Drainage Control and

Slope Stabilization on

Bluff Properties

Getting Started With Drainage Control

Drainage and erosion are a natural processes. Do not panic. Every coastal property has some degree of surface and groundwater flow. You will never be able to control these drainages entirely. So the goal of absolute drainage control is usually not technically feasible nor is it usually necessary. The practice of drainage control is really the practice of managing flows to the point where they are not contributing to accelerated erosion and landsliding along your coastal slope. Drainage and coastal erosion may be managed but not eliminated. Therefore, you must plan with them.

Surface and ground waters influence slope erosion and stability. Each year wet weather stresses many vulnerable properties to their points of failure which causes severe erosion and landsliding events around Puget Sound. These notable occurrences can usually be traced to the following issues: recent changes in the surface conditions around a property; accumulated small slope stability weaknesses that go undetected or unattended; or poor drainage system performance on a property.

You have probably observed some signs of slope distress during a wet weather season. As a coastal property owner, you should be aware of the role water plays in the short and long term stability of coastal slopes. Excessive soil erosion and land movements can create restoration costs and environmental impacts costs. Each of these costs is avoidable.
Although this website deals primarily with managing drainage issues along coastal slopes, other factors also influence slope stability and erosion of slopes. These factors include: subsurface geological characteristics; vegetation management on and above slopes; property modifications during property development; and coastal marine processes acting at the slope toe. Each of these factors should also be considered in your drainage planning to provide a comprehensive approach to slope stabilization and erosion control. Other Ecology publications are available to help with your planning.

The main sections are introduced on *Figure 1*. Each section builds on information presented in previous sections. So, it is important that you review each section of the website before skipping directly to specific sections.
Three basic steps can protect your slope against accelerated erosion and landsliding. ***First,*** understand your property. It is not an extensive effort to generally characterize your slope area and identify the water movement around the slope.
Second, identify problems and plan appropriate improvements into your site. Take the opportunity during property development to include drainage control with your landscaping work. On each coastal property, there are typical site constraints which must be considered. Identifying the opportunities and constraints of your site are key goals of your planning effort.
Third, carefully construct and maintain your drainage system. Taking the time to ensure that good materials and workmanship are used on your property cannot be overemphasized. Give your system periodic maintenance tune-ups.

Puget Sound Geology

Sand and gravel soils usually contribute to the stability of a slope in the absence of water. However, water readily flows through sand and gravel. Water can reduce the stability of the slope when it accumulates above a soil layer that is not as permeable as the sand and gravel. Water that accumulates above the impermeable soil layer and may flow laterally until it "daylights" as seepage on the slope face. In the Puget Sound region, the impermeable soil layer can be a silt layer within the sand and gravel unit or a silt/clay layer located under the sand and gravel deposits. The impermeable silt/clay layer was compacted under the weight of the overlying soil units and more importantly, the weight of the glaciers. Today's shoreline is a result of continuing geologic evolution since the time of the glaciers. At the top of the slope is a weathered zone (including topsoil) that is usually a few feet thick. Landslide debris and deposits from erosion and weathering can be found on the slope face and at the toe (bottom) of the slope. The debris and deposits usually consist of a jumbled mixture of all the geologic soil layers that make up the slope as well as vegetation that moved down the slope.

Information on the geology and the relative stability of coastal slopes can be found in the Coastal Zone Atlas of Washington (see links section for more information). This atlas can often be found in the public library reference or atlas section or at local county planning and engineering departments.

Natural Slope Processes

Under natural forces of gravity, wind, and water, coastal slopes continue to change. The slope will generally change from both erosion and soil mass movement (landsliding). The majority of erosion in the Puget Sound area is due to the wearing away of soil or rock by the movement or flow of water. Erosion can also include wearing away of soil by wind and ice. Landslides occur when a mass of soil moves down the slope under the force of gravity. Figure 4 shows the general form of various erosion and mass movement (landslide) features.

