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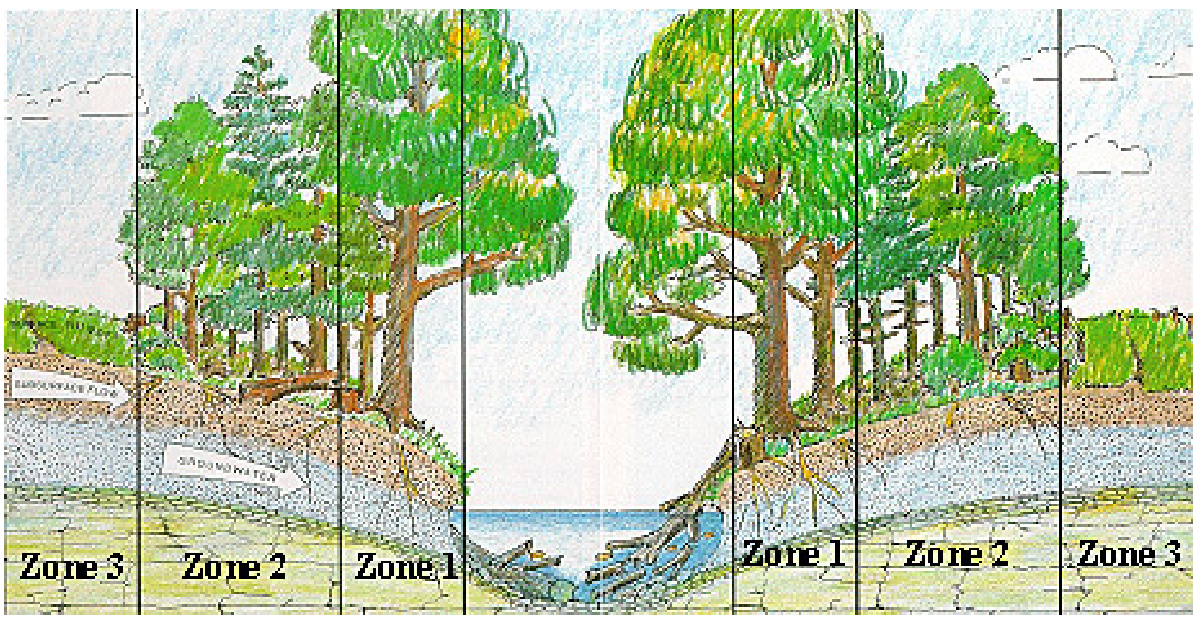
Flood Damage Reduction Research Program

Plant Material Acquisition, Layout, and Handling for Flood Control Projects

J. Craig Fischenich, Dinah N. McComas, and Hollis H. Allen

September 2001



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Contents

List of Figures

List of Tables

Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Flood Damage Reduction Research Program. The guidelines developed herein were products of Work Unit 33061, "Design and Maintenance of Vegetated Flood Control Channels." The Program Monitor was Mr. Richard J. DiBuono, HQUSACE. The Program Manager was Ms. Carolyn Holmes, Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. Principal Investigators for the work unit were Drs. J. Craig Fischenich, Environmental Laboratory (EL), ERDC, and Ronald R. Copeland, CHL.

The report was prepared by Dr. Fischenich, Mrs. Dinah N. McComas, CHL, and Mr. Hollis H. Allen, EL. Dr. Copeland, CHL, Mr. Jerry Miller, EL, and Ms. Robbin B. Sotir of Robbin B. Sotir & Associates, Inc., provided the technical review.

The study was performed under the direct supervision of Dr. Yen-Hsi Chu, Chief, River Sedimentation Branch, CHL, and under the general supervision of Mr. Thomas W. Richardson, Acting Director, CHL, and Dr. Edwin A. Theriot, Acting Director, EL.

At the time of publication of this report, Director of ERDC was Dr. James R. Houston, and COL John W. Morris III, EN, was Commander and Executive Director.

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1 Introduction

This report presents state-of-the-art environmental guidance for soil bioengineering treatments for flood control projects. Soil bioengineering is an integrated technology that uses sound engineering practices in conjunction with integrated ecological principles to access, design, construct, and maintain living vegetation systems to repair damage caused by erosion and failures in the land and to protect and enhance healthy functioning systems (Sotir 2001)

Designs of soil bioengineering treatments are chosen based on hydraulic impacts, environmental benefits, and the anticipated soils and hydrology. This report focuses on environmental considerations related to acquisition, handling, and placement of vegetation for soil bioengineering treatments. Guidelines for selection of species type and acquisition of those plant species are provided in Chapter 2. Chapter 3 provides guidelines for design of the riparian buffer zone adjacent to the stream. Chapter 4 provides guidance for handling plant materials for soil bioengineering projects. Chapter 5 provides guidance that can be used to develop cost estimates for some soil bioengineering applications. Some supplemental considerations are discussed in Chapter 6, and conclusions are provided in Chapter 7.

2 Plant Selection and Acquisition

There are two options for establishing vegetation along the stream corridor; one is to allow for natural colonization, and the other is to plant the desired vegetation. For viable natural colonization, there must be nearby sources of seeds or vegetative propagules that have access to the site. The composition of adjacent riparian vegetation communities can be a good guide for anticipating the composition of the colonized vegetation, but the targeted vegetation may need to be altered because of the project's impacts to hydrology or soil conditions. If planting is necessary to establish the desired community or to accelerate the development of plant cover, species must be selected that will meet project objectives and be competitive under the site conditions. Appropriate plant materials are selected by a plant specialist who coordinates with the site hydrologist, soil scientist, and/or geotechnical engineer. Selections are based on the site analysis and on evaluation of the plant communities in the nearby region. A preliminary planting plan is developed to be consistent with project goals and objectives, site conditions, and anticipated maintenance requirements. Guidelines are prepared for the subsequent design of an irrigation system, if needed, and specific measures for plant protection and maintenance are identified.

The plants must be available in adequate supply and in good condition during the planting time window. Plant material can be contract grown, acquired through a commercial nursery, or collected from natural populations. There are trade-offs in cost, labor, and quality of plant material among the plant material sources. Site preparations must be made prior to arrival of the plant material both for appropriate storage and to minimize the time plants are out of the ground. Timing is equally important if plants are established by seeding.

Once acquired, plants must be installed in the proper location using methods appropriate for the type of material used. Methods and procedures for the installation of plant materials are outlined in the planting plan. There also should be planning for the maintenance of plant materials and the site during the plant establishment period and for any required or otherwise appropriate monitoring and reporting of project progress and success. Maintenance of plants through control of nuisance species, insects, disease, erosion, and water level in managed systems can be crucial to their survival and growth.

Species Selection

Generally speaking, vegetation used for riparian revegetation projects consists of a mix of trees, shrubs, and herbaceous plants that are native to the region and well adapted to the climatic, soil, and hydrologic conditions of the site. A botanist familiar with local flora should be enlisted to select from among candidate species those most likely to meet project objectives. The composition of the riparian community in adjacent locations can be a good guide and is often used as a starting point for the revegetation design.

However, selection of plant species can be complicated by the fact that riparian communities are not always a distinct climax biotic community. Changes occur in species composition, diversity, structure, and function as a result of continual changes in site conditions. Factors originating outside the plant community (e.g., sedimentation and hydrologic alteration) and factors arising from within (e.g., increased soil fertility and shading) progressively change the habitat, allowing the plant community to evolve. Floods, erosion, and deposition frequently change habitats on dynamic streams, and the riparian vegetation may undergo perpetual succession. These influences must be considered in efforts to restore a habitat.

Recognizing that succession will occur is important regardless of any installed planting or seeding program because natural succession can create new communities of great value or negate the project goals and objectives. Given an adequate source of propagules for desirable species, a common approach for flood control, stabilization, and restoration projects is to select and establish pioneer species on the site and allow natural succession to dictate the configuration of the vegetation community over time. Alternatively, existing vegetation at the site and on similar nearby stable areas that have revegetated naturally can be a good indicator of the plant species to use.

Establishing diverse vegetation, either directly or through succession, is desirable for a number of reasons. A relatively large number of species provides an array of environmental tolerances. As the project site experiences fluctuations in various environmental conditions, such as water level, temperature, and herbivory, over time, some plants or species will not survive, while others may thrive. If the project is dominated by only one or two species, the project may fail with the death of only one species. Planting a variety of species increases the chances for success of at least a few species.

A diverse array of plant species is essential to a riparian system's ability to provide and sustain a number of functions. Monocultures, or communities with a single dominant species, are often considered to have limited value. The benefits of diverse communities are numerous. For example, establishment of a variety of desirable species will increase competition for resources and limit the potential for aggressive species to overtake a project site. In addition, a high number of plant species and structural complexity of natural ecosystems generally correlate with wildlife species richness, particularly for birds (Weins 1989).

Various plant species associations and hydrologic conditions provide required habitats for different life history phases of animals, such as feeding, winter cover, and breeding (Heitmeyer, Connelly, and Pederson 1989; Frazer, Gibbons, and Greene 1990). Further, as fully functioning components of a landscape, a variety of vegetation types in an area enables an exchange of genetic material among neighboring populations. Migration among populations helps maintain genetic diversity and repopulation of local extinctions. Vegetative diversity can be increased at a restoration site in numerous ways, such as:

a. Planting an array of different species in different amounts.

b. Planting a variety of growth forms (e.g., herbaceous species, ground cover, shrubs, saplings and tree species, emergents, floating hydrophytes, submerged hydrophytes, and free-floating species).

c. Planting species with a variety of life histories (e.g., annuals and short-lived or long-lived perennials).

d. Providing a range of site conditions (e.g., through elevation changes, creation of habitats with varying aspects/orientations) to support a diverse range of plant species.

e. Increasing margins or edges within a wetland (Davis et al. 1996).

Determination of the optimal diversity for a site should be made in conjunction with setting the project goals and design criteria. The concept of in-kind replacement assumes that the natural landscape reflects the optimal diversity by virtue of natural developmental processes and the adaptation of organisms to those conditions. While this condition may often be the case, disturbed landscapes, such as urban, agricultural, or mined areas, require a different approach. Selection of an appropriate diversity of species is an important step toward meeting project goals.

Many flood damage reduction and restoration projects are implemented in urban environments where the landscape and environmental conditions have been sufficiently altered so that true restoration aimed at achieving “natural” functions and pre-impact form is not feasible. Under these circumstances, and in many cases where such constraints do not exist, the success of a project, as viewed by the public, is often based on the visual appeal of the site after restoration.

The landscaping component of stream and riparian restoration projects is generally underemphasized, given its importance from the standpoint of visual success and public perception. Even projects that fully restore the desired functions for the site can be deemed a failure or, at best, only a marginal success if they do not also offer visual appeal. Species should be selected to provide the necessary color, texture, and shape to meet aesthetic objectives.

Almost all plants used in flood control, soil bioengineering, or restoration projects can be considered wetland plants, either obligative or facultative. Some exceptions occur in zones that are infrequently flooded, but all must be somewhat flood tolerant. Both herbaceous and woody plants are used. Herbaceous plants may be emergent aquatic plants like rushes and sedges or grasses and other forbs that require nonaquatic, but moist, conditions at least part of the year.

Plant Material Acquisition

Plans for acquiring plants must be made well in advance of the project implementation (sometimes 1 to 2 years). If commercial plant sources are not available (USDA Soil Conservation Service 1992), then onsite or offsite harvesting can be considered. When acquiring plants, consideration must be given to local or Federal laws prohibiting the acquisition of certain plants and the decimation of natural stands of wetland plants. Additionally, care must be taken to ensure that pest species are not collected and transferred to the project site.

Availability of plants of the appropriate species, size, and quality is often a limiting factor in the final plant selection and acquisition process. Some native plant species are very difficult to propagate and grow, and many desirable species are not commonly available commercially or are not available as good-quality plants. As demand increases and nurserymen gain more experience in growing native plant species, this limitation should become less important (Leiser 1992). Plant species composition and quantity can often be determined from the project objectives and functions desired. As a general rule, designers should specify as many species as possible and require the use of some minimum number of these species. Generally, maximum and minimum numbers of any one species should also be specified.

Three suitable methods to acquire plants for flood control, soil bioengineering, and restoration projects are: (a) purchase plants, (b) collect plants from the wild, and (c) propagate and grow plants. Each has noteworthy advantages, but also critical disadvantages that make plant acquisition and handling an important and complex process. Table 1 presents these advantages and disadvantages. Regardless of the method chosen, it is necessary to conduct the following steps (Pierce 1994; Allen and Leech 1997):

a. Determine the available hydrologic regime and soil types. General positioning of the plant type (e.g., emergent aquatic and shrubby willow) should be in accordance with the plant zone (splash, bank, and terrace) as specified by Allen and Leech (1997).

b. Prepare a list of common wetland plant species in the region (more preferably in the watershed containing the stream of concern) and match those to the hydrology and substrate of the target streambank reach.

c. Select species that will match the energy of the environment and the hydraulic conveyance constraints that may be imposed by the situation. For instance, one must be careful to use low-lying and flexible vegetation that lays down with water flows if hydraulic conveyance must be maximized. In such cases, use flood-tolerant grasses or grasslike plants and shrubby woody species.

d. Select species that will not be dug out or severely grazed by animals, especially muskrat (*Ondatia zibethieus*), nutria (*Myocastor coypes*), beaver, Canada geese, and carp (*Cyprinus carpio*). Other animals may influence plant growth and survival. If chosen plants are unavoidably

Table 1
Considerations for Plant Material Acquisition

Method	Advantages	Disadvantages
Purchase	Plants are readily available at the planting location in predicted quantities and at the required time. No special expertise is required to collect or grow the plants. No wild source for the plants must be found, and there are no harvesting permits to obtain from state or local governments. Cost can be more readily predicted and controlled.	Plants may arrive in poor condition. Selection of species is limited. Plants may not be adapted to the local environment. Cost may be high, and shipping cost needs to be considered. Quantities may be limited. Storing large quantities of plants may be necessary, and procuring adequate storage facilities may be difficult.
Collect from Wild	Plants are likely to be ecotypically adapted to the local environment. Plants can often be collected at a low cost. Plants can be collected as needed and will not require extended storage. Availability of species is very flexible and can be adjusted. No special expertise is required to grow the plants. A very wide diversity of plants is available.	Weedy species may be inadvertently transplanted to the project site. A suitable area or areas must be located. Plants may be stressed, diseased, or insect infested and not in an appropriate condition for planting. Rare plants may be harvested by mistake. Cost of collection and logistics may be very high. Outdoor hazards such as snakes, adverse weather, noxious plants, and parasites may interfere with collection efforts. Permits for collecting native plants are often required.
Grow	All the advantages of purchasing plants can be realized. The variety of species available can be as diverse as for plants collected in the wild, and plants can be planted in large quantities. Plants that are grown can be available earlier in the season than purchased or collected plants. Low cost is one of the primary reasons to grow stock for planting.	Space and facilities must be dedicated to growing plants. Personnel with time and expertise to grow the plants may not be available. The up-front investment in both fixed and variable overhead items to establish a growing facility may not be justified unless there is a large and continuing need for planting stock.

vulnerable to animal of human damage, plant protection measures must be used (e.g., placing fencing or wire or nylon cages around them or using repellents).

e. Determine any special requirements and constraints of the site. For instance, a site may be prone to sediment deposition, causing emergent aquatic plants to become covered with sediment and suffocate. This situation may necessitate the planting of willow as cuttings or posts to make the emergent plants less susceptible to complete coverage by sediment. In another instance, a site may have an almost vertical bank geometry, causing the water to become too deep to accommodate emergent aquatic vegetation. In this case, bank reshaping may be required.

f. Prepare a suite of species that will be suitable. Selection may be limited to plants currently available from commercial sources if there is no possibility of collecting in the wild or having plants contract grown.

