SLOPE STABILIZATION AND EROSION CONTROL USING VEGETATION

A MANUAL OF PRACTICE FOR COASTAL PROPERTY OWNERS

Sponsored by:

SHORELANDS & COASTAL ZONE MANAGEMENT PROGRAM
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Olympia

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Introduction

Puget Sound and its associated coastal waters have created a dramatic system of coastal landforms along which have developed the population centers of Western Washington. It is the natural beauty of this coastal system that continues to place residential pressures on coastlines. Construction practices on and around coastal slopes, in combination with the increasing stormwater runoff from developing properties around Puget Sound, contribute to the acceleration of slope erosion and landslide activity along coastal waterways.

Too often, well intended erosion control and slope stabilization programs do not recognize and incorporate vegetation as a legitimate design tool to address these slope processes. Primarily, these oversights are because the use of vegetation alone (soil bioengineering) or together with other slope stability structures (biotechnical engineering) for slope protection is poorly understood. Therefore, the value of vegetation along a slope is either under-estimated or ignored during the important project planning, design, and agency permitting periods.

When properly installed and maintained, vegetation can protect slopes by reducing erosion, strengthening soil, and inhibiting landslides which increase general slope stability. The use of vegetation to manage erosion and protect slopes is relatively inexpensive, does not require heavy machinery on the slope, establishes wildlife habitat, and can improve the aesthetic quality of the property. This publication introduces general soil bioengineering practices to coastal property owners so that they may realize the practical and financial benefits of using vegetation to control erosion and help stabilize slopes. ■

USING THIS PUBLICATION

Slope Stabilization and Erosion Control Using Vegetation provides coastal landowners and government officials with basic information concerning the nature and use of slope planting techniques to manage soil erosion and shallow seated land movements. Information is introduced on site evaluation, planning, vegetation systems, materials, planting techniques, and general compatibility of the installation with traditional property owner use. This publication is a companion document to another Washington State Department of Ecology publication entitled *Vegetation Management: A Guide for Puget Sound Bluff Property Owners*. The publications should be used together to foster a better understanding and appreciation for the role and maintenance of vegetation along the coastal zone of Puget Sound. The following sections present an idealized scheme of how these publications might be used by landowners and local government.

COASTAL LAND OWNERS

Readers who own coastal property and who are concerned about soil erosion control and shallow land movement prevention can use this and other Washington Department of Ecology publications to select and employ general slope protection practices which may be applicable to their property. Additionally, readers can access a wealth of information available through public agencies and library systems. For many situations, professional design assistance should be sought. The information provided in this publication provides the basic information necessary to make general planning decisions and simple installations on slopes. The manual is not intended as a substitute for professional geotechnical/biotechnical engineering design or site-specific consultation.

GOVERNMENT PERMIT AGENCIES

Readers working for government agencies, whose responsibilities may involve policy creation, geologically hazardous areas, and development/permit application reviews, can use this manual to help them determine whether projects address vegetative systems as a viable component of slope stability maintenance. Permitting agencies will find this publication useful in suggesting alternative slope maintenance practices to coastal land owners who are unfamiliar with the advantages of slope planting techniques. This publication may also allow agency personnel to better understand the cause and effect relationship of shoreline development and the continuing maintenance of slope stability and erosion control.

SELECTING A SLOPE MAINTENANCE PROGRAM

The coasts of Puget Sound contain a variety of landforms which can vary greatly in their composition and historical use. This makes it difficult to cover all of the problems landowners may encounter on their properties in this general publication. Nevertheless, this manual will introduce some general planting techniques that may be used alone or in combination with other revegetation programs and existing natural areas to protect coastal slopes.

It is important for you, the property owner, to understand your site characteristics, and the erosion and land movement processes which may effect it. Only then can you begin to select appropriate protection measures to reduce potential slope erosion and land movements.

The first step in the development of a slope maintenance program is to gather basic site information so that you may better identify and select suitable vegetative treatments for problem slope areas. The checklist on *page 11* will help you identify and organize your slope's key features and characteristics. The background information needed to fill out the checklist is generally contained in the section - *Understanding Your Property*. Use the checklist as a summary of your own site evaluation.

Once you have generally characterized the existing conditions and uses of your slope, the next practical step is to determine

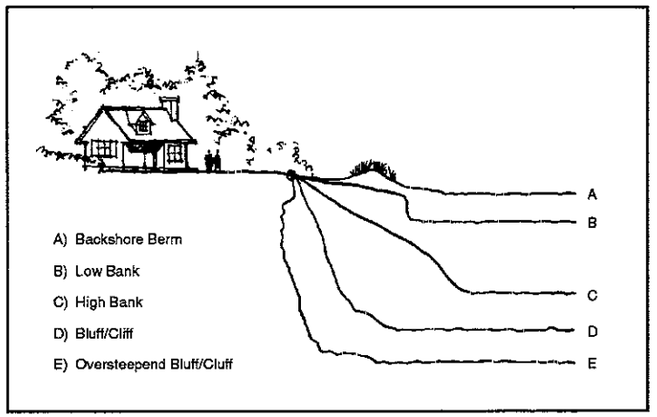


Figure 1 Typical Puget Sound Coastal Slope Profiles.

which slope planting techniques may provide solutions to your identified problems. Use *Table 1* as general guide to the appropriate slope protection measures for your site. The sections on the role of vegetation in slope stabilization and erosion control and vegetative planting techniques should be reviewed to determine the specific goals and limitations of each technique.

This publication addresses only the unconsolidated soil portions of coastal zone slopes. Bedrock exposures forming the cliffs of the Puget Sound coastal zone are not discussed in any detail in this publication because most vegetation installation techniques are not applicable to these areas. The general shapes of Puget Sound coastal slopes are illustrated in *Figure 1*. Use *Figure 1* to recognize some of the slope shapes that are familiar to you. When you

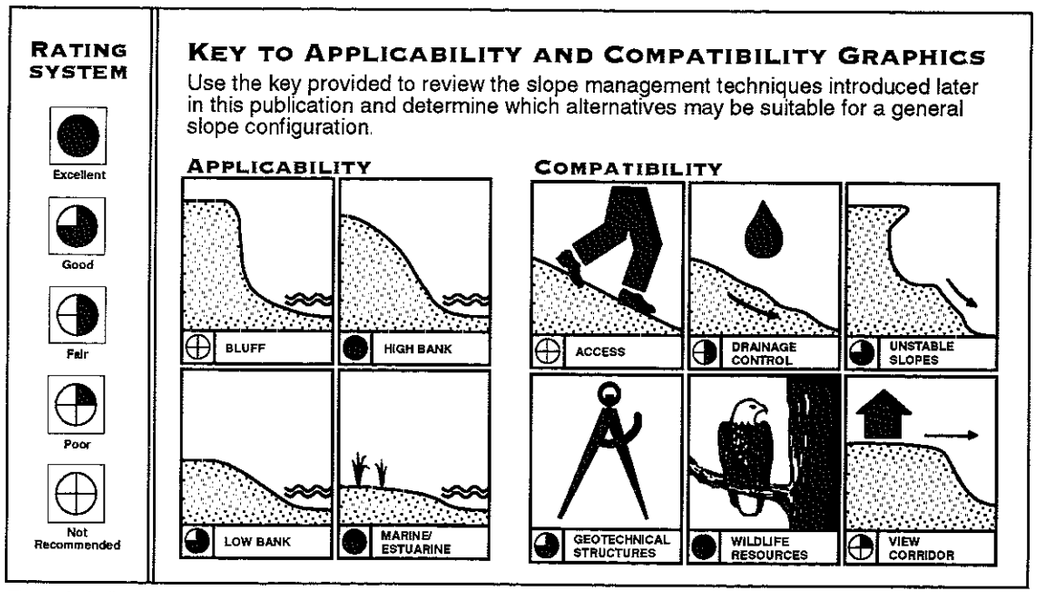


Figure 2. Indicates general applicability of slope management techniques using vegetation for typical slope shapes and compatibility of management techniques with existing or future coastline resource uses. The degree of general applicability or compatibility ranges from *Not Recommended* ⊕ to *Excellent* ● and is indicated accordingly in the graphics window.

identify your general slope shape(s), you can begin to understand the behavior of your property and start to account for erosion and landslide processes which may act upon your slope. You then can implement a number of vegetative slope protection measures discussed later in this manual.

The placement and maintenance of vegetation on a slope is important to a slope protection program. However, there are limits to the stabilization role that vegetation can perform which must be recognized at the onset of the planning process. First, vegetation alone can not control deep seated earth movements that may result from a combination of geologic and environmental influences. Additionally, the placement of vegetative components into actively failing slope areas such as landslides or earth flows can not be expected to have any short-term stabilization benefits until these movements are arrested and the sources of the problem are eliminated.

In cases where the toe of a coastal slope is exposed to all but the smallest of Puget Sound wave energies, you must recognize that vegetation alone will not stop long-term erosion. However, it may reduce the rate at which a slope toe is eroded to a potentially acceptable level.

UNDERSTANDING YOUR PROPERTY

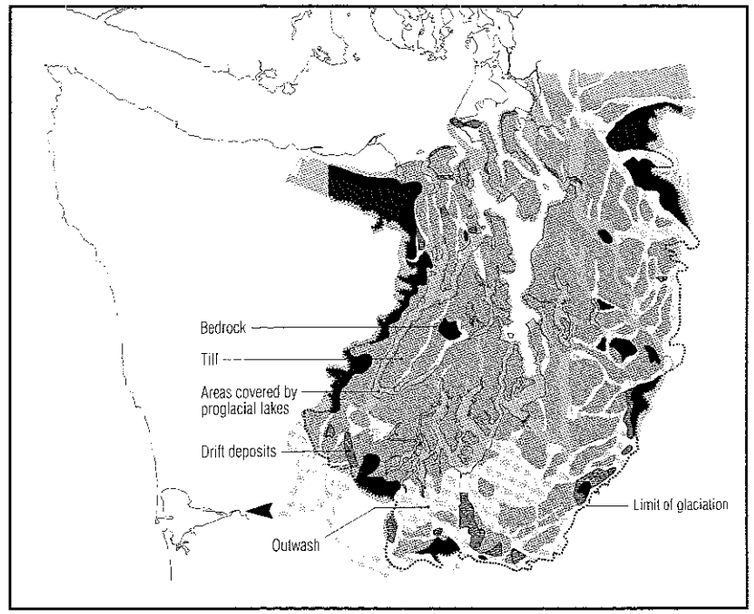


Figure 3. Glacial Sediments in the Puget Lowlands *(from Downing, 1983. Used with permission of the Washington Sea Grant Program)*

The locations of Puget Sound coastlines were established by the retreat of the last period of glaciation in the Puget Sound lowlands. Coastlines are continually modified by coastal marine processes and by the gradual natural rise in the sea level. Today, Puget Sound coastlines boast a range of shore forms which include high bluffs and rock cliffs, tidal mud flats, and sand and gravel beaches. You are probably most familiar with the common Puget Sound bluffs and their associated sand and gravel beaches which have varying slope heights and beach widths. The glacial deposits which define the general geologic composition of coastal slopes are illustrated in *Figure 3*. Glacial till is typically the most common geologic unit along Puget Sound coastlines and contributes heavily to the sands and gravels deposited on beaches. The effect of the slow rise in sea level over time in the Puget Sound area can be seen on *Figure 4*.