Puget Sound Coastal Slope Processes

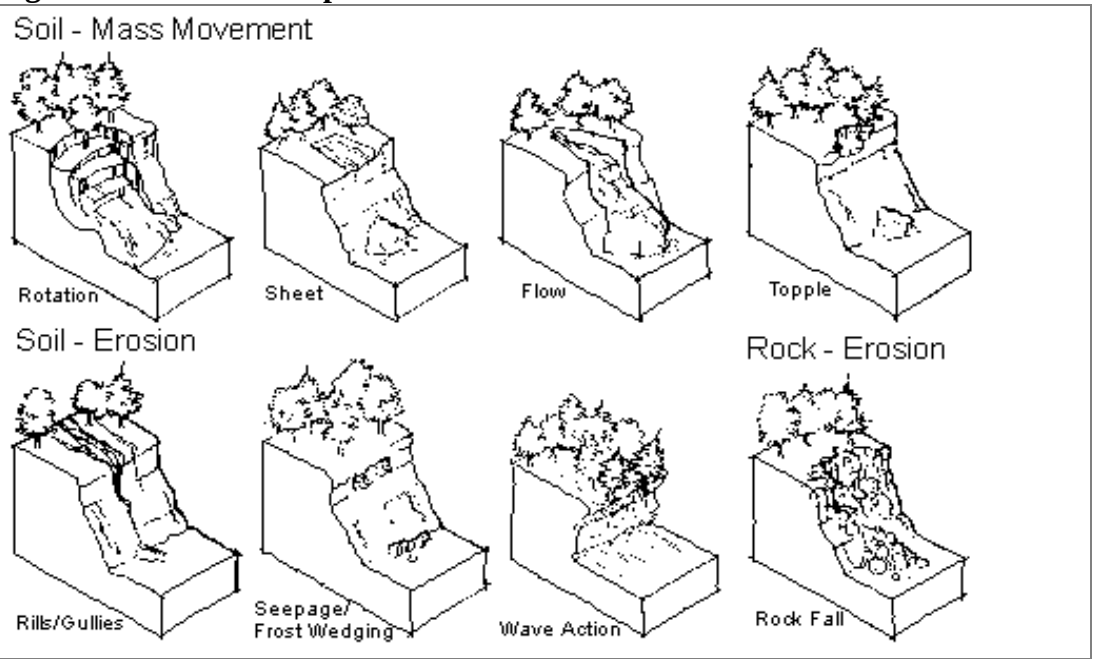

Figure 4. Typical Puget Sound Coastal Slope Processes

As erosion and landsliding occur, they change the shape of slopes. In general the overall shape of the slope will become flatter and less steep. This tends to increase the overall stability of a slope. However, erosion and landsliding can leave localized areas of a slope steep and unstable. Other factors can affect slope stability. For example, if slope topography is changed by adding soil to the top of slope or the toe of the slope is removed, the slope angle will eventually adjust under the forces of gravity to achieve a more stable slope configuration. Also, if significant water is added to the slope such as what might occur during and after intense rainfall, the sudden increases in surface water on the slope and ground-water seepage may reduce the stability of the slope to the point where a landslide occurs. Figure 5 schematically illustrates a landslide movement on a bluff face.

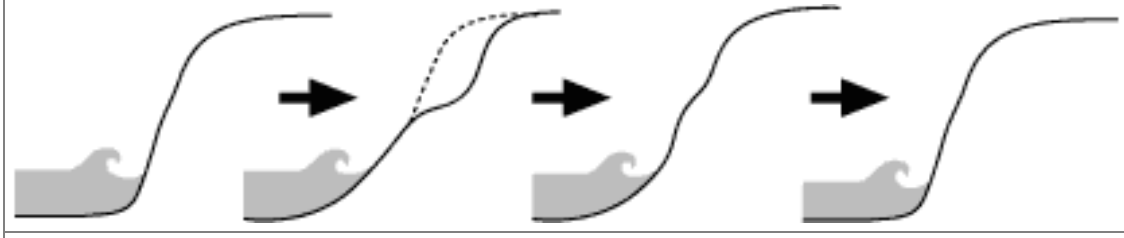

Figure 5. Change of a bluff face.

