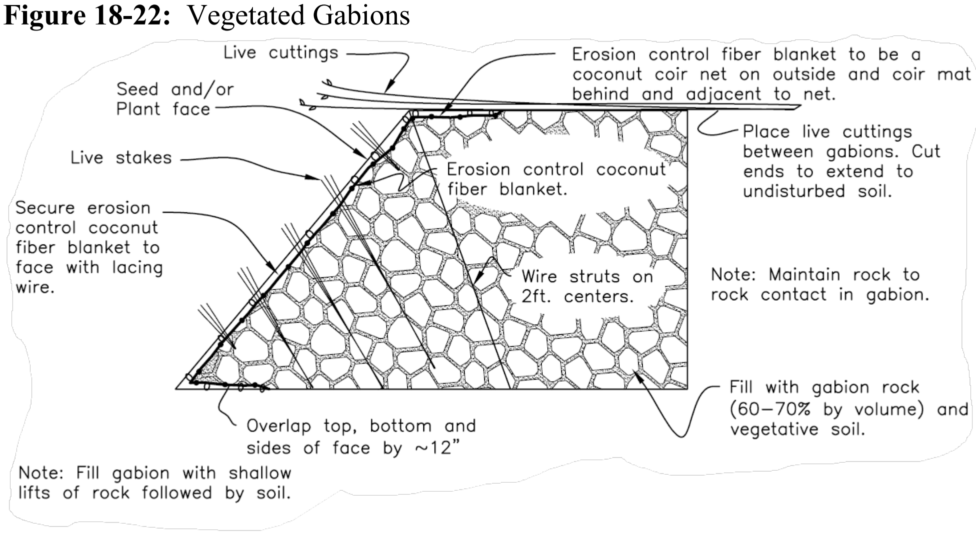


Figure 18-21: Cutting Placed Behind Rock



(9) **Vegetated Gabions**
Vegetated gabions involves including soil and vegetation within the rock of a traditional gabion installation. Rock to rock contact within the gabion is maintained to provide strength while the voids between the rock are filled with soil. Vegetation is installed between the gabions and within the gabions. A variety of approaches have been prepared by contractors as well as vendors. An example detail is provided in Figure 18-22. The design and construction of this technique is addressed in more detail in 210-NEH-654-14.

Figure 18-22: Vegetated Gabions



C. **Soil Bioengineering Materials**

(1) **Locating and Selecting Plant Materials**

(i) **Commercial Sources**

- Commercially grown plant materials are suitable sources of vegetation for use in soil bioengineering systems; however, it is necessary to allow adequate lead time for their procurement and delivery.
- The NRCS Plant Materials Program has selected superior cultivars of willows, dogwoods, and other species, which have been evaluated in soil bioengineering systems and are being produced commercially. The most desirable species and cultivars to use can be determined from specifications for critical area stabilization for each state.
- The information on plant tolerances in figure 18–23 should be used in selecting species appropriate for adverse site conditions. Plant materials specialists are closely involved with the testing of plants and can assist with up-to-date information on cultivar adaptation.

Figure 18-23: Plant Tolerance

Name	Location	Availability	Tolerance to deposition[1]	Tolerance to flooding [2]	Tolerance to drought [3]	Salt tolerance[4]
Acer negundo Boxelder	N, NE	Common	High	High	High	Medium
Alnus rubra Red alder	NW	Very common	High	Medium	Low	Low
Baccharis glutinosa Water wally	W	Common	Medium	High	Medium	Low
Baccharis halimifolia Eastern baccharis	S, SE	Common	Medium	High	Medium	Medium
Baccharis pilularis Coyotebrush	W	Very common	Medium	Medium	High	Medium
Baccharis viminea Mule fat	W	Very common	High	High	High	Medium
Betula papyrifera Paper birch	N, E, and W	Common	Medium	Medium	Medium	Medium
Betula pumila low birch	N, E, and W	Common	Low			Low

1. Tolerance to deposition—Regrowth from shallow coverage by soil (stream deposits, soil slips). High, Medium, or Low ability for regrowth.
2. Tolerance to flooding:
   • High—severely damaged after 10 to 30 days of flooding.
   • Medium—severely damaged after 6 to 10 days of flooding.
   • Low—severely damaged after 1 to 5 days of flooding.
3. Tolerance to drought—Resistance to drought (relative to native vegetation on similar sites) is High, Medium, or Low.
4. Salt tolerance—Tolerance (relative to salt tolerant native vegetation on similar sites) is High, Medium, or Low.