Herbaceous plants are usually acquired as sprigs, rhizomes, or tubers. Seeds are used when the threat of flooding is low in the bank and terrace zones, otherwise they would wash out easily unless seeded underneath or in a securely anchored geotextile mat or fabric.

Woody plants used for riparian projects usually consist of stem cuttings for those species that quickly sprout roots and stems from the parent stem. These are plants such as willow, some dogwood, and some alder. They can be supplemented by bareroot or containerized stock, particularly in the bank or terrace zones where they are not subjected to frequent flooding.

Purchasing plants

Prior to purchasing any plant materials, the design team should acquire a list of plant suppliers, such as "Directory of Wetland Plant Vendors" (USDA Soil Conservation Service 1992). They should also request vendors' catalogs and plant availability lists and determine in what condition plants from each supplier are delivered: potted, bareroot, rhizomes and tubers, or seed. They should match the plant list against species' availability and not assume that all advertised species will be available in needed quantities. Ordering samples, if available, to verify plant condition and identification is advisable. Contracts should include a flexible delivery schedule, allowing for unpredicted delays in planting. Some suppliers may grow plants on contract but these arrangements should be made several months to a few years before the plants are needed.

Collecting plants from the wild

Some native plant species have adapted to a variety of geographic areas, soil moisture conditions, and micro-environments. Collecting plants from the wild helps ensure that locally adapted plant populations (i.e., ecotypes) best suited to the site conditions are used in revegetation projects. Planting stock of inappropriate origin (i.e., adapted to a different environment) is likely to lower plant survival rates and jeopardize project success. The use of locally collected propagules for native plant revegetation projects maintains the integrity of the local gene pool. Care should be taken if this method is selected because of the possibility of contaminating the harvested donor plants with unwanted weedy species. Samples should be collected ahead of time in order to identify problems that may be encountered in collecting, transporting, and storing each species. Most native plant nurseries are willing to contract to grow locally collected plant materials, and their staff may collect the necessary propagules (e.g., seeds and cuttings) and/or provide advice on the proper collection methods and timing. Other considerations include:

a. Whenever possible, collect plant propagules either onsite or from suitable areas close to the restoration site, preferably from the same watershed.

b. Match the collection site to the restoration site for elevation, soils, slope, aspect, rainfall, annual temperature patterns, frost dates, and associated vegetation.

c. Properly identify all species and avoid donor plants of unknown origin (e.g., garden escapes).

d. Avoid collecting plant materials from isolated stands as this may diminish genetic variability at the collection site.

e. Collect seeds at their proper stage of ripening (i.e., at maturity).

f. Avoid collecting from unhealthy or atypical plants.

g. Collect equal amounts of propagules from suitable donor plants and from widely spaced donor stands.

h. Collect from at least 50 individual donor plants of the same species, especially when phenotypic variation (i.e., genetically visual variations in species appearance) is prevalent.

i. Do not collect more than 10 percent of available seed.

j. Contact both the state Department of Fish and Game and the U.S. Fish and Wildlife Service before collecting propagules from rare plant populations.

k. Obtain any required permits before collecting wetland plant materials.

l. Label collection bags with the species, collection site, date, and other pertinent information.

Growing plants

Plants used for revegetation projects can be grown in a greenhouse or other enclosed facility or, in the case of emergent aquatics, outdoor ponds or troughs containing water. In any case, the plants must first be acquired from the wild or other growers and propagated. If seeds are used for propagation, they must first be stratified (subjected to various treatments such as soaking and temperature differences); however, germination requirements for most wetland plant seeds are unknown. If a greenhouse is to be used, a number of limitations and constraints must be overcome, such as room for pots, adequate ventilation, and requirements for or problems associated with fertilizing, watering, and disease and pest control. Plants can be grown in coir carpets, mats, or rolls to facilitate early establishment, ease of transport, and rapid development. Emergent aquatic plants may be grown hydroponically and transported to the planting site ready to grow with roots already established in the carpet, mat, or roll.

3 Vegetation Layout in Riparian Buffer Zones

This chapter provides guidelines for design of the riparian buffer zone adjacent to the stream. First, the selection of buffer zone width is addressed and characteristics of the three sections of the buffer zone are described. Next, the importance of using a variety of plant species in the buffer zone is discussed. Guidelines for selecting percentages of each plant species and for spacing of plants are provided.

Because of their high edge-to-area ratio, riparian ecosystems have large energy, nutrient, and biotic interchanges between aquatic and terrestrial systems. The plant community composition and its associated habitat structure and productivity are largely determined by the timing, duration, and extent of flooding. Thus vegetation species and their planting position should be selected on a site-specific basis. In the context of determining the necessary vegetation layout, “site-specific” refers to a much smaller scale than flood protection specialists normally use. Variations of particular combinations of substrate, microclimate, nutrient content, and hydrologic regime within the order of a few inches can dramatically alter the potential for successful growth of a given plant species.

Selection of plants and their layout for flood control projects also involves consideration of the plants’ resistance to stream flows and their impact upon hydraulic conveyance. Thus, revegetation specifications, including species, planting location, and density, should be developed based on an evaluation of hydraulics and vegetation stability as well as the erosion control requirements, desired fish and wildlife habitat, aesthetics, plant material availability, and installation and maintenance requirements.

The layout of vegetation in the riparian zone of flood control, stabilization, and restoration projects requires consideration of the large-scale position of the riparian communities in the landscape as well as the spacing and arrangement of individual plants. Riparian buffer zones are strips of vegetation, either natural or planted, around water bodies. Buffer zones extend laterally from the top of bank or bankfull stage of the stream. Such vegetated zones help reduce the impact of runoff by trapping sediment and sediment-bound pollutants, encouraging infiltration, and by slowing and spreading stormwater flows over a wide area. They also help stabilize streambanks, reduce water temperatures, provide habitat for a number of wildlife species, and are an important landscape feature from an aesthetic perspective. These "greenbelts" around waterways can be used to protect the water and also provide parks and recreational areas for residents.

To create effective riparian buffers strips, land-use planners and design professionals must understand the functions of riparian ecosystems and recognize that riparian strips cannot be relied upon as complete buffers for the detrimental effects that can be caused by upland development. Upland activities and development must be designed and managed so that they will not overburden the moderating effects of buffer strips. Buffer zones, setbacks, and easements are most effective when used as part of a system that includes measures to reduce stormwater flows from upgradient development and measures to directly repair eroded streambanks and other existing damage to streams.

When employed in conjunction with other management practices such as stormwater detention and stream restoration, buffer strips can improve water quality and conserve wildlife populations. There is solid evidence that providing riparian buffers of sufficient width protects and improves water quality by intercepting nonpoint-source pollutants in surface and shallow subsurface water flow. Buffer strips also very clearly provide outright habitat for a large variety of plant and animal species, shade aquatic habitats, and provide litter fall and large woody debris that are critical for aquatic organisms. These areas also provide a visually appealing greenbelt and recreational opportunities and may help to stabilize streambanks.

Although the value of buffer strips is well recognized, criteria for buffer strip sizing are not well established. Economic and legal considerations have taken precedence over ecological factors in many cases, and most existing criteria address contaminant and nutrient loading. In general, the width and vegetation composition of buffer strips will dictate the extent to which the above benefits will be realized. Some benefits can be obtained from buffers as narrow as 3 m (10 ft) while others require thousands of feet. In general, the ability of buffer strips to meet specific objectives is a function of the vegetation species utilized and their density, buffer width and length, the slope, and the position in the landscape. Buffer width guidelines from the literature are summarized in Table 2.

General Design

Riparian buffers will vary in character and size based on environmental setting, proposed management, level of flood protection desired, and objectives. Standard guidance on buffers provides for variable widths from 11-30 m (35-100 ft). For urban lands, an additional grass filter strip (4.5 m (15 ft) or greater, upslope) is recommended to improve and sustain pollutant removal performance. "Buffer averaging," the practice of expanding and contracting buffer widths in order to account for stream channel meandering, property lines and infrastructure, and efficiency of protection measures is acceptable. A minimum buffer width of 11 m (35 ft) is recommended for flood control channels in urban environments. Buffer widths of 15 m (50 ft) or wider should be promoted as the appropriate width for optimizing a range of multiple objectives for water quality and fish habitat improvement.

Table 2
General Buffer Width Guidelines

Function	Description	Recommended Width[1]
Water Quality Protection	Buffers, especially dense grassy buffers on gradual slopes, intercept overland runoff, trap sediments, remove pollutants, and promote groundwater recharge.	6-30 m (20-100 ft)
Riparian Habitat	Buffers, particularly diverse stands of shrubs and trees, provide food and shelter for a wide variety of riparian and aquatic wildlife.[2]	9-90 m (30-300 ft) birds may require 300 m (1,000 ft) or more
Stream Stabilization	Riparian vegetation moderates soil moisture conditions in streambanks, and roots provide tensile strength to the soil matrix, enhancing bank stability.	9-15 m (30-50 ft)
Flood Attenuation	Riparian buffers promote floodplain storage due to backwater effects; they intercept overland flow and increase travel time, resulting in reduced flood peaks.	15-150 m (50-500 ft)
Detrital Input	Leaves, twigs, and branches that fall from riparian forest canopies into the stream are an important source of nutrients and habitat.	3-9 m (10-30 ft)

[1] Synopsis of values reported in the literature.
[2] A few wildlife species require much wider riparian corridors.

A three-zone riparian buffer concept is recommended to assist with planning, design, and long-term management (Figure 1). The width of each zone is determined by site conditions and objectives, as discussed in the following paragraphs.

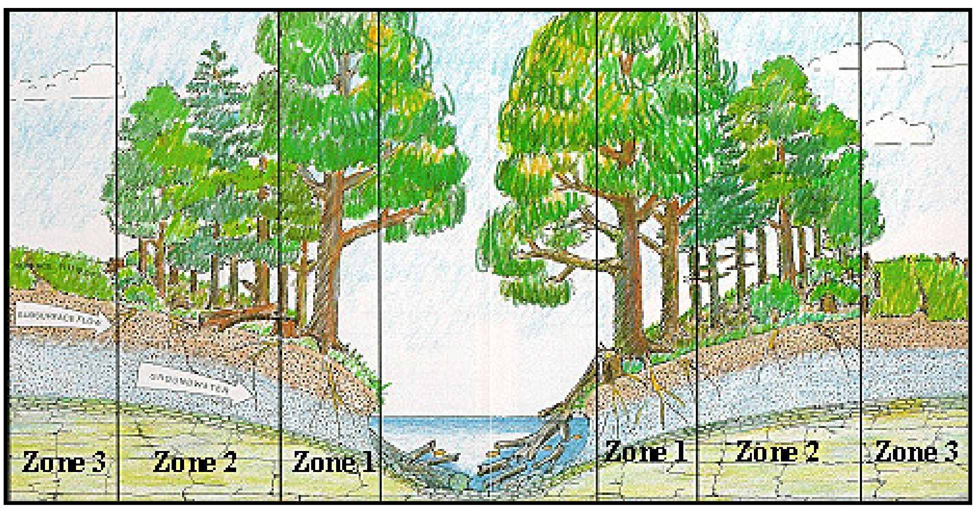

Figure 1. Depiction of a three-zone buffer approach developed for the Chesapeake Bay Watershed. This approach may be applicable to most forested riparian buffer strips in North America (from Welsch 1991).

a. *Zone 1.* Beginning at stream edge, Zone 1 functions as an extension of the stream or water body and is the area in which critical habitat and stream integrity objectives are achieved. Shade, detritus, and large woody debris are provided by mature forest vegetation. Vegetation in this zone helps reduce flood effects, stabilize streambanks, and remove some nutrients. Composition of the vegetation in this zone should be native, noninvasive trees and shrubs of a density that permits understory growth. The minimum width of Zone 1 is 3 m (10 ft).

b. *Zone 2.* Target vegetation in this zone is a managed riparian forest with a vegetation composition and character similar to natural riparian forests in the region. Extending upslope from Zone 1 for a minimum of 3 m (10 ft), the function of Zone 2 is to remove sediments, nutrients, and other pollutants from surface and groundwater. This zone provides most of the enhanced habitat benefits, allows for recreation benefits, and helps reinforce Zone 1.

c. *Zone 3.* Zone 3 is provided to slow runoff, infiltrate water, and filter sediment and its associated chemicals. It is the zone that provides the greatest water quality benefits. Zone 3 may contain grass filter strips, level spreaders or other features. It protects Zones 1 and 2. The minimum width of Zone 3 is 4.5 m (15 ft).