As a property owner, you will want to reduce the hazards associated with these natural processes to acceptable levels of risk. Your efforts should be directed to reducing factors which adversely affect slope stability. In some cases it is not economically or physically possible to eliminate or reduce all the adverse factors associated with slope stability and erosion.
With this website you can generally evaluate your slope drainage and identify measures that can be taken to improve slope stability and erosion.

Surface Water and Groundwater
Surface water and groundwater are the two sources of water that contribute to your coastal slope drainage and can accelerate erosion and slope stability problems. Figure 6 shows general drainage movement down a slope. Surface water (as the name indicates) is water that flows across or is ponded on the ground surface. This can include surface water features, sheet flows and concentrated flows. Surface water features can include puddles that form during rainfall. This water usually infiltrates into the soil and becomes groundwater. Other more permanent features include ponds and wetlands that also contribute to groundwater by infiltration. When surface water features become full and overflow they can contribute to concentrated flows or sheet flows.

Figure 6. General surface water and groundwater movement down coastal slopes.

Sheet flow is most easily recognized as a thin layer of water flowing over smooth paved areas. Sheet flow is common across parking areas, driveways, and large sloping expanses of lawn. Sheet flow can concentrate into rills and small channels. Sheet flow can also migrate to other areas and seep into more permeable surfaces such as sandy soils. This process converts surface water sheet flow into groundwater.

Concentrated surface water flow can originate as natural or constructed channels, streams, drainage ditches or as discharges from ponds and wetlands. Concentrated surface water flows can also include discharges from rooftops, roads, and parking areas. These flows are often collected and discharged through downspouts, drainage swales, culverts, and other drain pipes. Surface water flow volumes and velocities can be large and will generally occur during and after heavy rainfall periods. Less frequently they occur as a result of discharges from other sources such as fire hydrants, failing stormwater detention facilities, and drainage systems that are poorly maintained. Water velocity increases on steeper ground where the water flows faster due to the force of gravity.

Groundwater location and movement is generally related to the geology and soils comprising your slope. Groundwater can be located within several feet of the ground surface or deeper in the slope at a sand/clay boundary or in cracks and seams in hard soils or bedrock as shown on Figure 6. Groundwater often accumulates or seeps at more than one level in a slope.

Slope Stability and Drainage

The characteristics that influence the stability of your slope include geology, slope drainage, slope topography (shape and steepness), changes to slope topography by placing soil or removing soil from the slope, and undercutting from coastal erosion processes. This section focuses on slope drainage and how it affects slope stability. Later sections will discuss what you can or cannot do to change your drainage characteristics to improve slope stability.

Under the influence of gravity, water appearing as surface water or groundwater travels in the direction of least resistance. Water can move in many directions on the surface or in the soil but one fact remains constant - if it moves, it will ultimately move to a position of lower elevation. Often rain or surface water infiltrates into a weathered soil layer, perches on top of relatively impermeable glacial till, and exits on the slope face as seepage where it becomes surface water flow.

Deeper groundwater can also affect slope stability as it travels down through a sand and gravel layer and perches on a silt or clay layer. Perched groundwater can occur at shallow depths (less than 10 feet) or at greater depths below the crest of the slope. Often a slope will have several groundwater zones.

Groundwater often causes slope stability problems when it is present in a sand and gravel layer and is perched on top of a silt/ clay layer. The water can act as a soil lubricant which reduces the friction between the sand and silt/clay layers causing the sand to slide on top of the clay. In addition, as the groundwater daylights and exits the slope as seepage, it may erode the sand causing the soil above the sand to become unsupported and fail. Sometimes both the erosional and lubricating effects of groundwater are responsible for large landslides.