Figure 18-23: Plant Tolerance - continued

Name	Location	Availability	Tolerance to deposition[1]	Tolerance to flooding [2]	Tolerance to drought [3]	Salt tolerance[4]
Cornus amomum Silky dogwood	N, SE	Very common	Low	Medium	Medium	Low
Cornus racemose Gray dogwood	NE	Common	Medium	Medium	High	Low
Cornus rugosa Roundleaf dogwood	NE	Common				
Cornus sericea ssp. stolonifera Red osier dogwood	N, NE, and NW	Very common	Low	High	Medium	Low
Crataegus Sp Hawthorn	SE	Uncommon	Medium	Low	High	Low
Elaeagnus commutate Silverberry	N Cent.	Very common	High	Low	High	Medium
Ligustrum sinense Chinese privet	S, SE	Common	High	Medium	Medium	Low
Lonicera involucrate Black twinberry	E	Common	Medium	Medium	Low	Low
Physocarpus capitatus Pacific ninebark	NW, W	Common	Low	Medium	Low	Low
Physocarpus opulifolius Common ninebark	NE	Common	Low	Medium	Medium	Medium
Populus angustifolia Arrowleaf cottonwood	W	Common	Medium	Medium	High	Medium

1. Tolerance to deposition—Regrowth from shallow coverage by soil (stream deposits, soil slips). High, Medium, or Low ability for regrowth.
2. Tolerance to flooding:
   - High—severely damaged after 10 to 30 days of flooding.
   - Medium—severely damaged after 6 to 10 days of flooding.
   - Low—severely damaged after 1 to 5 days of flooding.
3. Tolerance to drought—Resistance to drought (relative to native vegetation on similar sites) is High, Medium, or Low.
4. Salt tolerance—Tolerance (relative to salt tolerant native vegetation on similar sites) is High, Medium, or Low.

Figure 18-23: Plant Tolerance - continued

Name	Location	Availability	Tolerance to deposition[1]	Tolerance to flooding [2]	Tolerance to drought [3]	Salt tolerance[4]
Populus balsamifera ssp. trichocarpa Black cottonwood	NW	Common	Medium	Medium	Medium	Medium
Populus deltoides Eastern cottonwood	MW, E	Very common	Medium	High	Medium	Low
Populus fremontii Fremont cottonwood	SW	Very common	Medium	Medium	Medium	Medium
Populus tremuloides Quaking aspen	NW	Very common	Medium	Low	Medium	Medium
Robinia pseudoacacia Black locust	NE	Common	Medium	Low	High	High
Rubus allegheniensis Allegheny blackberry	NE	Very common	Medium	Medium	Medium	Low
Rubus spectabilis Salmonberry	SW, NW	Very common	Medium	Medium	Medium	Low
Rubus strigosus Red raspberry	N, NE, and W	Very common	Medium	Low	Medium	Low
Salix exigua Coyote willow	NW	Fairly common	High	High	Medium	Low
ssp. interior Sandbar willow	N, SE	Common	High	High	Low	High
Salix amygdaloides Peachleaf willow	N, S	Common	High	High	Low	High

1. Tolerance to deposition—Regrowth from shallow coverage by soil (stream deposits, soil slips). High, Medium, or Low ability for regrowth.
2. Tolerance to flooding:
   - High—severely damaged after 10 to 30 days of flooding.
   - Medium—severely damaged after 6 to 10 days of flooding.
   - Low—severely damaged after 1 to 5 days of flooding.
3. Tolerance to drought—Resistance to drought (relative to native vegetation on similar sites) is High, Medium, or Low.
4. Salt tolerance—Tolerance (relative to salt tolerant native vegetation on similar sites) is High, Medium, or Low.