An example of a general, multipurpose riparian buffer design might consist of a 15-m- (50-ft-) wide strip of grass, shrubs, and trees between the normal bankfull water level and adjacent lands. Trees spaced 2-3 m (6-10 ft) apart occupy the first 6 m (20 ft) nearest the stream; shrubs spaced 1-2 m (3-6 ft) apart dominate the next 3 m (10 ft); and grass extends 6 m (20 ft) farther out. This design can be thought of as consisting of two rows of trees and shrubs that together constitute Zones 1 and 2 and 6 m (20 ft) of grass in Zone 3. Planting trees and shrubs in well-spaced rows makes maintenance activities such as mowing and mulching much easier. Care should be taken to offset the rows of trees and shrubs so as to form a diamond pattern. This design requires approximately 1.5 ha/km (6 acres per mile) of bank not counting any setbacks or easements.

This buffer design provides a modest level of riparian buffer benefits. Trees and shrubs near the waterway stabilize the bank, improve and protect the aquatic environment, and protect adjacent land from flood erosion and debris damage. Grass disperses and slows the flow of adjacent runoff which promotes settling of sediment and infiltration of nutrients and pesticides, while vigorously growing vegetation and soil microbes take up nutrients and some pesticides. Perennial vegetation provides wildlife habitat and visual diversity to an urban landscape.

The general design described above provides a useful starting point for developing more efficient buffer designs. Specific site conditions or project objectives may call for adjustments to the general design. Some examples of possible adjustments are presented in Table 3.

Plant Spacing and Arrangement

Plant spacing and arrangement are important factors in determining buffer zone success. Planting a mixture of plant species provides a diverse habitat for wildlife and avoids uniform disease susceptibility and uniform age range. Plans for landscape and beautification plantings should consider foliage color, shape, color and

Table 3
Buffer Adjustments

Rationale	Adjustment
Reducing buffer costs	Narrower buffer. Less overall benefit should be expected from a narrower buffer, particularly for nutrient and pesticide runoff control and for wildlife habitat. In general, however, a narrow buffer provides more benefits than no buffer at all. Narrower buffers require more careful selection of vegetation types in order to maximize benefits. Wider buffer. Federal, state, and privately supported incentive programs for conservation, forestry, or alternative products will vary in their requirements for vegetation type, minimum width, and management. Often, such programs require a greater land area than is provided by an 11-m (35-ft) buffer width.
Increasing overall buffer benefit	Wider buffer. This applies mainly to nutrient and pesticide runoff control and wildlife habitat. Such an adjustment may also better accommodate recreation features in the floodplain or riparian zone. Be aware that there may be decreasing added benefit for each additional unit of width, such as is commonly observed for sediment filtration. Acceptable width for aesthetic benefits, such as visual diversity, is entirely a matter of opinion.
Site conditions where some benefits are not needed	For ephemeral streams with negligible aquatic resources, trees and shrubs are not needed for providing shade, shelter, and plant litter. For warm-water fisheries, trees and shrubs may not be needed for shade and temperature control, unless there remains a need to control algae blooms. Trees and shrubs may still be required for providing debris for shelter and food as well as suitable shaded habitat for cold-blooded fauna, such as amphibians.
Emphasizing one benefit (high-priority) over others (lower priority)	To emphasize bank stabilization, place a greater proportion of the buffer width in shrubs and trees. On smaller streams, a narrower buffer that includes emergent aquatic vegetation as well as shrubs and trees may be sufficient. Where active erosion is occurring, flood-tolerant woody plants, such as willows, may be planted at the water's edge. Severe bank erosion may require intensive engineering. To emphasize filtering sediment from agricultural runoff, use a narrower buffer with the greatest proportion of width in grass. Dense, stiff grasses may perform better than bunchgrasses and short, flexible grasses. To emphasize nutrient and pesticide runoff control, particularly of soluble forms, a wider buffer and greater proportion of fast-growing grasses and trees are needed. Deep-rooted grasses may perform better than shallow-rooted grasses. To emphasize habitat for larger forest animals and some smaller animals, such as birds, a wider buffer is needed, with a greater proportion of width in shrubs and trees. More variety of plant species provides habitat for a greater diversity of animals. To avoid tree windthrow, which can damage streambanks and add excessive amounts of large debris to the waterway, substitute shrubs for trees or reverse tree and shrub positions in the buffer design, i.e., shrubs near bank and trees in the middle. Use deep-rooted, wind-firm tree and shrub species. This adjustment may be useful on wide, steep streambanks. To emphasize protection from flood damage to adjacent lands and structures, a greater proportion of the buffer should incorporate flood-tolerant trees and shrubs. Larger streams and rivers may require greater overall buffer width.

season of flowering, and mature plant height. Tree arrangement and spacing should allow for access lanes.

Plants are provided for the buffer zone using one or both of two methods: direct seeding or seedlings and cuttings. General guidelines for density of plantings depend on whether the primary plant stress will come from water erosion or from wind erosion. Direct seeding is frequently used for erosion control, for enhancing water quality, and at isolated sites. The amount of pure live seed to be used per unit area will be dictated by species. A local Natural Resource Conservation Service (NRCS) plant materials specialist should be consulted for optimal seed mixes and numbers.

Seedlings and cuttings should be evenly distributed over the planting site. If the primary plant stresses will be due to water erosion, trees should be planted with a minimum density of 1,680 plants/hectare (680 plants/acre) and shrubs should be planted with a minimum plant density of 6,720 plants/hectare (2,720 plants/acre). If the primary plant stresses will be due to wind erosion, planting densities per unit area will vary according to the extent of the planting and individual site plans.

Many factors affect species percentages within a plant selection. The desired ultimate composition of the plant community should be determined early in the planning stage. Each species considered should be evaluated in light of its function within the plant community (i.e., overstory, understory, shrub, groundcover, herbaceous, etc.), its dominance in the plant community, its growth characteristics, and its compatibility with other species. Aggressive, fast growing species such as *Sambucus* and *Populus* should be proportioned and managed to reduce conflict with slower growing species. Slower growing species such as *Acer circinatum*, *Gaultheria*, and *Picea* may require a higher percentage of representation to be successful in the development of the plant association. Some species may not be appropriate for the initial planting phase. These include many of the herbaceous understory plants, such as ferns, and others that demand a microenvironment that develops only over time. Table 4 provides guidance for minimum percentages of any one tree species in a revegetation plan.

Table 4
Species Diversity Guidelines for Trees

Number of Trees	Maximum Percent of Any One Species
10 to 19	50
20 to 39	33
40 or more	25

The spacing of plants at planting time is determined by the competitive strength of the plants at the end of the plant establishment period. A closer plant spacing requires a reduced percentage of trees and understory plants, such as *Corylus* and *Rhamnus*, to provide each room to develop and reduce excessive competition. Also, some densely spaced vegetation hinders weeds from establishing. Species that need support from surrounding plants to compete and develop into a functional plant association, like *Symphoricarpos*, *Rosa*, *Salal*, *Mahonia*, *Spiraea*, and *Philadelphis*, should be planted initially based on closure of the planting after approximately 3 years. The plants will form a thicket over time. This plant layer is important because weed control is its supportive role in the plant community. Other species that form groupings or groves should be spaced to support the development of individual plants that form the desired cluster. The following species may be considered for clustering: *Populus tremuloides*, *Corylus cornuta*, *Holodiscus*, *Mahonia*, and *Ribes*. Climax trees should be spaced to resemble the distribution in the natural plant community. Pioneer species should be spaced to quickly perform their function in the plant succession scheme without causing undesirable competition with desirable plants. A management program that includes periodic removal of plants that have outlived their function should be considered (Platts et al. 1987).

Guidelines for spacing of various plant types are provided below. Within the row, spacing as a general rule-of-thumb should be:

a. Small shrubs 1-2 m (3-6 ft).

b. Large shrubs 1.5-2.5 m (5-8 ft).

c. Evergreens 2-3 m (6-10 ft).

d. Deciduous trees 2.5-3.5 (8-12 ft).

The above spacing guidelines will be tempered by the size and species of the transplant population. The following example demonstrates the design process for selecting plant spacing and percentage. It is based on an example provided by the Washington State Department of Transportation's Environmental and Engineering Service Center on their web site http://www.wsdot.wa.gov.

> After the native plant revegetation concept has been accepted, the desired plant palette for the plant selection mixture must be developed. A road-side restoration mixture could be designed to consist of a shrub layer, like *Symphoricarpos albus*, *Rosa gymnocarpa*, and *Mahonia aquifolium,* an intermediate or understory species of *Holodiscus discolor*, *Corylus cornuta*, and *Acer circinatum,* and an overstory of *Pseudotsuga menziesii*, *Tsuga heterophylla*, *Alnus oregona*, and *Acer macrophyllum.* The shrub layer functions as the initial groundcover and weed control by early closure. A 1-m (3-ft) spacing per plant will provide this benefit. The size of the area being planned is important. For this example, 10,000 ft^2 has been selected. The calculations and logic might follow this pattern:
>
> *a.* With a 3-ft spacing there will be one plant per 9 ft^2, or 1,100 plants in the area being planted (10,000 $ft^2 \div 9$ ft^2 = 1,111 rounded to 1,100 total plants).
>
> *b.* An initial average spacing of 20 ft, or one plant per 400 ft^2, for the *Pseudotsuga menziesii, Alnus oregona*, and *Acer macrophyllum* is deemed desirable; 10,000 $ft^2 \div 400$ = 25 trees. Twenty-five trees equal 4 percent of the total number of plants, made up of 1.33 percent of each of the three species. After the rounding off, the "surplus" percentage is awarded to *Pseudotsuga menziesii* because of its less competitive nature. (Note: *Alnus oregona* is intended to function as a temporary cover crop and will mostly be removed during the initial 5 to 7 years.)

c. Site conditions are less favorable for *Tsuga*, thus the percentage has been boosted to 2 percent.

d. *Holodiscus discolor*, Corylus *cornuta*, and *Acer circinatum* are desired at about a 10-ft spacing, or one plant per 100 ft^2. This equals 110 plants or 10 percent of the total. *Acer circinatum* is favored with 4 percent, and the *Holodiscus* and *Corylus* are each assigned 3 percent.

e. The remaining 84 percent is the shrub layer and is shared by *Symphoricarpos*, *Rosa*, and *Mahonia*. Observations of native forest plant communities have documented *Symphoricarpos* dominating with *Rosa* and *Mahonia* interspersed, mostly in small clusters. The decision is to award *Symphoricarpos* with 50 percent, *Rosa* with 20 percent, and *Mahonia* with 14 percent.

The final mixture is presented in the following tabulation, with quantities based on the arbitrary area of 10,000 ft^2.

Botanical Name	Common Name	%	Spacing	Quantity[1]	Notes
Acer macrophyllum	Big-leaf maple	1	-	10	Minimally 10 ft apart
Alnus oregona	Red alder	1	-	10	Minimally 10 ft apart
Pseudotsuga menziesii	Douglas fir	2	-	25	Minimally 10 ft apart
Tsuga heterophylla	Western hemlock	2	-	25	Minimally 10 ft apart
Holodiscus discolor	Creambush	3	-	35	Clusters of 3-5
Corylus cornuta	Beaked hazelnut	3	-	35	Clusters of 3-7
Acer circinatum	Vine maple	4	-	45	Minimally 6 ft apart
Mahonia aquifolium	Oregon grape	14	3ft × 3ft	150	Clusters of 3-7
Rosa gymnocarpa	Wood rose	20	3ft × 3ft	225	Clusters of 15-25
Symphoricarpos albus	Snowberry	50	3ft × 3ft	650	Distribute evenly

[1] Plant spacing of the plant mixture is 3 ft on center. Trees are randomly distributed throughout the planting area. Quantities for seedlings, shrubs, and groundcovers are rounded off to the nearest multiple of 5 for trees and intermediates, and 25 for shrubs (Platts et al. 1987)

4 Handling Plant Materials

This chapter provides guidance for handling plant materials for soil bioengineering projects. Appropriate plant care prior to planting for cuttings, live stakes, live fascines, brushlayering, and container plants is discussed. Also discussed are design details relative to sizing, placement, and planting of several types of soil bioengineering applications.

Plants need to be handled carefully to ensure their survival between the phases of acquisition (purchasing, growing, or harvesting from the wild) and transplanting because they will undergo transportation and planting shock. Many problems associated with poor plant survival occur from the handling of the plants between the nursery or collection site and the project planting site. Generally, the live plant material needs to be kept cool, moist, and shaded. If the plants die, then the soil bioengineering project is much more prone to failure even though dead plant materials can offer some erosion control.

Harvested Woody Plants

Woody plants, particularly cuttings, should be collected when dormant. Their probability for survival decreases if they are harvested and planted in a non-dormant state. Bareroot or unrooted cuttings can be stored for several months if kept in a cool, moist, and dark environment until planting (Platts et al. 1987). Cuttings can be kept in a cooler, root cellar, garage, or shop floor (Hoag 1994b). Often, cuttings are placed on burlap and covered with sawdust or peat moss and then moistened and covered with more burlap.

Soaking cuttings prior to planting is important because it initiates the root growth process within the inner layer of bark in willows and poplars. Both recently harvested and stored cuttings should be soaked prior to planting. Hoag (1994b) advocates soaking cuttings for a minimum of 24 hours before planting. Some research recommends soaking the cuttings for as much as 10 to 14 days (Briggs and Munda 1992; Fenchel, Oaks, and Swenson 1988). Cuttings need to be removed from the water prior to root emergence from the bark (usually 7 to 9 days) (Peterson and Phipps 1976).

When woody plants are moved from the nursery, holding area, or harvesting area to the project site, they should continue to receive careful handling, being kept moist and free from wind desiccation. This can be achieved by ensuring they are covered with a light-colored (to reflect heat), moist tarp. Cuttings can be moved to the project site in barrels containing water or by some similar method. Actual planting should follow the digging of holes as soon as possible, preferably no longer than 2 to 3 minutes, to ensure that the excavated soil does not dry out. Only moist, recently excavated soil should be used for backfill of the planting hole. Backfill should be tamped firmly to eliminate voids and to obtain close contact between the root systems and the native soils. When using containerized or balled and burlap stock, excess soil should be smoothed and firmed around the plants leaving a slight depression to collect rainfall. These types of plants should be placed 2.5 to 5 cm (1 to 2 in.) lower than they were grown in the nursery to provide a soil cover over the root system (Leiser 1994).