Surface water flow can infiltrate into the soil and saturate a loose or weathered layer of soil on the slope crest or face. The saturated soil is heavier and may also be lubricated by the water. This can also cause the soil to move downslope as a debris flow or mudslide.

Slope Erosion and Drainage

Surface water flow can cause erosion of soils on the crest and face of your waterfront slope. Usually, the most severe erosion occurs where surface water flows are concentrated. The steeper the slope angle and higher the slope, the greater the potential is for erosion. Some soil types are more erodible than others. For example, soils such as sand and gravel are more prone to erosion than are silt and clay. However, once silt and clay are disturbed, they are highly erodible. Erosion can also cause soil on adjacent slope areas to become steeper to the point that they are susceptible to landsliding.

Surface water often causes severe erosion to coastal slopes where pipes are allowed to discharge onto the slope. Over time the water discharging from the pipe erodes away vegetation and soil (or rock). If this process continues, the soil erodes until the pipe no longer directly discharges onto the slope. Instead, the water discharges like a waterfall cascading down onto the slope. The farther water falls, the faster it drops and the more energy the water has when it impacts the soil. With more energy the erosion progresses at a faster and faster rate. Ultimately, the erosion undermines the pipe (which then can break) and potentially results in a rapid retreat or erosion of the top of the slope.

This same scenario can be repeated for concentrated surface drainage that flow over the top of a slope. Over time, concentrated flows can create a substantial gully. If water volumes are large and/or velocities are high, a deep gully can form very quickly, even within hours.

Sheet flow can also lead to substantial erosion. Sheet flow naturally tends to concentrate into small rills and channels of water. Flow concentration occurs more rapidly on bare ground, sloping ground, and where long distances are involved. The small rills and channels can concentrate into larger and larger features if left unattended.

It is critical that surface water flows be controlled since they can lead to rapid, severe erosion of your property. Control is particularly important for newly developed or modified property. Something as simple as regrading your driveway can change surface water flow patterns and cause erosion. Often the first heavy rain locates potential problem areas. Immediate adjustments to new site development and existing site properties should be performed to avoid erosion problems. The use of erosion control methods during construction (short term) and for long term erosion prevention are important for reducing the effects of erosion on slopes (see links section for more information).

Evaluating Slope Drainage

Slope surface water and groundwater can have a major impact on coastal slope erosion and stability. In landslide prone areas, the presence of groundwater in your slope or surface water on your slope is usually the primary factor leading to landsliding and erosion.

Severe erosion and landsliding typically occur during or shortly after periods of heavy rainfall. It is important to understand the magnitude of water flows that can be involved with coastal properties. The quantity of water affecting coastal slope areas can be quite significant. A large storm can drop over 4 inches of water in a relatively short (24-hour) period. If this water falls on the roof and driveway surfaces of a typical waterfront residence (say 5,000 to 10,000 square feet of area), it can result in over 25,000 gallons of water. Additionally, if this pattern is repeated on many hundreds of properties which are upslope of your property, it can have serious erosion and slope stability implications for your property.

Although rain falls on property regardless of site features (i.e. trees versus houses), site development does tend to cause more rapid and concentrated runoff. Also, on undeveloped land much of the rainfall never reaches the ground. It is captured by foliage and evaporates back into the atmosphere. If rapid concentrated runoff is permitted to flow onto or into the slopes it can have a serious impact on slope stability and erosion. Because of the impact to coastal slopes, it is important that you understand your specific slope drainage conditions and identify the sources contributing water into and onto your slope. If you can identify the sources of slope surface and groundwater, you can then take steps to control some of these sources. The Coastal Property Owner Slope Drainage Checklist can help you organize the observation of surface water and groundwater conditions on your property. You may also share your checklist observations with other professionals who assist you in your drainage control efforts.