Figure 18-23: Plant Tolerance - continued

Name	Location	Availability	Tolerance to deposition[1]	Tolerance to flooding [2]	Tolerance to drought [3]	Salt tolerance[4]
Salix bonplandiana Pussy willow	W and MW	Very common	Medium	Medium	Low	
Salix eriocephala ssp. ligulifolia Erect willow	NW	Comon	High	High	Medium	Low
Salix gooddingii Goodding willow	SW	Very common	High	Medium	Medium	Low
Salix hookeriana Hooker willow	NW	Common	High	High	Low	Medium
Salix humilis Prairie willow	N, NE	Very common	Medium	Medium	High	Low
Salix lasiolepis Arroya willow	W	Common	High	High	Medium	Low
Salix lemmonii Lemmon willow	W	Comon	High	High	Medium	Low
Salix lucida Shining willow	N, NE	Very common	Medium	Medium	Medium	Low
ssp. lasiandra Pacific willow	NW	Very common	High	High	Low	Low
Salix lutea Yellow willow	W	Very common	Medium	Medium	Medium	Low
Salix nigra Black willow	N, SE	Very common	High	High	Medium	Medium
Salix purpurea Streamco	N, S, E, and W	Very common	High	High	Medium	Low
Salix scouleriana Scoulers willow	NE	Very common	High	High	Medium	Low
Salix sitchensis Sitka willow	NW	Common	High	Medium	Medium	Low
Salix X cotteti Bankers willow	N, S, E, and W	Uncommon	High	High	Medium	Low

1. Tolerance to deposition—Regrowth from shallow coverage by soil (stream deposits, soil slips). High, Medium, or Low ability for regrowth.
2. Tolerance to flooding:
   - High—severely damaged after 10 to 30 days of flooding.
   - Medium—severely damaged after 6 to 10 days of flooding.
   - Low—severely damaged after 1 to 5 days of flooding.
3. Tolerance to drought—Resistance to drought (relative to native vegetation on similar sites) is High, Medium, or Low.
4. Salt tolerance—Tolerance (relative to salt tolerant native vegetation on similar sites) is High, Medium, or Low.

Figure 18-23: Plant Tolerance - continued

Name	Location	Availability	Tolerance to deposition[1]	Tolerance to flooding [2]	Tolerance to drought [3]	Salt tolerance[4]
Salix discolor Red willow	N, NE	Very common	High	High	High	Medium
Sambucus cerulea Blueberry elderberry	W	Common	Medium	Medium	Medium	Low
Sambucus canadensis American elderberry	NE, SE	Very common	High	Medium	Medium	Low
Sambucus racemose Red elderberry	NW	Common	Medium	Low	Medium	Low
ssp. pubens Scarlet elder	NE	Common	Medium	Medium	Medium	Low
Spiraea alba Meadowsweet spirea	N, E	Common	Low	Medium	Medium	
Spiraea douglasii Douglas spirea	NW	Common	Medium	Medium	Medium	Low
Spiraea tomentosa Hardhack spirea	NE	Common	Medium	Medium	Medium	Medium
Symphoricarpos albus Snowberry	N, NW, and E	Common	Low	Low	High	High
Viburnum alnifolium Hubbiebush viburnum	E	Common	Medium	Medium	Medium	Low
Viburnum dentatum Arrowwood viburnum	E	Common	Medium	Medium	Medium	Low
Viburnum lentago Nannyberry viburnum	S, SE	Fairly common	Medium	Low	Medium	Low

1. Tolerance to deposition—Regrowth from shallow coverage by soil (stream deposits, soil slips). High, Medium, or Low ability for regrowth.
2. Tolerance to flooding:
   - High—severely damaged after 10 to 30 days of flooding.
   - Medium—severely damaged after 6 to 10 days of flooding.
   - Low—severely damaged after 1 to 5 days of flooding.
3. Tolerance to drought—Resistance to drought (relative to native vegetation on similar sites) is High, Medium, or Low.
4. Salt tolerance—Tolerance (relative to salt tolerant native vegetation on similar sites) is High, Medium, or Low.