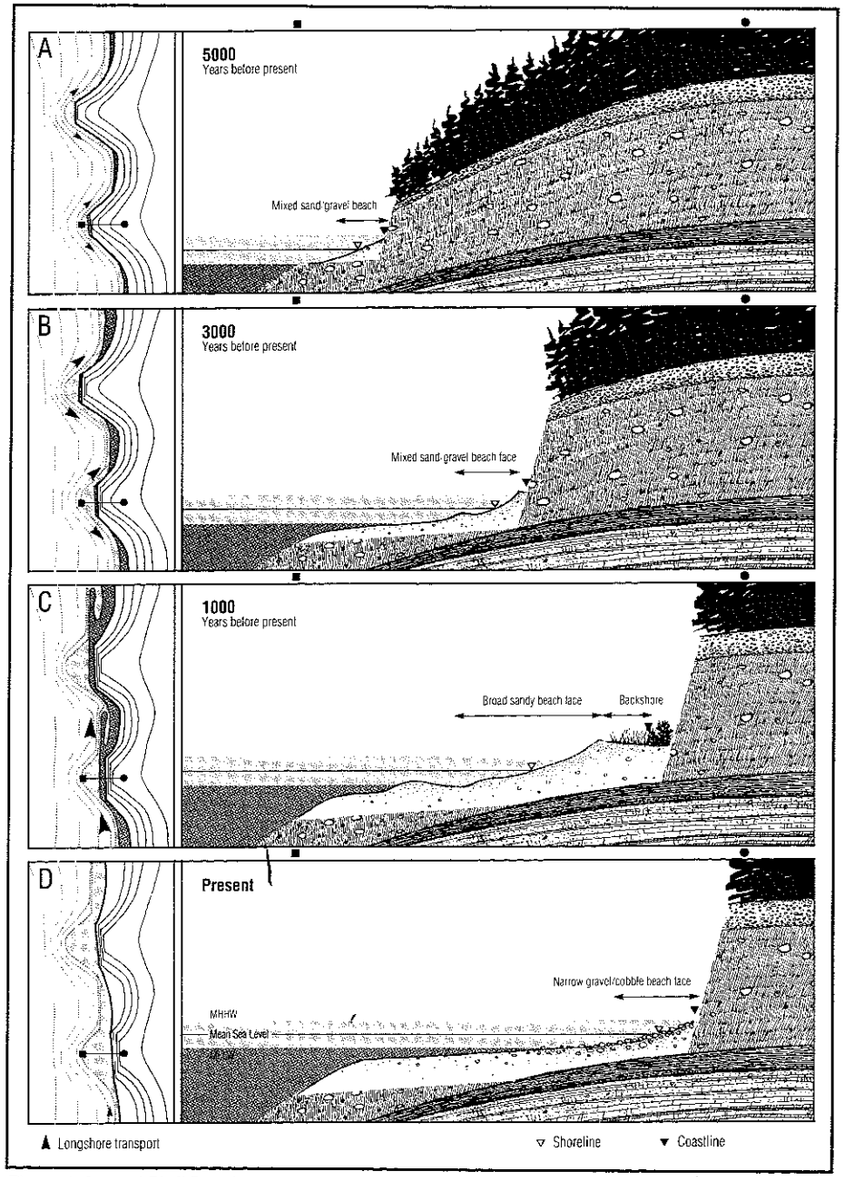


Figure 4. Coastal Bluff Development. Left: Evolution of a gravel and cobble beach. The longshore transport diagrams illustrate the direction of material movement along the beach. Right: Sea level since the last glaciation *(from Downing, 1983. Used with permission of the Washington Sea Grant Program).*

THE ART OF SITE EVALUATION

Selection of a successful vegetation program requires that the landowner spend time understanding what is happening around their slope. This means that you need to start keeping a mental list of your observations on the behavior of your slope and note deviations from that typical behavior. Observations made during periods of heavy precipitation, strong winds, freeze-thaw, heavy wave action, or other local slope movements are extremely important and empowers you to help provide solutions to your situation. The Ecology publication - *Vegetation Management: A Guide for Puget Sound Bluff Property Owners* will also be helpful to you in performing your site evaluation - particularly as it relates to existing vegetation.

Your site observations should be grouped into the following general categories: (1) the nature of the slope toe, face, and crest – noting the existing slope soil and vegetation conditions; (2) identify known slope problems or potential hazardous areas; and (3) note factors you feel contribute to slope erosion and stability problems.

The *Coastal Property Owner Checklist* provided in this manual will allow you to start organizing your observations. Additional information about your slope site should also be added to the checklist as necessary. The following discussion will aid you in completing your checklist.

• SLOPE ANGLE AND HEIGHT

To determine the angle of your slope, an easy method is illustrated in *Figure 5*. It is a simple device which can be constructed with a protractor and a yardstick. The protractor is fastened securely to a yardstick with a string and weight attached as shown. When the yardstick is held up and aligned with what appears to be the average slope of the land, the slope angle can be read directly from the protractor. This slope angle can then be converted to the appropriate horizontal/vertical ratio as shown.

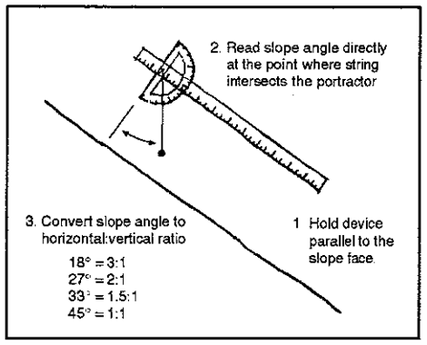


Figure 5. Slope Angle Determination

The quickest way for you to estimate slope height is to visually estimate the height of some nearby vertical structure on the slope (i.e. tree or bluff face) and then estimate how many tree heights would equal the overall slope height.

• SOIL

Site specific information noting soil types, thicknesses, and moisture conditions is very helpful to you when you select both plant species and planting techniques to be used in your program. Observing the types of vegetation already living on the slope is a good clue to slope soil conditions The County Soil Conservation Service, Soil Conservation Districts and Cooperative Extension Agents are good sources of information and expertise on soil characteristics.

• MICROCLIMATE
Puget Sound coastal weather is strongly influenced by changing topographic and atmospheric conditions. The degree of precipitation, available sunlight, temperatures, and wind can change radically from one coastline sector to another and consequently from site to site. These factors should be recognized in your site evaluations and planning effort which includes both planting and drainage control elements.

• DRAINAGE
Water in and on the slope is the most common agent causing erosion and slope instability and should be adequately examined during the site evaluation and planning effort. Observations of your slope's drainage conditions should include a careful search for seepage from the slope face. Surface water runoff should also be investigated and is best observed during periods of heavy rainfall. Pipe discharges and uncontrolled drainages across poorly vegetated surface soil are typical slope erosion problems. Visual observation of surface water runoff problems include watching for thin layers of water flowing across the slope face. Surface water runoff contained in channels usually starts in small rills in the upper soil horizon and then through time erodes into gullies which downcut into the slope. Runoff which concentrates into channels creates greater problems for slope stabilization programs because of the magnitude of erosive forces.

• VEGETATION
Evaluation of the existing slope vegetation is the key final observation of the slope because it should confirm your previous observations. Use the presence of vegetation (or lack of it) to confirm or modify your site evaluation. Vegetation will exist in areas which favor its establishment. As you identify specific types of vegetation on your slope, you can consult other references (see recommended reading section) to determine the range of environmental conditions (i.e. soils type and moisture, light preferences, etc.) which the observed plants tolerate. You should then be able to confirm your original observations. If your observations indicate that these species should not typically grow on your slope, you may want to perform your evaluations again or investigate whether the site has recently been disturbed or modified.

SLOPE EROSION
Loss of your slope's surface soil layers by the action of wind, water, and ice are what is referred to as soil erosion processes. Rainfall is the major factor along Puget Sound coastlines. However, wind and frost wedging do act upon some exposed slopes. The rates of erosion can be controlled by reducing the sources of runoff to the slope and/or by modifying the nature of the site conditions which influence runoff rates (e.g. soil type, slope length and steepness, ground roughness, type of vegetation covering the slope, and exposure to winds). A typical formation of rills and gullies is shown schematically on *Figure 6*.

Wind and frost wedging erosion can be reduced by allowing plant foliage to cover exposed slope areas. The foliage creates a physical and thermal barrier which protects the surface soils.

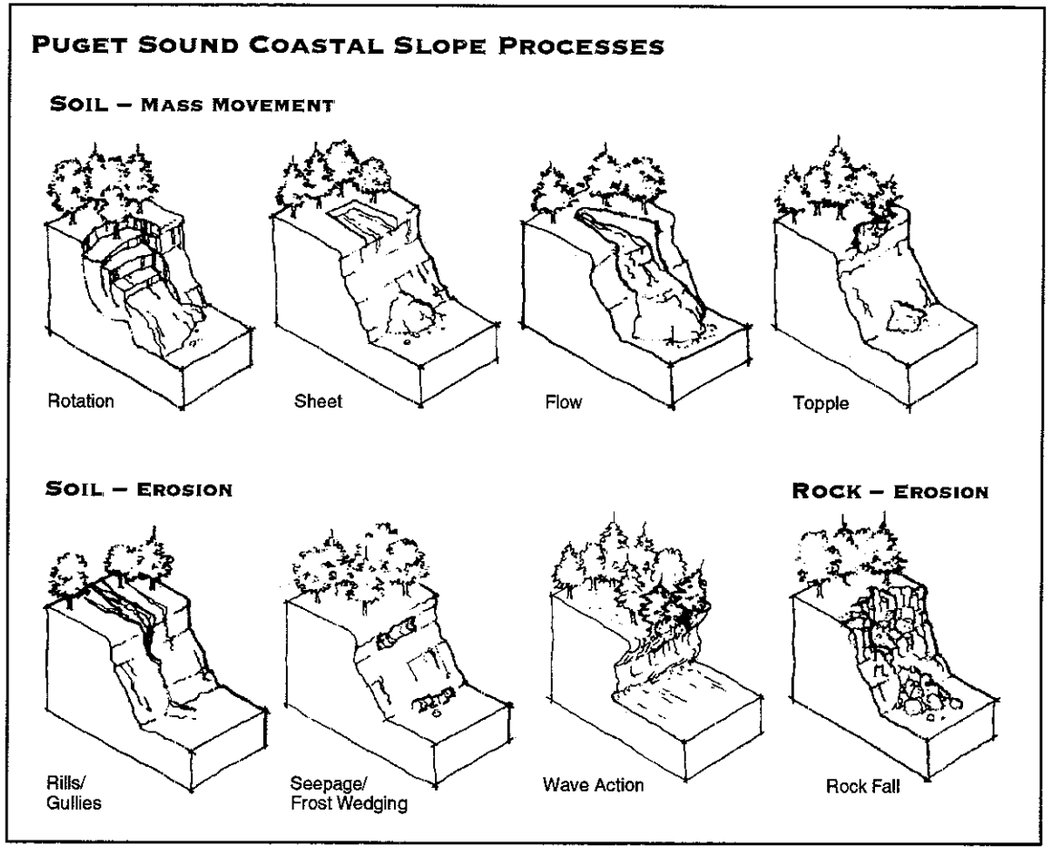
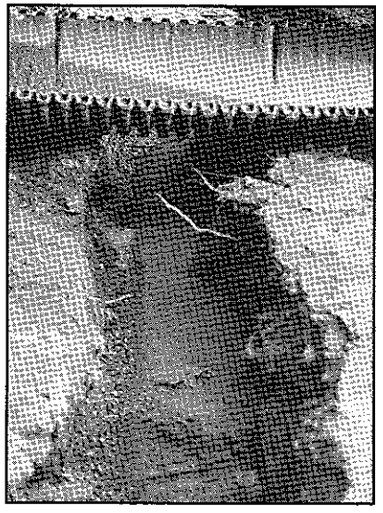


Figure 6 Typical Puget Sound Coastal Slope Processes

Soil Mass Movement

When a downward movement of relatively intact masses of slope material occurs, it is called a mass movement (instead of erosion). Mass movements can take the form of landslides, earth/debris flows and slumps, and rock falls/earth topples. *Figure 6* illustrates these basic soil movement processes. These events have been lumped together by planning agencies and the pubic and are generally called landslides. For simplicity, mass movements will be referred to as landslides in this manual. Recognition of active or historical landslide areas is important. Should you believe landsliding has occured or that there is the potential for landsliding on or adjacent to your property, it would be prudent to secure the assistance of a professional geotechnical engineer prior to the site planning process. It is important to reiterate that vegetation can be used to control shallow seated landsliding which is common along coastal slopes. However, it does not address deep seated landslide events. Vegetation can also be a valuable component of biotechnical engineering design solutions to these deep seated potential landslide conditions. Consult a geotechnical/biotechnical engineer for design input on stabilization alternatives.



