

United States
Department of
Agriculture

Forest Service

Technology &
Development
Program

7700—Transportation Management
September 2000
0077 1801—SDTDC



SOIL BIOENGINEERING

An Alternative for Roadside Management

A Practical Guide

Soil Bioengineering An Alternative for Roadside Management A Practical Guide

**Lisa Lewis
Soil Scientist
National Riparian Service Team
USDA Forest Service**

September 2000

**San Dimas Technology &
Development Center
San Dimas, California**

Information contained in this document has been developed for the guidance of employees of the Forest Service, USDA, its contractors, and cooperating Federal and state agencies. The Department of Agriculture assumes no responsibility for the interpretation or use of this information by other than its own employees. The use of trade, firm, or corporation names is for the information and convenience of the reader. Such use does not constitute an official evaluation, conclusion, recommendation, endorsement, or approval of any product or service to the exclusion of others that may be suitable.

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, sex, religion, age, disability, political beliefs, sexual orientation, or marital or family status. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202)720-2600 (voice and TDD).

To file a complaint of discrimination, write USDA, Director, Office of Civil Rights, Room 326-W, Whitten Building, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410 or call (202) 720-5964 (voice and TDD). USDA is an equal opportunity provider and employer.

CONTENTS**INTRODUCTION**

Purpose and Scope	1
Objectives	1
Benefits and Limitations	1
History of Soil Bioengineering	2
Basic Soil Bioengineering Concepts	5
Site Evaluation and Design Checklist	6
Project Planning and Implementation Checklist	6
Site Preparation	6
Project Work	7
Plant Materials	7
Plant Movement Guidelines	8
Gene Pool Conservation Guidelines	8

TECHNIQUES FOR PROJECT IMPLEMENTATION

Native Plant Cuttings and Seed Collection	9
Salvaging and Transplanting Native Plants	11
Planting Containerized and Bare Root Plants	12
Distribution of Seed, Fertilizer, and Certified Noxious Weed-free Straw or Hay	13
Live Staking	14
Installation of Erosion Control Blanket	16
Construction of Live Cribwalls	18
Live Fascine	23
Brushlayering	25
Willow Fencing Modified with Brushlayering	27
Branchpacking	28
Live Gully Repair	30
Vegetated Geotextile	31
Log Terracing	32
Bender Board Fencing	37

REFERENCES CITED	41
-------------------------	-----------

MAP

Map 1	Seed zones	10
-------	------------	----

FIGURES

Figure 1	Live stake	15
Figure 2	Installation of erosion control blanket	17
Figure 3	Installation of erosion control mat	18
Figure 4	Live cribwall construction	20
Figure 5	Live cribwall construction	20
Figure 6	Live cribwall construction	20
Figure 7	Live cribwall-stepped full, half and toelog construction	22
Figure 8	Live cribwall battered construction	22
Figure 9	Live fascines	24
Figure 10	Brushlayering and brushlayering with log terrace	26
Figure 11	Willow fencing modified with brushlayering	27
Figure 12	Branchpacking	29
Figure 13	Live gully repair	30
Figure 14	Vegetated geotextile	31
Figure 15	Log terrace installation	33
Figure 16	Log terrace construction	33
Figure 17	Anchoring and filling gaps	35
Figure 18	Removal of slope overhang	36
Figure 19	Bender board fencing	38

DEDICATION

To Clifford Gershom Jordan my grandfather, who farmed 150 acres of southwest Georgia's sandy clay loam soils with a team of mules, never once using mechanized equipment. And to his beloved helpmate my grandmother Rachel Culbreth Jordan, also known as Miss Pinky. From this land, they grew and hand-harvested cotton, peanuts, and corn. From their garden, she canned fruits and vegetables, creating the most beautiful art gallery I have ever seen, her pantry. Their spirits circle my every step.

Heartfelt thanks to my parents, Betty Jordan Phillips and Charles Andrew Phillips, whose loving guidance and support made possible my career as a soil scientist.

To Dave Craig, silviculturalist, district ranger, and mentor. His artful management of the land and people will never cease to amaze me.

And to Marsha Stitt, whose support through this arduous task made possible this publication.

ACKNOWLEDGEMENTS

Special thanks to Larry Ogg, and crew members of the Washington Conservation Corps, who provided a technical review and who contributed to the application and evolution of several soil bioengineering stabilization methods listed in this guide. Their hard work, creativity, and enthusiasm, led to the stabilization of over a thousand erosion sites on the Olympic Peninsula.

The author would also like to acknowledge the following contributions. Kevin Finney who provided information on the history of soil bioengineering as well as several photographs for the document. Robbin Sotir provided a technical review, furnished figures and photographs of several of the described techniques. Mark Cullington also provided several of the USDA Forest Service photographs and Susan Clements and George Toyama provided valuable assistance in turning these many pages into a book.

The author extends a thank you to the following individuals for the time they offered in review and comment: Forrest Berg, Dave Craig, Mark Cullington, Wayne Elmore, Ellen Eubanks, Kevin Finney, Shannon Hagen, Chris Hoag, Susan Holtzman, Steve Leonard, Marcus Miller, Tom Moore, Kyle Noble, Larry Ogg, Janice Staats, Ron Wiley and Janie Ybarra.

The content of this publication must be credited to the work of Arthur von Kruedener, Charles Kraebel, Donald Gray, and Robbin Sotir—all pioneering soil bioengineering practitioners.

FORWARD

Contents of this document are directed primarily to areas that have 30 inches or more annual precipitation. However, several techniques included in this guide can be used in semi arid and arid environments. Work with vegetation and soil specialists to understand what plants you can use in these environments.

INTRODUCTION

Purpose and Scope

Transportation systems provide tremendous opportunities and, if properly located on the landscape with well-designed drainage features, can remain stable for years with negligible affects to adjoining areas. Roads, however, are often linked to increased rates of erosion and accumulated adverse environmental impacts to both aquatic and terrestrial resources.

Transportation systems provide access and allow utilization of land and resources. Development priorities usually emphasize access, safety, and economics while environmental concerns refer to operational and maintenance problems such as surface condition; plugged drainage structures, including ditchlines; mass failures and surface erosion; or reduced access.

This is not new information to land managers. Road maintenance personnel, for example, face a substantial task in maintaining roads under their jurisdiction. Major storms resulting in significant increases in road related erosion events and impacts to adjoining resources have compounded their challenge.

Objectives

Considerable funds are expended annually in an effort to improve road conditions and adjoining resources. Historically, engineers relied primarily on hard/conventional solutions, or “non-living” approaches, for slope and landslide stabilization. The purpose of this publication is to provide viable alternatives known as soil bioengineering. This is not to argue one solution is better than the other, but to provide additional alternatives, and to encourage an integration of these two practices. Land managers need all available tools to effectively do their jobs. This publication is an effort to meet that need.

Specifically, this publication provides field personnel with the basic merits of soil bioengineering concepts

and gives examples of several techniques especially effective in stabilizing and revegetating upland roadside environments. The information provided in this document is intended to stimulate additional interest for the reader to seek out and use other bioengineering publications.

Benefits and Limitations

Soil bioengineering is an excellent tool for stabilizing areas of soil instability. These methods should not, however, be viewed as the sole solution to most erosion problems. Soil bioengineering has unique requirements and is not appropriate for all sites and situations. On certain surface erosion areas, for example, distribution of grass and forb seed mixes, hydromulching, or spreading of a protective layer of weed-free straw may be satisfactory and less costly than more extensive bioengineering treatments. On areas of potential or existing mass wasting, it may be best to use a geotechnically-engineered system alone or in combination with soil bioengineering. Project areas require periodic monitoring. On highly erosive sites, maintenance of the combined system will be needed until plants have established. Established vegetation can be vulnerable to drought, soil nutrient and sunlight deficiencies, road maintenance sidecast debris, grazing, or trampling and may require special management measures to ensure longterm project success.

Benefits of soil bioengineering include:

- Projects usually require less heavy equipment excavation. As a result, there is less cost and less impact. In addition, limiting hand crews to one entrance and exit route will cause less soil disturbance to the site and adjoining areas.
- Erosion areas often begin small and eventually expand to a size requiring costly traditional engineering solutions. Installation of soil bioengineered systems while the site problem is small will provide economic savings and minimize potential impacts to the road and adjoining resources.

SOIL BIOENGINEERING

- Use of native plant materials and seed may provide additional savings. Costs are limited to labor for harvesting, handling and transport to the project site. Indigenous plant species are usually readily available and well adapted to local climate and soil conditions.
- Soil bioengineering projects may be installed during the dormant season of late fall, winter, and early spring. This is the best time to install soil bioengineered work and it often coincides timewise when other construction work is slow.
- Soil bioengineering work is often useful on sensitive or steep sites where heavy machinery is not feasible.
- Years of monitoring has demonstrated that soil bioengineering systems are strong initially and grow stronger with time as vegetation becomes established. Even if plants die, roots and surface organic litter continues playing an important role during reestablishment of other plants.
- Once plants are established, root systems reinforce the soil mantle and remove excess moisture from the soil profile. This often is the key to long-term soil stability.
- Soil bioengineering provides improved landscape and habitat values.

History of Soil Bioengineering

The following text is an excerpt from a paper presented by Kevin Finney, Landscape Architect, at the Eleventh Annual California Salmonid Restoration Federation Conference in Eureka, California, March 20, 1993.

Soil bioengineering is the use of live plant materials and flexible engineering techniques to alleviate environmental problems such as destabilized and eroding slopes, streambanks and trail systems. Unlike

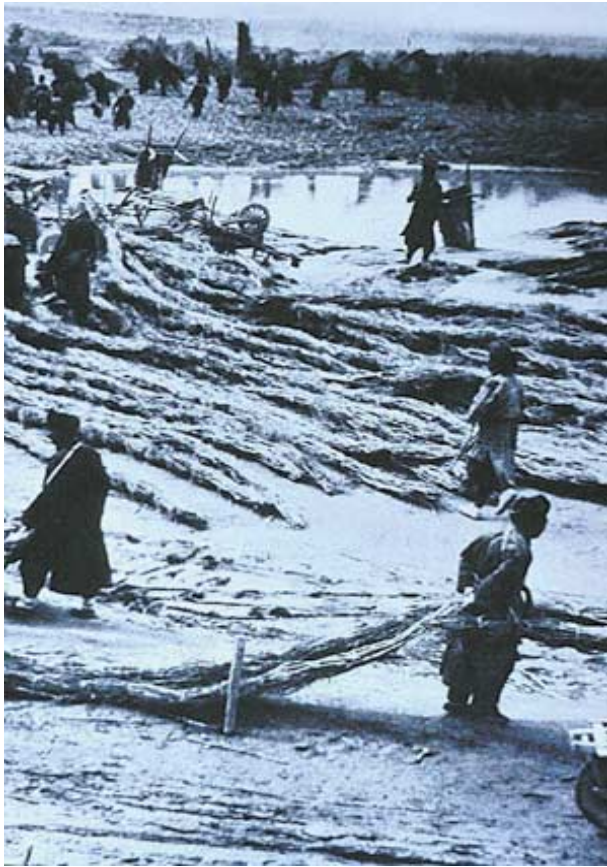
other technologies in which plants are chiefly an aesthetic component of the project, in soil bioengineering systems, plants are an important structural component.

The system of technologies, which today we call soil bioengineering, can be traced to ancient peoples of Asia and Europe. Chinese historians, for example, recorded use of bioengineering techniques for dike repair as early as 28 B.C. Early western visitors to China told of riverbanks and dikes stabilized with large baskets woven of willow, hemp, or bamboo and filled with rocks. In Europe, Celtic and Illyrian villagers developed techniques of weaving willow branches together to create fences and walls. Later, Romans used fascines, bundles of willow poles, for hydroconstruction.



China 28 B.C. Bundling live stems for use in riverbank and dike repair. Kevin Finney

By the 16th Century, soil bioengineering techniques were being used and codified throughout Europe from the Alps to the Baltic Sea and west to the British Isles. One of the earliest surviving written accounts of the use of soil bioengineering techniques, a publication by Woltmann from 1791, illustrated use of live stakes for vegetating and stabilizing streambanks (Stiles, 1991, p.ii). About the same time, other early soil bioengineers working in Austria were developing live siltation construction techniques, planting rows of brushy cuttings in waterways for trapping sediment and reshaping channels.



China Early 1900's. Bundling live stems for use in riverbank and dike repair. Kevin Finney

Much of the development and documentation of soil bioengineering techniques, since the Industrial Revolution, has been done in the mountainous areas of Austria and southern Germany. Extensive logging of the forests in the region resulted in increased environmental problems, much like what we see in the United States today. Such problems as extreme slope erosion, frequent landslides and avalanches, and severe streambank degradation, required repair. By the turn of the century, European soil bioengineers had begun to find new applications for old folk technologies, using them to develop methods to deal with the new environmental problems. These early soil bioengineers, mostly foresters and engineers by training, began to study traditional techniques and to publish their work. This compiled body of knowledge is where the soil bioengineering profession would develop in the following decades.



Europe Early 1900's. Cutting and collection of live stems for soil bioengineering. Kevin Finney

The biggest boost to development of new soil bioengineering techniques in Europe came as a result of political developments during the 1930's. Financial restrictions of pre-war years in Germany and Austria favored use of low cost, local materials and traditional construction methods for public works projects. Construction of the German Autobahn system, during this time, involved extensive applications of soil bioengineering technologies. Use of indigenous materials and traditional methods was also consistent with spreading nationalist ideology. In 1936, Hitler established a research institute in Munich charged

SOIL BIOENGINEERING

with developing soil bioengineering techniques for road construction (Stiles, 1988, p.59). Although this development work was lost, a Livonian forester named Arthur von Kruedener, the head of the institute, continued to work in the field and is known in central Europe as the father of soil bioengineering.

At the same time the Germans were establishing their research institute, some of the most important early soil bioengineering work in the United States was being done in California. Charles Kraebel, working for the USDA Forest Service, was developing his “contour wattling” techniques for stabilizing road cuts. Kraebel used a combination of bioengineering techniques including live stakes, live fascines, and vegetative transplants to stabilize degrading slopes in the National Forests of central and southern California. His use of the term “wattle” to describe his live fascine systems, has stuck with us and continues to be used today. Kraebel’s work was well documented in USDA Circular #380, published in 1936. Two years later the Soil Conservation Service, now known as the Natural Resource Conservation Service (NRCS), began a study of bluff stabilization techniques along the shores of Lake Michigan. That agency’s work, which included use of live fascines, brush dams, and live stakes was published in 1938 (Gray and Leiser, 1982, p.188).



USA 1930's.
Installation of live
fascines. USDA
Publication

During the post-war period, European soil bioengineers returned to studying, developing and evaluating new techniques. In 1950, a committee of soil bioengineers from Germany, Austria, and Switzerland was formed to standardize emerging technologies that became part of the German National System of Construction Specifications, the DIN (Robbin B. Sotir & Associates, Inc. n.d.).

Arthur von Kruedener’s book, *Ingenieurbiologie*, (Engineering biology), was published in 1951 and it was the mistranslation of the German title which gave us the English term we use today. The use of the term bioengineering has caused some confusion and has proven problematic for researchers who find, in this country, the term most often refers to an area of medical research. NRCS now refers to this work officially as “soil bioengineering,” a term which emphasizes the soil component of the system.

German and Austrian soil bioengineers continued to perfect their techniques and to publish their work through the 1950’s and 60’s. This was an important step in launching a more structural approach, laying the foundation for development of the professional field of soil bioengineering. In the United States, two important projects were carried out in the 1970’s and 80’s. These include Trials of Soil Bioengineering Techniques in the Lake Tahoe Basin designed by Leiser and others (1974), and Revegetation Work in Redwood National Park (Reed and Hektner, 1981, Weaver, et al., 1987). Both of these studies have been well documented and provide important information about application of soil bioengineering techniques in the western United States.

In 1980, Hugo Schiechl’s *Bioengineering for Land Reclamation and Conservation* was published in Canada. It presents, for the first time in English, the work of many important European soil bioengineers including Lorenz, Hassenteufel, Hoffman, Courtorier, and Schiechl himself. The book made technologies, and history of their

development and applications, accessible to the English speaking world. In 1997, another Schiechl book was published, *Ground Bioengineering Techniques for Slope Protection and Erosion Control*. To date, his writings remain the most important work on soil bioengineering in the English language.