Live Stakes and Posts

Cuttings to be used as live stakes and posts should be dormant when planted. These cuttings should be prepared from woody plants that root adventitiously (e.g., *Salix* and *Populus* spp.), obtained from as near the site as possible, and free from obvious signs of disease such as cankers or splits in the bark or insects. The diameter of cuttings should be not less than 1 cm (3/8 in.), and larger cuttings are generally preferable. The length of cuttings should be a minimum of 45 cm (18 in.), but no shorter than necessary to reach adequate moisture in the soil. Figure 2 is a schematic showing live stake placement and conditions after growth has occurred.

Cuttings should be cut to size in any expedient manner not resulting in frayed ends. During preparation, the proper basipetal orientation (tops up, bases down) of cuttings should be maintained. Cuttings should be tied in bundles sized for handling and the cut tops painted with a water-base paint (e.g., interior latex paint) to seal the cuts and identify the tops. Alternatively, the bases may be cut at an angle to facilitate driving as well as identifying the ends.

Cuttings should be prepared no longer than 1 week before planting unless they are to be placed in cold storage. Cuttings should be maintained in moist conditions at all times. They may be stored out-of-doors in shade and submerged in water, either in natural streams or ponds or in containers. When stored in containers, the water should be changed daily. They may be wrapped in wet burlap or plastic and stored under refrigeration at 0 to 7 °C (32 to 45 °F). The cuttings should be kept moist until planted by carrying them in planting bags or buckets, covered with water, moist vermiculite, sawdust, or similar material.

Cuttings may be pushed into ground that is soft. In hard ground, cuttings should be planted with dibbles, star drills, or other devices to avoid damaging the bark. Cuttings should not be driven with sledge-type hammers, but deadblow hammers are acceptable. Cuttings should be placed in the ground to within 5 to 15 cm (2 to 6 in.) of the tops or should be cut leaving no more than 15 cm (6 in.) exposed. The soil should be tamped firmly around the cuttings to provide a firm hold, and no air pockets or voids should remain around the cuttings.

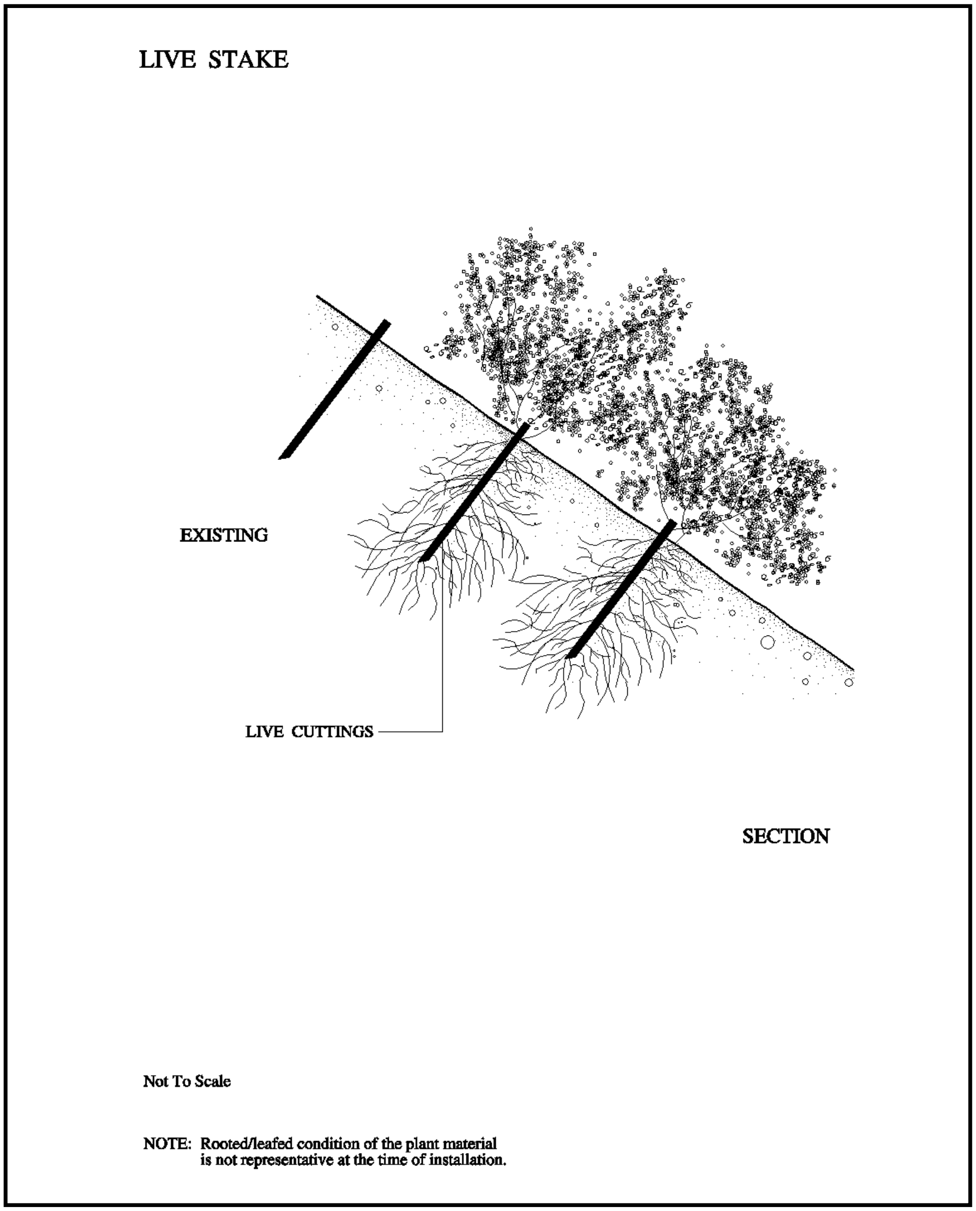

Figure 2. Live stakes (courtesy of Robbin B. Sotir & Associates)

Live Fascines or Wattles

Live fascines are often referred to as wattles or vice versa; however, there are some subtle differences as explained below. Live fascines and wattles, or wattling bundles, are used to create live, sprouting bundles of brush that serve to intercept water from upslope, or they can be used to armor the toe of a brushmattress as explained later. Live fascines are different from wattles in terms of their shape and how they are constructed, but both serve the same purpose. Live fascines are cylindrical in shape with basal ends of willow branches or similar material appearing on both ends. They are abutted together by pushing the bundles together, by overlaping, or by intertwining the branches. Wattles or wattling bundles are cigar-shaped bundles and are formed by alternating the basal ends of branches during construction so they are tapered on both ends. Then, the bundles are overlapped like "rabbit joints" in carpentry, and, where they are overlapped, they form a cylinder. Both live fascines and wattles should be prepared from live, shrubby material from species that will root, such as *Salix* spp. (willow) and some *Cornus* spp. (dogwood). Both live fascines and wattling bundles may vary in length, depending on material available. Bundles of wattles should taper at the ends and should be 30 to 46 cm (1 to 1-1/2 ft) longer than the average length of stems to achieve this taper. The maximum diameter of the basal ends is 4 cm (1 1/2 in.). When compressed firmly and tied, each bundle should be 20 to 30 cm (8 to 12 in.) in diameter.

The basal stems of wattles should be placed alternately (randomly) in each bundle so that approximately half the butt ends are at each end of the bundle. Stems of live fascines should be placed such that only basal ends appear at the ends of the bundle. Bundles should be tied on 30- to 38-cm (12- to 15-in.) centers with a minimum of two wraps of binder twine, or heavier tying material, with a non-slipping knot. Tying may be done with strapping machines as long as the bundles are compressed tightly. Figure 3 is a schematic of a live live fascine or wattle with a geotextile underneath called coir, an erosion control fabric made from coconut husks.

Bundles should be prepared not more than 2 days in advance of placement when kept covered and in shade. When provisions are made for storing the bundles in water or for sprinkling them often enough to keep them constantly moist, covered, and in the shade, they may be prepared up to 7 days in advance of placement.

Both live fascines and wattling bundles should be laid in trenches dug to approximately half the diameter of the bundles. Wattling bundles should be placed with ends overlapping at least 30 cm (12 in.). The overlap must be sufficient to allow the last tie on each bundle to overlap. Bundles should be covered immediately and staked. Workmen are encouraged to walk on the bundles as work progresses to further work the soil into the bundles. Ten to twenty percent of the bundle should be left exposed when all construction is completed. This allows better rooting and helps intercept water and detritus.

Bundles should be staked firmly in place with vertical stakes on the downhill side not more than 60 cm (24 in.) on center and with stakes through the bundles at not more then 90 cm (36 in.) on center. When bundles overlap between two previously set guide or bottom stakes, an additional bottom stake should be used at the midpoint of the overlap. The overlap should be "tied" with a stake through the ends of both bundles and inside the end tie of each bundle. Stakes may be made of live willow stems greater than 4 cm (1.5 in.) in diameter or they may be construction stakes (2 by 4 by 24 to 2 by 4 by 36 in., cut diagonally) or a mixture of the two. Reinforcing bar may be substituted, but is not generally recommended unless wood stakes cannot be driven into the soil. All stakes should be driven to a firm hold and a minimum of 46 cm (18 in.) deep. Where soils are soft and 24-in. stakes are not solid (i.e., if they can be moved by hand), 36-in. stakes should be used. Where soils are so compacted that 24-in. stakes cannot be driven 46 cm (18 in.) deep, 3/8- or 1/2-in. reinforcing bar should be used for staking. When rebar is used, the tops should be bent over to hold the wattling in place.

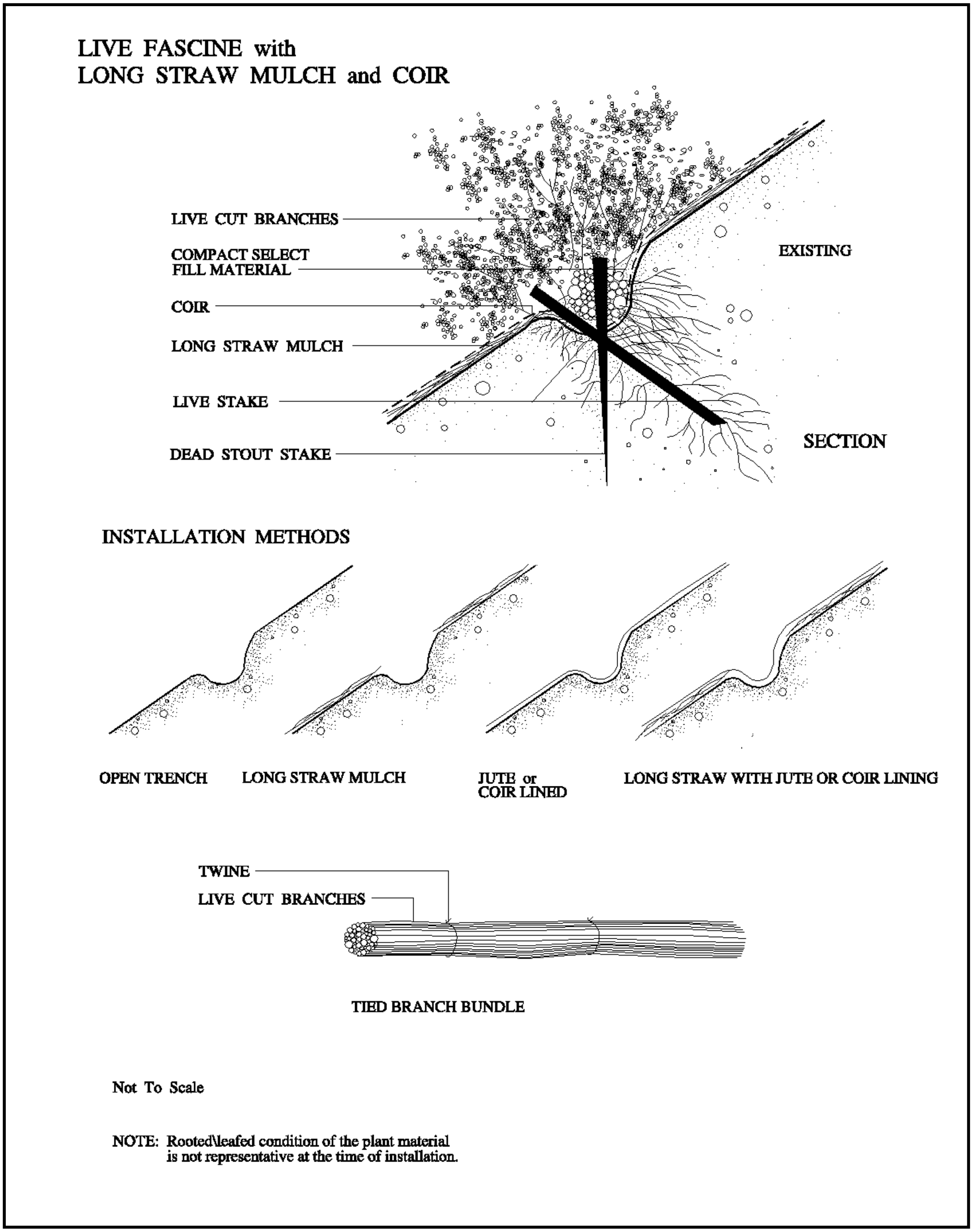

Figure 3. Live fascine or wattling schematic (courtesy of Robbin B. Sotir & Associates)

Work should progress from the bottom of the slope to the top, and each row should be covered with soil and packed firmly behind and into the bundle by tamping or walking on the bundles or by both these methods. Exposure of the wattling to sun and wind should be minimized throughout the operation. Trenches should be dug only as rapidly as the wattling is being placed and covered to minimize drying of the soil in the trench and the backfill.

Branchpacking or Brushlayering

Live, dormant brush of willow or other adventitiously sprouting species should be used. When there is a shortage of willow, up to 50 percent of the brush may be of nonadventitious species. When nonadventitious species are used, they should be mixed randomly with the other species. Length of brush should vary according to the particular installation and should be specified on the plans. The length may vary from 0.5 to 2.5 m (2 to 8 ft) or more. Hand-trenched brush-layering used for small gully repair should be from 0.5 to 1 m (2 to 3 ft) long. Hand trenching should start at the bottom of the slope. Trenches should be dug 0.5 to 1 m (2 to 3 ft) into the slope, on contour, and with a downward slope of 10 to 20 deg below the horizontal.