Initial shallow-seated landsliding

Special Needs Areas

Should you recognize or suspect that your property or adjacent properties contain any of the following landforms or slope conditions, you should contact the appropriate government agencies to acquire assistance in these technical areas. You may also want to have consultations with technical experts in these areas:

1) Historical or Recent Land slides/Areas designated as Geologically Hazardous Areas [A, F]
2) Unstable Slope Fills [A, F]
3) Planting Vegetation on Slopes Steeper than 1.5 Horizontal to 1 Vertical (33 degrees) [F]
4) Coastal Marine Erosion [A, B, D, G]
5) Wetlands [A, B, C, H]
6) Habitat for Endangered, Threatened, Rare Animal Species (e.g. bald eagle or osprey nests/alternate nests/perch trees) [E]

A - County Planning Office Dept. of Community Development
B - Washington Dept. of Ecology
C - Army Corps of Engineers
D - Washington Dept. of Fisheries
E - Washington Dept. of Wildlife
F - Geotechnical/Biotechnical Professional
G - Coastal Engineering Professional
H - Wetland Professional

Coastal Property Owner Checklist

What landform(s) are located on my property? (check glossary definitions)

- ☐ Low Bluff (for this publication, ≤ 10 feet)
- ☐ High Bluff (for this publication, > 10 feet)
- ☐ Low Cliff (not generally applicable to this publication)
- ☐ High Cliff (not generally applicable to this publication)
- ☐ Low Bank (for this publication, ≤ 10 feet)
- ☐ High Bank (for this publication, > 10 feet)
- ☐ Beach with Backshore Berms of Sand/Gravel/Cobbles (marine/estuarine)
- ☐ Wetlands (check with the County Planning Office)

Property Description and Observations

- ____ What is the elevation of the house above the high tide water surface?
- ____ What is the average angle of the slope face?
- ____ Do waves reach the toe of the slope?
- ____ What are the diameters of beach sediments around the slope toe? (e.g. sand/gravel/cobbles)
- ____ Has the slope face been recontoured or filled?
- ____ What is soil material type(s) of the slope?

Factors Influencing Slope Erosion and Stability

- **Surface Water Runoff, Wind and Frost Wedging**

Can the effects of surface water runoff be visually identified?

- ☐ Rainfall impact erosion
- ☐ Soil rills and gullies
- ☐ Winter freeze-thaw evidence
- ☐ Wind erosion
- ☐ Pipe discharge erosion

What does your property contribute to runoff?

- ☐ Significant upland impervious surface
- ☐ Drainage pipe discharge onto slope
- ☐ Sprinkling/irrigation/hot tub releases
- ☐ Other _____

- **Groundwater**

Is there evidence of groundwater in the slope?

- ☐ Seepage or damp surfaces seen on the slope face
- ☐ Active or historical landslides

What are your contributions to groundwater in the slope?

- ☐ Water infiltration areas (roof and curtain drains)
- ☐ Septic system
- ☐ Irrigation systems

- **Vegetation**

____ Is there vegetation on or adjacent to the slope?

If yes, where is it and what are the species.

_____

_____

If no, is there evidence of past vegetation? What happened to it and what were the species? (check other properties)

_____

_____

____ Is there evidence of vegetation movement down the slope?

- **Marine Waters**

____ Is there a noticeable beach width above the high water line?

____ Are wave energies eroding the toe of the slope?

____ Are there coastal erosion control structures along the beach of your or neighboring properties? (e.g. bulkheads)

____ If yes, are these structures causing erosion?

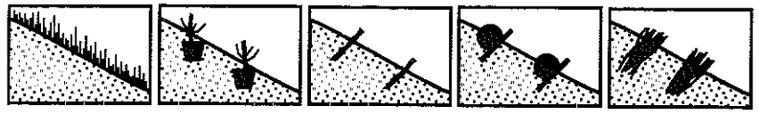
____ Is your property flood prone?

- **Slope Use**

How do you use the slope?

- ☐ Access to the beach (trail/road/stairs/other)
- ☐ Vegetation removal for view maintenance
- ☐ Horticultural/garden areas
- ☐ Waste/debris fills
- ☐ Natural greenbelt including slope crest

General Applicability



Advantages/ Disadvantages	Seeding (mixed species)	Container Bare Root	Live Staking	Contour Wattling	Brush Layering
Rainfall Erosion: Foliage intercepts raindrops	●	●	●	●	●
Runoff Erosion Control: Roots bind surface soil particles	●	●	●	●	●
Wind Erosion Control: Plants reduce wind exposure	●	●	●	●	●
Frost Action Erosion Control: Roots restrain soil movement	●	●	●	●	●
Slope Stabilization: Reinforce soil & resists shallow seated landsliding		●	●	●	●
Slope Stabilization: Plants help dewater slope		●	●	●	●
Runoff Erosion Control: Plants filter soil particles from runoff	●			●	●
Immediate Erosion Control/Slope Stabilization	●				
Slope Stabilization: Resistance to deep seated landsliding					
Low initial maintenance	●				
Low long-term maintenance	●	●	●	●	●
Low impact construction	●	●	●	●	
Plants prevent slope undercutting by waves					
Relative low-cost construction	●	●	●	●	●
Plants combine with other structural features	●	●	●	●	●
Aesthetic/wildlife benefits		●	●	●	●

Table 1. General Applicability of Slope Protection Plant Techniques

The Role of Vegetation

To comprehend the benefits and contributions of how vegetation influences soil erosion and slope stability, you may think of its role as either hydrological or mechanical in nature. The mechanical contributions arise from the physical interactions of either the foliage or root system of the plant with the slope. The hydrological mechanisms are those processes of water use and movement in the slope when living plant materials exist in the soil. The general roles that vegetation plays in slope maintenance and reinforcement are summarized in *Table 2*. The net effect of vegetation is usually beneficial to slope stability.

Vegetation and Slope Stability

Legend: (+) Beneficial to stability (–) Adverse to stability

Mechanism	Influence
Hydrological Mechanisms	
Foliage intercepts rainfall, causing absorptive and evaporative losses that reduce rainfall available for infiltration.	(+)
Roots and stems increase the roughness of the ground surface and the permeability of the soil, leading to increased infiltration capacity.	(–)
Roots extract moisture from the soil which is lost to the atmosphere via transpiration, leading to lower pore-water pressure.	(+)
Depletion of soil moisture may accentuate desiccation cracking in the soil resulting in higher infiltration capacity (uncommon around Puget Sound).	(–)
Mechanical Mechanisms	
Roots reinforce the soil, increasing soil shear strength.	(+)
Tree roots may anchor into firm strata providing support to the upslope soil mainly through buttressing and arching.	(+)
Weight of trees surcharges the slope, increasing normal and downhill force components.*	(+)/(–)
Vegetation exposed to the wind which transmits forces into the slope (Degree of adverse effect is dependent upon exposure and health of vegetation Typically a minor consideration for Puget Sound Inland Waterways)	(–)
Roots bind soil particles at the ground surface reducing their susceptibility to erosion.	(+)

Table 2. Vegetation and Slope Stability *(Source: Modified from Greenway, 1987)*

* Tree weight in some situations is benefical to slope stability Trees should not be arbitrarily cut to "unweight" slopes

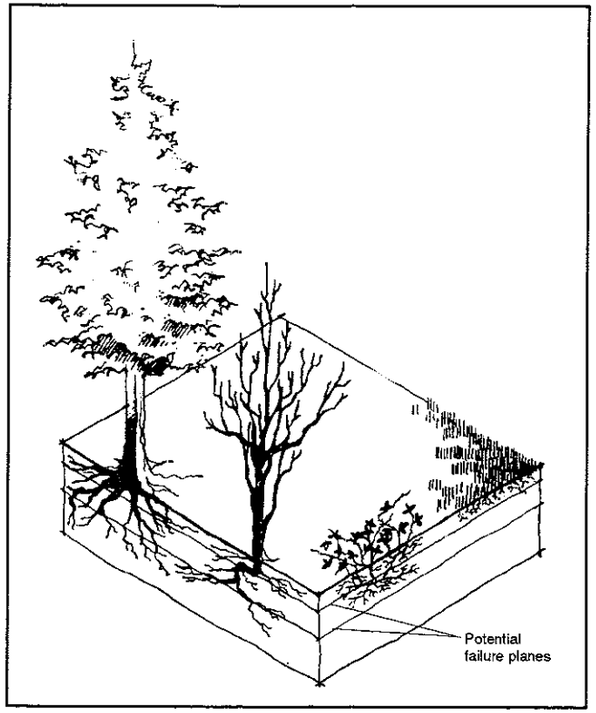


Figure 7. Root Reinforcement of a Slope

The protection of the slope against shallow seated landsliding is a key benefit of a revegetation or existing vegetation maintenance program. The function that mixed vegetation provides by increasing the apparent cohesion of the surface soil structure of a slope is illustrated in *Figure 7* The different types of root systems that plants provide can strengthen potential shallow-seated failure planes on your slope by both fiber reinforcement of the near surface soil and binding soil structure together into a larger unit through tap or lateral root networks.

An Ounce of Prevention

No amount of slope disturbance followed by replanting should replace rational site planning when it comes to avoiding slope disturbances. Should you have the option, maintain all the native vegetation you can and potentially accept the natural retreat of the slope crest. Accordingly, you should plan the location of your residence carefully. Maintaining a greenbelt along slope crests is good practice. Do not assume cutting trees to "unweight" your slope is benefical to slope stability – often it is not. Also, remember as a general rule, do not introduce water onto or into your slope.

Planning and Installation Goals

Since you have now spent time observing your slope features and have begun to understand what is happening around your slope, you should be able to establish some basic planning and planting goals which address the problems you have noted. You should divide the slope into different areas if this makes sense based on your observations. This may allow you to accomplish different goals in those areas. Now is the time for you to consider any drainage improvements to your slope (see *For More Information*). These improvements should be compatible with your planting program.