Hugo Schiechl's, *Bioengineering for Land Reclamation and Conservation*. Kevin Finney

Subsequent publications, including Gray and Leiser's *Biotechnical Slope Protection and Erosion Control* and Sotir and Gray's *Soil Bioengineering for Upland Slope Protection and Erosion Reduction* in the United States, Gray and Sotir's 1996 *Biotechnical and Soil Bioengineering Slope Stabilization*, and the British Construction Industry Research and Information Association's *Use of Vegetation in Civil Engineering* have made bioengineering technologies better known in the engineering profession. However, there is still resistance to the techniques in many countries.

Soil bioengineering approaches most often use locally available materials and a minimum of heavy equipment, and can offer local people an inexpensive way to resolve local environmental problems. The public's increased environmental consciousness often makes soil bioengineering solutions more acceptable than traditional "hard" engineering approaches.

Despite, and maybe because of, the differences in approach and philosophy between soil

bioengineering and other engineering methods of addressing environmental problems soil bioengineering technologies are especially appropriate today. The scale and range of environmental problems require consideration of new technologies even when, as illustrated earlier, they are in fact centuries old.

Basic Soil Bioengineering Concepts

By knowing the climate and vegetation of an area, it is possible to predict the nature of the soils. There are, however, many exceptions resulting from differences in parent materials, drainage, slope, and the time the soil has been exposed to these environmental conditions.

Projects require more than site evaluation and measurement. Design should consider the natural history and evolution, as well as, cultural and social uses of the surrounding landscape. An awareness of these factors, and how they shape present and potential future landscape, is critical for project success. Knowledge of current and future land management goals is also important. A proposed soil bioengineering project within a forested landscape, for example, requires an understanding of the area's geologic and glacial history; its propensity for wild land fires, wind storms, and floods; occurrence and trends of natural and management related erosion; history of road construction methods and current maintenance practices; sequence of vegetation removal and revegetation efforts; and fire management history. This information provides interesting lore and insight on the project area's potential and capability.

In addition to understanding landscape scale patterns, it is important to observe trends within erosion sites. Whether erosion occurs naturally or through human-induced activities, a site begins to heal itself immediately upon "failure". In mountainous terrain, for example, wood may become embedded in the slope, terracing eroding soils. Once an angle of repose has been achieved

between these natural terraces, vegetation begins to establish. Herbaceous plants usually provide initial vegetative cover on these sites. This initial cover also assists in establishment of soil microorganisms. Typical succession patterns go from exposed ground, through a herbaceous stage, to pioneer shrub, and tree, and finally to a climax tree stage. The primary goal is to examine and document these trends. Soil bioengineering designs are intended to accelerate site recovery by mimicking or accelerating what is happening naturally.

Site Evaluation and Design Checklist

There are many soil bioengineering systems. Selection of the appropriate technique, or techniques, is critical to successful restoration. At a minimum, consider the following:

Climatic Conditions

- Precipitation types, levels, timing, and duration.
- Temperatures, including extremes.

Topography and Aspect

- Slope gradient, terrain shape, elevation of project area, and direction of sun exposure. Climates near the ground can vary considerably within short distances. South facing valleys, for example, receive more direct sun rays, causing higher soil temperatures, increased evaporation, more rapid snowmelt in the spring, and generally drier conditions than on the more shaded north facing side. This difference will influence erosion rates and the composition and vigor of vegetation.

Soils

- Underlying substrate.
- Root and water permeability, moisture holding capacity, and nutrient availability.
- Identify conditions above, below, or within your project site which may have an affect on your project and incorporate these considerations into your design.

Water

- If applicable, stream and fish types affected by the erosion site.
- Location of natural drainage channels and areas of overland flow from road surface.
- Identify areas for safe water diversion.
- Note condition of ditch line and culvert inlets and outlets.

Vegetation

- Plant types and amount growing within and adjacent to the project site. This is especially important to identify colonizing species.
- Locations for, and preparation of future plant and seed collection.

Erosion Process

- Type of mass wasting or surface erosion features, including seepage.
- Source of eroding material: road fill slope, cut slope, landing, etc.
- Trend of site—improving naturally, remaining uniform, or worsening.

Project Planning and Implementation Checklist

Site Preparation

- Develop and implement a communication plan to keep all involved, interested, and informed.
- Establish clear project objectives. Have these objectives reviewed, further developed and approved by participants, including the local road manager.
- List all project phases. Under each phase, catalogue and schedule all work items. For each work item, list responsible party and the date their tasks must be completed. Identify and resolve timing conflicts. Build flexibility into the schedule.

- Sites often require earthwork prior to and during installation of a soil bioengineering system. Timing conflicts can occur between scheduling heavy equipment, hand labor work, plant collection, and use.
- Select the right equipment for the job.
- Identify and remove work hazards such as rocks, boulders, and tree stumps.
- Determine storage and staging areas, and access routes for people and machinery to minimize site disturbance and improve efficiency.
- Ensure coordination between heavy equipment operator and handcrew.
- Temporarily divert excess water.
- Stockpile excavated soils for later use and retain or salvage existing vegetation for later use.
- Provide and maintain temporary surface erosion and sediment control measures.

Project Work

- Before beginning the project, conduct an on-site field pre-work meeting. At a minimum, include those with vegetation and soils skills.
- Avoid earthwork in saturated soils. Schedule heavy equipment work during periods of low precipitation.
- Collect plant materials during the dormant season. Keep them protected from wind and heat. Best results are obtained when installation occurs the same day materials are prepared; however, some believe greater success can be realized if stems are soaked in water five days prior to planting. Further research shows that cut stems are still viable after being refrigerated several months prior to planting, under the

proper temperature and humidity condition. Although opinions differ on length of storage, all agree proper storage and use are critical. Protecting stems from wind and keeping them cool and moist are essential.

- Inspect project work daily. “You get what you inspect, not what you expect.”

Plant Materials

Living vegetation is the most critical component of a soil bioengineered system. Existing vegetation, and knowledge of predisturbance and surrounding area plant communities, can inform the designer of project limitations, opportunities, and long term ecological goals. Work with local plant experts, such as botanists and silviculturalists, to select the most appropriate plant species for your project.

Which plants to use are affected by the following factors:

- Site characteristics (topography, elevation, aspect, soil moisture and nutrient levels)
- Existing vegetation
- Intended role of vegetation in the project such as rooting characteristics
- Growth characteristics and ecological relationships of the plants
- Availability
- Logistical and economic constraints

Plants which can resist mechanical stresses of erosion, floods and landslides, while developing a strong, stabilizing root system are best suited for soil bioengineering applications. Examples of riparian plants suitable for soil bioengineering work include, but are not limited to, willows, dogwoods, cottonwoods, big leaf maples, spruce, cedars, aspen, and alders.

Plants better suited for dryer and poorer soil conditions include bitter brush, snowberry, white pine, lodgepole pine, vine maple, Douglas maple, oceanspray, red elderberry and salmonberry. The best indicator of what plant materials one should consider

SOIL BIOENGINEERING

for a soil bioengineering project are the plants growing on, or adjacent to the project site. Work with local vegetation specialists to understand the limitations and opportunities encountered when stabilizing an erosion site.

Most commonly, plant materials are chosen from among those available on the site or nearby. Alternatively, the soil bioengineer may find an area where the vegetation will be removed, or salvaged, for future development. Logistical concerns are also important in the selection of plant material.

A single species may serve the primary structural requirement of the vegetation in a soil bioengineered system. However, it is preferable to use a mixture of species with varying but complimentary characteristics. Benefits of using multiple species include:

- Less susceptible to devastation by disease or pests
- Offers combinations of deep and shallow rooting species and high and low elevation vegetation
- Allows the system to respond to changes in site conditions
- Offers greater diversity and habitat values

Plant Movement Guidelines

The reason for setting plant movement guidelines is to increase likelihood of plants surviving, growing to maturity, and reproducing. Chance of success is much greater if locally collected materials are used.

Upland plant species

Use local seed (collection) zones to identify where best to collect seed, cuttings, or plants. A seed zone is an area having a defined boundary and altitudinal limits within which landform and climate are sufficiently uniform. A silviculturalist or botanist will direct you to this source of information. Map 1 provides an example of a seed zone map in Washington State.

Based on climatic and physiographic information, seed zones were developed in 1966 to reduce risk of maladaptating commercial tree species and to provide structure for commercial seed trade. Each zone has geographic boundaries and is additionally divided into 500-foot elevation intervals. Seed lots are coded by both seed zone and elevation band.

When collecting seeds, cuttings, or plants for smaller projects (perhaps a one-time collection) the elevation band can extend approximately 250 feet above and below the site.

Shrubs, forbs, grasses, and riparian species

Use watershed boundaries as seed, cuttings, and plant collection and transplant zones with 500-foot elevation intervals. Planting seeds, cuttings, or plants outside the seed zone, or watershed, should be done only after consultation with a silviculturist or botanist.

Gene Pool Conservation Guidelines

Just as important as plant movement guidelines are making sure the seed lots, cuttings, or plant lots are genetically diverse. To prevent loss of genes in the population, use a minimum of 30 to 50 unrelated donor plants. Collecting equal number of seeds, cuttings, or plants from each donor plant or area will also ensure representation by as many parent plants as possible.

Donor plants should also be separated by sufficient distance to reduce risk of relatedness i.e., originating from the same rhizome or root system, or for outcrossing plants having one or both parents in common.

TECHNIQUES FOR PROJECT IMPLEMENTATION

Native Plant Cuttings and Seed Collection

Advantage: Inexpensive. Use of local stock. Better adapted to local climate and soil conditions.

Disadvantages: Can have high mortality if collection and storage not performed correctly. Can be expensive.

Tools needed:

Hand pruners, hand clippers, untreated twine burlap sacks (moistened and lined with wet leaves or mulch), plastic sheeting.

For seed collection:

Paper bags, cool, dry storage area

Procedure:

- Collect from 30 to 50 parent plants in good condition. Never take more than 50 percent of seed or cuttings from a given area.
- Collect an equal number of seeds or cuttings from each plant.
- Use watersheds (and 500 foot elevation intervals) for collection of seeds or cuttings of shrubs, forbs, grasses, and riparian tree species. The elevation band can be considered to extend approximately 250 feet above or below the site.
- For plant cuttings, use young shoots (1 to 2 years old). Older and larger stems tend to have higher mortality. Refer to Plant Materials section for information on preferred plant species.
- Protect cuttings from wind by covering with plastic sheeting. Protecting stems from wind and keeping them cool and moist are essential.
- Seeds collected should be ripe, or mature.



Harvesting with loppers. Robbin Sotir & Associates



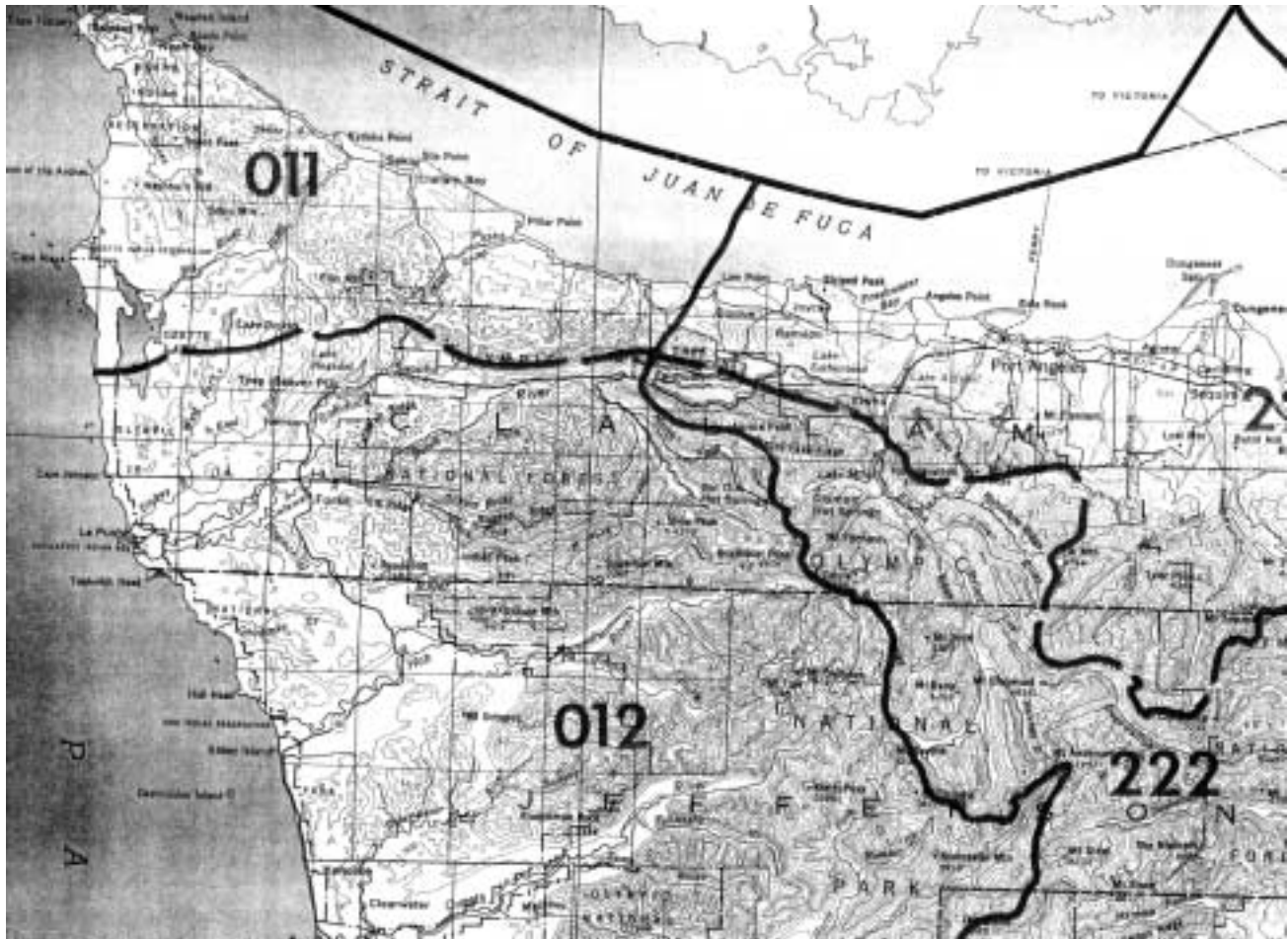
Harvesting with brushsaw. Robbin Sotir & Associates



Harvesting with chainsaw. Robbin Sotir & Associates

SOIL BIOENGINEERING

Note: A seed zone is an area having a defined boundary and altitudinal limits within which landform and climate are sufficiently uniform.
Refer to map 1.



Map 1—Seed zones.



Salvaging plants. USDA Forest Service

Salvaging and Transplanting Native Plants

Advantage: Inexpensive.

Disadvantages: Can have high mortality if salvaging and transplanting not performed correctly and timely. Soil moisture deficiency, and over exposure to air and heat, are critical factors in plant mortality.

For trees, shrubs, forbs and riparian species, use watershed boundaries as collection zones with 500 foot elevation intervals. The elevation band can extend approximately 250 feet above or below the site.

Plants should be dormant during salvaging and transplanting.

Tools needed:

A flat-bladed spade, metal file (for sharpening the spade), hand clippers (for pruning), burlap sacks (moistened and lined with leaves or mulch), plastic sheeting.

Procedure:

Salvaging

- Locate a small and healthy plant growing by itself. Trees and shrubs growing in clumps, connected by underground runners, are less likely to survive transplanting.
- Clear area around plant of leaves and twigs. Shrubs can be pruned if they have a few long branches (over 4 feet). Have a moist burlap sack nearby, lined with wet leaves or mulch.
- Dig in a circle approximately eight inches from the main stem. A larger excavated area of one foot may be required if it is a large shrub or seedling (3 to 4 feet high). Gently work the spade under the plant's roots and lift the root ball out on the shovel blade. Immediately place the root ball into the moistened burlap sack. If you are unable to remove entire root ball, collect as much of the root system as possible. It is especially critical to protect fine root hairs of the plant. It is also important to protect excavated plants from direct air and heat exposure.