(2) **Harvesting Indigenous Species**

(i) Correctly selected indigenous species harvested from existing stands of living woody vegetation are the preferred soil bioengineering materials. The use of indigenous live materials requires careful selection, harvesting, handling, and transporting. They should result in plants that have deep and strong root systems, are relatively inexpensive, are usually effective, and can be installed quickly.

(ii) Live plant materials can be cut from existing native or naturalized stands found near the project site or within practical hauling distance. The source site must contain plant species that will propagate easily from cuttings. Cuttings are normally 1/2 to 2 inches in diameter and range in length from 2 to 6 feet.

(iii) Chain saws, bush axes, loppers, and pruners are recommended for cutting living plant material. Safety precautions must be followed when using these tools. Onsite plant material should be harvested with great care. In some places a large area can be cut, but other sites require selective cutting. Cuts should be made at a blunt angle, 8 to 10 inches from the ground, to assure that the source sites will regenerate rapidly and in a healthy manner. The harvesting site should be left clean and tidy. Remnant materials that are too large for use in soil bioengineering projects should be chipped or left in piles for wildlife cover. A site may be needed again for future harvesting and should be left in a condition that will enhance its potential for regeneration.

(iv) Avoid diseased and rotting material as well as material suffering from insect infestation.

(v) Binding and storage—Live cuttings should be bundled together securely at the collection site for easy loading and handling and for protection during transport. Side branches and brushy limbs should be kept intact.

(vi) Transporting—The bundles of live cuttings should be placed on the transport vehicles in an orderly fashion to prevent damage and facilitate handling. They should be covered with a tarpaulin during transportation to prevent drying and additional stress.

(vii) Handling—Live cuttings should arrive on the job site within 8 hours of harvest and should be installed immediately. This is especially critical when the ambient temperature is 50 °F or above.

(viii) Live cuttings not installed on the day they arrive should be promptly placed in controlled storage conditions and protected until they can be installed. When in storage, the cuttings must receive continuous shade, must be sheltered from the wind, and must be continuously protected from drying by being heeled into moist soils or stored in uncontaminated water. All live cuttings should be removed from storage and used within 2 days of harvest.

(3) **Installing Plant Materials**

(i) **Timing**—Installation of live cuttings should begin concurrently with earth moving operations if they are carried out during the dormant season. All construction operations should be phased together whenever possible. The best time for installation of soil bioengineering systems is during the dormant season, which generally occurs from September to March throughout most of the United States. Each geographic area has a specific dormant season within this broad range, and yearly variations should be taken into account.

(ii) **Planting medium**

- Soil bioengineering projects ideally use onsite stockpiled topsoil as the planting medium of choice. Gravel is not a suitable material for use as fill around live plant materials. Soil bioengineering systems need to be installed in a planting medium that includes fines and organic material and is capable of supporting plant growth. Muddy soils that are otherwise suitable should not be used until they have been dried to a workable moisture content. Heavy clays should be mixed with organic soils to increase porosity. Select soil backfill does not need to be organic topsoil, but it must be able to support plant growth.
- Soil samples of the onsite materials should be taken prior to installation of live woody cuttings. Soil samples should also be taken of all fill materials that are brought to the site prior to use. Nutrient testing by an approved laboratory should include analyses for a full range of nutrients, metal contents, and pH. The laboratory reports should also include recommended fertilizer and lime amendments for woody plant materials.
- All fill soil around the live vegetative cuttings should be compacted to densities approximating the surrounding natural soil densities. The soil around plants should be free of voids.

(4) **Quality Control**

Maintaining quality control throughout installation and maintenance operations will ensure a successful soil bioengineering project. The following guidelines are recommended:

(i) **Pre-construction**

- Select plant species for conformance to requirements.
- Locate and secure source sites for harvesting live cuttings or commercial procurement.
- Define construction work area limits.
- Fence off sites requiring special protection.
- Complete and inspect the following preparations:
  - Layout
  - Excavation, systems excavation
  - Bench size, shape, angle
  - Preparation of site; i.e., clearing, grading, and shaping
  - Disposal of excess gravel, soil, and debris
  - Depth of excavation
  - Vegetation to be removed/preserved
  - Stockpiling of suitable soil and/or rock