Typically, the slope can be separated into at least three areas: the crest, face, and toe. Planting objectives are usually slightly different in these zones. At the slope toe, you may be concerned with providing plants which resist down-slope soil movements, are tolerant to wet soils or occasional saltwater spray, and can handle changes to coastal marine deposition or erosion processes. On the slope face you may decide to select plants and planting techniques which tolerate a range of soil and light conditions, can handle some soil movements, can resist shallow seated landsliding, manage surface runoff, and are compatible with other slope uses. Along the slope crest you may want to revegetate a buffer area to strenghten soils and reduce erosion. Pulling these objectives together is an important milestone in your planting effort. Obtain assistance if you find the planning process is complicated for your situation.

Slope Preparation for Planting

The first task of your planting program will be to prepare the planting area just prior to planting, avoiding and protecting against wet weather conditions. This task requires that soil areas be prepared keeping disturbance to a minimum according to the requirements of each planting technique. Once the slope has been prepared, you should mark the positions or alignments of your planned plantings. Excavations should be performed concurrently with plant installations. This will allow installations to proceed effectively and reduce your total time on the slope.

Plant Species Selection

An effective method to properly select plant species involves coordinating your site conditions and planting objectives with the recommendations of local nursery publications and qualified native plant professionals. Plant material can be both purchased or gathered depending upon your own situation or plant availabilities. Your local native plant nurseries and state agencies involved in revegetation programs should be able to assist you in locating appropriate planting materials. The Hortus Northwest Journal to native plant sources is a valuable resource or you can contact DNR and SCS for potential plant sources. You should use *Table 3* in this manual as a starting point for your plant selections. There are still many other species from which to choose. It is generally not desirable to select ivy, Scot's broom or other ornamental exotic plants. Selecting native plants will usually increase the success of the planting program and reduce your long-term maintenance requirements.

Seeding and planting of vegetation should be done carefully. In many cases, grass and legume seed mixtures will have to be seeded by hand scattering along the face of the slope. The seed should then be covered with an appropriate mulch material. For large scale planting on hard-to-reach areas, machines called hydroseeders which spray mixtures of seed, water, and mulch materials are recommended. These applications are commonly used by the Soil

Continued on page 24

PLANT SELECTION GUIDE*

NAME	FORM & HABIT	MATURE SIZE	WATER[1] REQUIREMENTS	LIGHT[2] REQUIREMENTS	SOIL REQUIREMENTS	ROOTING[3] CHARACTERISTICS	RECOMMENDED SPACING	PLANTING[4] CONDITION	COMMENTS[5]
Red Alder *(Alnus rubra)*	Deciduous tree; seeds prolifically on bare soil	Height: 80'+ Spread: 40'	Moist conditions, No data	Full Sun	Any soil	Fibrous, Moderately deep	10'+	Bareroot seedlings up to 3' tall; larger plants in containers	Fast grower in poor mineral soils; typical 40-50 year lifespan; large limbs become brittle; provides food for birds
Pacific Willow *(Salix lasiandra)*	Deciduous multi-stemmed tree; does not spread	Height: 40'+ Spread: 25'	Wet conditions, Usage high?	Full Sun	Any soil — tolerates shallow flooding during the growing season	Fibrous, Moderately deep and widespread	6'+ for rooted plants; 2' for whips or cuttings	Rooted plants to 10' tall in containers; cuttings 18"-24"; whips 4'	Fast grower in saturated or shallowly flooded areas; 25 year lifespan — large limbs become brittle, tend to break off; stumps produce long, fast-growing whips; easily rooted
Scouler Willow *(Salix scouleriana)*	Deciduous tree or shrub; does not spread	Height: 30' Spread: 15'	Dry-Moist conditions, Usage high?	Full Sun	Any soil	Fibrous, Moderately deep and widespread	6' for rooted plants; 2' for whips or cuttings	Rooted plants to 10' tall in containers; cuttings 18"-24"; whips 4'; whips not recommended	Of the willows listed here, this species tolerates the driest conditions
Sitka Willow *(Salix sitchensis)*	Deciduous tree or shrub; does not spread	Height: 30' Spread: 25'	Moist conditions, Usage high?	Full Sun	Any soil	Fibrous, Moderately deep and widespread	6' for rooted plants; 2' for whips or cuttings	Rooted plants to 10' tall in containers; cuttings 18"-24"; whips 4'; whips not recommended	Fast grower in moist to saturated soils; widely used for streambank stabilization
Douglas Fir *(Pseudotsuga menziesii)*	Coniferous tree; does not spread	Height: 200'+ Spread: 50'	Dry-Moist conditions, Usage moderate	Full Sun	Any soil	Tap - Modified Tap, Shallow to deep and widespread	10'+	12"-18" bareroot seedlings; larger plants in containers	Generally not considered a primary species for slope face stabilization; high root strength but typical shallow rooting characteristics in thin coastal soils; can be planted in stands in slope crest greenbelts; good eagle and osprey perch and nest trees; potential for wind throw in thin or disturbed soils

Table 3. Plant Selection Guide (Partial listing of appropriate native plants for erosion control and slope stabilization)

The Role of Vegetation

PLANT SELECTION GUIDE (CONT.)

NAME	FORM & HABIT	MATURE SIZE	WATER[1] REQUIREMENTS	LIGHT[2] REQUIREMENTS	SOIL REQUIREMENTS	ROOTING[3] CHARACTERISTICS	RECOMMENDED SPACING	PLANTING[4] CONDITION	COMMENTS[5]
Northern Black Cottonwood *(Populus trichocarpa)*	Deciduous; does not spread	Height: 100 + Spread: 40'	Moist conditions, Usage high	Full Sun	Any soil - tolerates shallow flooding during the growing season	Fibrous, Shallow to deep and widespread, extensive	6'+ for rooted plants; 2' for whips or cuttings	Rooted plants to 10' tall in containers; cuttings 18"-24"; whips 4' tall	Fast grower in moist to saturated soils; also widely used for streambank stabilization; potential for wind throw
Red-Osier Dogwood *(Cornus stolonifera or Cornus sericea)*	Deciduous shrub; does not spread	Height: 20' Spread: 20'	Moist-Wet, No data	Full Sun Sun/Shade	Any soil - tolerates shallow flooding during the growing season	Fibrous, Shallow	3'+ for rooted plants; 2' for cuttings	Rooted plants to 6' tall in containers; bareroot & cuttings 18"-24" tall	Attractive shrub that produces bright red stems
Black Twinberry *(Lonicera involucrata)*	Deciduous shrub; does not spread	Height: 10' Spread: 8'	Moist, No data	Full Sun	Any soil	Fibrous, Shallow	4'+	Rooted plants to 6' tall in containers; bareroot 18"-24" tall	Produces yellow twin flowers and black twin-berries; some success reported from cuttings
Ninebark *(Physocarpus capitatus)*	Deciduous shrub; does not spread	Height: 15' Spread: 10'	Moist, No data	Full Sun Sun/Shade	Any soil	Fibrous, Shallow	4'+	Rooted plants to 6' tall in containers; bareroot 18"-24" tall	Produces masses of tiny white flowers which change to reddish seed clumps
Cascara *(Rhamnus purshiana)*	Deciduous tree/shrub; does not spread	Height: 25 Spread: 15'	Moist, No data	Full Sun	Any soil	Tap, Moderately deep	4'+	Rooted plants to 6' tall in containers; bareroot 18"-24" tall	Shiny, black berries are favored by Cedar Waxwings
Salmonberry *(Rubus spectabilis)*	Deciduous shrub; spreads by underground runners to form thickets	Height: 8' Spread: 6'	Moist, No data	Sun/Shade Full Shade	Any soil	Fibrous, Shallow	4'+	Rooted plants to 4' tall in containers; bareroot 6"-8" tall; cuttings 18"-24"	Spreads quickly once established; berries provide food for a variety of songbirds
Hooker Willow *(Salix hookeriana)*	Deciduous shrub; does not spread	Height: 20' Spread: 15'	Moist-Wet, No data	Full Sun	Any soil	Fibrous, Moderately deep	3'+ for rooted plants; 2' for cuttings	Rooted plants to 6' tall in containers; bareroot & cuttings 18"-24" tall; whips 4'; whips not recommended	A horticultural variety, "Clatsop," has been developed by the Soil Conservation Service for its vigor, disease resistance & attractive foliage; salt spray tolerant
Red Elderberry *(Sambucus racemosa)*	Deciduous shrub; does not spread	Height: 15' Spread: 10'	Moist, No data	Full Sun Sun/Shade Full Shade	Any soil	Fibrous, Shallow	4'+	Rooted plants to 6' tall in containers; bareroot 18"-24" tall	Produces red, non-edible berries; some success reported from woody cuttings

The Role of Vegetation

PLANT SELECTION GUIDE (CONT.)

NAME	FORM & HABIT	MATURE SIZE	WATER[1] REQUIREMENTS	LIGHT[2] REQUIREMENTS	SOIL REQUIREMENTS	ROOTING[3] CHARACTERISTICS	RECOMMENDED SPACING	PLANTING[4] CONDITION	COMMENTS[5]
Douglas Spiraea *(Spiraea douglasii)*	Shrub; spreads by seed & underground runners to form seed	Height: 8' Spread: 6'	Moist-Wet conditions, No data	Full Sun	Any soil - tolerates shallow flooding during the growing season	Fibrous, Shallow	3' for rooted plants; 2' for cuttings	Rooted plants to 6' tall in containers; bareroot & cuttings 18"-24" tall	Spreads quickly & aggressively in most sites
Snowberry *(Symphoricarpos albus)*	Deciduous shrub; spreads by underground runners to form thickets	Height: 4 Spread: 3	Dry-Moist conditions, No data	Full Sun Sun/Shade Full Shade	Any soil - tolerates shallow flooding during the growing season	Fibrous, Shallow	2'+	Rooted plants to 24' tall; bareroot 6'-18" tall	Tolerates high winds and often grows on vegetated slopes overlooking salt water
Salal *(Gaultheria shallon)*	Evergreen shrub; spreads by underground runners to form thicket	Height: 3' Spread: 3'	Dry-Moist conditions, No data	Sun/Shade Full Shade	Any soil - tolerates shallow flooding during the growing season	Fibrous, Shallow	2'+	Rooted plants 4' to 12' tall	Widely available; difficult to establish; slow growing; tolerates salt spray
Ocean Spray *(Holodiscus discolor)*	Deciduous shrub; does not always spread aggressively	Height: 10'+ Spread: 6'	Dry-Moist conditions, No data	Full Sun Sun/Shade	Any soil - tolerates shallow flooding during the growing season	Fibrous, Moderate	4 +	Rooted plants to 2' tall in containers; bareroot 6'-12" tall	Produces attractive sprays of creamy-white flowers; will root spread
Vine Maple *(Acer circinatum)*	Deciduous shrub; does not always spread aggressively	Height: 15 + Spread: 10'	Moist conditions, No data	Sun/Shade Full Shade	Any soil - tolerates shallow flooding during the growing season	Fibrous Moderate	8'+	Rooted plants to 4' tall in containers; balled & burlapped plants to 10' tall	Large specimens widely available; spreads by root and seed
Kinnickinick *(Arctostaphylos Uva-ursi)*	Low-growing shrub; spreads to form a dense, evergreen carpet	Height 8 Spread: 6	Dry conditions, No data	Full Sun	Any slightly acid soil	Fibrous, Shallow	2'	Rooted plants in containers	Widely available evergreen ground cover; tolerates salt spray
Thimbleberry *(Rubus parviflorus)*	Deciduous shrub; spreads by underground runners to form thickets	Height: 4 Spread: 4	Moist conditions, No data	Full Sun Sun/Shade	Any soil	Fibrous, Shallow	3'	Rooted plants in containers	May be difficult to find in some native plant nurseries
Indian Plum *(Oemleria cerasiformis)*	Deciduous shrub; spreads by underground stems to form open stands	Height: 10 Spread: 6	Moist conditions, No data	Full Sun Sun/Shade Full Shade	Any soil	Fibrous w/horizontal, underground runners. Shallow	4'+	Rooted plants to 4' in containers; bareroot 6'-8' tall	Male and female flowers are on separate plants; only female flowers produce the attractive "plums"
Evergreen Huckleberry *(Vaccinium ovatum)*	Evergreen shrub; does not spread	Height: 6 Spread: 3	Dry-Moist conditions, No data	Sun/Shade Full Shade	Slightly acid	Fibrous, Shallow	3'+	Rooted plants to 2' tall in containers	Attractive, but slow growing; difficult to establish; tolerates salt spray

The Role of Vegetation

Plant Selection Guide (cont.)