Transplanting

- Salvaged plants should be planted within two hours of lifting. Keep plants moist and free from air and heat exposure.
- Holes should be dug overly large. Recommendation is to dig two times the volume of root ball. Larger holes will be required in "tighter" soils. If available, add a small amount of low dose time-release fertilizer and mix into the soil. Note: For bareroot and container plants, do not add fertilizer the first year. Planting holes must be deep enough so the downslope side of the rootball is entirely buried.
- Roots should be carefully spread out so none are kinked or circling. Protect roots, especially fine root hairs on the main root system. Add water, if available, when the plant is half installed to reduce voids and increase root and soil contact. If possible, water when planting is completed.



Planting vegetation. USDA Forest Service

- On-site soil should be used to backfill the hole. Firmly tamp the soil around the plant. Be careful not to over compact the soil. Once transplanted, prune the plant to conserve “fuel” for root development. Prune to balance tops with roots. For example if you cut off roots, cut back tops by about 1/2. Use clippings as mulch around the plant.
- Transplanting a microsite: Depending on site conditions, and project objective, it may be preferred to salvage and transplant a small section of ground. This ground section usually contains several plants with roots, seed, soil, soil microorganisms, and duff materials. This technique provides great benefits to the area trying to revegetate. For transplanting small sections of ground, excavate an area large enough to “plant” the entire piece. Lay it in the excavated area and level with adjoining ground. Use excavated soil to secure edges of transplanted piece. Tap gently in place. Whenever possible, water the transplant.

Planting Containerized and Bare Root Plants

Advantages: Best application for long term increase in mechanical strength of soils. Can be quickly applied to slopes, materials are inexpensive, creates a rooting zone over time to protect soils from erosion.

Disadvantages: Can have high mortality if planting not performed correctly. Soil moisture deficiency, and over exposure to air and heat, are critical factors in plant mortality.

Containerized and bare root plants must be installed with careful attention to protect their root systems.

Tools needed:

Hoedad or dibble , tree planting bag, water for root dipping of bare root plants.

Procedure:

- The planting hole should be dug deep and wide enough to fully accommodate the natural configuration of the root system.
- The roots should be carefully spread out so none are kinked, circling, or jammed in the bottom of the planting hole.
- On-site soil should be used to backfill the hole and the plant firmly tamped, but not overly compacted into the ground. Add water, if available, to reduce voids that can desiccate roots.



Distribution of seed and fertilizer. USDA Forest

Distribution of Seed, Fertilizer, and Certified Noxious Weed-free Straw or Hay

Advantages: Can be quickly applied to slopes, materials are inexpensive, creates shallow fibrous rooting zone in the upper foot or so of the surface profile which binds near-surface soils and protects soil surfaces from surface water runoff, wind, and freeze-thaw erosive forces.

Disadvantages: Not adequate alone for mitigating highly eroded surface erosion areas or for landslide stabilization.

Seeding should be applied in combination with planting trees and shrubs to provide root reinforcement of surface soils. Best times to apply include spring and early autumn. If project is implemented in autumn, it is critical to allow adequate time for good root and leaf development (approximately 4 inches) prior to winter. Refer to Natural Resource Conservation Service technical guide for seeding dates available in every U.S. county.



Spreading straw mulch. USDA Forest Service

Seeding involves application of grass, forb, and woody plant seed mixes to erosion areas.

Tools needed:

McLeod rake, hand seeder, protective respiratory mask.

Procedure:

- Round top edge of slope failure (fig. 18). For project success, it is critical to address this “initiation point”, or chronic source of the erosion. A common initiation point for these failures is located at the upper boundary of the site. For project success, it is critical to remove, or round off, slope overhang (figure 18).
- Smooth all eroding areas such as rills or gullies. In addition, prepare a seed bed by slightly roughening area. Do this by raking across slope face, never downslope. Raking downslope can create depressions for channeling water.



Slope terracing. USDA Forest Service

SOIL BIOENGINEERING

- Create terraces on contour when slopes exceed 35 percent. Dig these terraces 10 to 14 inches deep across slope face. Spacing usually varies from 4 to 10 feet depending on conditions (fig. 2). The objective is to accelerate establishment of plants by reducing slope angle and steepness between each terrace.
- Broadcast seed, fertilizer, and weed-free straw. Make sure your seed is covered with at least 1/4 inch of soil. Seed and fertilize as required by mix directions. For example, a mix may consist of 1 part seed (annual rye and forb mix) and 3 parts fertilizer (16/16/16). Organic amendments, in place of fertilizers, also work well. Work with local vegetation and soils specialists to determine desirable seed species and soil nutrient needs. In addition, determine if burying seed is critical for germination.
- Hand spreading of mulch is sufficient. However, machine application spreads materials more evenly and requires less mulch for full coverage. As a result, machine application may be more economical than hand distribution.
- In addition to mulching the site, it is critical to protect areas from additional surface water flow, specifically overland flow from roads. Direct water flow away from the project area by constructing crossdrains across the road surface several feet prior to the project area. Location and number of crossdrains needed will depend on several factors including road gradient and whether or not the road is outsloped or insloped above project area. Crossdrains are cut approximately 6 inches deep across road surface to a vegetated, stable point on the fillslope. These hand-excavated drains are a temporary measure until heavy equipment is available to dig deeper water diversions. An alternative to crossdrains, or an additional measure to consider, is to install drain rock and allow the water to move through the project area.



Live staking. Robbin Sotir & Associates

Live Staking

Advantages: Overtime a living root mat develops soil by reinforcing and binding soil particles together and by extracting excess soil moisture. Appropriate technique for repair of small earth slips and slumps that usually have moist soils.

Disadvantages: Does not solve existing erosion problems (excluding benefits from associated mulch), live staking is not a short-term solution to slope instabilities.

Tools needed:

Hand pruners and clippers, untreated twine, deadblow or rubber hammer, burlap sacks (moistened and lined with wet leaves or mulch).

Procedure:

Vegetative cuttings are living materials and must be handled properly to avoid excess stress, such as drying or exposure to heat. They must be installed in moist soil and adequately covered with mulch. Soil must be tamped to eliminate or minimize air pockets around buried stems.

Installation is best accomplished in late fall at onset of plant dormancy, in the winter as long as the ground is not frozen, or in early spring before budding growth begins.

Live staking involves insertion and tapping of live, rootable vegetative cuttings (e.g., willow, cottonwood,

and red-osier dogwood) into the ground. If correctly prepared and placed, the live stake will root and grow.

- Live cuttings are usually 1/2 to 1 1/2 inches in diameter and 18 to 36 inches long. Materials must have side branches cleanly removed and bark intact. Young shoots, 1 to 2 years of age work best. Older and larger stems have a higher rate of mortality but can be successful with additional treatment e.g. bark scoring and rooting hormones.
- Cut basal end at an angle for easy insertion into the soil. Cut top square (figure 1).
- Best results are obtained when installation occurs the same day stakes are prepared; however, some believe greater success can be realized if stems are soaked in water 5 days prior to planting. Further research shows that cut stems are still viable after being refrigerated several months prior to planting. Although opinions differ on length of storage, all agree proper storage and use are critical. Protecting stems from wind and keeping them cool and moist are essential.
- Orient buds up.
- Tap live stake into the ground at right angles to the slope. Installation may be started at any point on the slope face.
- Two-thirds to three-quarters of the length of the live stake should be installed into the ground and soil firmly packed around it after installation (figure 1). The more stem exposed to air, the more moisture is lost. This moisture is critical for root development.
- Install live stakes 2 to 3 feet apart using triangular spacing. Density of installation should range from 2 to 4 live stakes per square yard.
- Be careful not to split stakes while tamping them into the ground. Covering the stake with a 2 by 4-inch wood section will cushion the blows, thus protecting the stake from splitting. Trim damaged top area.
- Rebar can be used to make a pilot hole in firm soil. Tamp the live stake into the ground with a deadblow (hammer filled with shot or sand) or rubber mallet.

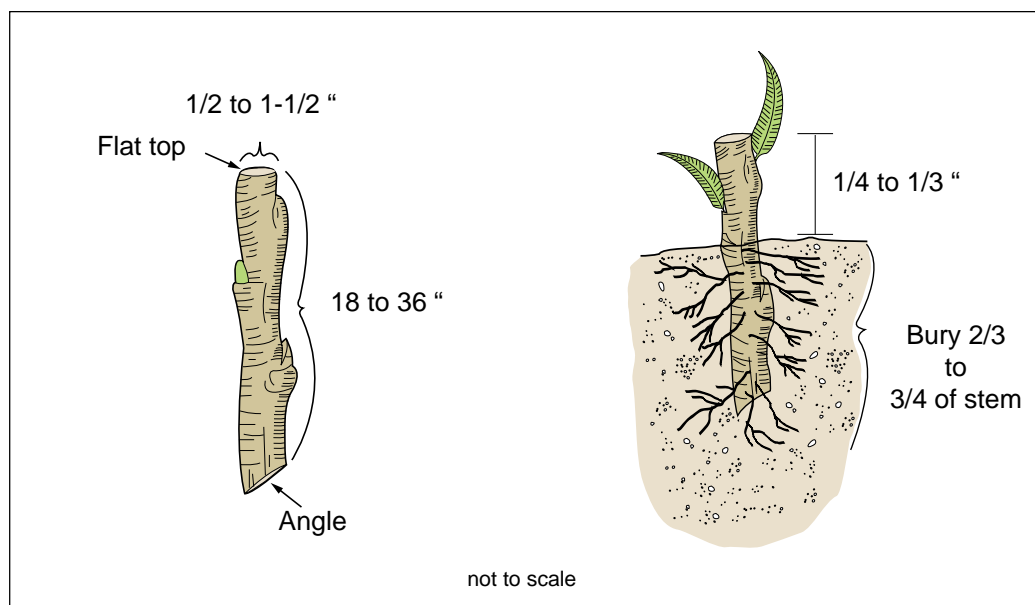


Figure 1—Live stake.



Hand excavated terraces for erosion control blanket. USDA Forest Service

Installation of Erosion Control Blanket

Advantages: Excellent for mitigating surface erosion. The blanket offers immediate and uniform slope protection from rain and overland water flow if it is installed in full contact with the soil surface.

Disadvantages: Can be labor intensive and expensive. Requires numerous wood stakes or live stems. Too much grass within the blanket will lead to over competition for moisture, sunlight and nutrients and may result in high tree and shrub mortality.

Installation of erosion control blankets involves site preparation, trenching, application of grass and/or forb seed mix and fertilizer, and installation of fabric. This technique is suitable for treating surface erosion areas, especially fillslopes where there is a concentration of surface water runoff (figure 3).

Tools needed:

McLeod rake, hand seeder, 6-inch spikes and 2-inch pieces of rubber or fire hose, hand pruners and clippers, heavy duty scissors, deadblow or rubber hammer.

Procedure:

- Round top edge of slope failure (figure 18). For project success, it is critical to address initiation point, or chronic erosion source, of the slope failure. The common initiation point for these



Rolling out erosion control blanket. USDA Forest Service

failures is located at the upper boundary of the site. For project success, it is critical to remove, and or round off, slope overhang (figure 18).

- Smooth all eroding areas such as rills or gullies. In addition, roughen entire site. Do this by raking across, and not downslope. Raking downslope can lead to channeling water.
- Create a small berm on road edge (figure 2).
- Excavate terraces 10 to 14 inches deep and 5 feet apart (figure 2).
- Broadcast seed and fertilizer on treatment area as required by mix directions. An example, one seed mix may include 1 part annual rye and 3 parts 16/16/16 fertilizer. Organic amendments can be used in place of inorganic fertilizers.
- Roll out blanket parallel with road between trenches. Fabric edges should lay evenly across bottom and top trenches. Begin matting installation at bottom two trenches (figure 2).
- Follow these directions for remaining rows. The upper row of fabric should overlap the lower row. Lay edge of top row of fabric into shallow terrace created while excavating the berm at road edge (figure 2).

- To secure fabric into road edge, nail 60D spikes through a hose piece washer. If road surface is not too compacted, use dead wood stakes instead of nails. Nail or stake every 3 to 4 feet across top row of fabric at road edge (figure 2). Once nailed, rake bermed soil back over matting edge. Note: Check with road manager to ensure maintenance activities will not require blading road edge at fabric site. Road blading would lead to tearing out sections of the project. If this is a major concern, install upper edge of fabric a few 4 to 6 inches below the road edge.
- To secure fabric to slope face, install live stakes into fabric across slope and through terraces.

Optimum spacing of these stakes ranges from 2 to 3 feet. Maximum spacing between stakes should not exceed 4 feet (figure 3).

- Tamp live stakes in, leaving $\frac{1}{4}$ to $\frac{1}{3}$ of stem above ground and $\frac{3}{4}$ to $\frac{2}{3}$ below ground (figure 1). Trim stakes, if more than $\frac{1}{3}$ is exposed. Average length of stake ranges from 18 to 36 inches. Stakes should be flat cut on top and diagonal cut on bottom so they will be installed correctly and easily (figure 1). Remove top sections of stakes damaged during installation. If you are not working in moist soil e.g. riparian area, the willows will not survive. In these cases, it would be more cost effective to use wood stakes instead.

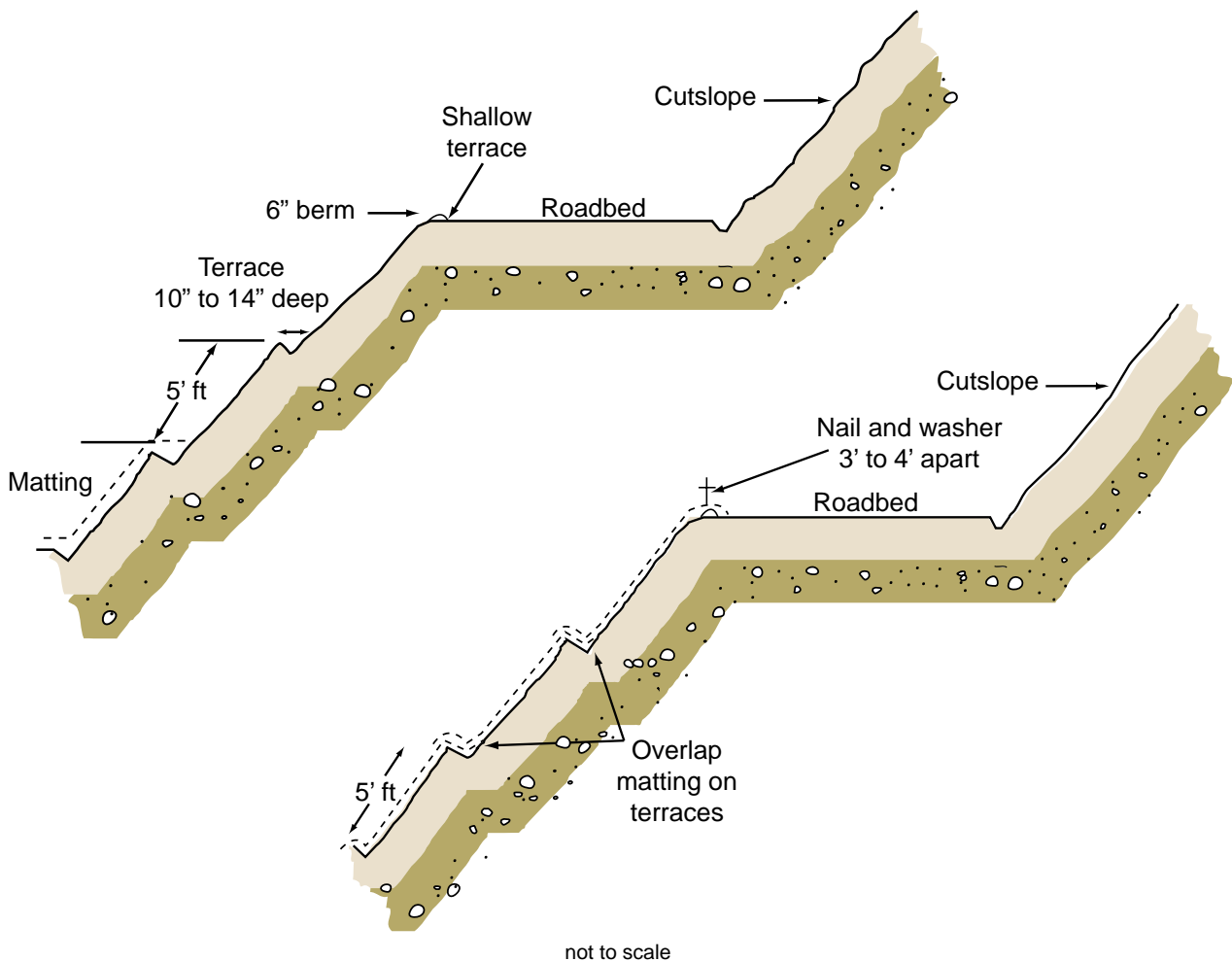


Figure 2—Installation of erosion control blanket.