(ii) **Construction**

- Inspect each system component, at every stage, for the following:
  - Angle of placement and orientation of the live cuttings
  - Backfill material/rock and stone material
  - Fertilizer, method and quantity applied
  - Lime, method and quantity applied
  - Preparation of trenches or benches in cut and fill slopes
  - Staking
  - Pruning
  - Stock handling and preparation
  - Soil compaction
  - Watering

- Ensure that proper maintenance occurs during and after installation.
- Inspect daily for quality control.
  - Check all cuttings; remove unacceptable material and use fresh stock for replacement installations.
  - Continuously check all items in the preconstruction and construction inspection lists.
  - Inspect the plant materials storage area when it is in use.

(5) **Establishment Period**

(i) **Interim Inspections**—Inspections should be made after the soil bioengineering measures have been installed. The following schedule is recommended:

- Inspect biweekly for the first 2 months. Inspections should note insect infestations, soil moisture, and other conditions that could lead to poor survivability. Immediate action, such as the application of supplemental water, should be taken if conditions warrant.
- Inspect monthly for the next 6 months. Systems not in acceptable growing condition should be noted and, as soon as seasonal conditions permit, should be removed from the site and replaced with materials of the same species and sizes as originally specified.
- Needed reestablishment work should be performed every 6 months during the initial 2-year establishment period. This will usually consist of replacing dead material.
- Extra inspections should always be made during periods of drought or heavy rains. Damaged sections should always be repaired immediately.

(ii) **Final Inspection**

- A final inspection should be held 2 years after installation is completed. Healthy growing conditions should exist.
- Healthy growing conditions in all areas refer to overall leaf development and rooted stems defined in Figure 18-24.

Figure 18-24: Percent Healthy Growing for Final Inspection

Technique	Healthy growing conditions
Live cuttings	70-100% growing
Live fascines	20-50% growing
Live cribwall	30-60% growing
Brushlayers	40-70% growing
Branchpacking	40-70% growing
Live gully repair	30-50% growing
Vegetated rock wall	50-80% growing
Vegetated gabion	40-60% growing
Joint planting	50-70% growing

- Growth should be continuous with no open spaces greater than 2 feet in linear systems. Spaces 2 feet or less will fill in without hampering the integrity of the installed living system.

(6) **Maintaining the System**

(i) After inspection and acceptance of the established system, maintenance requirements should be minor under normal conditions. Maintenance generally consists of light pruning and removal of undesirable vegetation. Heavy pruning may be required to reduce competition for light or stimulate new growth in the project plantings. In many situations, installed soil bioengineering systems become source sites for future harvesting operations. The selective removal of vegetation may be required to eliminate undesirable invading species that should be cut out every 3 to 7 years.

(ii) More intensive maintenance will sometimes be required to repair problem areas created by high intensity storms or other unusual conditions. Site washouts should be repaired immediately. Generally, reestablishment should take place for a 1-year period following construction completion and consist of the following practices:

- Replacement of branches in dead unrooted sections
- Soil refilling, branchpacking, and compacting in rills and gullies
- Insect and disease control
- Weed control

(iii) Gullies, rills, or damaged sections should be repaired through the use of healthy, live branch cuttings preferably installed during the dormant season. The repair should use the branchpacking system for large breaks and the live gully repair system for breaks up to 2 feet wide and 2 feet deep. If the dormant season has passed, the use of rooted stock may be considered.