Name	Form & Habit	Mature Size	Water[1] Requirements	Light[2] Requirements	Soil Requirements	Rooting[3] Characteristics	Recommended Spacing	Planting[4] Condition	Comments[5]
Nootka Rose *(Rosa nutkana)*	Deciduous shrub; spreads by underground runners to form thickets	Height: 6' Spread: 3'	Moist conditions, No data	Full Sun	Any soil, prefers rich soils	Fibrous, Shallow (not extensive)	3'	Rooted plants to 2' tall in containers; bareroot to 18" tall; cuttings 12"-18"	Thickets of spring stems create a formidable barrier; produces attractive, pink flowers followed by large, red hips; tolerates salt spray
Red Currant *(Ribes sanquineum)*	Deciduous shrub; does not spread	Height: 8' Spread: 6'	Dry-Moist conditions, No data	Full Sun Sun/Shade	Any soil	Fibrous, Shallow (not extensive)	6'+	Rooted plants to 4' tall in containers; bareroot to 18" tall	One of our finest ornamental natives; produces clusters of white to red flowers
Wax Myrtle *(Myrica californica)*	Evergreen shrub; does not spread	Height: 15' Spread: 8	Dry-moist conditions, No data	Full Sun Sun/Shade	Slightly acid, with organic matter	Fibrous, Moderate	10'+	Rooted plants to 10'	Tolerates salt spray; high wildlife usage
Native Plant Seed Mixes	Annual and perennial grass and forb mixes available	Height: 1'-2' Spread: varied	Dry-Wet conditions, Medium - high	Species/mix dependent	Species/mix dependent	Fibrous, Shallow	Apply as recommended	Seed	Woody plant seeds also available (success typically low); very slow to establish; avoid exotic commercial mixes; seed mixes typically used in conjunction with other vegetation plantings; typically short-term erosion control technique

Table 3 based on information from: Myers Biodynamics staff experience; Binns 1980; Stevens & Vanbianchi, 1993; Kruckeberg 1982

Footnotes

[1]Water Requirements

- Dry - Once established, tolerates dry soil conditions during the growing season
- Moist - Requires moist soil throughout the growing season
- Wet - Tolerates saturated soil year-round
- Usage - Relative water uptake by plant [e g , high or no data]

[2]Light Requirements

- Full Sun - Requires sun throughout the day
- Sun/Shade - Requires shade for about ½ the day
- Full Shade - Requires shade throughout the day

[3]Rooting Characteristics

- Fibrous - Lacks a central root; root mass composed of fibrous lateral roots
- Tap - With a stout, central main root

Shallow, Moderate, Deep refers to relative rooting depth (influenced by soil and groundwater conditions)

[4]Planting Condition

Sizes given are those that are generally found in nurseries; other sizes may also be available

[5]Comments

Growth rate; ornamental & wildlife value; wind/salt spray tolerance; maintenance; average life span

Continued from page 15

Conservation Service and other agencies.

Where broadcast seedings are made, time of seeding for grasses and legumes is very important. Seeding should be avoided in July, August, and September wherever possible as extensive drought periods can occur. Legume-based mixtures should be seeded as early as possible but no later than mid-June. Grass-based mixtures can be seeded before and after July through September. It should be realized that healthy, herbaceous ground covers may require an initial fertilizer application to achieve higher successes. Select native species and use a slow-release formulation (do not over fertilize)

Woody plant materials should come from plant stock which is dormant and should be planted immediately. Materials can be installed up to 48 hours after cutting if they are kept cool and moist by covering cuttings with moist mulch.

Willow, cottonwood, and dogwood can be planted as cuttings or saplings and are particularly good for seep zones and other wet areas of slope faces. However, avoid planting willows near artificial drains because their roots seek water and may eventually clog or disrupt the drains. When planting other shrubs and trees on slope areas, consult qualified nursery people to determine appropriate species for your conditions.

Mulching

Mulching of seeded or planted areas is of particular importance to slope plantings. Mulch protects against rain and wind while seeds are germinating and plants propogating. It also reduces loss of soil moisture during extended dry periods. Because of the severe nature of most coastal slope areas, a mulch cover addition is necessary if vegetation is to be established from seed.

A wide variety of mulches can be used. These range from scattered straw to sprayed fiber. More common materials and methods may include: hay or straw ($1^1/_2$-2 tons/acre), jute netting, plastic netting (not recommended), manure or compost (not recommended), wood fiber, or fiber matting. Check with your local Soil Conservation Service office, nursery people, or garden and farm centers to get more information on local availability or suitability for your situation.

One other short-term anchoring method which has helped to stabilize slopes during vegetation establishment in some areas susceptible to shallow soil movements involves "nailing down" a slope face with 5 foot metal fence posts. The posts are driven perpendicularly into the slope face in a grid pattern with 10-15 feet spacings between them. The posts are cross-connected with heavy wire or cable which has the effect of tying the entire slope face together from top to bottom and side to side. The posts should be driven in almost all the way into the ground, wired, and then the slope should be planted and mulched.

Planting Program

Planting Zones

Without using more advanced stabilization techniques, the maximum slope to be considered for vegetative stabilization is 1.5 horizontal to 1 vertical (1.5H:1V). There are many good plants in the form of grasses, vines, shrubs, and minor trees that can be used for slope stabilization projects. Plant selection is dependent upon the goals of your erosion control program and site conditions. Typically, effective programs incorporate structural diversity in plant selections (trees/shrubs with ground covers) and use a mix of species.

• Slope Crest

The vegetation along the edge of the top of the slope serves as a protective buffer for the slope face. If possible, you should maintain or reestablish a greenbelt which would provide a buffer between the slope face and residential structures. This is particularly important in areas where slopes are too steep and too high for economically feasible stabilization methods. For example, some coastal high bluffs in residential areas along Seattle, Tacoma, Edmonds, and Port Townsend waterways may be too severe to attempt stabilization. In cases like these, you may choose to maintain a strip of dense natural vegetation along the bluff edge. The roots of the vegetation can strengthen a bluff's resistance to slumping or sliding. If the bluff edge is currently cleared, a strip may be left undisturbed and a revegetation program implemented.

• Slope Face

Vegetation should be established on patchy and barren slope faces or terraces to reduce erosion. Planting practicality depends greatly on the character of the slope, and particularly on the slope angle. A slope of 1.5H:1V (33 degrees) should be considered the dividing line between a manageable slope and a slope steep enough that vegetation would be difficult or impossible to establish without employing other reinforcement techniques.

If room exists at the top of a slope, low slopes can be graded back to a gentler configuration. 3H:1V or flatter slopes are ideal because these slopes can be prepared and planted with wheeled vehicles. However, in most coastal areas, slopes are too steep or too high for mechanical planting techniques. Slope regrading may be neither economically feasible nor technically desirable for the individual property owner.

Various species and mixtures of species can be planted on slope faces and expected to succeed in this rather severe environment. These include seed mixtures of grasses and legumes and a range of shrubs and minor trees.

Large trees should be used on the face of slopes sparingly and with caution. Should these trees

collapse because of undermining of the root system by erosion or by windthrow, large volumes of earth can be disturbed by the tree roots when they pull from the slope. The resulting large, bare areas are opened to further erosion, which may endanger adjacent land and vegetation. New major trees should not generally be established on the face of coastal slopes. Existing major trees should be closely monitored for signs of undercutting and toppling. If the trees become unstable, they should be cut before they fall. Root systems should be left intact to bind the soil for a short period of time while new live, well-rooted vegetation establishes itself. Establishing new vegetation prior to felling a tree would be advantageous to the slope protection program.

• Slope Toe

In those situations where the bottom of your slope is susceptible to frequent or periodic wave attack, vegetation alone will not be adequate as an erosion control tool. In such cases a form of structural toe protection may also be required. If the toe is not subject to coastal marine erosive forces, trees and woody shrubs can be useful in resisting upland landsliding and tolerating the dynamic changes in the coastal shore system. Vegetation at the slope toe can sometimes help reduce marine erosion to manageable levels.

Planting Times

Late fall and early spring are usually the best times for slope installations. During these periods plants are semi-dormant, the slope soils are easiest to work, and vegetative cover is at a minimum. If slope moisture is an installation problem, fall usually provides the best opportunity to work with the slope.

Maintenance

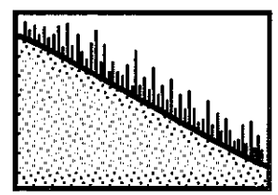
Use the Ecology publication - *Vegetation Management: A Guide for Puget Sound Bluff Property Owners* to plan for a range maintenance considerations in your erosion control program. Most programs do not have significant long-term maintenance requirements

Planting Techniques

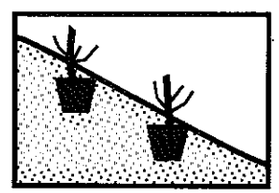
When you review the following planting techniques remember that the descriptions are meant to introduce general slope planting techniques to coastal landowners. As a result, a technique may not be adequately discussed to the level of detail required for your unique property characteristics.

It is always advisable to consult additional resources prior to undertaking your site work. Additionally, these and other techniques may be combined with structural/mechanical slope stabilization designs (biotechnical engineering) which are also beyond the scope of this manual.

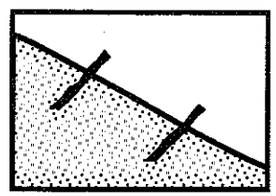
Six General Planting Techniques



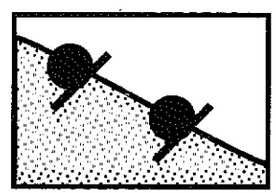
Seeding (Mixed Species)



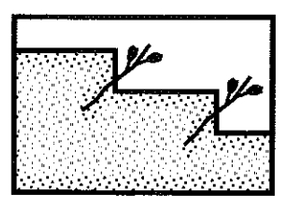
Container or Bare Root



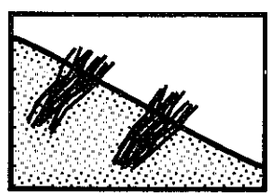
Live Staking



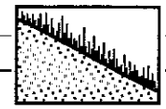
Contour Wattling



Avoidance/Retreat or Biotechnical Solutions



Brush Layering



SEEDING

• DESCRIPTION AND FUNCTIONS

Seeding involves the application of grass, forb, and woody plant seed mixes to slope areas. Seeds may be applied to slopes by broadcasting seed mixes onto the slope by hand or by placing seed into small holes placed into the slope. Hydroseeding is also another option used for hard to access locations. Seeding creates a shallow fibrous rooting zone in the upper foot or so of the surface profile which binds near-surface soils and protect soil surfaces from surface water runoff, wind, and freeze-thaw erosive forces. Seeding is usually applied in combination with other planting techniques to address most erosion control issues.