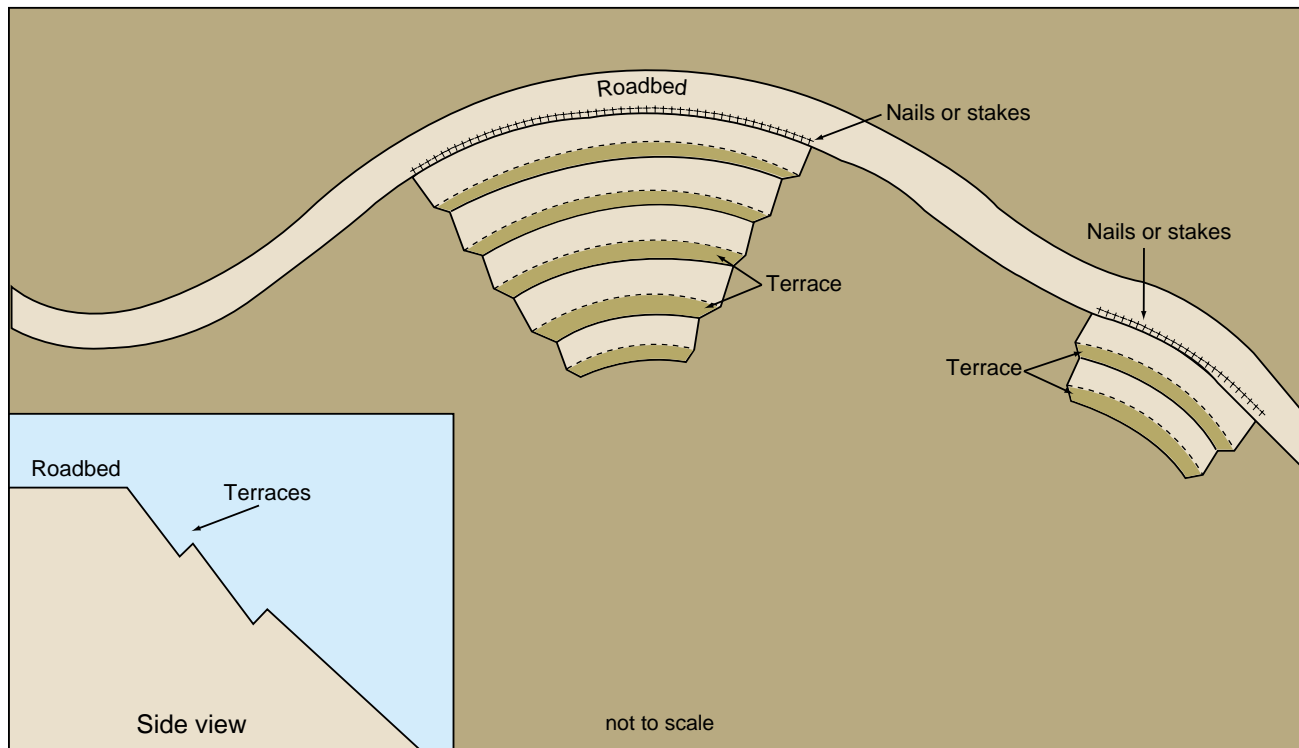


Figure 3—Installation of erosion control mat.



Live cribwall one month after construction. USDA Forest Service

Construction of Live Cribwalls

Advantages: Appropriate at base of a cut or fillslope where a low wall, or log, may be required to stabilize toe of the slope and reduce slope steepness. Useful where space is limited and a more vertical structure is required. Provides immediate protection from erosion, while established vegetation provides long term stability. Aesthetically more pleasing and possibly less expensive compared to conventional gabion baskets.

Disadvantages: Not designed for or intended to resist large, lateral earth stresses. Depending on soil quality of cutslope, may have to use commercial fill material. Can be labor intensive and expensive to construct. Can have high mortality if willow stems are not collected when dormant, not cut and used the same day, or mishandled in transfer.

A live cribwall consists of a hollow, box-like interlocking arrangement of untreated log or timber members. The structure is filled with suitable backfill material and



Live cribwall during construction. USDA Forest Service

layers of live branch cuttings, such as willow or dogwood, which root inside the crib structure and extend into the slope. Cribwall should be tilted or battered back if constructed on a smooth, evenly sloped surface. Once live cuttings root and become established, subsequent vegetation gradually takes over the structural functions of wood members (figure 8). Coordinate with road manager prior to construction. Often, their primary concern is the structure will block water flow in the ditch line. Make sure the design takes this concern into consideration.

Basic design ideas are from Sotir and Gray, 1982 and 1992. The following description and guide, however, includes several changes.

Tools needed:

Chainsaw, McLeod rake, deadblow or rubber hammer, 8 to 12 inch spikes or rebar, shovels, hand pruners, and clippers.

Procedure:

- A. Starting at lowest point of the slope, excavate loose material until a stable foundation is reached.
- B. Place first course of 4 to 8 inch diameter logs or timbers at front and back of excavated foundation, approximately 4 to 5 feet apart and parallel to the slope contour. These are your main beams (figure 4).
- C. Lay 4 to 5 foot long and 4 to 8 inch diameter cross beams (either conifer or hardwood) across

main beams. Spike or wire cross beams to main beams, front and back (figure 5).

- D. Fill inside of main frame with soil. Note: Some gravel and rock can be used, however, willows will have more vigor if soil conditions are favorable. If consequence of project failure is high, it is critical to use commercial fill material.
- E. Lay 5 foot long and 1/2 to 3 inch diameter trimmed live cut branches (3 to 6 inches apart, depending on soil moisture) between cross beams and into cutbank. On the bottom layer, lay the basal ends of live cut branches under back main beam and on top of front main beam (figure 5 and figure 6). Note: The purpose is to take full advantage of excess water at slope base. If you do not have excess soil moisture conditions, you do not have to lay butt ends of branches under back main beam. Instead, you can lay them directly over this beam.
- F. Following "A" and "B", start second layer. The only difference is set main beams back the width of bottom main beams and into cutbank. This allows cribwall to lean into cutbank and keeps fill material from falling out of front of cribwall (figure 7).
- G. Fill frame with soil.
- H. Lay 4 to 5 foot long live cut branches on top of front and back main beams and between cross beams. Lay these live branches approximately 3 inches apart (figure 5). Spacing of branches depends on availability of moisture and can range from side-by-side to 6 inches apart.
- I. Continue constructing layers following "E", "F", and "G" until you reach specified height.
- J. If needed, construct wings or flanges to catch soil at structure's edges and to key in the structure to the slope face.

- K. Cribwall should be tilted back if constructed on a smooth, evenly sloped surface. This can be accomplished by excavating the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure (figure 8).
- L. May be constructed in a stair-stepped fashion, with each successive layer of timbers set back 6 to 9 inches toward back cut slope face from previously installed course.

Half Cribwall

- To insure minimum road width of 14 feet, it may be necessary to construct a half cribwall. This is done by cutting cross beams width in half, from 4 to 2 feet wide at base of cribwall (figure 7) and gradually increasing cribwall width, by layer, as desired cribwall height is being achieved (figure 7 and figure 8).

Toe Log Technique

- The toe log technique is a handy tool for very small cutslope erosion features e.g., 10 feet high by 15 feet wide. Place a 20 to 24 inch diameter log along the base of the erosion site. Lay 5 foot long and 1/2 to 1 inch diameter live cut branches (side-by-side to 6 inches apart, depending on soil moisture) on top of the log and into cutbank (figure 7). The purpose is to take full advantage of excess water at slope base. Place soil behind the log with soils from the slope face. Toe logging is a quick and effective tool in stabilizing base of slopes. However, it is only effective when sites are small and only slightly over steepened. It is very important to use the right size log for existing slope condition.

When constructing a live cribwall, half cribwall, or toe log, the initiation point of the slope failure must be addressed. The common initiation point, or source of chronic erosion, for these failures is located at the upper boundary of the site. For project success, it is critical to remove, or round off, slope overhang (figure 18).

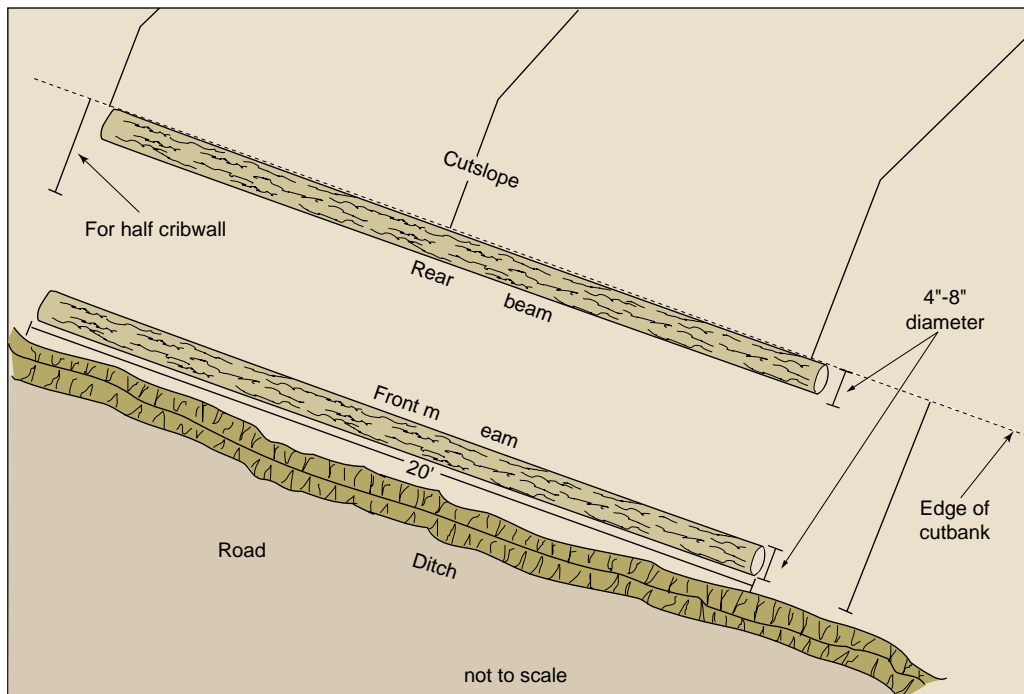


Figure 4—Live cribwall construction.

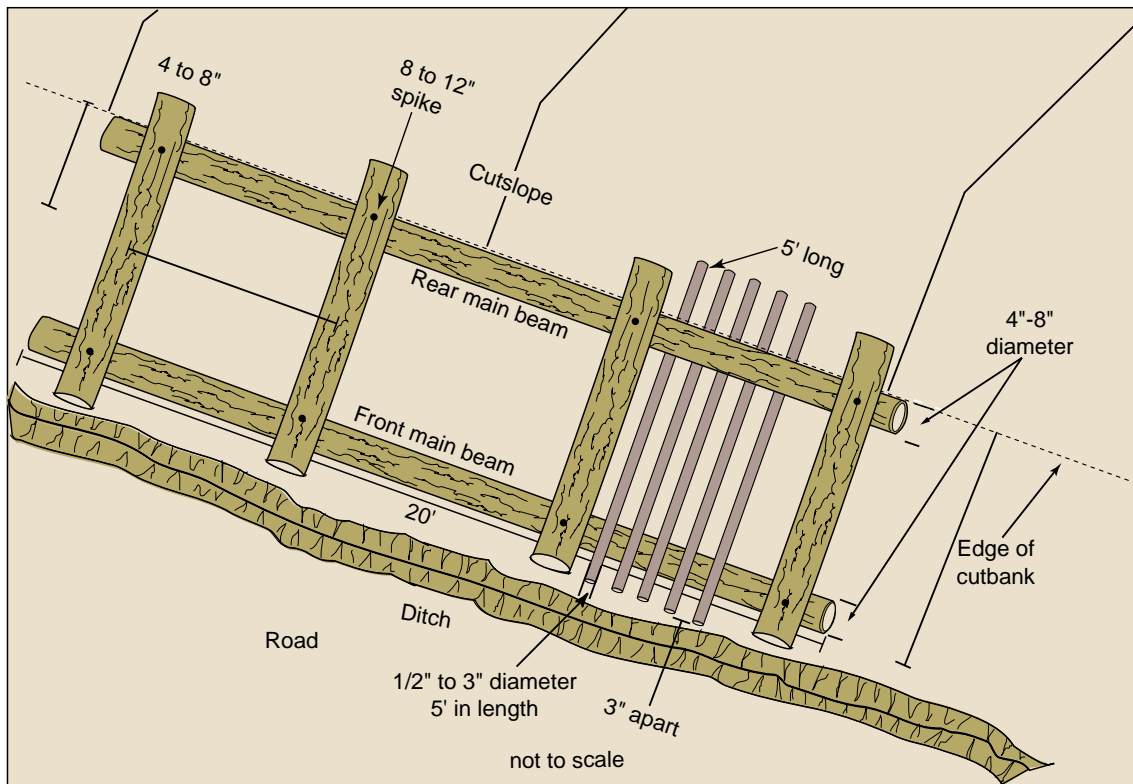


Figure 5—Live cribwall construction.

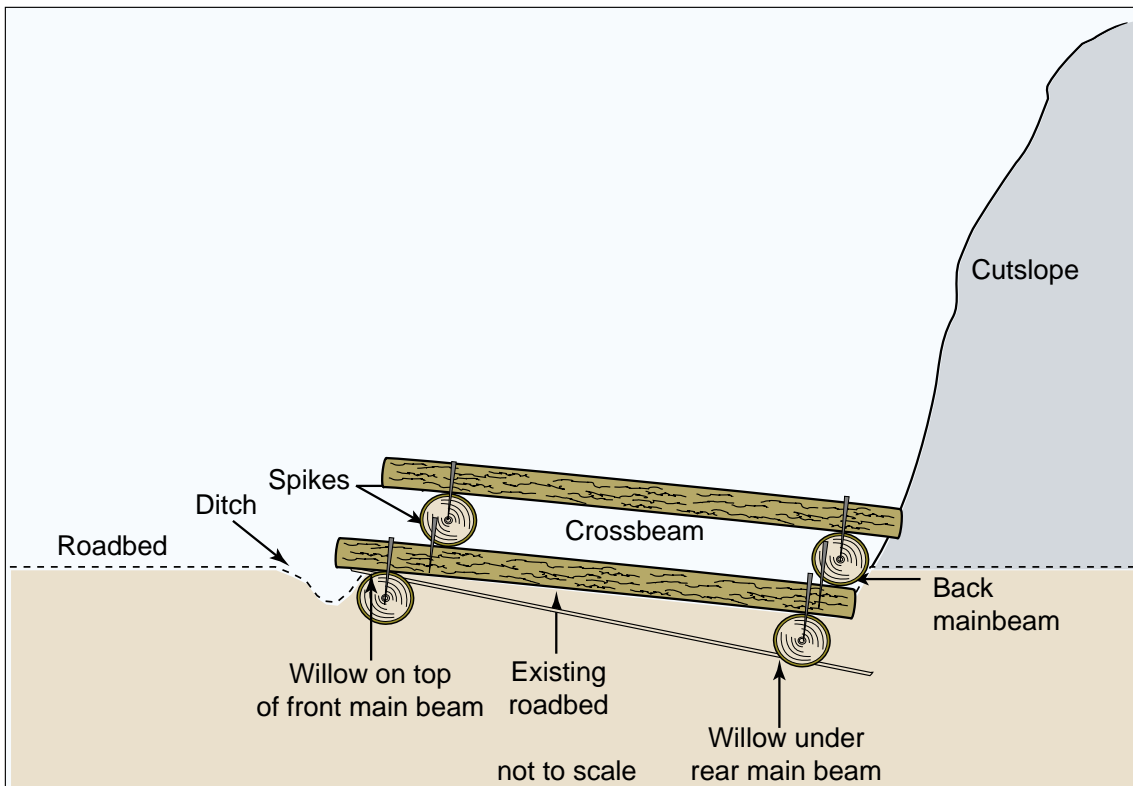


Figure 6—Live cribwall construction.