Brush should be placed with basal ends oriented into the slope with 15 to 45 cm (6 to 18 in.) of the growing tips extending beyond the finished fill face. Branches should be arranged in criss-cross fashion using three to five layers approximately 5 cm (2 in.) deep with soil layers in between. Brush should be 7.5 to 10 cm (3 to 4 in.) thick in hand-trenched placement work and 13 to 15 cm (5 to 6 in.) thick in fill work. Thickness should be measured after compression by the fill or covering soil. Figure 4 is a schematic of brushlayering. Brush layers should be placed on successive lifts of fill. Each layer should be covered with soil immediately following placement and the soil compacted to 90 percent of maximum. Covering may be done by hand or with machinery. Interplanting of woody plants (transplants and/or unrooted willow cuttings) and grasses should follow placement of the brushlayering as specified for the site. A lower spread rate should be used for grasses, such as half the normal, to reduce competition to the brushlayer system.

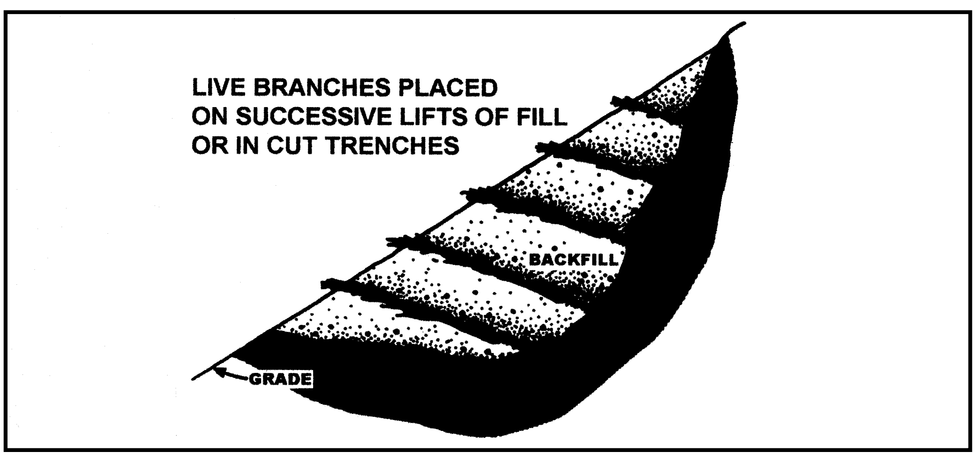

Figure 4. Schematic diagram of brushlayering (from Leiser 1983)

Brushmattress or Brushmatting

A brushmattress, sometimes called brushmatting (Figure 5), is a combination of the thick layer (mattress) of interlaced live willow switches or branches and a live fascine. Both are held in place by wire and stakes. The branches in the mattress are usually about 2 to 3 years old and 1.5 to 3 m (5 to 10 ft) long. Basal ends are usually not more than about 3.5 cm (1.5 in.) in diameter. They are placed perpendicular to the bank with their basal ends inserted into a trench at the bottom of the slope in the splash zone, just above any toe protection, such as riprap. The branches are cut from live willow plants and kept cool and moist until planting. The willow branches will sprout after planting. The live branches are harvested and planted in the dormant period, either in the late fall after bud set or in the early spring before bud break. A compacted layer of branches 10 to 15 cm (4 to 6 in.) thick is used and is held in place by either woven wire or tie-wire. Wedge-shaped stakes, often called dead stout stakes, 5 by 10 by 60 to 90 cm (2 by 4 by 24 to 36 in.) or longer, diagonally cut are used to hold the wire in place. No. 11 or 12 galvanized annealed wire is a suitable tie-wire. It is run perpendicular to the branches and also diagonally from stake to stake and usually tied by use of a clove-hitch. If woven wire is used, it should be a strong welded wire, 5- by 10-cm (2- by 4-in.) mesh. The dead stout stakes are driven firmly through the wire as it is stretched over the mattress to hold it in place. The wedge of the stake actually compresses the wire to hold the brush down. Live fascines, or wattling, described earlier, are bundles of live branches of willow or similar species that are laid over the basal ends of the brushmattress material and staked with dead stout stakes.

The brushmattress should be covered immediately with soil and tamped. Soil should be worked into the brushmattress by tamping and walking on it. Watering soil into it and successive filling is even better. All but the edges of the brushmattress should be covered with soil, and about 75 percent of the live fascine should be covered leaving some of each exposed to facilitate sprouting of stems rather than roots.

Container-Grown Plants

Containerized plants must be healthy and shapely, with roots and top growth showing no evidence of having been damaged, restricted, or deformed. Containers should have a minimum size of 130 cu cm (9 cu in.) in volume and a depth of 20 cm (8 in.). The growing medium should be any medium that will produce good-quality plants, usually a well-drained, well-aerated medium. Soil mass in the container should be sufficiently filled with roots so that it will maintain its integrity when removed from container. Plants must be free of disease, insect pests, parasites, eggs, and larvae and are subject to inspection and approval at the place of growth and/or upon delivery. Roots should be in good condition and actively growing with white tips. Top growth should be commensurate with root growth and be a minimum of 12.5 cm (5 in.) high. Plant stems should be turgid. Branch structure should be similar to naturally occurring plants of that species. Root to shoot ratio should be approximately 1:1. Plants should be acclimated to the planting site, or “hardened off” prior to planting. Shrub species should be pruned during production,

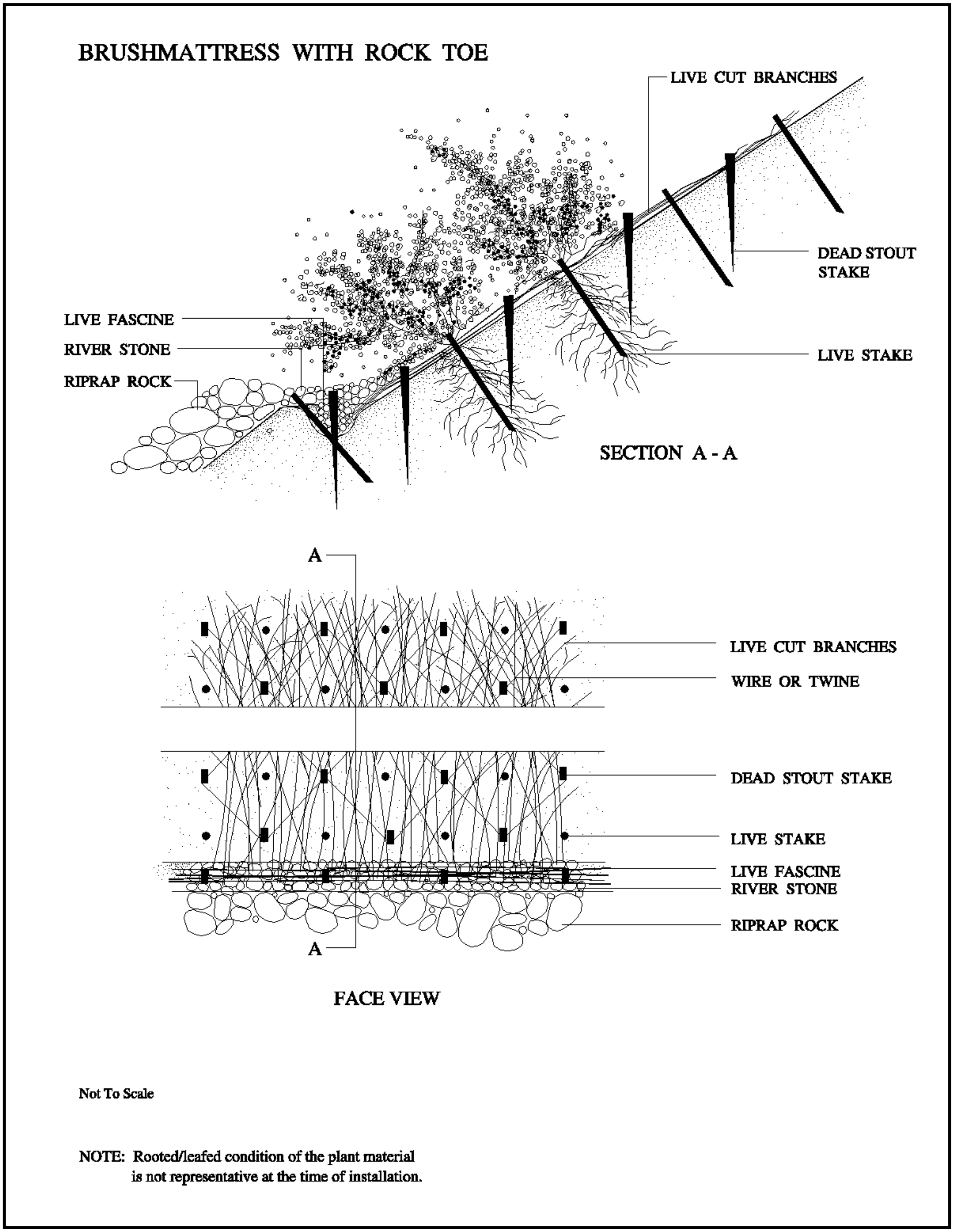

Figure 5. Brushmattress (courtesy of Robbin B. Sotir & Associates)

if necessary, to stimulate branching and avoid "legginess," (i.e., bare lower stems and inability to stand upright).

Planting on slopes should proceed from the top to the bottom of the slope, which is opposite of live fascine, wattling, and brushlayering installation. Plantings should be randomly staggered to avoid straight rows. Patterns and densities may vary within a site to avoid unfavorable site conditions such as rock outcroppings, existing vegetation, and engineering structures. Pits for trees and shrubs should be excavated to a minimum of 1.5 times the size of the container. The side of the planting pit should be vertical and lightly scarified, and the bottom should be loosened to a minimum additional depth of 15 cm (6 in).

The planting should take place no longer than 2 to 3 minutes following digging the hole. The plants should be removed from containers just prior to planting. Containers should be cut on at least two sides and removed without damage to the root ball. The roots should be "teased" away from the root ball with fingers. Some roots may need to be pruned if their spiraling around the plant is causing girdling. The plant should be set upright and in the center of the pit. Next, the plant should be adjusted by mounding native soil in the bottom of the pit so that the root ball will be at finished grade. Fertilizer, when required, should be placed with at least 5 cm (2 in.) of soil cover and no closer than 5 cm (2 in.) to the root ball. Plants should be set 2.5 to 5 cm (1 to 2 in.) lower than they were grown in the nursery, as indicated by a rootcollar, to provide a soil cover over the root system. Only the moist excavated soil should be used for backfill. The backfill should be tamped firmly to eliminate voids and to obtain intimate contact between the root systems and the native soils. Excess soil should be smoothed and firmed around the plants, leaving a slight depression to collect rainfall.

All plants should be thoroughly watered during and after planting. Water used in installation of plantings should be clean, clear, and free from injurious amounts of oil, salt, acid, alkali, or any other toxic substance. Containers should not be cut prior to the time of planting. Plants that have settled should be reset to proper grade.

Herbaceous Plants

As a general rule, handling requirements for herbaceous plants are even more rigorous than for woody plants because they are usually obtained in the spring when nurseries have them ready to ship or when they are readily identified in the wild for collection. At those times, they are very susceptible to desiccation mortality. Consequently, they must be kept in a moist, shaded condition or in water-filled containers from the time of collection from the wild or receipt from the nursery to the time of transplanting. If herbaceous plants are identified and tagged for collection in the spring or summer, they can be collected when dormant in the late fall or winter. During those times, they can be handled more freely but should still be prevented from drying out. Transportation from the nursery, holding area, or harvesting area to the project site should be in a covered vehicle. If the weather is very hot, cooling may be necessary, either from refrigeration or ice. Exposure to high winds should be avoided. Plants can be placed in a water-filled ditch and covered with soil in a shaded area for several days while awaiting planting. It is best not to store plants longer than necessary, and delivery should be scheduled to match planting dates.

Herbaceous plants can be grown from seed or from collected rhizomes, tubers, or rooted stems or rootstock from the wild. Most wetland plant seed needs to be stratified and will not germinate under water even after stratification. An experienced wetlands nursery person should be consulted before attempting to grow wetland plants from seed. Often, a cold treatment under water is necessary for stratification (Pierce 1994). There are various other stratification methods of wetland plants, such as hot and cold temperature treatments and treatments with various fertilizers. Rhizomes, tubers, and rooted stems and rootstock of wetland herbaceous plants can be grown outside in wet troughs, ditches, or ponds containing fertilized sand and peat moss. Water is necessary to keep the rhizomes, tubers, etc. from drying out.

Plants can be grown in a greenhouse during colder months; however, these plants will require hardening before transfer to the project site. Hoag (1994b) stated that hardening can be accomplished by removing the plants from the greenhouse and placing them in a cool, partially shaded area for 1-2 weeks. A lathe or slat house can be used. Some are constructed with snow fencing that has wooden slats woven together with wire. According to Hoag (1994b), this type of structure allows a small amount of direct sunlight and solar radiation through the slats, but not enough to burn the plants. A partially shaded spot near the planting site is another option. The plants should be well watered and misted during the hardening off period. Plants should continue to receive regular irrigation when moved from the nursery to the project site. All plants should be watered immediately before planting (i.e., the same day) so that moisture in the containers is at or near field capacity. Plants should be handled in such a way that neither overheating nor excessive drying occur.

Grass Seeding

All seed should be delivered to the site tagged and labeled. Seed should have a minimum pure live seed content of 80 percent (percent purity × percent germination) and weed seed should not exceed 0.5 percent.