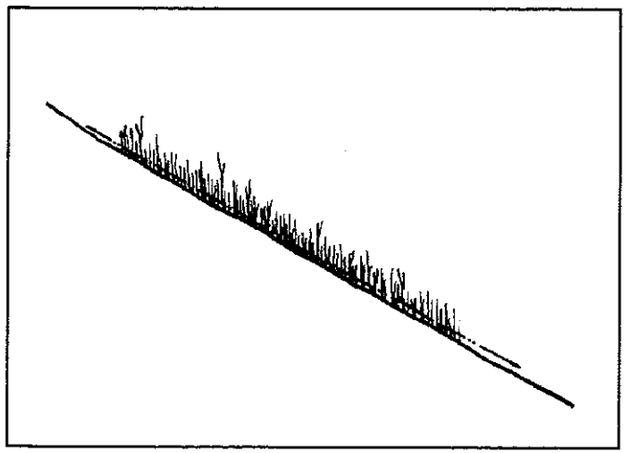


Figure 8. Seeding (grasses shown here) with erosion control mulch

• PLANNING CONSIDERATIONS

Drilling soil holes into the slope area can reduce the seed quantities required. Practically, this method is best used on mild slopes, in smaller prescription areas, and for woody plant seed stock which is more expensive that grass seed mixes. Typically, a 3-inch diameter by a 4-inch deep hole is a good size for the planting hole. Make sure surrounding soil is loosened around the hole so that future root systems can develop. Drop a slow release fertilizer capsule to the bottom of the hole and cover with about $3^1/_2$ inches of soil. Then place about 20 seeds into the hole and cover the seed as directed by the seed supplier.

Broadcast seeding is the most common application method employed in projects. Seeds are scattered uniformly by hand onto the slope. If the application area soil has been roughened slightly, seed germination will be more successful. It is also important to make sure precipitation does not wash seeds down the slope. Mulch seed immediately to keep seeds from being blown and washed away, or eaten by wildlife, and to keep the surface soils moist. Fertilize areas as required by mix directions. Hydroseeding is another application method that uses seed mixed with water, fertilizer, and sometimes mulches to spray apply the mixture onto expansive or hard to reach slope areas.

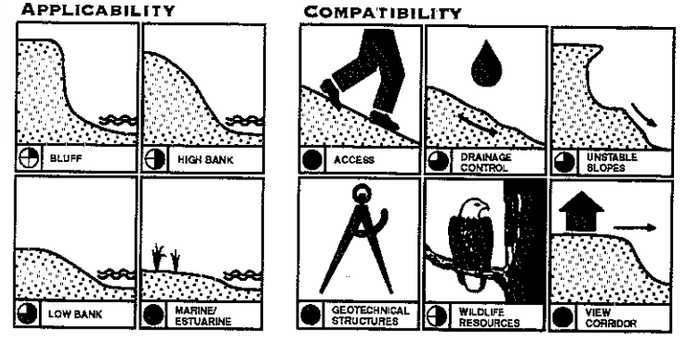
• LIMITATIONS

Good for mild erosion problems or in combination with other techniques. The shallow fine rooting systems of grasses and forbs do not significantly increase the shear strength of the surface soil profile and limit landsliding. Woody plants seeded into slopes need five to ten years to begin to develop extensive rooting networks. Woody plant roots do a better job providing root reinforcement of the surface soils but are less effective than native grass mixes at reducing erosion at the soil surface. Seed germination for all species require that soils to be kept moist. Seeding should include mulching to achieve adequate erosion control. Seed mixes using combinations of wild strawberry, wild ginger, oxalis, sword fern and bracken fern have been reported to be more successful than grass-based mixes for some sites.

• ADVANTAGES AND DISADVANTAGES

Advantages: Seeding can be quickly applied to slopes, materials are inexpensive, and technique is compatible with many slope situations.

Disadvantage: Seeding does not readily self-repair eroding slope areas. Seeding is not adequate to be used alone for highly eroded areas or for shallow seated landslide stabilization.



Slope seeding with long straw mulch and jute matting

CONTAINER OR BARE ROOT PLANTING

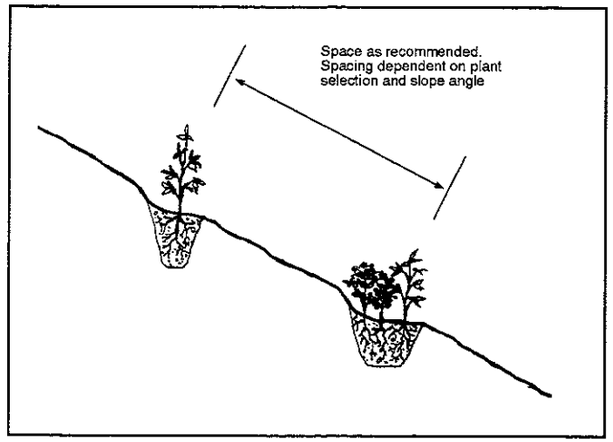


Figure 9. Container/bare root planting (single or bunch planting)

• DESCRIPTION AND FUNCTION

Container and bare root planting involves placing single or bunches of rooted plants into excavated holes on the slope. This method can be used for woody plants or for non-woody plants which will eventually spread into a uniform root coverage. Container and bare root plant material can be purchased directly from nurseries or gathered from other sites and propagated by the landowner. Transplants from nearby areas (away from the slope) can also be used. Rooted plant materials offer the property owner the most immediate solution to developing an erosion control and slope stabilization program that can secure a slope.

• PLANNING CONSIDERATIONS

Use rooted pant materials when you need a fast action program for specific slope areas. This allows you to avoid the critical germination period for seeding programs or root development period for cuttings. Place material into positions on the slope during the fall or spring. When placing material in holes make sure you loosen the root ball or in the case of base root plants, make sure roots are not bound or bent upwards in the holes. Install according to the specific requirements of each plant or plant grouping. It is common practice to prune the plants after installation which will allow a greater percentage of available plant energy to be used for developing healthy rooting systems.

Because the immediate slope stabilization expectations of using rooted materials are often too high, it is a good idea to use plant groupings or bunch plantings. This method allows you to place plants which have slightly different rooting and foliage characteristics which may strengthen the overall reinforcement program. Bunch planting also allows the plants best suited for the slope environment to eventually dominate the plant community. Finally, in cases where one species used is not healthy or has been recently stressed, you have provided some safety factor in your planning by planting numerous species. Mulching around the plants is recommended as a minimum.

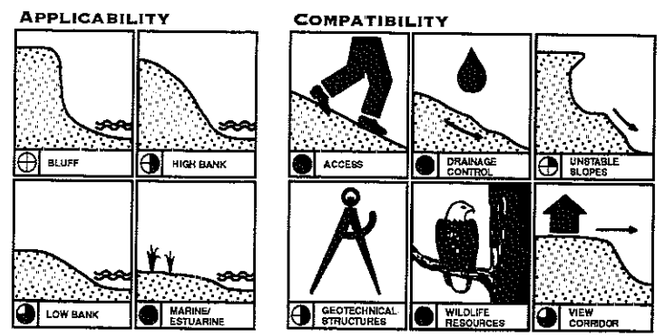
• LIMITATIONS

Container planting does not address gully erosion control problems. Landowner must identify available plant sources ahead of time to have the quantity, species, and rooted condition necessary for the program. Container plants can be relatively expensive.

• ADVANTAGES AND DISADVANTAGES

Advantages: Well developed rooted plant materials installed for faster slope stabilization, typically higher plant success, minimal slope disturbance using planting holes.

Disadvantages: Relative cost of materials, hard to install into some mulching systems, initial watering requirements.



Container plants (Red-osier dogwood and Salal shown)

LIVE STAKING

• DESCRIPTION AND FUNCTION

Live stakes are sections of woody plants that are cut into lengths and placed into the slope. The plant material is installed during the fall or spring when the original plant (and consequently cuttings from it) are dormant. The plant materials used for stakes are usually hardy species which root easily and eventually grow into mature woody shrubs that reinforce the soil structure of the slope. (See *Table 3* for some cutting species alternatives.)

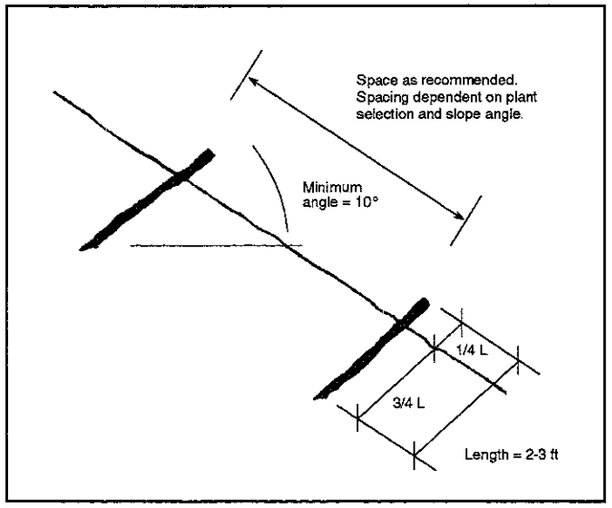


Figure 9 Live staking

• PLANTING CONSIDERATIONS

Woody plants which have good rooting characteristics make good staking plant stock. Stakes are generally 2 to 3 feet long and $^1/_2$ to $1^1/_2$ inches in diameter and can be collected from sections or branches of plants from donor sites. Stakes should be flat cut on the top and diagonal cut on the bottom so they will be installed correctly.

Staking can be used alone and with other planting techniques. Typically, if stakes are used alone on the slope they will be spaced across the slope as recommended for each species and slope situation. Each row should have the same spacing but should alternate stake positions so that if you look down or up slope no two consecutive rows should have stakes directly above or below one another (a diamond pattern). Stake rooting will be most effective if the stake is not positioned vertically but positioned at an angle off horizontal so that rooting can occur more effectively along the entire below ground length as shown on *Figure 9*.

Stakes are typically be placed into predrilled holes using rebar sections which are slightly smaller than the diameter of the stakes. Gently tap stakes into holes with soft mallets or other instruments. Remove the top section of the stakes that get damaged during installation. It is good practice to mulch the staked area after the installation is completed.

Live staking is also used with contour wattling to secure wattles along a contour. The method of stake installation is the same as described for independent stakes.