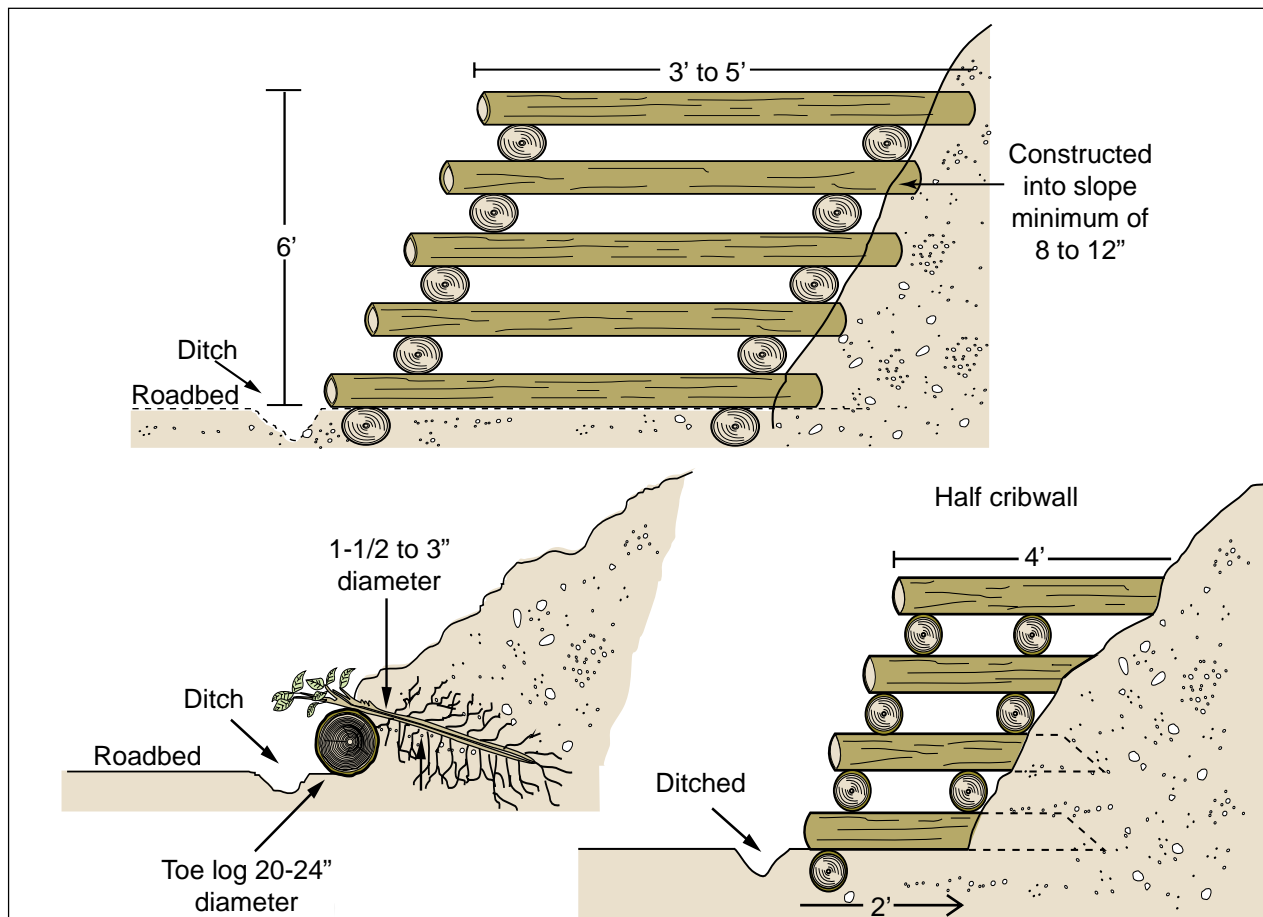


Figure 7—Live cribwall-stepped full, half and toelog construction.

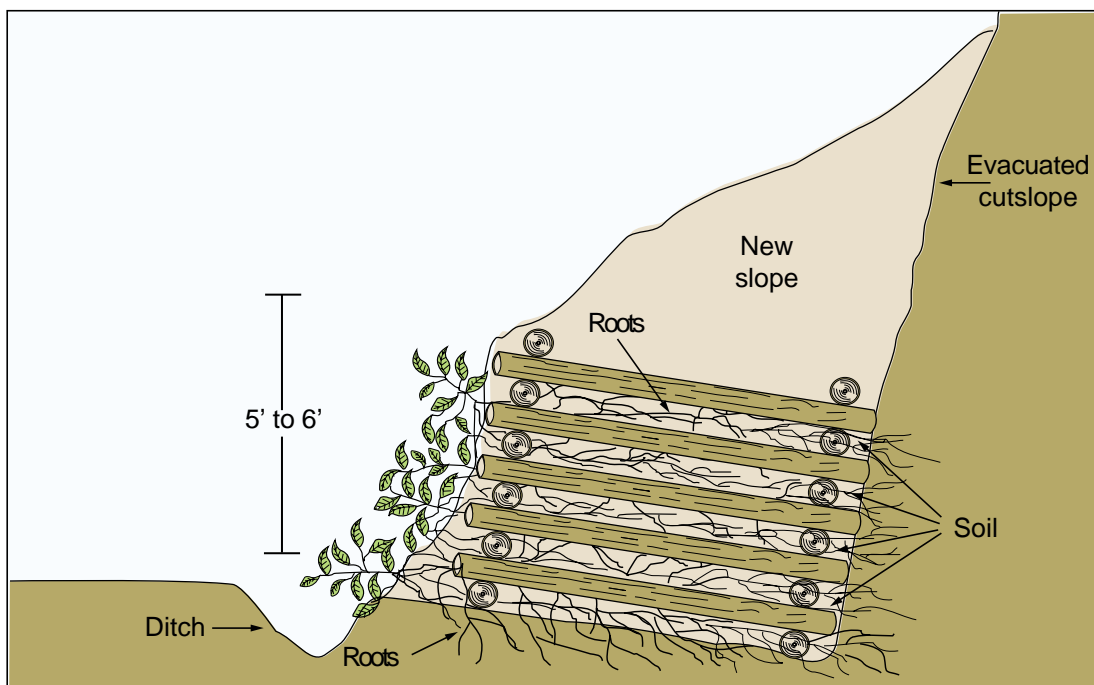
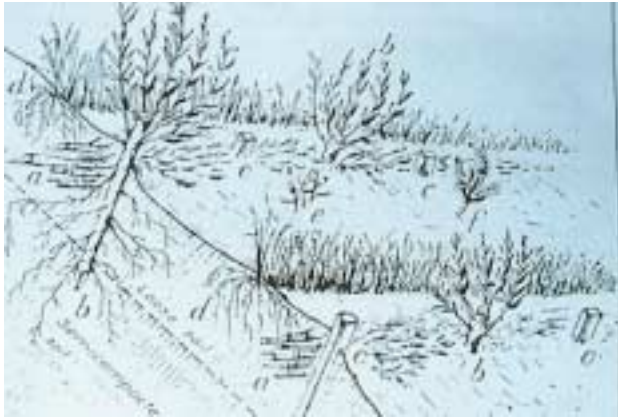


Figure 8—Live cribwall battered construction.



Live fascines illustration. Kraebel

Live Fascine

Advantages: Immediately reduces surface erosion or rilling. Suited to steep, rocky slopes, where digging is difficult. Capable of trapping and holding soil on the slope face, thus reducing a long slope into a series of shorter steps. Can also be used to manage mild gully erosion and can serve as slope drains when bundles are angled. Best suited for moist soil conditions. Note: Where soil moisture is not sufficient for supporting live materials, fascines can also be constructed of plant stems not intended for rooting. The bundle still traps and holds sediments and reduces slope length and steepness between terraces. Plant vegetation on and/or between the terraces. As in all projects, living recovery is dependent on successfully establishing the vegetation.

Disadvantages: On steep or long slope lengths, high runoff velocities can undermine live fascines near drainage channels. Significant quantity of plant material is required and can dry out if not properly installed. Best suited for riparian, moist soil, conditions. Otherwise, high plant mortality could occur.

Live fascines (Kraebel, 1936; and Sotir and Gray, 1982 and 1996), also referred to as contour or willow wattling, are long bundles of branch cuttings bound together into sausage like structures (figure 9).

Tools needed:

Hand pruners and clippers, untreated twine (not hemp), pulaski or hazel hoe, deadblow or rubber mallet, McLeod rake. dead plant materials.

Procedure:

- Excavate 10 to 14 inch deep terraces along slope contour and the full width of treatment area. Spacing of terraces averages between 5 to 7 feet, with a goal of 1:1 slope. Terrace placement is a function of slope and should be calculated. Terrace excavation, and live fascine installation, should progress from base of project up to slope crest.
- Bundle willow branches. Other species such as red-osier dogwood or snowberry can be used. For best results, cut and use plant materials same day. (See comments in Live Staking about collection and timing of installation.) Butt ends and top ends are usually laid alternately until a bundle has been created which looks like an 8 to 10 inch wide sausage. Plant materials should be about 1/2 to 5 inches in diameter and about 4 to 8 feet in length (figure 9). Bundles are then tied together using up to 20 percent dead material and bound with untreated lengths of twine. Note: Use of up to 20 percent dead materials retains structural properties of live fascine and bundle still has enough live material to grow.
- Lay bundle across terrace, splice together ends of each (figure 9) and do not overlap. Bundles should be 1/4 to 1/3 exposed.



Live fascine installation. USDA Forest Service



Live facine installation-angled. Robbin Sotir & Associates

- Next, live stake the downslope side of terraces at middle and overlap points to hold live fascines in the terrace. Be sure to splice ends of bundles. In addition, place wood stakes through live fascines every two feet. Wood stakes should be driven directly through bundle center (figure 9). Live willow and wood stakes should be 1 to 3 inches in diameter and 2 to 3 feet long. Stakes should be flat cut on top and diagonally cut on bottom to ensure appropriate and easy installation. Remove top section of live stakes damaged during installation.
- Stand in completed terrace and begin excavation of second terrace. This process will allow soil from second terrace to cover first row. Walk on wattles to compact and to gain good soil fascine contact.
- If available, water fascine to work soil into the bundle for increased soil contact and decreased desiccation.
- Move upslope to next terrace alignment and repeat process (figure 9).

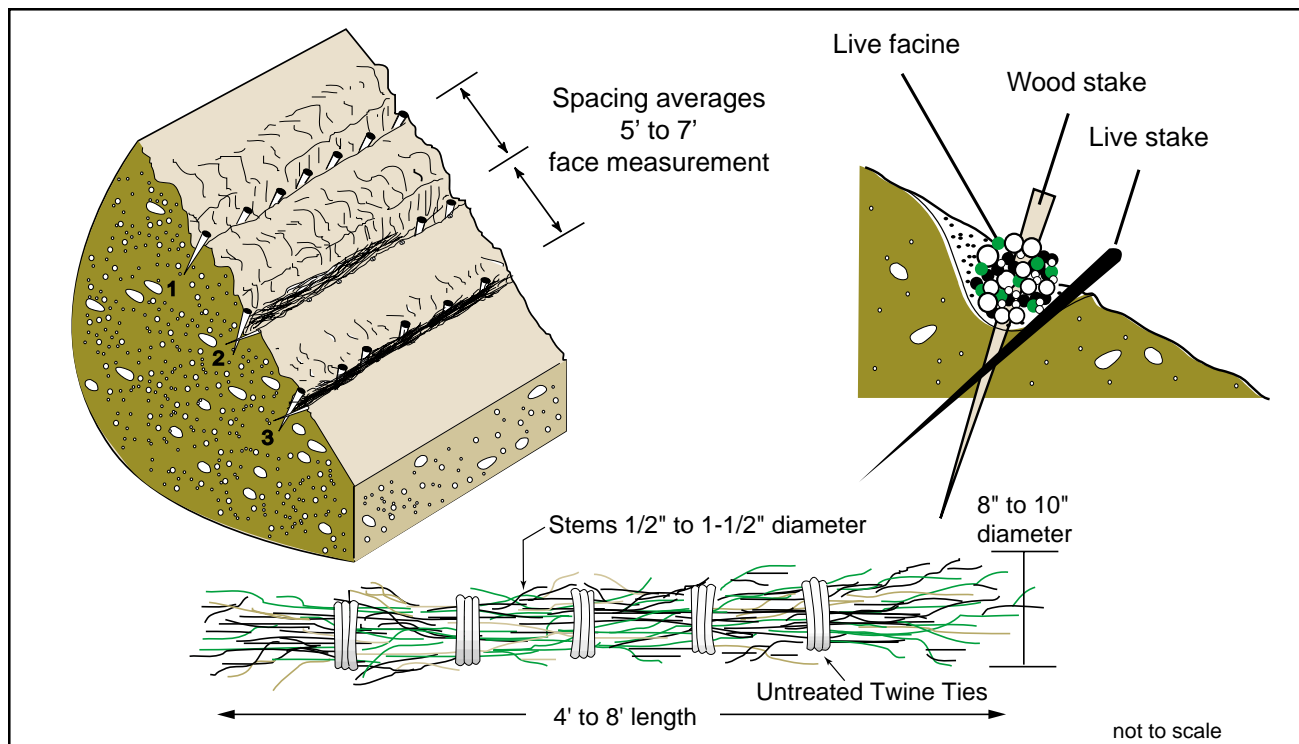


Figure 9—Live fascines

Brushlayering

Advantages: Breaks up slope length into a series of shorter slopes separated by rows of brushlayer. Reinforces soil as roots develop, adding resistance to sliding or shear displacement. Reinforces soil with unrooted branch stems. Provides slope stability and allows vegetative cover to become established. Traps debris on slope. Aids infiltration on dry sites. Dries excessively wet sites.

Disadvantages: Recommended on slopes up to 2:1 in steepness and not to exceed 15 feet in vertical height. Labor intensive.

Brushlayering (Sotir and Gray, 1982 and 1992) consists of placing live branch cuttings in small terraces excavated into the slope. Terraces can range from 2 to 3 feet wide. This technique is similar to live fascine systems because both involve cutting and placement of live branch cuttings on slopes. The two techniques differ in the orientation of the branches and depth they are placed in the slope. In brushlayering, cuttings are oriented perpendicular to slope contour (figure 10). This placement is more effective from the point of view of earth reinforcement and mass shallow stability of the slope.

Tools needed:

Hand pruners and clippers, untreated twine (not hemp), pulaski or hazel hoe, shovel, deadblow or rubber hammer, McLeod rake.



Digging terraces for brushlayer installation. Robbin Sotir & Associates.

Procedure:

- Begin project at base of treatment area. Excavate terrace so that approximately 1/4 of average brush length extends beyond slope face. Do not over excavate. This technique can trigger soil movements during installation. It is important, therefore, to perform installation in phases and to avoid excavating more area than is necessary to install plant materials (figure 10).
- Lay an appropriate amount (i.e., 20 to 25 stems per yard) of single or multiple mix of live brush species along trench sidewall. Length of stems can vary from 3 to 4 feet and diameter 1/2 to 3 inches (figure 10).
- Stand in completed terrace and begin excavation of second terrace. This process allows soil from second terrace above to cover first brushlayer row. Compact and slightly mound soil behind brushlayers.
- Move upslope to next trench alignment and repeat process (figure 10).

Brushlayers modified with log terracing: installing a short, small log (figure 10) can modify brushlayers. The log provides additional support to the brushlayer, reduces slope angle, and serves as a small terrace to “catch” rolling rocks, rather than allowing them to roll down the slope and damage vegetation.