When preparing seed-beds, fertilizer is mixed in with the soil when warranted. Fertilizer should be ammonium-phosphate-sulfate and should be delivered in unbroken and unopened containers, labeled in accordance with applicable state regulations, and bearing the warranty of the producer for the grade furnished. Fertilizer should be uniform in composition, dry and free flowing, and granular or pelleted. Fertilizer should be mixed into a tilled or harrowed bed of loosely compacted soil. If seeds are to be placed in a moist zone along the stream, water-soluble fertilizers and broadcast fertilization have obvious disadvantages, as such applications would be highly mobile. Side dressing with time-release, low-solubility fertilizers, is frequently used to overcome this difficulty. Osmocote and Magamp are granular, slow-release formulations of inorganic fertilizer appropriate to wetland plantings (Knutson and Woodhouse 1983). Fertilizer should be evenly distributed, applied less than 2 weeks prior to seeding, and applied prior to hand raking or dragging.

Straw, wood fiber, and tackifier (a gluelike substance that holds mulch fibers together) can be used as seed mulch. Straw should be new, derived from cereal grains, and free from mold and noxious weed acid. Straw should be furnished in air-dried bales. Wood fiber should be wood cellulose fiber that contains no germination- or growth-inhibiting factors. It should be produced from nonrecycled wood such as wood chips or similar material and should have the property of even dispersion and suspension when agitated in water. It should be colored with a nontoxic, water-soluble green dye to provide a means of metering for even distribution. Tackifier should consist of seed husks (*Psyillium*) so that, when combined with wood fiber and water, it is evenly dispersed and suspended.

Seeding should be done as early in the "planting window" as possible. Biotechnical construction and fall planting of transplants and unrooted cuttings should be done before grass seeding. If construction schedules dictate spring seeding, this seeding should be accomplished as early as possible

Grading, gully or rill repairs, and biotechnical installations should be accomplished prior to seeding. Graded slopes should be left rough. All physical erosion control improvements, such as water diversion channels, earth berms, dikes, and ditches, should be installed prior to grass seeding.

Grass seed should be uniformly distributed at the rate (mass/surface area) recommended for the particular species used and the degree of site severity. Seeds should be broadcast by mechanical or power-operated spreaders. The area should be hand raked or dragged after seeding to partially cover the bed. Care should be exercised to avoid damaging the transplants and cuttings.

All grass-seeded areas should be mulched within 2 working days following seeding unless prevented by weather and approved by the project engineer. Straw should be uniformly distributed at the rate of 3.4 to 4.5 metric tons per hectare (1.5 to 2 tons per acre). Straw may be applied in two ways, either by hand or with a straw blower. Spreading of whole straw should be by hand. Straw should be crimped into the ground using digging or tile spades to avoid damaging transplants, or it may be anchored with tackifier. All straw applied with a straw-blowing machine should be anchored with tackifier, as described below. Application by blower should occur only when wind velocities are low enough that the straw is not blown off the slope. Such applications should be anchored with tackifier on the day of application.

Tackifier should be mixed to form a slurry and applied by hydroseeder or similar equipment with a continuous agitation system of sufficient operating capacity to produce a homogeneous slurry. The discharge system should be capable of applying the slurry at a continuous and uniform rate. Mixing, agitation, and application should be carried out as a continuous operation.

5 Cost Estimates

This chapter provides guidance that can be used to develop construction cost estimates for some soil bioengineering applications. Costs will vary significantly depending on specific site conditions. The objective here is to provide general information on the types of equipment and materials that may be required for project construction and to provide information on labor rates. Relative costs and complexity of various streambank protection measures are listed in Table 5.

Table 5
Streambank Erosion Protection Measures, Relative Costs, and Complexity

Measure	Relative Cost	Relative Complexity
Live stake	Low	Simple
Live fascine	Moderate	Moderate
Brushmattress	Moderate	Moderate to Complex
Branchpacking	Moderate	Moderate to Complex
Conventional vegetation	Low	Simple to Moderate
Conventional bank armoring (riprap)	Moderate	Moderate

Soil bioengineering treatments are normally, but not always, less expensive than traditional methods of streambank erosion control (e.g., riprap revetment or bulkheads). Cost depends on the environmental setting and the project objectives, and can vary tremendously due to availability of materials, hauling distances, prevailing labor rates for the geographic area, and a host of other factors.

When comparing soil bioengineering methods with traditional engineering applications, each must be considered on its own merits, comparing life-cycle costs (i.e., the net present value of investigation, design, and construction, plus future management and replacement). Soil bioengineering will require a higher investment early in the project life to ensure that the living system is established. Soil bioengineering applications have a higher risk during the first 1 to 2 years after construction. Maintenance costs should drop off when vegetation becomes established and the vegetation in the soil bioengineering treatment continues to develop through growth and natural invasion and strengthen the streambank. Some maintenance costs may be associated with the soil bioengineering treatment later in the project life, especially after flood events.

Equipment

In estimating costs, consideration should be given to the equipment and materials required for vegetation handling, fabrication, installation, and planting at the implementation stage. The tools required and the planting techniques will depend on the type of vegetation (i.e., woody or herbaceous), size of plants, type of soils, size of the project, and site conditions. Freshwater herbaceous plantings with low wave or current energy environments may call for tools like spades, shovels, and buckets. In contrast, high-energy environments of waves and currents may require chain saws, lopping and hand pruners for the preparation of woody cuttings and materials for woody soil bioengineering methods, or sledge hammers for driving stakes in soil bioengineering treatments such as live fascines, wattling, and brushmatting. A list of suggested hand tools for construction of a soil bioengineering project is given in Table 6. Specialized equipment may be required, especially when moving sod or mulches containing wetland plants or plant propagules. When soil bioengineering projects are located in a pristine stream system where riparian corridors are extremely valuable, particularly in large, urban settings, equipment size and type constraints are often placed upon the project. Thus, downsized front-end loaders and walking excavators are sometimes required to minimize disturbance of existing vegetation and soil.

Table 6
Suggested Hand Tools

Item
Axe - regular size
Chain saw chains
Chain saw pants
Dead blow hammers - 4 lb.
Eye protection goggles
Files - chain saw
Files - loppers
Files - shovels & hand clippers
Hammers - regular
Hand pruning shears
Leather work gloves
Loppers
Mattock - pick & hoe
Measuring tapes - 100 ft
Round point shovels
Shovel handles
Sledge hammer - regular size 8 lb.
Sledge hammer handle - 8 lb.
Sledge hammer, hand size 2 lb.
Sledge hammer handles - 2 lb.
Wire cutters

Other equipment and materials may include fertilizers, soil amendments (e.g., lime), fencing for plant protection, and irrigation equipment for keeping plants alive during dry conditions. Other equipment and materials for keeping plants alive before they are planted may include shading materials such as tarps, buckets with water for holding plants, and water pumps and hoses for watering or water trucks.

Labor Rates for Soil Bioengineering Treatments

Labor rates for various kinds of vegetative and soil bioengineering treatments have been quoted in the literature. These rates may provide some guidance in estimating labor costs for soil bioengineering applications. However, specific project requirements could vary significantly. Labor estimates for various types of projects are summarized in Table 7, and more details are provided in the following paragraphs.

Brushmattress or Brushmatting

Table 7
Vegetative and Soil Bioengineering Labor Estimates

Method	Labor Required
Live Fascine or Wattling	2-5 m/hr
Brushlayering	2-5 m/hr
Brushmattress	0.2-1.0 m^2/hr
Dormant Posts	10-20 posts/hr
Coir Fascine	1.5 m/hr
Sprig Planting	4.0-20 m^2/hr
Seedling Planting	30-120 plants/hr
Ball & Burlap Shrubs	10-25 plants/hr
Containerized Plants	20-40 plants/hr
Seeding	0.02-0.2 ha/hr
Hydroseeding	0.05-0.15 ha/hr

The cost of the brushmattress is moderate according to Schiechtl (1980), requiring 2 to 5 man-hours per square meter. A crew of 20 students from an Engineer Research and Development Center (ERDC) training session, using hand tools, installed about 18 m^2 (200 ft^2) of brushmattress at a rate of about 1 man-hour per square meter (10 ft^2). This rate included harvesting the brush, cutting branches to appropriate lengths, and constructing the mattress. This rate of production compares favorably to an average rate of 0.92 m^2 (10 ft^2) brushmattress per man-hour by a leading soil biongineering firm in the United States (Allen and Leech 1997).

Brushlayering

There are few references on the cost of brushlayering. Schiechtl (1980) reported the cost to be low, presumably in comparison to techniques using riprap or similar materials. A crew of 20 students from an ERDC training session, using hand tools, installed about 20 m (65 ft)of brushlayering along one contour-slope in about 30 min. This equates to 2 m (6.5 ft) per man-hour (Allen and Leech 1997). Often, costs can be reduced if machinery such as bulldozers or graders can gain access to the site, reducing the hand labor required in digging and filling the trenches.

Vegetative Geogrid

A vegetative geogrid is a rigorous brushlayering technique that employs geosynthetics for added stability. Man-hour costs for 37 m (123 ft) of a 1.8-m- (6-ft-) high vegetative geogrid installed on the Upper Truckee River, California, included 3 days for each of 1 foreman/equipment operator, 1 equipment operator, 2 laborers, and 1 supervisor/ project manager. Thus, 120 man-hours were expended on that project, assuming an 8-hr day. This effort equates to about 0.3 man-hour per linear meter (1 man-hour per linear foot) of treated bank. About 66 percent of the costs of this treatment can be attributed to labor.

Live Fascine or Wattling Bundles and Cuttings

Leiser (1983) reported man-hour costs for installing wattling and willow cuttings at Lake Tahoe, California, to be about 2 lineal meters (6 lineal feet) of wattling per man-hour and 46 small willow cuttings per man-hour. Robbin B. Sotir & Associates quoted an average installation rate of 1.5 lineal meters (5 lineal feet) of live fascine production per man-hour (Leiser 1983). Obviously, if one were to place a coir fabric between contours of wattling bundles, production rates would decrease substantially. According to Sotir, who has done this extensively, it would probably decrease the amount of linear length per man-hour by half.

Dormant Willow Post Method

Roseboom et al. (1995) reported that soil bioengineering work on a 180-m (600-ft) reach at Court Creek, Illinois, required five men two 8-hr days to install 675 willow posts 3.5 m (12 ft) tall on 1.2-m (4-ft) centers. Included in the work was an excavator operator and 4 workers and the installation of a rock toe (18 metric tons (20 tons) of 25-cm (10-in.) riprap) with a coir geotextile roll (described in Chapter 6) along 90 m (300 ft). Also, 60 cedar trees were laid and cabled along the toe of the slope to trap sediment. This effort equates to about 17 posts per man-hour, which includes harvesting and installing the willow posts, plus the other operations mentioned (i.e., site shaping and cedar tree installation).

Standard Seeding

The cost for broadcast seeding per square meter can vary considerably according to some literature sources. Reported costs in man-hours per square meter vary from 0.004 (Kay 1978) to 0.07 (Schiechtl 1980) (0.00037 to .0065 man-hours per square foot) depending on the degree of slope and the type of seeds used.

Hydroseeding

Depending on the material used and the distance to adequate water supply, 4,000 to 20,000 m^2 (43,000 to 215,000 ft^2) can be hydroseeded by one hydroseeder machine per day (Schiechtl 1980). A hydroseeder normally uses a two-man crew.

Hydromulching

Mulching is often applied over seeds by a hydromulcher, which is similar to a hydroseeding machine. For hydromulching or mechanical mulching without seeds, about 0.12 to 0.50 man-hours per square meter (0.011 to 0.046 man-hours per square foot) is estimated (Schiechtl 1980). Mulching after seeding increases the cost per unit area considerably. Hydromulching with a slurry of wood fiber, seed, and fertilizer can result in a cost of only 0.008 man-hour per square meter (0.00074 man-hour per square foot) according to calculations derived from Kay (1978), who reviewed contractor costs in California. These above man-hour calculations assume: (a) use of a four-man mulching machine, (b) seed and fertilizer applied at a rate of 1.7 metric tons per hectare (0.75 ton per acre), and (c) an application rate of 1.8 metric tons per hour (2 tons per hour).

Sprigs, Rootstocks or Plugs, Rhizomes, and Tubers

Costs for digging grasses and other herbaceous plants in their native habitat and transplanting propagules will vary depending on the harvesting system used, the placement of the plants, and the site. For digging, storing and handling, and planting 1,000 plants of sprigged wetland grasses and sedges, Knutson and Inskeep (1982) reported construction time of about 10 man-hours. Sprigs of this type were placed on 0.5-m (1.6-ft) centers, which would cover 250 m^2 (2,700 ft^2). For the same kinds of plants, Allen, Webb, and Shirley (1984) reported a rate equivalent to 400 plants per 10 man-hours for digging, handling, and planting single sprigs. According to Knutson and Inskeep (1982), using plugs of any species (grass or forb) is at least three times more time-consuming than using sprigs (30 man-hours per 1,000 plugs).

Bareroot Tree or Shrub Seedlings

Depending on type of plant and local conditions, the reported costs of planting vary considerably. On good sites with deep soils and gentle slopes, Allen and Leech (1997) experienced planting up to between 100 and 125 plants per man-hour. Logan et al. (1979), however, estimated that only 200 to 400 plants per day per person could be achieved on sites like the banks of the upper Missouri River.

Ball and Burlap Trees or Shrubs

Planting costs for this type of transplant will range from 10 to 25 plants per man-hour (Schiechtl 1980).

Containerized Plantings

The cost of plantings varies depending on plant species, pot type, and site conditions. By using pots other than paper, 20 to 40 plants per man-hour can be planted. With paper pots, up to 100 plants per man-hour can be planted (Schiechtl 1980). Logan et al. (1979) stated that the cost for hand-planting containerized stock ranges from half the cost for bareroot seedlings to a cost equal to or exceeding container seedlings.

6 Supplemental Considerations

Mulches

A mulch is any material applied to the soil surface for protection or improvement of the area covered. Mulches are frequently applied around plants to modify the soil environment and enhance plant growth. The mulch material may be organic (e.g., bark, long straw, wood chips, leaves, pine needles, grass clippings) or inorganic (e.g., gravel, pebbles, polyethylene film, woven ground cloth). If bark or wood chips are used, they should be weathered because oxidation of fresh material can draw nutrients, such as nitrogen, from the surrounding soil. Mulching has the following beneficial effects on the soil and plants.

a. Mulches prevent loss of water from the soil by evaporation. Moisture moves by capillary action to the surface and evaporates if the soil is not covered by a mulch.

b. Mulches suppress weeds when the mulch material itself is weed-free and applied thickly enough to prevent weed germination or to smother existing small weeds.

c. A more uniform soil temperature can be maintained by mulching. The mulch acts as an insulator that keeps the soil cool under intense sunlight and warm during cold weather.

d. Mulching prevents crusting of the soil surface, thus improving absorption and percolation of water into the soil and, at the same time, reducing erosion.

e. Organic mulches improve soil structure. As mulch decays, it adds organic material to the soil. Decaying mulch may also add nutrients to the soil.

f. Mulches add to the beauty of the landscape by providing a cover of uniform color and interesting texture.

g. Mulched plants will produce roots in the mulch that surrounds them. These roots are produced in addition to the roots that a plant produces in the soil. As a result, mulched plants have more roots than unmulched plants.