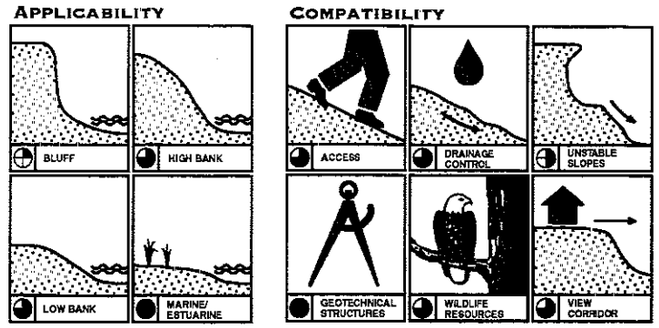
• LIMITATIONS

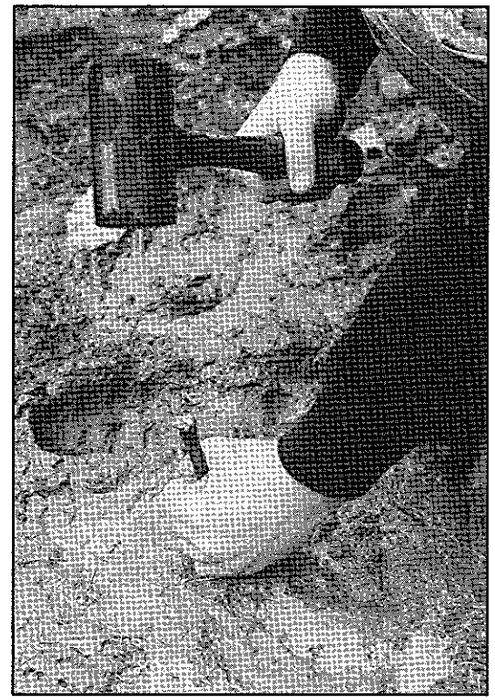
Used on slopes of 1.5 horizontal to 1 vertical or flatter. The best time for staking installation is fall and spring which requires careful planning to perform slope work in this time period. Often the planting period for many projects is planned for the summer and early fall and this typically results in low propagation of the cuttings and ultimately poor slope protection performance of the vegetation system. Live staking does not provide an immediate solution to slope stabilization.

• ADVANTAGES AND DISADVANTAGES

Advantages: Stake sources are plentiful and inexpensive, can be planted with minimal surface preparation/disturbance, can be placed into irregular (but stable) slope surfaces, helps reduce slope soil moisture.

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





Live stake installation

CONTOUR WATTLING

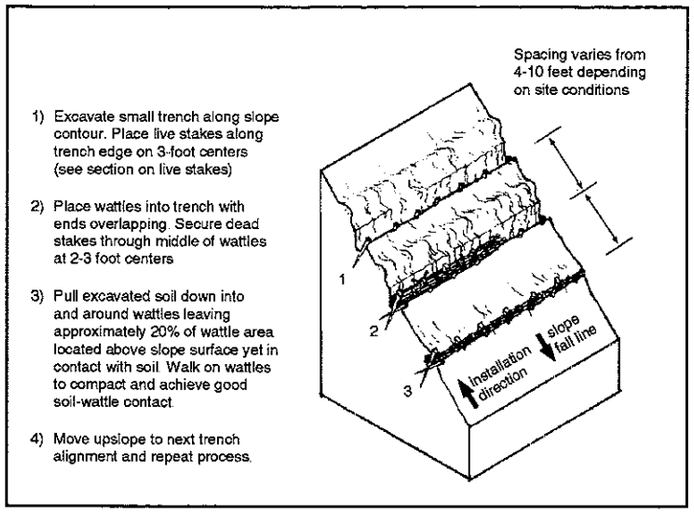


Figure 10. Contour wattling

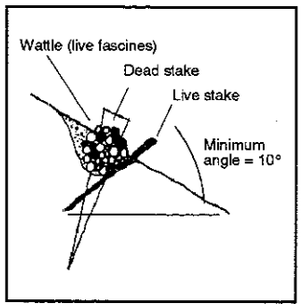


Figure 11. Contour wattling detail.

• DESCRIPTION AND FUNCTION

Contour wattling is an erosion control planting method which can also be used to stabilize very shallow soil structure against landsliding. The method involves packing lengths of woody plant material into cables or bundles (sometimes called live fascines) about 8 to 10 inches in diameter. The bundles are laid continuously along slope contours as shown in *Figure 10*. The cabling effect along the slope helps to intercept surface water runoff and route it laterally before it creates erosion problems. The wattles help trap sediment by creating barriers (living fences) to protect down slope areas against material falls or erosion.

• PLANNING CONSIDERATIONS

Woody plants which are particularly suitable to contour wattling are willow, red-osier dogwood, and snowberry. Wattling is generally considered good for slopes of 1.5H:1V or less. The installation of wattles along slopes requires a greater degree of planning prior to installation. Generally, wattles are placed horizontally in shallow trenches along preselected alignments on the slope at a single contour elevation. The wattles are placed into the trenches and partially covered creating what appear like slope terraces. Wattling installation along a slope face should progress from the slope toe upslope to the crest until planting is complete.

Wattles are created by laying plant materials length wise between two bucking horses (or modified sawhorses). Plant materials should be about $\frac{1}{2}$ - $1\frac{1}{2}$ inches in diameter and about 4 to 8 feet in length. Butt ends and top ends are usually laid alternately until a bundle has been created that looks like an 8 to 10 inch wide cigar. Bundles are then tied together using untreated lengths of twine. This process is repeated until you fabricated the length of wattling necessary to finish a contour length. Next you live stake the downslope side of the trenches to hold the wattles in the trench overlapping the ends of bundles slightly. Place dead stakes (2 foot long section of a 2 x 4 stud cut diagonally) through the wattles every two feet. Finally, pull the soil from the trench excavation down into the wattles and compact into the trench by walking on the bundles. Make sure there is good soil-plant contact around and in the wattle.

About 80 percent of the wattle should be buried *below* the existing soil surface as shown in *Figure 11*. Leave the remaining area above the existing soil surface then cover with soil to intercept water and create mild slope terraces. At this time it is good to excavate the next upslope trench and then repeat the process. It is important to get the plant materials into the trenches before they have a chance to lose critical stem moisture. Seeding and mulching should follow immediately after installation.

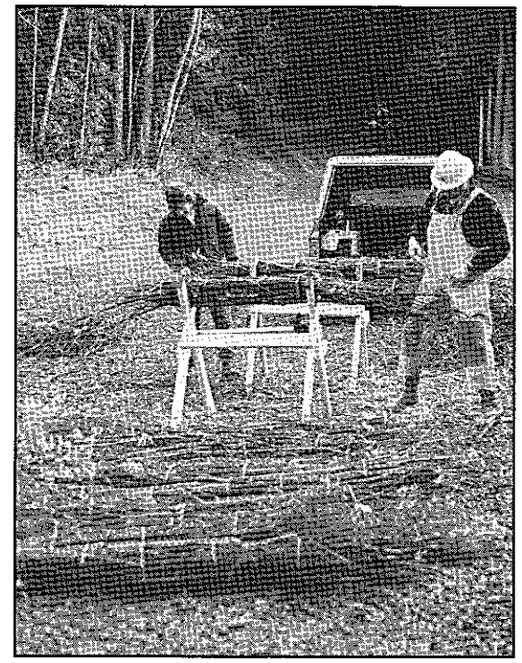
• LIMITATIONS

There is a significant quantity of plant material required for this technique. Installation is best performed with a labor crew of 3 to 4 people. The technique is time consuming if quality work is performed. For dry sites, summer watering maybe initially necessary.

• ADVANTAGES AND DISADVANTAGES:

Advantages: Good erosion control technique, can be used to manage mild gully erosion, can serve as slope drains when wattle cables are angled slightly.

Disadvantages: On steep or long slope lengths, high runoff velocities can undermine wattling near drainage channels, can dry out if not properly installed, covered, or maintained.



Wattle construction

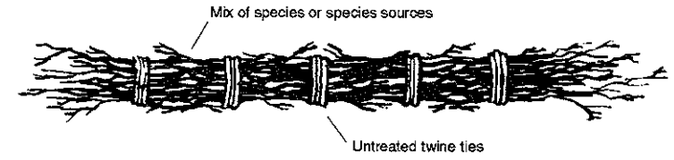
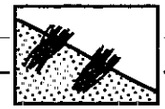


Figure 12. Wattle detail



BRUSH LAYERS

1) Excavate trench so that approximately 1/4 of average brush length extends beyond slope face. Do not over excavate.

2) Lay an appropriate mix of brush species and/or brush species from different sources along trench sidewall.

3) Pull excavated soil down into trench and compact soil into the original slope configuration. Slightly mound soil behind brush layers.

4) Move upslope to next trench alignment and repeat process.

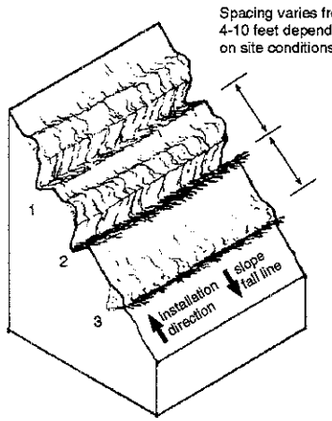


Figure 13. Brush layering

• DESCRIPTION AND FUNCTION

Brush layer planting consists of live woody plant material placed into the slope face along trenches excavated along slope contours as shown in *Figure 13*. This technique is most applicable to areas subjected to cut or fill operations or areas that are highly disturbed and/or eroded.

Layering provides the best technique to achieve soil reinforcement to resist potential shallow-seated landsliding events. Brush layers act as live fences to capture debris moving down the slope.

• PLANNING CONSIDERATIONS

This technique can be very disruptive to native soils and can trigger soil movements during installation. It is important to perform installation in phases and not to excavate more area than is necessary to install plant materials. If there are large quantities of loosened soils on the slope, layering is a good slope stabilization approach. Also, if imported soil material will be used to restore eroded areas, brush layering should be considered. It is best to install materials into the imported fill area and avoid disturbing existing soil structures. Use brush layering on slopes up to 1.5H:1V or in highly eroded gully areas. Plant material should be prepared as described under contour wattling except for the length of the collected material.

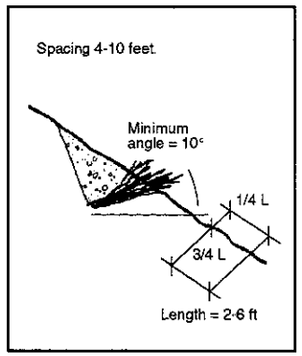


Figure 14. Brush layering detail

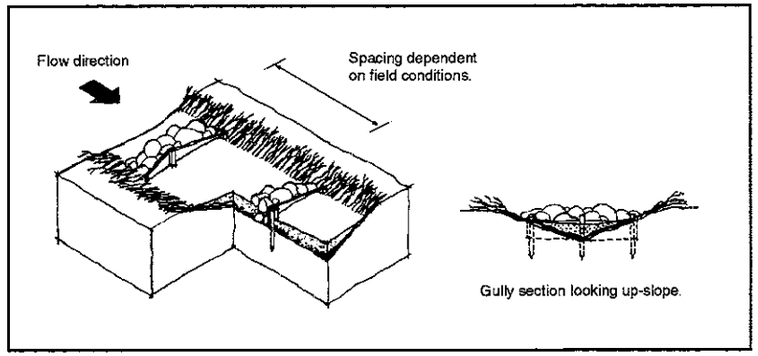


Figure 15. Brush layering for gullies

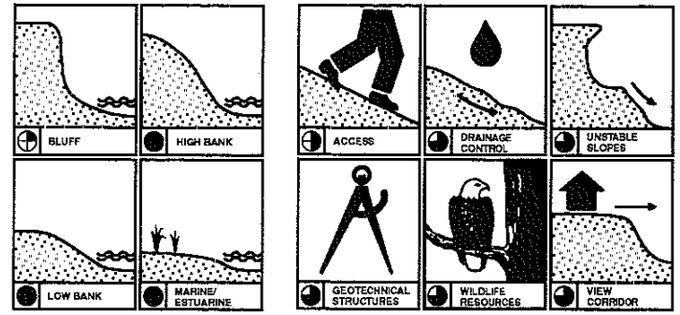
• LIMITATIONS

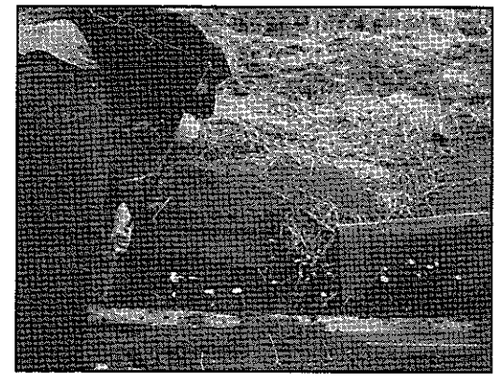
Not good for dense, stiff soil structures. Not recommended as a solution to gully erosion control unless technique shown on *Figure 15* is used to rehabilitate gullies.