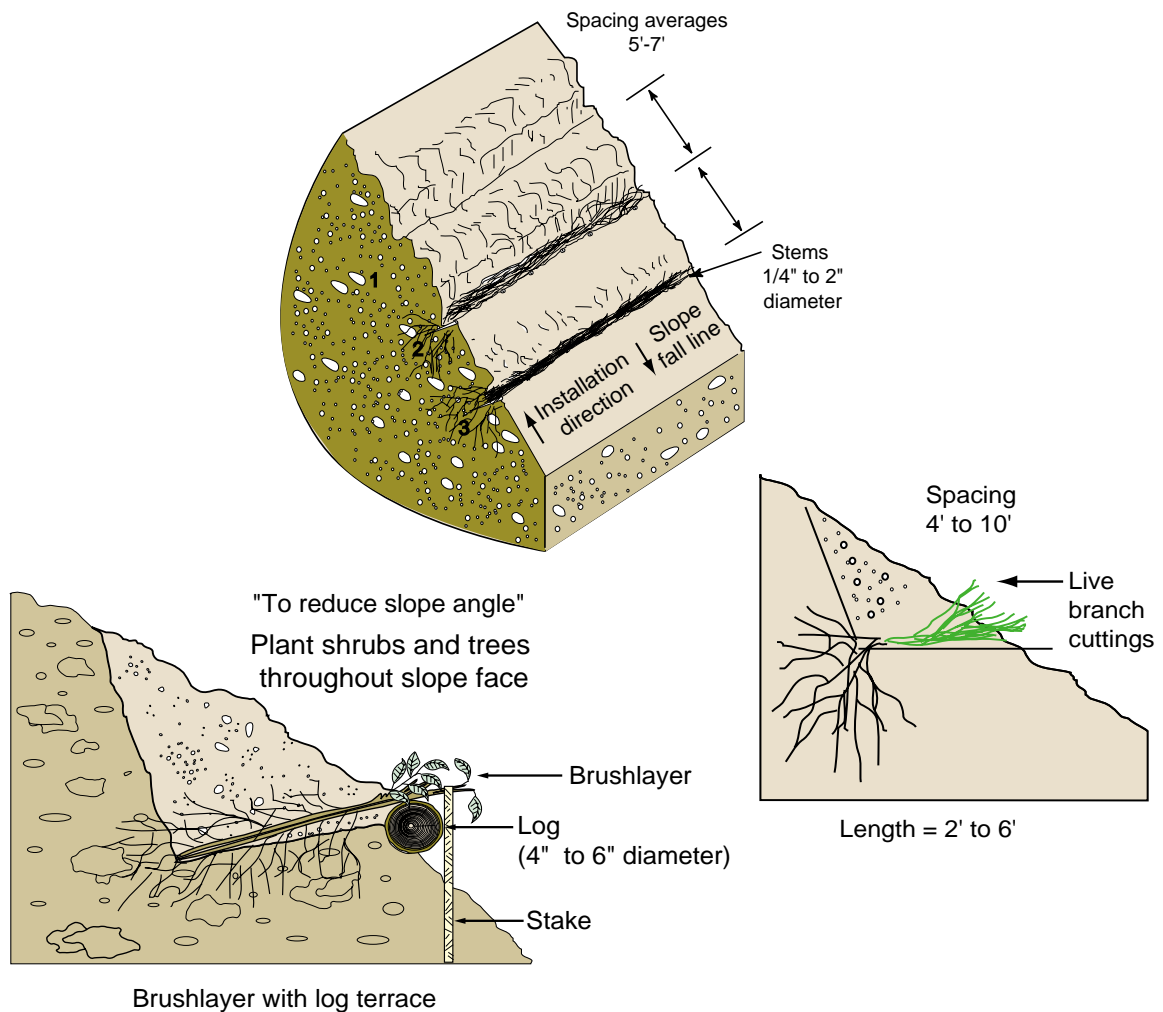
Brushlayer installation. Robbin Sotir & Associates



Brushlayering just after installation. Robbin Sotir & Associates



Brushlayering 3 months after installation. Robbin Sotir & Associates



not to scale

Figure 10—Brushlayering and brushlayering w/ log terrace.



Willow fencing with brushlayering. USDA Forest Service

Willow Fencing Modified with Brushlayering

Advantages: These structures reduce slope angle, providing a stable platform for vegetation to establish. Willow fences trap rolling rocks and sliding debris and protects vegetation growing lower on the slope. Willow fences provide support for small shallow translational or rotational failures. Sites where fine textured soils can provide ample summer moisture, or where seepage of groundwater provides moisture, are suitable for willow/brushlayering fence installations. These structures can also be constructed on dryer sites, however, expect high willow mortality. In these situations, the willow shelf is considered a temporary planting platform. It is important, therefore, to establish deeper rooting shrubs and trees within the shelf. When the structure begins to decay, root systems of other plants will serve as the permanent feature.

Disadvantages: Significant quantity of plant material is required. Moist site conditions are required for the fence to sprout and grow.

Willow fencing with brushlayering is essentially a willow fence supported on a short brushlayer. Specifically, it is a short retaining wall built of living cuttings with a brushlayer base (figure 11). Willow fencing can also be used without base brushlayering (Polster, 1998).

Tools needed:

Hand pruners and clippers, pulaski or hazel hoe, McLeod rake, deadblow or rubber hammer, wood stakes or rebar.

Procedure:

Brushlayering

- Begin project at base of treatment area. Excavate 16 to 20 inch deep trenches along slope contour and for full width of treatment area. Spacing of trenches averages between 5 to 8 feet full measurement depending on site conditions. This technique can cause additional erosion during installation, therefore, it is important to construct project in phases and to avoid excavating more area than is necessary to install plant materials (figure 11).

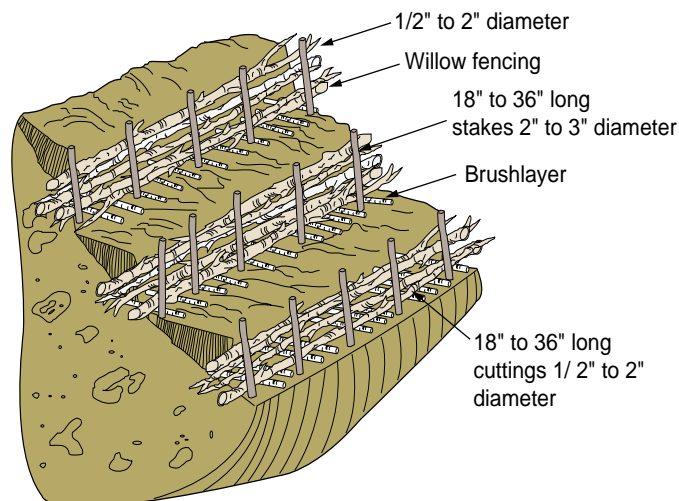


Figure 11–Willow fencing modified with brushlayering.

- Lay live brush stems along base of trench. Length of stems average 16 inches in length and diameter of 1/2 to 2 inches. Approximately 1/4 of average brush length should extend beyond slope face (figure 10).

Willow fencing

- Install supporting 18 to 36 inch long wood stakes, cuttings, or rebar. Average diameter of stakes ranges from 2 to 3 inches.
- Place a few shrub cuttings 18 to 36 inch long, and 1/2 to 2-inch diameter, cuttings behind these supports.
- Place enough soil behind these supports to hold the shrub cuttings in place.
- Stand in the trench and begin excavation of second row. This process will allow soil from second trench to cover first willow fencing/brushlayer row.
- Compact and slightly mound soil on brushlayer and behind willow fence.
- As more soil is added, add additional cuttings until the final height of the fence is achieved. A goal should be to construct a 2:1 slope, or less, between the top of the willow fence and the bottom of the one above.
- Move upslope to next trench alignment and repeat process (figure 11).



Branchpacking just after installation. Robbin Sotir & Associates

Branchpacking

Advantages: As plant tops grow, branchpacking system becomes increasingly effective in retarding runoff and reducing surface erosion. Trapped sediment refills localized slumps or holes, while roots spread throughout the backfill and surrounding earth to form a unified mass (figure 12).

Disadvantage: Not effective in slump areas greater than 4 feet deep or 5 feet wide.

Branchpacking (Sotir and Gray, 1992) consists of alternating layers of live branch cuttings and compacted backfill to repair small localized slumps and holes (figure 12).

Tools needed:

Hand pruners and clippers, deadblow or rubber hammer, untreated twine, McLeod rake, shovel, wood stakes.



Branchpacking just after installation. Robbin Sotir & Associates



Branchpacking post installation. Robbin Sotir & Associates

Procedure:

- Starting at lowest point, drive wooden stakes vertically 3 to 4 feet into the ground. Set them 1- to 1 1/2 -feet apart. Wooden stakes should be 5 to 8 feet long and made from 3-to-4 inch diameter poles or 2 by 4 lumber, depending upon depth of particular slump or hole.
- Place a layer of live cut branches 4 to 6 inches thick in bottom of hole, between vertical stakes, and perpendicular to the slope face (figure 12). Crisscross branches with growing tips generally oriented toward slope face. Some basal ends of branches should touch the back of the slope.
- Install subsequent layers with basal ends lower than the growing tips of the branches. This is to insure developing root systems will be located at water collection points on the slope.
- Each layer of branches must be followed by a layer of compacted soil to ensure soil contact with branch cuttings.
- Final installation should match existing slope. Branches should protrude only slightly from the filled face.
- The soil should be moist or moistened to insure live branches do not dry out.

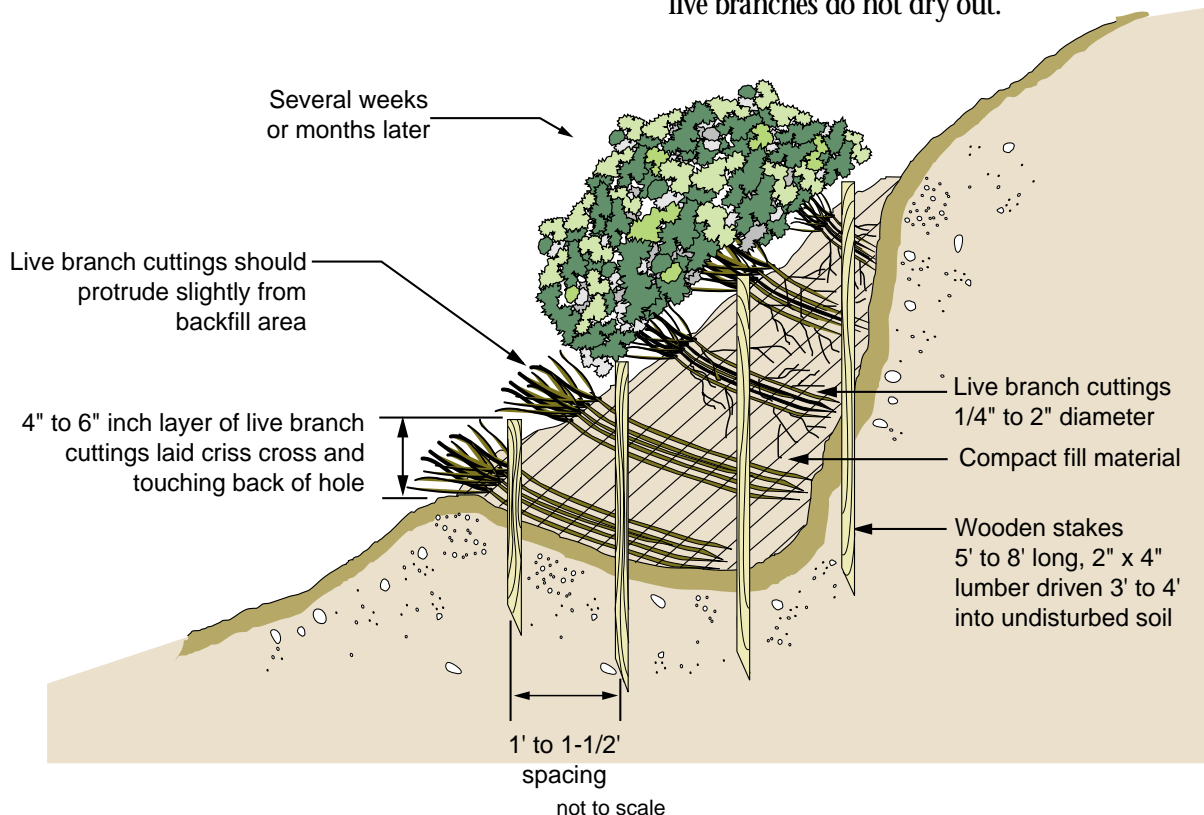


Figure 12–Branchpacking.

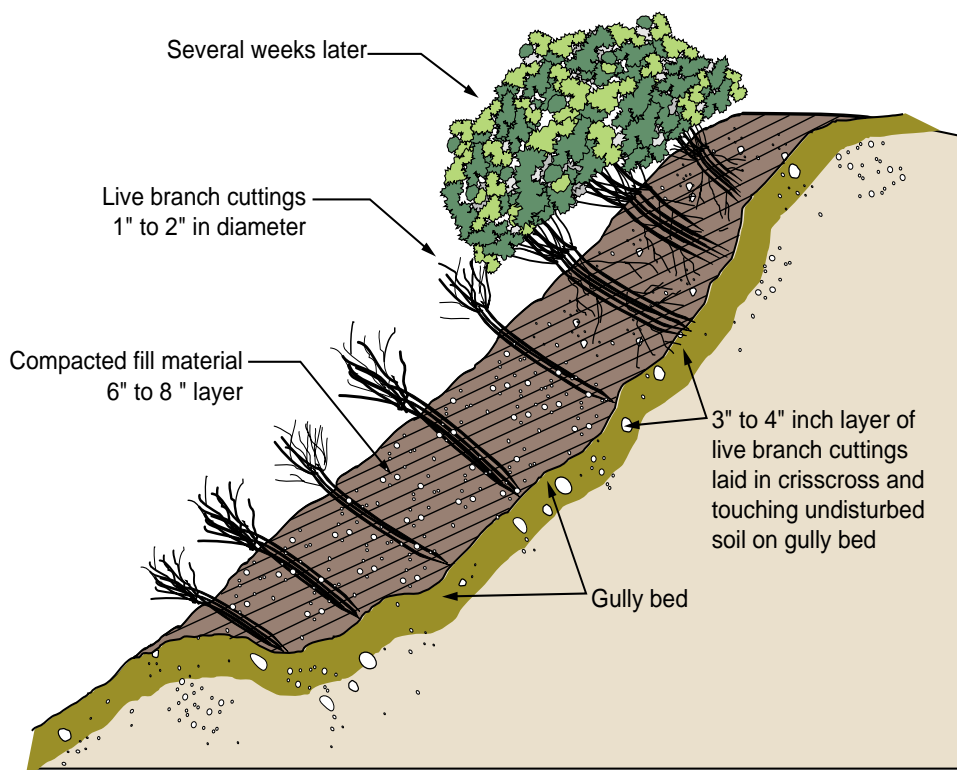


Figure 13—Live gully repair.

Live Gully Repair

Advantages: Offers immediate reinforcement to compacted soil, reduces velocity of concentrated flow of water, and provides a filter barrier to reduce rill and gully erosion.

Disadvantages: Limited to rills and gullies which are a maximum of 2-feet wide, 1-foot deep, and 15- feet long.

Live gully repair (Sotir and Gray, 1992) utilizes alternating layers of live branch cuttings and compacted soil to repair small rills and gullies. Similar to branchpacking, this method is more appropriate for repair of rills and gullies.

Tools needed:

Hand pruners and clippers, shovel, McLeod rake, untreated twine.

Procedure:

- Starting at lowest point of the slope, place a 3- to 4-inch thick layer of live cut branches at lowest end of the rill or gully and perpendicular to the slope (figure 13).
- Cover with 6-to 8-inch layer of soil.
- Install live cut branches in a crisscross fashion. Orient growing tips toward slope face with basal ends lower than growing tips.
- Follow each layer of branches with a layer of compacted soil to ensure soil contact with live branch cuttings.