Mulch can be applied around established plants at any time. Newly set plants should be mulched after they are planted and thoroughly watered. Organic mulches will gradually decompose and need replenishing to function effectively as a mulch. Shallow plant roots that grow into moist mulch will die if the mulch is allowed to dry, decay, or wash away. Frequency of mulching replenishment depends on the mulching material. Grass clippings and leaves decompose very rapidly and should be replenished often. Other organic mulches such as cypress mulch, pine bark, and wood chips break down very slowly and need be replenished only every year or two. Once plants in a ground cover or shrub bed have formed a solid mass by touching one another, the mulching requirement is reduced. The plants create their own mulch by dropping leaves, flowers, and fruit. Leaves from surrounding trees also may fall in the beds and provide additional "free mulch." Most organic mulches will change from their original colors to a weathered gray color with age. There are several ways of restoring color to mulches. One approach is to apply a thin layer of fresh mulch (2.5 cm (1 in.) or less) to the surface of the existing mulch. This approach is labor intensive and expensive and can result in an excessively thick mulch layer. Another approach is to shallow rake the existing mulch to restore a freshly mulched appearance. A third choice is to use a mulch colorant. Mulch colorants are dyes that are sprayed on the mulch to restore its color. Manufacturers claim they are harmless to both plants and animals, but applicators should use them cautiously because they can cause skin and eye irritation.

Inorganic mulches such as gravel, pebbles, and stones are considered permanent mulches and rarely need replenishing. Still, small particles will eventually move down into the soil and a thin layer of the material will need to be added to the existing layer. Leaves and other debris need to be regularly removed from the top of these materials to maintain a neat appearance.

The amount of mulch to apply depends on the texture and density of the material. Many wood and bark mulches are composed of fine particles and should not be more than 5 to 7.5 cm (2 to 3 in.) deep after settling. Excessive amounts of these fine-textured mulches around shallow-rooted plants can suffocate their roots, causing poor growth. Coarse-textured mulches, such as pine needles and pine bark nuggets, that allow good air movement through them can be maintained as deep as 10 cm (4 in.).

Mulches composed solely of shredded leaves, small leaves, or grass clippings should never exceed a 5-cm (2-in.) depth. These materials have flat surfaces and tend to mat together, restricting the water and air supply to plant roots.

Erosion Control Materials

Erosion control materials (ECMs) play an important role in many streambank restoration projects. ECMs include the wide variety of natural and synthetic fabrics, meshes, and grids used to prevent soil erosion and reinforce vegetation. They fill a void between the erosion resistance of bare soil and that provided by a hard armor. If properly installed and under the right circumstances, these materials can withstand relatively severe flow conditions. Many engineers have adopted the design procedures presented by the Federal Highway Administration (FHWA) in its most recent manual, HEC-15 (FHWA 1988). This design methodology uses maximum shear stress calculations in determining the suitability of various lining materials.

Manufacturer performance data may be used in determining the suitability of an ECM for a project. These data should be the result of performance testing on the product installed as the manufacturer recommends. Therefore, the expected performance from each product is best achieved by specifying "per manufacturer's published recommendations." The Texas Transportation Institute recently conducted testing of many ECMs and has available guidance for their application (Fischenich 2001).

One of the more common types of ECMs used in restoration designs are the temporary mats and fabrics intended to provide erosion protection only until vegetation can become well established and assume this function.

There are two distinct categories of temporary ECMs, photodegradable and biodegradable. Within these two categories is a wide range of products made from such natural fibers as straw, coconut (coir) fiber, wood excelsior, flax, and jute. The different fibers provide significantly different characteristics, features, and benefits. These ECMs are entirely degradable, meaning that biological organisms break down the fibers over time (biodegradable) or sunlight accomplishes the same objective (photodegradable).

The length of time required to break down these fibers depends on the amount of moisture and sunlight to which the fibers are subjected. In general, straw, excelsior, and jute erosion control products last for a shorter time period than do those made of coir or flax. Manufacturers indicate that some materials, such as straw blankets, will remain in recognizable form for only a couple months while others, such as coir-fiber blankets, remain in good condition for up to 6 years. Projects using temporary erosion-control products must be designed so that the vegetative component is well established prior to the degradation of the ECM. A summary of the more common temporary ECMs follows.

a. *Temporary blankets.* These products combine synthetic, photodegradable netting with fiber matrices and are primarily used for seedbed mulching. The most common blankets feature a mixed straw/coir fiber matrix sewn between a lightweight bottom net and a heavy-duty top net. The heavy-duty top net and addition of coconut fibers give the blanket greater durability, longevity, and effectiveness than straw, jute, and excelsior blankets.

b. *Coir-fiber geotextiles.* These products are nets or grids constructed from a loose coir fiber that is twisted into twine. The strength of a coir-fiber geotextile increases with the number of twines in the warp, the weft, or both. The open area of the coir geotextile decreases with the number of twines in the warp and weft. Because of their high tensile strength and relative durability, coir-fiber geotextiles are used for a wide variety of restoration projects and for many different soil bioengineering techniques.

c. Prevegetated coir-fiber mats. Prevegetated mats are loose coir-matrix mats in which emergent aquatic vegetation is grown hydroponically. They are similar to sod and, when containing mature plants, can be 5 cm (2 in.). thick, 5 m (16.5 ft) long, and 0.9 m (3 ft) wide and weigh about 3 kg/m (2 lb/ft) (although these dimensions can vary depending on manufacturer). These mats are designed for use where velocities are low (generally less than 0.6 m/sec (2 ft/sec)) or where wave heights are less than 0.3 m (1 ft) and slopes are less than or equal to 1:5. Generally, roots have grown through the mat and are in direct contact with the soil when installed. The primary use of prevegetated mats is for projects that have a narrow planting window because of the date of installation.

Coir Geotextile Rolls

The coir geotextile roll (CGR) is a sausagelike roll of nonwoven fibers made from coconut husks bound within a woven mesh rope made from either polyethylene or coir rope. The CGR incorporates wetland plants (usually as rooted sprigs or cuttings) whose roots become interlocked with the CGR fibers. The CGR with its plants is used along the face of eroded streambanks and acts principally to armor the bank, although it can also be configured to act as a current deflector. The CGR has the potential to accumulate sediment and, together with the plants, develop a strong network of interlocking roots and plant stems.

The primary design considerations for use of a CGR are: (a) elevation along the bank with respect to the hydrology of the stream, (b) sustained velocity and shear-stress thresholds that the CGR must withstand, and (c) toe and flank protection. A site suited to a CGR requires a hydrologic regime that both keeps the invert of the roll wet during most of the growing season and sustains flows sufficient to keep wetland plants growing well. They are not intended for flows of long durations that exceed the plants' flood tolerance. Given these requirements, streams best suited to CGRs are perennial and small to moderate in size, with a relatively consistent water surface elevation associated with an extended baseflow.

Another important factor in site selection is that it not be subject to massive amounts of sediment movement that could smother plants within the roll. CGRs have been effectively used, however, to trap soils from upper bank failures and establish conditions for subsequent colonization or planting. When thus used, planting should not be attempted until the upper bank has stabilized.

Other important considerations in site selection are shade conditions, type of substrate in which the CGRs will be placed, and the CGRs' relation to the channel thalweg. Most wetland plants that are suitable for planting within a CGR are shade intolerant or require at least partial sunlight. Therefore, as a general rule, the CGR should be placed where some sunlight exists. There are exceptions in which shade tolerant plants, such as Baltic rush (*Juncus balticus)* or some species of burreed (*Sparganium* spp.), can be relied on. Local USDA Natural Resource Conservation Service offices should be consulted for other local shade tolerant plants for the area of interest.

Substrate conditions are also important in site selection because the CGR must be securely anchored. If the substrate is noncohesive material such as sand or silt, anchoring may be problematic because of the lack of friction to hold the anchors in place. Conversely, substrates laden with interspersed rock or with an underlying rock layer can adversely impact anchor penetration without special equipment or materials.

The CGR should also generally not be placed immediately adjacent to the thalweg. If such placement is a necessary design feature, then the CGR must be enhanced with stone to protect it from scour and undercutting. Toe armor (i.e., rock) guards against the undercutting of the treatment, and flank hardening guards against currents working their way behind the treatment and causing it to fail from flanking. Protection to guard against undercutting and flanking the treatment is essential for success. For toe and flank protection, rock bolsters should be designed for velocities and shear stresses exceeding allowable limits for the soils underlying the CGR. Flank protection can also be aided by keying the ends of the CGR into the banks at both ends and protecting it with a rock bolster. The ends should be keyed into the bank by inserting at least 2 linear feet of roll into the bank with rock (which is also keyed into the bank) on the upstream side. For banks susceptible to significant erosion, keys or refusals should extend farther into the bank.

Elevation of the CGR with respect to the stream hydrology is of utmost importance. Elevation of the CGR must be sufficient to absorb water but not so low as to subject the included vegetation to complete submergence for a long period of time (> 21 days on average) during the growing season (Figure 6). Conversely, it must not be so high as to completely dry out and desiccate the planted vegetation. If stacked rolls are used, they must be in a position to be wetted often or to absorb groundwater percolating from the bank. An exception to this requirement for periodic wetting is when willow whips or some other woody plant is used in between stacked CGRs as brush layers with their basal end inserted well

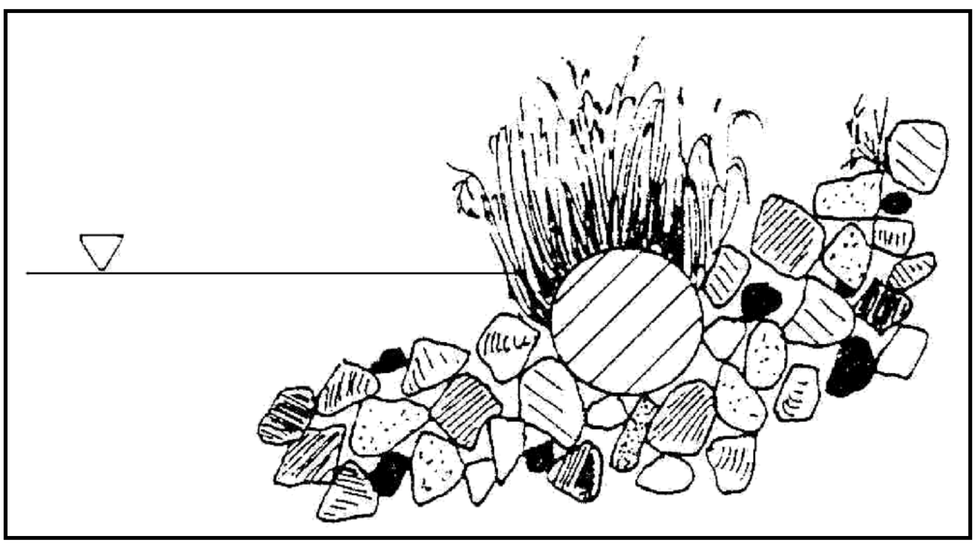

Figure 6. CGR shown at an appropriate elevation to sustain aquatic plant growth

into a moist zone within the bank. In such cases, CGRs are primarily intended to provide temporary sediment and erosion control.

Few data have been collected for shear or velocity tolerances of the CGR. Available data come largely from empirical information or from vendors' design criteria (Table 8). Designers are urged to exercise caution in considering limiting velocity or shear stress criteria as the only design criteria. Failure of CGRs can be attributed to several mechanisms, notably flanking, undercutting, and anchor failure.

Table 8
Stress Type and Stress Levels for the CGR

CGR Type	Velocity	Shear
Roll with coir rope mesh (staked only w/o rock bolster)	< 1.5 m/sec (5 ft/sec)	9.6-38 Pa (0.2-0.8 lb/ft^2)
Roll with polypropylene rope mesh (staked only w/o rock bolster)	< 2.4 m/sec (8 ft/sec)	38-144 Pa (0.8-3.0 lb/ft^2)
Roll with polypropylene rope mesh (staked w/ rock bolster)	< 3.7 m/sec (12 ft/sec)	>144 Pa (>3.0 lb/ft^2)

Other design considerations include the number and sizes of rolls needed to cover a streambank. The length of bank-reach being eroded will determine the number of rolls needed. Rolls normally come in 3- or 6-m (10- or 20-ft) lengths, but can be custom tailored to fit certain situations if warranted.

Irrigation Options

Three principal types of irrigation systems are used for restoration and stabilization projects: (a) trickle or drip systems, (b) spray systems, and (c) mobile systems. Flood systems (a fourth option) are generally more applicable to agricultural crops than streambank and riparian projects and are not covered in this report. Table 9 compares the merits and disadvantages of each system.

Trickle systems apply water directly to the root zone of plants by means of applicators (orifices, emitters, porous tubing, or perforated pipe) operated under low pressure. The applicators can be placed on or below the surface of the ground. Trickle systems are the most efficient way to water and maintain a specific range of soil moisture without excessive water loss, erosion, reduction in water quality, or salt accumulation.

Spray systems use sprinkler heads and pressure to distribute water over vegetation in a fashion that mimics rainfall. Spray systems can be further divided into underground, surface, and overhead systems depending on the location of the piping systems. Underground systems tend to be costly and are useful only in cases where permanence is required or where vandalism may present a problem.