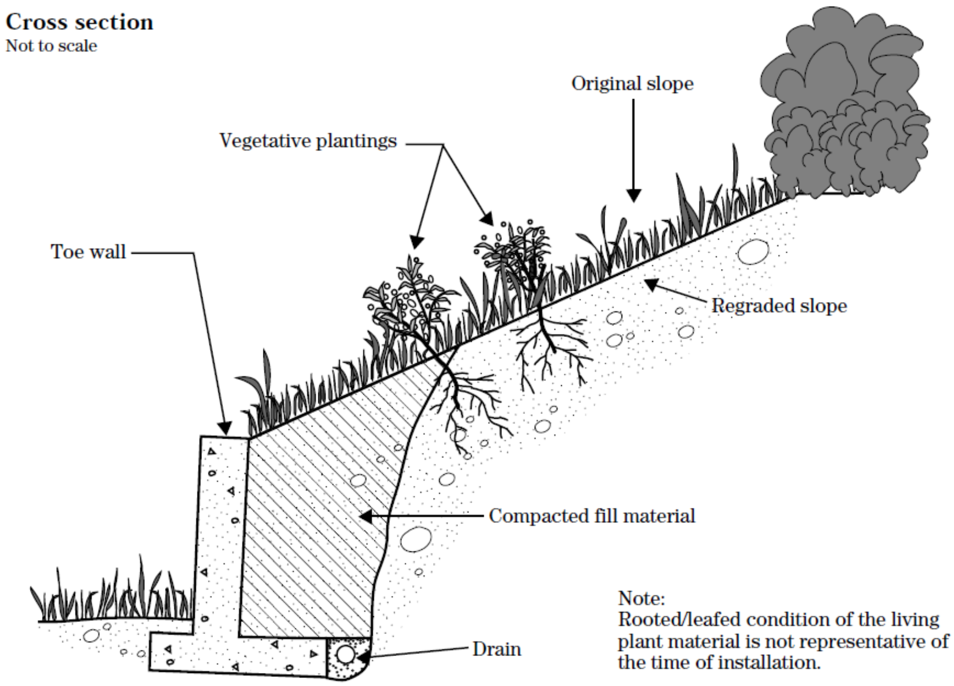
D. **Vegetated Structures**

(1) Vegetated structures consist of either low walls (fig 18-25) or revetments (concrete or rock and mortar) at the foot of a slope with plantings on the interposed benches.

(2) A structure at the foot of a slope protects the slope against undermining or scouring and provides a slight buttressing effect. In the case of low walls, it allows regrading of the slope face to a more stable angle without excessive retreat at the crest. Vegetation planted on the crest of the wall and the face of the slope protects against erosion and shallow sloughing. In the case of tiered structures, the roots of woody plants grow into the soil and backfill within the structure, binding them together. The foliage in front covers the structure and enhances its appearance.

(3) These systems are not soil bioengineering structures, as their plant materials represent little or no reinforcement value to the structure.

Figure 18-25: A Low Wall with Plantings Above



(4) Several basic types of retaining structures can be employed as low walls. The simplest type is a gravity wall that resists lateral earth pressures by its weight or mass. The following types of retaining structures can be classified as gravity walls:
   (i) Masonry and concrete walls
   (ii) Crib and bin walls
   (iii) Cantilever and counterfort walls
   (iv) Reinforced earth and geogrid walls

(5) In addition, each of these can be modified in a variety of ways to fit nearly any condition or requirement. For further discussion of standard engineering design requirements and specifications see NEH, Section 6, “Structural Design” as well as 210-NEH-654.

650.1804 Definitions

Batter—The angle of the front face of a retaining structure with respect to a vertical plane.

Bench—A horizontal surface or step in a slope

Buttressing—Lateral restraint provided by earth or rock masses and embedded structural columns, such as piles and well-rooted tree trunks.

Brushlayer—Live branch cuttings laid in crisscross fashion on benches between successive lifts of soil.

Concrete cribwall—A hollow, structural wall formed out of perpendicular and interlocking concrete beams.

Cut face—The open, steep face of an excavated slope.

Cutting—A branch or stem pruned from a living plant.

Crib structure—A hollow structure constructed of mutually perpendicular, interlocking beams or elements.

Dead stout stake—A 2 by 4 timber that has been cut into a specific shape and length.

Face planting—Planting live cuttings and other vegetation in the frontal openings of retaining structures.

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

Grade stabilization—The maintenance of a gentle, noneroding gradient on a watercourse or land surface. This is usually accomplished by means of structural measures or by regrading (lengthening) the slope.

Gravity retaining walls—Retaining structures that resist lateral earth forces and overturning primarily by their weight.

Grid wall—A lattice or grid-like array of timbers that are fastened or anchored to a slope. The grid spaces are filled with topsoil and then seeded or planted.

Joint planting—The insertion of live branch cuttings between openings or interstices of rocks, blocks, or other inert armor units and into the natural ground.