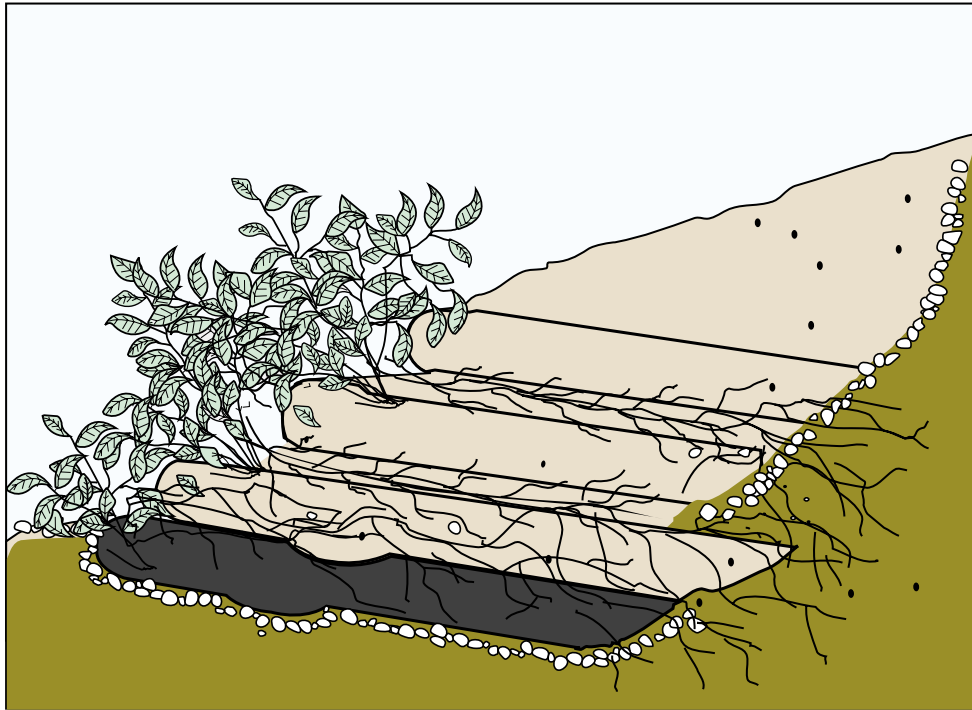


Figure 14—Vegetated geotextile.

Vegetated Geotextile

Advantages: Retards rill and gully erosion, stabilizes fill banks. Is less expensive than other retaining walls such as gabion or Hilfiker baskets.

Disadvantage: Can be expensive if heavy equipment required.

Synthetic or organic geotextile wrapped around lifts of soil with a mix of live branches placed between layers. There are numerous opportunities of blending geotechnical-engineered systems with soil bioengineering. The following is one example.

Tools needed:

Backhoe, geotextile, hand pruners and clippers, McLeod rake, shovel, untreated twine.

Procedure:

- Excavate lower edge of slope break and bench backcut. Compact the soil layer. Note: Structural integrity is dependent on compacted soil layers. Even with mechanized firming, soils support live cuttings.
- Lay first layer of geotextile down into the bench.
- Fill lowest lift with gravel, fold back, and stake securely.
- Fill subsequent layers with soil and layers of live cut branches (figure 10) and alternate with lifts (figure 14). Each layer must be compacted.
- The structure can be built with a vertical face or stair-stepped and sloped back into the hillside.



Installation - cutslope stabilization with log terracing. USDA Forest Service

Log Terracing

Advantages: Logs create terraces reducing length and steepness of slope, provides stable areas for establishment of other vegetation such as trees and shrubs.

Disadvantages: Labor intensive and with potential safety hazards.

Tools needed:

Chainsaw, PV pole, blocks and cable, power winch, shackles and chokers, pulaski, Mcleod, and shovel wood stakes, hand pruner and clippers, traffic control signs.

Procedure:

- The technique utilizes alternating terraced logs to stop surface erosion on eroding slopes. Stopping the erosion is critical for successful revegetation efforts. Specifically, log terracing shortens slope length and gradient between each structure, providing stable planting areas throughout most of the slope face (figure 15).
- Prior to beginning a log terracing project, place traffic control signs several hundred feet on both sides of your project area. Then climb slope to locate and remove potential safety hazards. These hazards include loose tree root wads, unstable rocks, and boulders. This inspection will also provide a different visual

perspective of the site. This “top-down” viewpoint is usually the best place to formulate your project design.

- Begin log terracing at the base of the slope and work your way uphill. This should prevent undercutting of any terrace or log you place above. It also provides a stable and secure footing area for project work.
- Log terracing consists primarily of 3 main steps. These steps include moving, installing, and anchoring logs to specified points on an eroding hillside.

Moving

- Try not to cause any additional erosion or damage log terraces you have already excavated. This can be accomplished by setting up a skyline or carefully using a straight dragline with block and cable.

Installation

- Use a minimum of 12-inch diameter logs. Sixteen or 20-inch diameter logs work best. The most common error in log terracing is using logs that are too small in diameter.
- Use existing slope features, such as tree stumps, rock outcroppings, or natural slope benches, to secure one or both ends of the logs. These natural features make project work easier, safer, and work better than stakes or rebar for keeping the log in place on the slope.
- Excavate terraces 1/3 the width of the log diameter deep and for full length of the log. With rope (or cable), blocks, and winch, place the logs into position (figure 16).

Anchoring

- Depending on site conditions, attempt to space log terraces 10 to 20 feet apart.

- Anchor logs into the slope using 3-to 5-inch diameter wood stakes or 3/4 inch rebar.
- Stake length should be 4 times the diameter of the log. A 12-inch diameter log, for example, would require 48-inch long stakes, and a 16-inch diameter log, 64-inch long stakes.
- Once in place, drive stakes vertically into slope just below the log. Two thirds of the stake should be driven into the ground. These stakes should be spaced every 4 feet across the length of the log (figure 17). Another recommended technique is to drill holes through the log and anchor with rebar. Two thirds of total length should be inserted into the ground. Bend over any excess rebar.
- When utilizing tree stumps and rock outcroppings for anchor points, gaps may occur between log and soil surface. This gap must be filled. To do so, excavate a trench uphill from the log and place a smaller log flush with the log structure (figure 17).
- There are many possible patterns for log terracing. The following 3 have proved useful for stabilization efforts (figure 15). Whatever pattern utilized, it is absolutely critical no gaps exist between the log and soil surface.

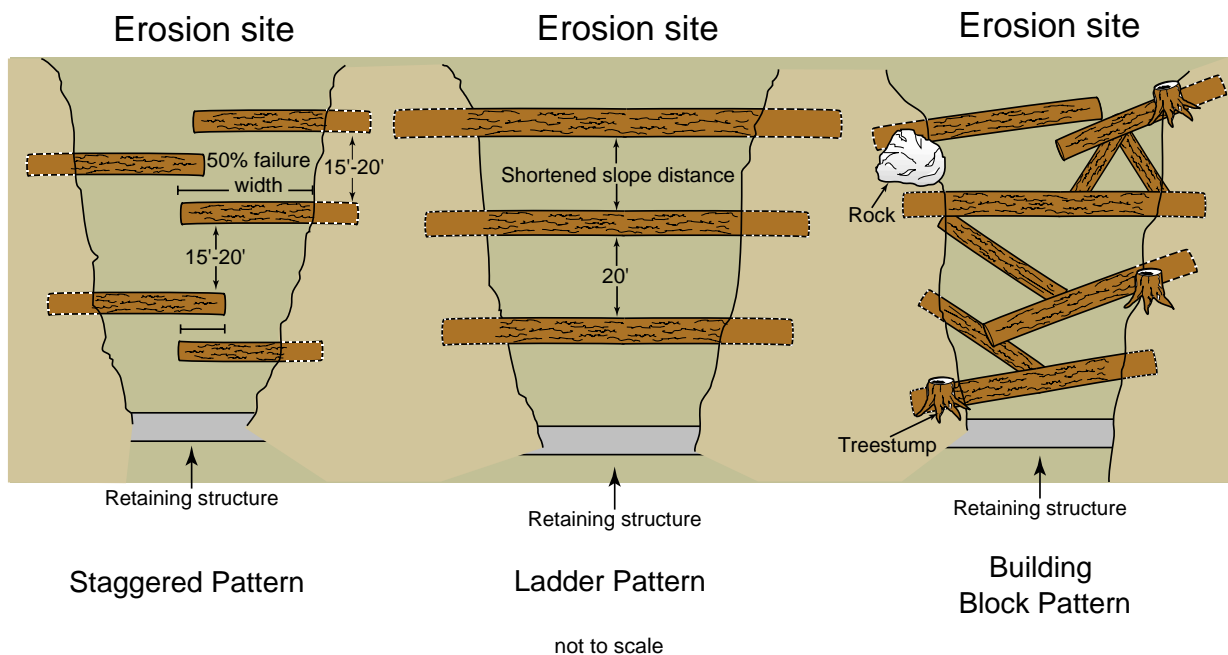


Figure 15—Log terrace installation.

Staggered

Using logs with lengths greater than 50 percent of the width of the erosion site. These logs should overlap each other and be anchored into stable soils on either side of the failure site.

Ladder

Logs extend across full width of erosion site and should be anchored into stable soils on either side of failure site.

Building block

This method best mimics what happens naturally on an eroding slope. Begin the project at the slope base. This area is stable and will provide a secure base to build off of as you work your way up slope. There is no set pattern. Design and log placement pattern will evolve as the project progresses. Be creative.

- Once the slope has been stabilized with log terracing, it is critical to address the upper portion of the slope failure. This area is often referred to as the slope overhang. Addressing this area is critical since it is the source of the surface erosion. Without removing this erosion source, project success is unlikely. Cut away the overhang so slope angle will allow seed to germinate and plants to establish. Try to angle the slope to blend with the new slope gradient created with log terracing. Often this will require a cut 5 to 6 feet upslope. This is the most difficult portion of a log terracing project and will often result in removing vegetation. This vegetation, however, can be transplanted to other areas on the slope.

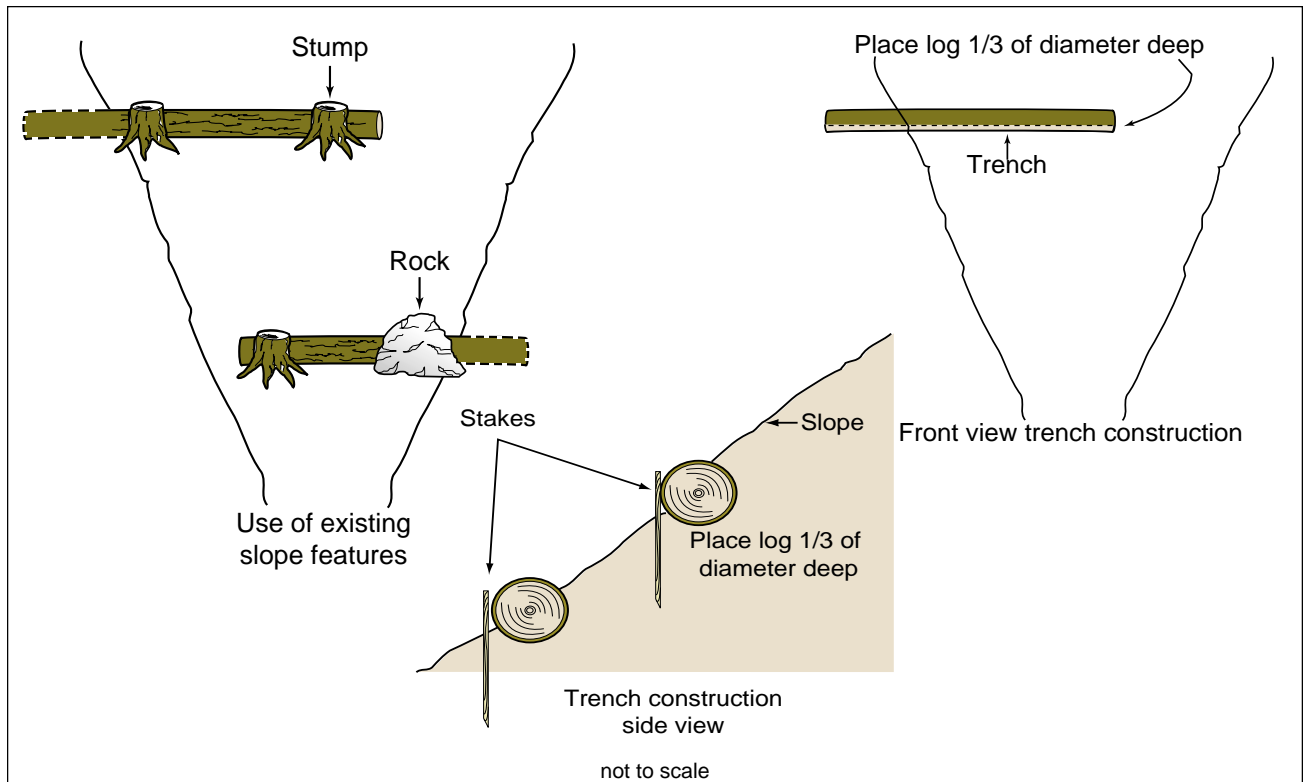


Figure 16—Log terrace construction.

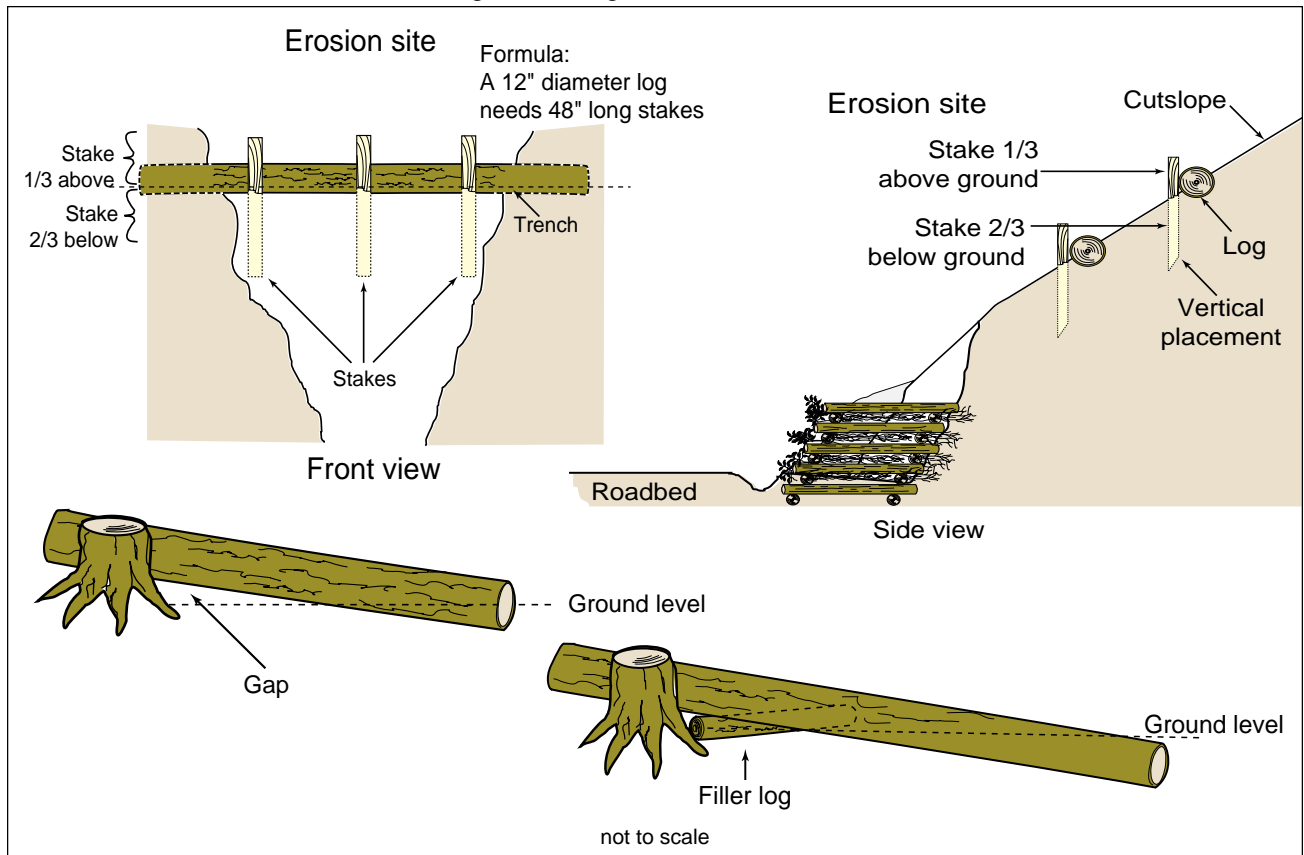


Figure 17—Anchoring and filling gaps.