• ADVANTAGES AND DISADVANTAGES:

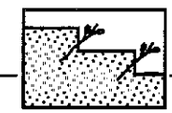
Advantages: Good immediate soil reinforcement and slope dewatering function, good erosion control capabilities for dry debris

Disadvantages: Labor intensive procedure, technique is intolerant to development of water channels (rills and gullies). Therefore, use technique for appropriate site conditions.





Brush layering in fill unit



AVOIDANCE/RETREAT OR BIOTECHNICAL SOLUTIONS

Although avoidance is not truly a planting procedure, it should be discussed as a viable technique to weigh when it comes to slope restoration using geotechnical engineering design and stability construction. For some sites it will be more economical for home-owners to relocate structures away from slope crests than to mobilize construction crews to perform traditional advanced geotechnical slope stabilization.

If structures can be relocated, greenbelts and low-impact slope planting may proceed with less risk to structures

Biotechnical engineering solutions use both vegetation and inert structural designs to address steep slopes greater than 1.5H:1V, known landslide areas, complicated drainage issues, and slope restoration programs.

For More Information

Elizabeth C. Miller Library
Center for Urban Horticulture
3501 NE 41st Street
Seattle, WA 98195
206/543-8616
Continuing Education
206/685-8033

International Society of Arboriculture, Pacific NW Chapter
P.O. Box 15729
Seattle, WA 98115
206/365-3901

Plant Amnesty
906 NW 87th Street
Seattle, WA 98117
206/783-9813

Puget Sound Water Quality Authority
P.O. Box 40900
Olympia, WA 98504
800/547-6863

Washington Native Plant Society
P.O. Box 576
Woodinville, WA 98072

Planning and Engineering Departments:

Washington Department of Ecology (WDOE)

Washington Sea Grant Program

Environmental Protection Agency (EPA)

National Oceanic and Atmospheric Adminstration (NOAA)

U.S. Army Corp of Engineers

U.S.D.A. Soil Conservation Service District Offices

Washington State University Extension Offices

Washington State Department of Fisheries (W.D.F.)

Washington State Department of Wildlife (W.D.W.)

Washington D.O.E. Shorelands Publications:

Vegetation Management: A Guide for Puget Sound Bluff Property Owners

Marine Shoreline Erosion: Structural Property Protection Methods

Shoreline Bluff and Slope Stability: Management Options

Note: This section and the glossary developed jointly with the Department of Ecology - Shorelands and with Elliott Menashe, 1993

Glossary

APPARENT COHESION
The resistance to soil particles separating from one another which is independent of soil particle forces.

BANK
The rising ground bordering the sea, a river, or lake. Also see BLUFF and CLIFF

BEACH
The zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation (usually the effective limit of storm waves) The seaward limit of a beach is the extreme low water line. A beach includes FORESHORE and BACKSHORE

BEARING CAPACITY
The load per unit area which the ground can safely support without excessive deformation.

BEDROCK
A general term for the rock, usually solid, that underlies soil or other unconsolidated, surficial material

BIOENGINEERING
In soil applications, refers to the use of live plants and plant parts to reinforce soil, serve as water drains, act as erosion prevention barriers, and promote dewatering of water laden soils

BIOTECHNICAL
In slope stability engineering, refers to the use of both live plant material and inert structures to stabilize and reinforce slopes.

BLUFF
An unvegetated high bank composed largely of unconsolidated deposits with a near-vertical face overlooking a body of water

BLUFF CREST
Upper edge or margin of a shoreline bluff.

BLUFF FACE
The sloping portion of a high bank

BLUFF TOE
The base of a bluff where it meets the beach.

BUFFER
A protective strip of vegetated land

CLEAR-CUT
A timber harvest method which removes all the trees on an area in one operation

CLIFF
A high, very steep to perpen-dicular or overhanging face of rock rising above the shore.

COASTAL ZONE
The sea-land fringe area bordering the SHORELINE where to coastal waters and adjacent lands exert a measurable influence on each other

COHESION
The internal resistance of indi-vidual soil particles to separate from one another

COMPETENCE
(1) In hydrology the ability of a current of water or wind to transport particles, emphasizing the particle size rather than the amount, measured as the diameter of the largest particle transported (2) In structural geology a sediment or rock layer, rigid and strong enough to transmit the thrust of flooding by lateral compression and capable of sustaining the weight of overlying strata or man-made structures without losing its structural integrity when arched or exposed to loading.

DECIDUOUS
Losing leaves or needles in the fall.

DRAINAGE (SOIL)
The rapidity and extent of the removal of water from the soil by surface runoff and by down-draw flow through the soil. Also, the natural and artificial means for improving this removal by a system of surface and subsurface conduits.

EARTHQUAKE
A sudden motion or trembling in the Earth caused by the abrupt release of slowly accumulated strain (by faulting or by volcanic activity)

EROSION
The wearing away of rock or soil and the movement of the resulting particles by wind, water, ice, or gravity, but usually excluding Mass Movements

EVERGREEN
A plant which retains its needles or leaves for more than one growing season.

EXTREME HIGH WATER (EHW)
The average height of the highest tidal waters reached during the year over a 19-year period

FEEDER BLUFF
An eroding shoreline bluff which supplies material to accreting shorelines

FLOW
A MASS MOVEMENT involving rapid flowage of wet soil, rock, and displaced vegetation as a VISCOUS mass down a slope or a channel; including mudflow, debris flow, and earthflow

FORMATION - (GEOLOGIC)
The ordinary unit of geologic mapping recognized by field criteria consisting of a larger, persistent, and mappable strata of predominantly one kind of rock or sediment type

GEOTECHNICAL
Refers to the application of civil engineering technology to some aspect of the earth.

GEOTECHNICAL STRUCTURES
Along coastal slopes, refers to slope protection designs such as retaining wall, revetments, and designed slope recontouring

GULLY
Large intermittent drainage channel developed from the erosion forces of drainages occuring from surface water runoff.

HARDPAN
A hard, impervious, often clayey layer of SOIL lying just below the surface. Sometimes synonymous for TILL

IMPERMEABLE
Having a TEXTURE that does not permit fluids to move through it freely.

INFILTRATION
The movement of water or solutions into or through a rock or soil through its INTERSTICES or fractures; the flow of rain water into soil material

INTER-DEPENDENT
A group of plants which growing together protect each individual from disturbance by wind, erosion or other natural processes Often shallow rooted trees will remain windfirm because they form a wide, spreading root mat

INTERSTICES
Openings or spaces in rock or soil that are not occupied by solid matter

INTERSTICES OR FRACTURES
The flow of rain water into soil material.

JOINT
A crack (parting or fracture) formed in rock by movements normal to the cracks and without shear movements (by displacement) of the rock on either side of the crack

LANDFILL
(1) The solid waste disposal process using land as the final disposal site (2) A fill area specifically for the purpose of creating additional dry land, usually accomplished by covering a wet or swampy area or slope face with sand or other suitable material.

MASS MOVEMENT
A unit movement of a portion of the land surface down a slope as a SLIDE, a FLOW, or SOIL CREEP in which gravity is the main driving force

NATURAL LANDSCAPE ELEMENTS
The natural watercourses, topography, hydrology and vegetation which comprise a particular site.

OVERSTORY
The portion of a forest that forms the upper crown cover.

PERCENT SLOPE
The direct ratio (multiplied by 100) between the vertical and the horizontal distance for a given slope; e g., a 3-foot rise in a 10-foot horizontal distance would be a 30 percent slope.

POORLY SORTED
Unconsolidated deposits that consist of particles of many sizes mixed together in an unsystematic manner so that no one size fraction predominates.

RILL
A tiny drainage channel cut in a slope by the flow of water Can develop into a gully with continuing erosion.

RUNOFF
That part of the precipitation that appears in uncontrolled surface streams, drains, or sewers It is the same as streamflow unaffected by artificial diversion, imports, storage, or other works of man in or on the stream channels

SATURATED
A condition in which the INTERSTICES of a material are filled with a liquid, usually water

SEISMIC
Pertaining to earthquakes or earth vibrations, including those that are man-made, e.g., explosions and underground nuclear blasts.

SHEAR STRENGTH
Resistance to lateral movement or failure along a potential failure surface.

SHORELINE
The intersection of a specified plane of water with the BEACH; it migrates with changes of the tide

SLIDE
A MASS MOVEMENT resulting from failure of SOIL or rock along a rotational or planar surface

SLOPE
The inclination of the land surface from the horizontal percentage of slope is the vertical distance divided by the horizontal distance, then multiplied by 100.

SLUMP
A SLIDE characterized by a rotary movement of a generally independent mass of rock or earth along a curved slip surface.

SOIL
In engineering work a soil is any earthen material, excluding hard bedrock, composed of 1) loosely bound mineral and organic particles, 2) water, and 3) gases
In agriculture, a soil is the loose surface material capable of supporting plant growth, and having properties resulting from the integrated effect of climate and living matter on the decomposition of bedrock and surficial deposits

SOIL ARCHING
A phenomena that transfers lateral soil pressure to adjacent rigid members (trees, piles, etc.) anchored in an unmoving soil or rock zone.

SOIL CREEP
The gradual and steady downhill movement of soil and loose rock material on a slope

STRATA
A layer of soil

STRATIGRAPHIC SECTION
Any sequence of rock units found in a given region (the oldest at the bottom and the youngest at the top).

TABLELANDS
The tops of bluff areas usually developed for homesites.

TENSILE STRENGTH
Resistance to rupture or failure due to tensile forces or pulling

THINNING
Tree removal in a forest stand that reduces tree density and numbers in a given area Most discussions of thinning stress increased growth and yield of timber.

TILL
POORLY SORTED and generally unstratified sediments, deposited directly by and underneath a glacier. Usually very hard and compact, with good bearing capacity and low permeability.

TOE OF SLOPE
See Bluff Toe

UNCONSOLIDATED
Said of sediment whose particles are loose and not cemented together.

UNDERCUTTING
The removal of material at the base of a steep slope or cliff or other exposed rock by the erosive action of waves, running water, or sand-laden wind

UNDERSTORY
Trees or other plants which tolerate reduced-light conditions and normally grow beneath the forest canopy.

UPLAND
A general term for elevated land above the beach which lies above the EXTREME HIGH WATER level.

WETLANDS (BIOLOGICAL)
Lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surfaces or the land is covered by shallow water

WETLANDS (JURISDICTIONAL)
Land forms which support under normal conditions a predominance of hydrophytic (wetland) vegetation, hydric (wetland) soil types, and wetland hydrology Typically, they are jurisdictionally defined as: "Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions (Federal Interagency Committee for Wetland Delineation, 1989)"

WINDTHROW
Trees blown over by the wind. Usually caused by thinning or adjacent clearing

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