Table 9
Comparison of Irrigation Systems

Trickle or Drip Irrigation	Underground Spray Systems	Surface/Overhead Spray Systems	Mobile Irrigation
Affordable	Expensive	Moderate cost	Inexpensive
Simple installation	Moderate installation	Simple installation	No installation
Unobtrusive	Unobtrusive	Unattractive	Unobtrusive
Vandal prone	Vandal proof	Vandal prone	Vandal proof
Convenient	Convenient	Convenient	Inconvenient
Temporary/movable	Permanent/immovable	Temporary/movable	Temporary/highly mobile
Not suitable for herbaceous	Suitable for all vegetation	Suitable for all vegetation	Suitable for all vegetation
Erosion resistant	Promote erosion	Promote erosion	Variable erosion
Moderately freeze resistant	Freeze resistant	Freeze susceptible	Freeze resistant
Low volume/pressure	High volume/pressure	High volume/pressure	Low volume/pressure

Mobile irrigation systems can be the least expensive option for watering plants used in soil bioengineering or restoration projects. This option includes removable systems ranging from large long-range sprinklers used in conjunction with fire hoses to standard garden hoses and consumer-grade sprinklers supplied with low-head effluent pumps placed in the adjacent stream. If irrigation is required, it should be deep enough, 30 cm (12 in.), to encourage deep rooting of the installed vegetation.

7 Conclusions

Design criteria for soil bioengineering treatments are generally lacking. Work is underway to develop specific guidance. A first consideration is whether or not the site will naturally colonize with desirable species or if planting will be required. If planting is necessary, vegetation establishment considerations should be reviewed in light of the potential hydraulic impacts and desired environmental benefits as well as anticipated soils and hydrology. Appropriate plant materials should be selected by a plant specialist who coordinates with the site hydrologist, soil scientist, and geotechnical engineer and should be based on the site analysis and on evaluation of the plant communities in the nearby region. Next, a planting plan should be developed consistent with project goals and objectives, site conditions, and anticipated maintenance requirements. Guidelines are also prepared for the subsequent design of an irrigation system (if needed), and specific measures for plant protection are identified.

Plans for acquiring plants must be made well in advance of the project implementation, sometimes 1 to 2 years in advance. There are three suitable methods to acquire plants for flood control, soil bioengineering, and restoration projects: (a) purchase plants, (b) collect plants from the wild, and (c) propagate and grow plants. Each method has noteworthy advantages but also critical disadvantages that make plant acquisition and handling an important and complex process. When acquiring plants, considerations must be given to local or Federal laws prohibiting the acquisition of certain plants and the decimation of natural stands of wetland plants. Additionally, care must be taken to ensure that pest species are not collected and transferred to the project site.

The landscaping component of stream and riparian restoration projects is generally underemphasized given its importance from the standpoint of visual success and public perception. Even projects that fully restore the desired functions for the site can be deemed a failure or, at best, only a marginal success if they do not also offer visual appeal. Plans for landscape and beautification plantings should consider foliage color, shape, color and season of flowering, and mature plant height.

A diverse array of plant species is essential to a riparian system's ability to provide and sustain a number of functions. Planting a variety of species increases the chances for success of at least a few species. Establishment of a variety of desirable species will increase competition for resources, limiting the potential for aggressive species to overtake a project site. A high number of plant species and the structural complexity of natural ecosystems generally correlate with wildlife species richness.

In riparian ecosystems, the plant community composition and its associated habitat structure and productivity are largely determined by the timing, duration, and extent of flooding. Vegetation species and their planting position should be selected on a site-specific basis. In the context of determining the necessary vegetation layout, “site-specific” refers to a small scale, within the order of a few meters (feet) if elevation relations to water levels are considered. However, the layout of vegetation used for flood control, stabilization, and restoration projects in the riparian zone also requires consideration of the large-scale position of the riparian communities in the landscape. The spacing and arrangement of individual plants must be planned also.

Selection and layout of plants for flood control projects involve consideration of the plants’ resistance to stream flows and their impact on hydraulic conveyance. Thus, revegetation specifications, including species, planting location, and density, should be developed based on an evaluation of hydraulics and vegetation stability, erosion control requirements, desired fish and wildlife habitat, aesthetics, plant material availability, and installation and maintenance.

A three-zone riparian buffer concept is recommended to assist with planning, design, and long-term management. The width of each zone is determined by site conditions and objectives. Zone 1 functions as an extension of the stream or water body and is the area in which critical habitat and stream integrity objectives are achieved. Composition of the vegetation in this zone should be native, noninvasive trees and shrubs of a density that permits understory growth. Target vegetation in Zone 2 is a managed riparian forest with a vegetation composition and character similar to natural riparian forests in the region. This zone provides most of the enhanced habitat benefits and allows for recreation benefits. Zone 3 is provided to slow runoff, infiltrate water, and filter sediment and its associated chemicals. Zone 3 may contain grass filter strips, level spreaders, or other features.

Vegetation must be planted properly. Methods and procedures for the installation of plant materials are detailed in the planting plan. Plants should be handled carefully to ensure their survival between acquisition and transplanting. Many problems associated with poor plant survival occur from the handling of the plants between the nursery or collection site and the project planting site. Planting and seeding operations should be conducted at the optimal time. The optimal window of opportunity for most planting extends throughout the dormant winter season. Planning also needs to detail the maintenance of both the plant materials and the site during the plant establishment period and during any monitoring of project progress and success. Maintenance of plants, through control of nuisance species, erosion, and water level, in managed systems can be crucial to their survival and growth.

Woody plants, particularly those expected to root adventitiously, should be collected when dormant. Bareroot or unrooted cuttings must be kept cool, moist, and in the dark until they are planted. Cuttings should be dormant. Live fascine or wattling bundles should be prepared from live, shrubby material from species that root from the stem. For branchpacking or brushlayering, live but dormant brush of willow species should be used.

When plants are moved from the nursery, holding area, or harvesting area to the project site, they should continue to receive careful handling. Exposure of the plants to sun and wind should be minimized throughout the planting operation. Trenches or holes should be dug only as rapidly as the plants can be placed and covered to minimize drying of the soil in the trench and the backfill. Mulch can be applied around established plants at any time. Newly set plants should be mulched after they are planted and thoroughly watered. The mulch material may be organic (e.g., bark, wood chips, leaves, pine needles, or grass clippings) or inorganic (e.g., gravel, pebbles, polyethylene film, or woven ground cloth).

Soil bioengineering treatments are normally much less expensive than traditional methods of streambank erosion control. Costs can, however, vary tremendously depending on availability of materials, hauling distances, prevailing labor rates for the geographic area, and a host of other factors. When cost-comparing soil bioengineering methods with traditional engineering applications, each method must be considered on its merits and by comparing life-cycle costs. In practice, operation and maintenance expenses for well-designed work are low, and quantitative comparison of different methods is difficult unless a method is being considered that obviously requires expensive monitoring and future maintenance and reinforcement. A sophisticated analysis requires a comparison of planning and "life-cycle" costs, the procedure for which will usually be specified by institutional policy.

For small projects, costs can be closely estimated and are based principally on construction labor and materials. Consideration should be given to the equipment and materials required for vegetation handling and planting at the implementation stage. The tools required and the planting techniques will depend on the type of vegetation. For large projects, the final estimate should consider incidental items such as rights-of-way, engineering and design, supervision and inspection of construction, repair of staging areas, operation and maintenance, and contingencies. These items may simply be estimated as a percentage of construction cost, or a more precise estimate may be appropriate.

Contingencies are routinely expressed as a percentage of the estimated cost, but if unpredictable changes in site conditions or materials or fuel costs would impact some methods more than others, good practice would be to weight the estimate of contingencies.

Erosion control materials (ECMs) play an important role in many streambank restoration projects. ECMs include the wide variety of natural and synthetic fabrics, meshes, and grids used to prevent soil erosion and reinforce vegetation. They fill a void between the erosion resistance of bare soil and that provided by a hard armor.

Project planning must determine if there will be a need for an irrigation system. Three principal types of irrigation systems are used for restoration and stabilization projects: (a) trickle or drip systems, (b) spray systems, and (c) mobile systems.

Designing a vegetation plan is becoming an essential part of stream restoration or flood control projects. There are four major parts to a vegetation plan: (a) plant identification, (b) plant acquisition, (c) plant layout, and (d) plant handling. It is crucial to allow sufficient time in the plan for plant acquisition. Plant layout requires careful consideration of the objectives of the project and the efforts to ensure diversity maintenance. A key to plant layout is that the final result appear random and natural. Timing is crucial in plant handling. Plant acquisition and planting must be coordinated to ensure maximum plant survival as well as maximum success of the vegetation plan. Always treat vegetation with respect, as the living component it is.

References

Allen, H. H., Leech, J. L. (1997). "Bioengineering for streambank erosion control," Technical Report EL-97-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Allen, H. H., Webb, J. W., and Shirley, S. O. (1984). "Wetlands development in moderate wave-energy climates." Proceedings of the Third Symposium on Coastal and Ocean Management, American Society of Civil Engineers, Clearwater Beach, FL.

Briggs, J. A., and Munda, B. (1992). "Collection, evaluation, selection, and production of cottonwood poles for riparian area improvement," Final Report to the U.S. Fish and Wildlife Service, U.S. Department of Agriculture Soil Conservation Service, Tucson Plant Materials Center, Tucson, AZ.

Davis, M. M., Mitchel, W., Wakeley, J. S., Fischenich, J. C., and Craft, M. H. (1996). "Environmental value of riparian vegetation," EIRP TR EL-96-16, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Federal Highway Association. (1988). "Design of roadside channels with flexible linings," HEC-15, FHWA-IP-87-7, Washington, DC.

Fenchel, G., Oaks, W., and Swenson, E. (1988). "Selecting desirable woody vegetation for environmental mitigation and controlling wind erosion and undesirable plants in the Rio Grande and Pecos River Valleys of New Mexico," Five-year interim report (1983-87), U.S. Department of Agriculture Soil Conservation Service, Los Lunas Plant Materials Center, Los Lunas, NM.

Fischenich, C. (2001). "Stability thresholds for stream restoration materials," ERDC TN-EMRRP-SR-29, EMRRP Technical Notes Collection, U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://www.wes.army.mil/el/emrrp

Frazer, N. B., Gibbons, J. W., and Greene, J. L. (1990). "Exploring Fabens' growth model with data on a long-lived vertebrate *Trachemys scripta* (Reptilia: Testudinata)," *Copeia* 1990(1), 112-18.

Heitmeyer, M. E., Connelly, D. P., and Pederson, R. L. (1989). "The Central, Imperial, and Coachella valleys of California." *Habitat management for migrating and wintering waterfowl in North America*. L. M. Smith, R. L. Pederson, and R. M. Kaminski, ed., Texas Tech. University Press, Lubbock, TX.

Hoag, C. (1994). "The stinger," TN Plant Materials No. 6, June 1994, U.S. Department of Agriculture Soil Conservation Service, Boise, ID.

Kay, B. L. (1978). "Mulches for erosion control and plant establishment of disturbed sites." Proceedings of ALCA Revegetation Erosion Control Symposium, 1-3 August 1978, Denver, Colorado, 111-29.

Knutson, P. L., and Inskeep, M. R. (1982). "Shore erosion control with salt marsh vegetation," Civil Engineering Technical Aid, No. 82-3, U.S. Army Engineer Coastal Engineering Research Center, Fort Belvoir, VA.

Knutson, P. L., and Woodhouse, W. W., Jr. (1983). "Shore stabilization with salt marsh vegetation," Special Report 9, U.S. Army Engineer Coastal Engineering Research Center, Fort Belvoir, VA.

Leiser, A. T. (1983). "Reservoir shoreline revegetation," Notes from U.S. Army Corps of Engineers training course *Wetlands Development and Restoration,* Duck, NC.

__________. (1992). "Biogeotechnology for slope protection and erosion control," Notes from *Reservoir Shoreline Erosion/Revegetation Workshop,* June 1992*,* Fergus Falls, MN, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1994). "Biotechnical approaches for shoreline erosion control," Notes from *Reservoir Shoreline Erosion/Revegetation Workshop*, 28 March – 1 April 1994, Lewisville and Ray Roberts Lakes, Denton, TX, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Logan, L. L., Allen, H. H., Aufforth, A., et al. (1979). "Vegetation and mechanical systems for streambank erosion control," unpublished report for U.S. Army Corps of Engineers, Omaha District, U.S. Department of Agriculture Forest Service, Norther Region, and the North Dakota State Forest Service.

Peterson, L. A., and Phipps, H. M. (1976). "Water soaking pretreatment improves rooting and early survival of hardwood cuttings of some populus clones," *Tree Planter's Notes* 27(1), 12, 22.

Pierce, G. J. (1994). Notes from *Reservoir Shoreline Erosion/Revegetation Workshop, 28 March – 1 April 1994,* Lewisville and Ray Roberts Lakes, Denton, TX, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Platts, W. S., Armour, C., Booth, G. D., et al. (1987). "Methods for evaluating riparian habitats with applications to management," General Technical Report INT-221, U.S. Department of Agriculture Forest Service, Intermountain Research Station, Ogden, UT.

Roseboom, D., Hill, T., Rodsater, J., et al. "Installation and monitoring of willow post bank stabilization enhancements," unpublished report for the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Schiechtl, H. (1980). *Bioengineering for land reclamation and conservation.* The University of Alberta Press, Edmonton, Alberta, Canada.

Sotir, R. B. (2001). "Integration of soil bioengineering techniques for watershed management." Proceedings of ASCE Wetlands Engineering and River Restoration Conference, 27-31 August 2001, Reno, NV.

U.S. Department of Agriculture Soil Conservation Service. (1992). "Directory of wetland plant vendors," Technical Report WRP-SM-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Weins, J. A. (1989). "Spatial scaling in ecology," *Func. Ecol.* 3, 385-97.

Welsch, D. J. (1991). "Riparian forest buffers," NA-PR-07-91, U.S. Department of Agriculture Forest Service, Radnor, PA.

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14. ABSTRACT

This report focuses on consideration related to the acquisition, handling, and placement of the vegetation for bioengineering treatments and riparian restoration efforts associated with flood control projects. Successful designs are based on consideration of hydraulic impacts and environmental benefits, the anticipated soils and hydrology, and the approach by which the vegetation is obtained, handled, and installed. Selection of species type and their acquisition; guidelines for the design of riparian buffer zones, for handling plant materials, and for development cost estimates; and some supplemental considerations are presented in this report.

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