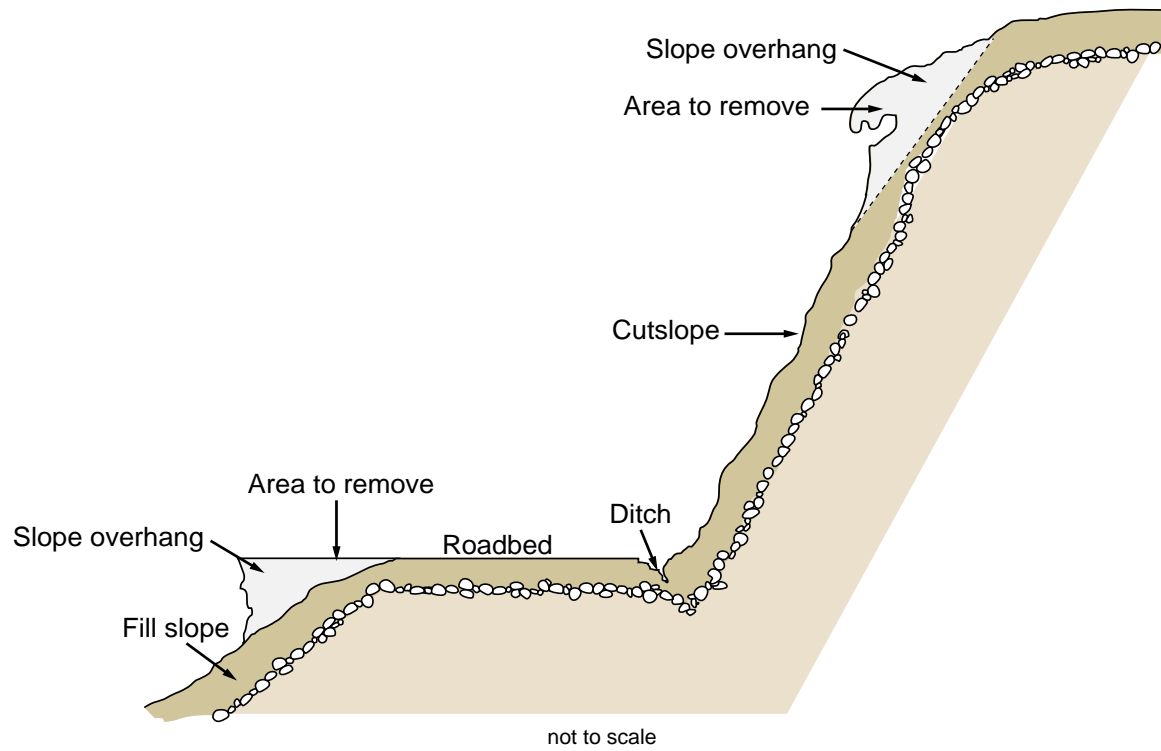


Figure 18—Removal of slope overhang.



Bender Board Fencing

Advantages: These structures reduce slope angle, providing a stable platform for vegetation to establish. Like willow fencing, bender board structures trap rolling rocks and sliding debris and protects vegetation growing lower on the slope. Bender board fences provide support for small translational or rotational failures.

Dry sites where soils receive very little precipitation this type of structure. The bender board shelf is considered a temporary planting platform. It is important, therefore, to establish deeper rooting shrubs and trees within the shelves. When the structures begins to decay, root systems of other plants will serve as the permanent feature.

Disadvantage: Significant quantity of plant material is required.

Redwood or cedar bender board fencing is essentially a fence supported on a short layer of shrub or tree stems. Specifically, it is a short retaining wall built of redwood or cedar bender fencing with a stem layered base.

Tools needed:

Hand pruners and clippers, pulaski or hazel hoe, McLeod rake, deadblow or rubber hammer, wood stakes.

Procedure:

Stem Layered Base

- Begin project at base of treatment area. Excavate a 24-inch deep terrace along slope contour and for full width of treatment area. The back of the terrace should be dug with an approximate 70 degree angle. To allow ample planting platforms, space terraces about 5 feet apart.
- Lay 2 feet 6-inch long stems and 2 feet 6-inch long wood stakes (50/50 mix) 2-inches apart and for full length of terrace. Diameter can range from 1/2 to 2-inches. Approximately 6-inches will extend beyond slope face.

Bender board Fencing

- Drive supporting 4 foot 6-inch (2 by 2) long stakes 2 to 3 feet into ground, spaced 1 foot apart, and perpendicular to the slope. Rebar may be used instead of wooden stakes.
- Weave 10 foot long bender boards through these stakes until the wall reaches a height of 2 feet. Once complete the bender board fence wall should be at a 15 degree angle to the slope. Note: As shown in photo, some bender board are too brittle to weave.
- Once the wall frame is constructed, carefully rake enough soil into the terrace to cover the stem layered base.



SOIL BIOENGINEERING

- Stand in terrace and begin excavation of second row. This process will allow soil into the terrace to cover the stem layered base.
- A goal should be to construct a 2:1 slope, or less, between the top of the bender board fence wall and the bottom of the one above.
- Move upslope to next terrace alignment and repeat process.

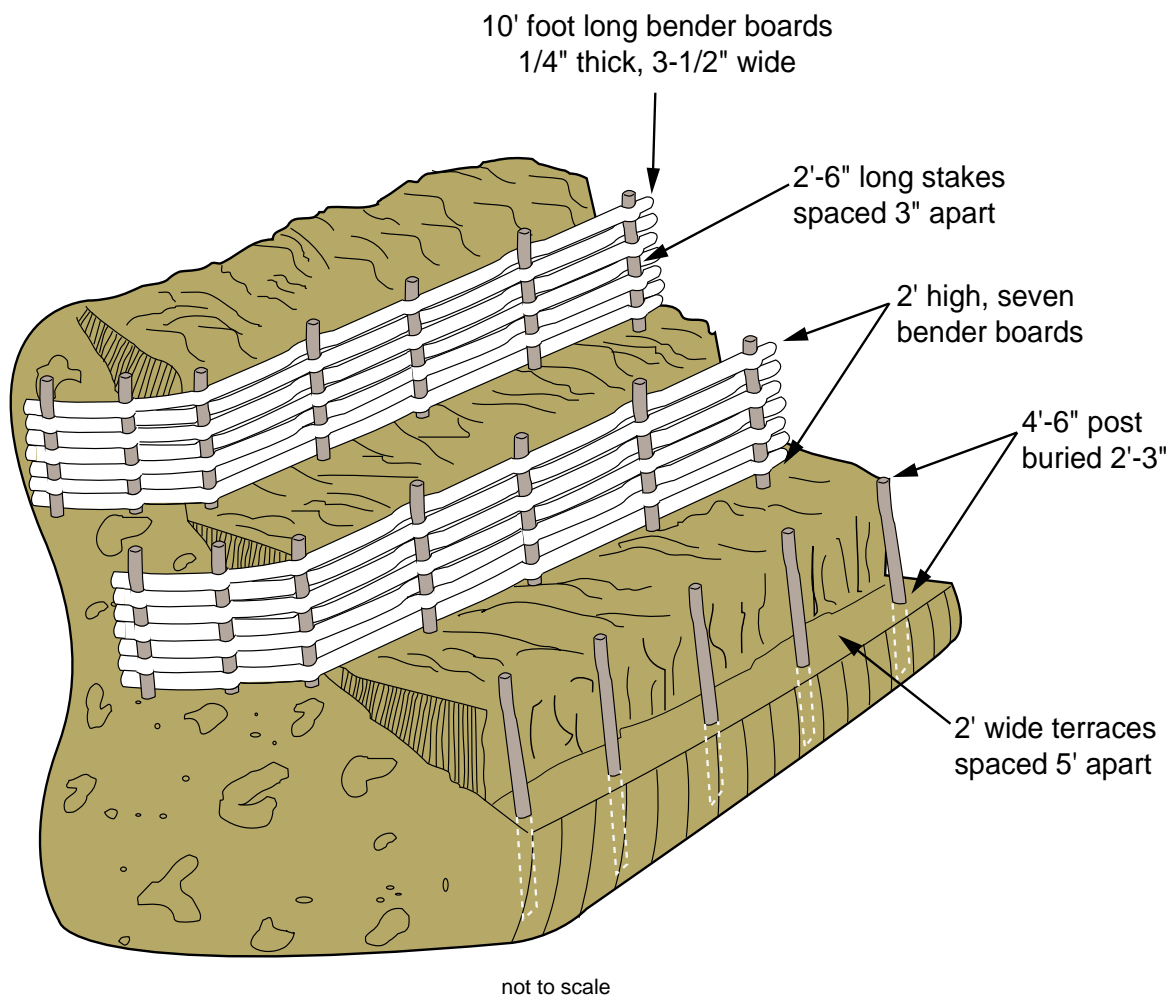


Figure 19—Bender board fencing.

REFERENCES CITED

- Bach, David H. and MacAskill, I.A. 1984. *Vegetation and Landscape Engineering*, Granada, London.
- Bennett, Francis W. 1975. *Methods of Quickly Vegetating Soils of Low Productivity, Construction Activities*. U.S. Environmental Protection Agency, Washington, D.C.
- Brosius, Myra. 1985. "*The Restoration of an Urban Stream Using Geomorphic Relationships and Biotechnical Streambank Stabilization*." Athens, GA: University of Georgia. Thesis
- Chandler, R.J. 1991. *Slope Stability Engineering*. Institution of Civil Engineers. Thomas Telford Publishing Company.
- Chatwin, S.; D. Howes; and D. Swanson. 1994. *A Guide for Management of Landslide Prone Terrain in the Pacific Northwest*. Second edition. Ministry of Forests. Crown Publications. Victoria, BC:
- Christensen, M. and J. Jacobovitch. 1992. *Revegetation Projects: Everything You Wanted to Know About Live Staking*. Unpublished report for King County Dept. of Public Works, Surface Water Management Div. Seattle, WA.
- Coppin, N.J. and I.G. Richards. 1990. *Use of Vegetation in Civil Engineering*. Butterworths. London, England.
- Coppin, Nick J. and R. Stiles. 1989. *The Use of Vegetation in Slope Stabilization, Landscape Design with Plants*, Second Edition, ed. by Brian Clouston, Boca Raton, Florida. CRC Press: 212-234.
- Edlin, H.L. 1949. *Woodland Crafts in Britain*, B.T. London: Batsford Ltd, London.
- Finney, Kevin P. 1993. *BioEngineering Solutions, A Tool for Education*. Eugene OR: University of Oregon. Thesis
- Finney, K. 1993. *History of Soil Bioengineering*. Eugene OR: Masters Thesis, University of Oregon. Thesis.
- Gray, D.R. and A.T Leiser. 1982. *Biotechnical Slope Protection and Erosion Control*. New York: Van Nostrand Reinhold Company. New York.
- Gray, D.H.; Leiser, T. Andrew; and C. A. White. 1980. *Combined Vegetative Structural Slope Stabilization Civil Engineering*, 50(1):82-85.
- Gray, D. R. and Sotir, R.B. 1996. *Biotechnical and Soil Bioengineering Slope Stabilization*. John Wiley and Sons, Inc.
- Greenway, D.R. 1987. *Vegetation and Slope Stability*. In: Slope Stability. John Wiley and Sons Ltd. Chapter 6.

SOIL BIOENGINEERING

Johnson, A.W. and J.M. Stypula. eds. 1993. *Guidelines for Bank Stabilization Projects In the Rivertine Environments of King County*. County Department of Public Works, Surface Water Management Division, Seattle, WA.

Kraebel, C.J. 1936. *Erosion Control on Mountain Roads*, U.S.D.A. Circular No. 380 Washington D.C., USDA.

Kraebel, C.J. 1933. *Willow Cuttings for Erosion Control*, Technical Note No. 1. Berkely, California USDA, California Forest Experiment Station.

Larson, F.E. and W.E. Guse 1981. *Propagating Deciduous and Evergreen Shrubs, Trees, and Vines with Stem Cuttings* Pacific Northwest Coop. Ext. Pub. PNW152.

Leiser, Andrew T.; J. J. Nussbaum; Kay, Burgess; Paul, Jack; and W. Thornhill. 1974. *Revegetation of Disturbed Soils in the Tahoe Basin*. California Department of Transportation, Sacramento, California.

Lewis, E.A. and L.W. Ogg. 1993. *Soil Bioengineering Project Descriptions*. Unpublished report for Olympic National Forest, Hood Canal Hanger District.

Leys, Emil. 1978. Wilhelm Hassenteufel 80 Years Old, Garten und Landschaft in China, Vol. 4, Part 3, Cambridge: The University Press.

Maleike, R. and R.L. Hummel. 1988. *Planting Landscape Plants* Wash. State Univ. Coop. Ext. Pub. EB1505.

Polster Environmental Services. 1998. *Soil Bioengineering for Forest Land Reclamation and Stabilization*. British Columbia Ministry of Forests.

Robbin B. Sotir & Associates, *A Brief History of Soil Bioengineering*. Unpublished and undated manuscript

Schiechtl, Hugo. 1980. *Bioengineering For Land Reclamation and Conservation*. Edmonton, Canada. The University of Alberta Press.

Schiechtl, H. M. and R. Stern. 1997. *Ground Bioengineering Techniques for Slope Protection and Erosion Control*. Blackwell Science Publications. ISBN: 0-632-04061-0.

Sotir, R.B. and D.H. Gray. 1992. *Soil Bioengineering for Upland Slope Protection and Erosion Reduction*. Engineering Field Handbook. Soil Conservation Service. Chapter 18.

Stiles, Richard. (172): 57-61.

1988. *Engineering with Vegetation, Landscape Design*, (172): 57-61.

Stiles, Richard. 1991. *Re-inventing the Wheel? Landscape Design*, (203):

Weaver, W.E. and M.A. Madej. 1981. *Erosion Control Techniques Used in Redwood National Park*. In: Davies, T.R.H. and A.J. Pearce, eds. *Erosion and Sediment Transport in Pacific Rim Steeplands*. Washington D.C. Int'l Assoc. Hydrological Sciences: 640-654. IAHS-AISH Pub. 132.

Westmacott, Richard. 1985. *The Rediscovered Arts of Twilling and Wattling. Landscape Architecture*, 75(4):95-98.

White, Charles A. and A.L. Frank S. 1978. *Demonstration of Erosion and Sediment Control Technology*; Lake Tahoe Region of California, EPA-600/2-78-208, Municipal Environmental Research Laboratory, Office of Research and Development, US Environmental Protection Agency, Cincinnati, Ohio.

Ziemer, R.R. 1981. *Roots and the Stability of Forested Slopes*. In: Davies, T.R.H. and A.J. Pearce, eds. *Erosion and Sediment Transport in Pacific Rim Steeplands*.

About the Author...

Lisa Lewis graduated in 1987 from Fort Valley State University, Fort Valley, Georgia with a Bachelor of Science degree in Soil and Plant Sciences. Lisa began her career with the Forest Service in August 1987 on the Hood Canal Ranger District. She continued her career in the Pacific Northwest and since 1998 she has been a soil scientist with the National Riparian Service Team (NRST). As a member of the NRST, Lisa provides training and technology transfer; consulting and advisory services and program review for riparian restoration nationwide. She specializes in road management issues and soil bioengineering techniques.

Library Card

Lewis, Lisa. 2000. Soil bioengineering—an alternative to roadside management—a practical guide. Technical Report 0077-1801-SDTDC. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center. 44 p.

This publication provides field personnel with the basic merits of soil bioengineering concepts and gives examples of several techniques especially effective in stabilizing and revegetating upland roadside environments. The information provided in this document is intended to stimulate additional interest for the reader to seek out and use these and other soil bioengineering applications.

Soil bioengineering is the use of live plant materials and flexible engineering techniques to alleviate environmental problems such as destabilized and eroding slopes. Unlike other technologies in which plants are chiefly an aesthetic component of the project, in soil bioengineering systems, plants are an important structural component.

Keywords: Soil bioengineering, road management, road maintenance, restoration, erosion, native plant materials, revegetation

Additional single copies of this document may be ordered from:

USDA Forest Service
San Dimas Technology and Development Center
ATTN: Richard Martinez
444 E. Bonita Avenue
San Dimas, CA 91773
Phone: (909) 599-1267 x201
Fax: (909) 592-2309
E-Mail: rmartinez/wo_sdtcdc@fs.fed.us
FSNotes: Richard Martinez/WO/USDAFS

For additional technical information, contact

Lisa Lewis at the following address:

USDA Forest Service
National Riparian Service Team
3050 NE 3rd Street
P.O. Box 550
Prineville, OR 98854
Phone: (541) 416-6788
E-Mail: l3Lewis@or.blm.gov

An electronic copy of this document is available on the Forest Service's FSWeb

Intranet at:

<http://fsweb.sdtcdc.wo.fs.fed.us>