Lateral earth pressure—The horizontal pressure exerted by soil against a retaining structure.

Live cribwall—A hollow, structural wall formed out of mutually perpendicular and interlocking members, usually timber, in which live cuttings are inserted through the front face of the wall into the crib fill and/or natural soil behind the wall.

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

Live fascines—Bound, elongated sausage-like bundles of live cut branches that are placed in shallow trenches, partly covered with soil, and staked in place to arrest erosion and shallow mass wasting.

Live cutting—Cuttings from living branches that are tamped or inserted into the earth. The cuttings eventually root and leaf out.

Mass movement—The movement of large, relatively intact masses of earth and/or rock along a well defined shearing surface as a result of gravity and seepage.

Mass wasting—See “Mass movement.”

Reinforced earth—Strengthening of a soil fill by utilizing tensile inclusions, such as metal strips, woody fibers, wire mesh, or fabric.

Shallow mass movement—Near-surface sliding or movement of earth and/or rock masses usually along planar failure surfaces parallel to the slope face.

Slope flattening—Reduction in slope angle by excavation and regrading in order to achieve a more stable slope.

Soil arching—Restraint of soil movement through an opening or gap as a result of transfer of shear stress from the deforming (or moving) soil mass to adjacent stationary (nonyielding) portions of the soil.

Soil bioengineering—Use of live, woody vegetative cuttings to repair slope failures and increase slope stability. The cuttings serve as primary structural components, drains, and barriers to earth movement

Steel bin wall—Hollow wall sections constructed of steel that are bolted together and filled with rock or gravel to serve as a gravity retaining wall.

Stepped-back reinforced wall—A reinforced earth retaining wall in which successively higher portions of the wall are set back from the front in stepped fashion.

Surface armoring—Placement of an armor layer, composed of rock, brush matting, gabion mattresses, stabilized earth, etc., on the ground surface.

Tiered retaining wall structures—Retaining structures in which successively higher portions of the structure are set back from the front in stepped fashion. Crib, gabion, and reinforced earth walls can be erected in this fashion.

Toe wall—A low, structural wall erected at the toe or base of a slope to provide support and protect against undermining.

Undermining—The removal of lateral support at the base of a slope by scour, piping erosion, or excavation.

Vegetative cuttings—Live, cut stems and branches of plants that will root when embedded or inserted in the ground.

Vegetated earth buttress—An earthen mass placed against the base or toe of the slope to improve stability. Vegetation can be planted on the face of the buttress or introduced into the buttress in the form of brushlayers.

Vegetative measures—The use of live cuttings, seeding, sodding, and transplanting in order to establish vegetation for erosion control and slope protection work.

Vegetated rock gabions—See "Vegetated structures."

Vegetated rock walls—See "Vegetated structures."

Vegetated structures—A retaining structure in which living plant materials, cuttings, or transplants have been integrated into the structure.

Vegetated structural revetments—Porous revetments, e.g., a gabion mattress or riprap, into which live plants or cuttings can be placed or inserted.

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650.1806 Acknowledgments

A. The first version of this chapter was prepared in 1992 under the guidance of **Ronald W. Tuttle,** national landscape architect (retired), and steering committee members **David C. Ralston,** national design engineer (retired), and **Curtis W. Sharp,** national plant materials specialist (retired), Natural Resources Conservation Service (NRCS), Washington, DC.

B. **Robbin B. Sotir & Associates** and **Dr. Donald H. Gray** are the principal authors of this manuscript.

C. **Carolyn A. Adams,** landscape architect (retired); **Leland M. Saele,** design engineer (retired); **Gary E. Formanek,** agricultural engineer (retired); and **Frank F. Reckendorf,** sedimentation geologist (retired); NRCS Portland, Oregon, edited the manuscript to extend its applicability to most geographic regions and to fit it to agency programs.

D. In 2020, **Jon Fripp**, stream mechanics civil engineer, National Design, Construction, and Soil Mechanics Center, Fort Worth, TX, and **Kelly Ramsey,** hydraulic engineer, NRCS-Virginia, under the guidance of **Jo Johnson**, national geologist, provided updates and revisions to follow format and current technical guidance.