Evaluating Surface Water

The best time to observe surface water flows is during periods of rainfall. Put on your raingear and walk around on your property. Make notes on the locations where you see surface water flows including where they originate, along what path they flow, and where they go. Pay particular attention to roof, driveway, and parking drainage. Also, note the behavior of flows from drainage ditches, culverts, and pipes that are located on your property or that originate on adjacent properties and discharge onto your property. Figure 7 (below) shows some common surface water problems on slopes.

Evaluating Groundwater

You usually will not know groundwater is present unless you observe it "daylighting" as seepage on your site. Daylighting groundwater can be present on level or gently sloping upland portions of your site or on the slope crest, face, or toe. You might also encounter shallow groundwater while digging into the soil on your site.

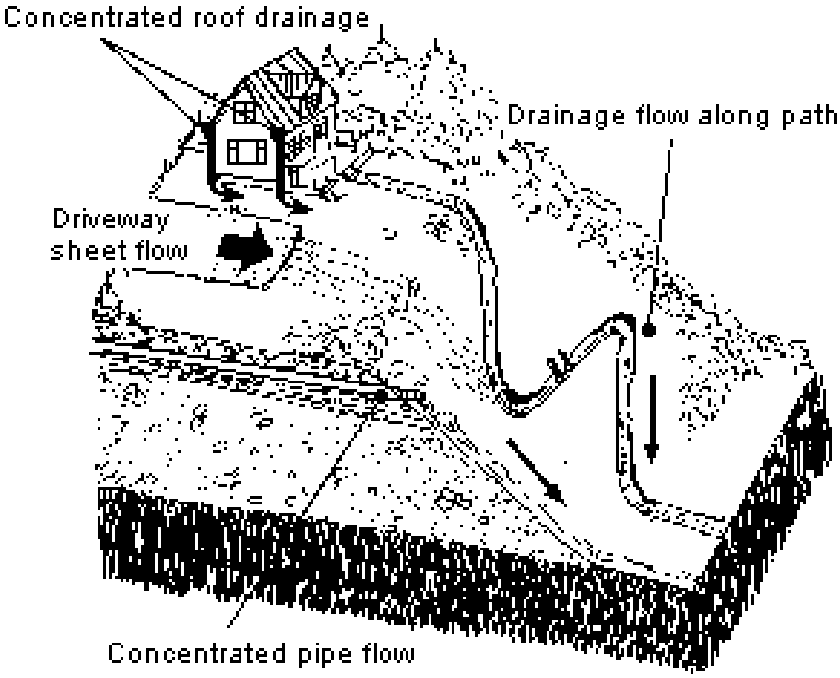

Figure 7. Common surface water problems

Groundwater indicators are generally similar for gentle or steep site slopes. However, on level or gently sloping uplands you may have trouble identifying where groundwater daylights due to standing surface water. Distinguishing between surface water and groundwater on level or gently sloping ground may require you to observe the site during drier weather periods when surface water is minimal.

Because seepage is related to the geology of your site, groundwater will often daylight on the slope at the contact between different soil types and often where there is a change in the slope angle. It is important to try and identify the locations of groundwater discharges that appear on your slope (slope crest, face, and toe). The locations may help you and others assess whether there is a practical or cost effective approach to manage slope drainage. The best time to observe your slope for groundwater is late in the wet season (mid to late winter into spring) and during a dry period between storms. During a dry period daylighting groundwater should not be misidentified as strictly surface water flow.

Figure 8 shows typical ground-water evidence on a slope.
When looking for indications of groundwater seepage during a dry period look for:
A wet sheen or surface water appearing along a zone on the slope.
A wet soil zone on the slope.
Distinct changes in slope vegetation. Look for vegetation adapted for wet soils located along a zone on the slope. A few common indicator plants are horsetail, willows, salmonberry, and skunk cabbage. These plants may also be located below active seepage zones.
Daylighting groundwater seepage at soil layer boundaries.
Daylighting groundwater seepage at changes in the slope angle.

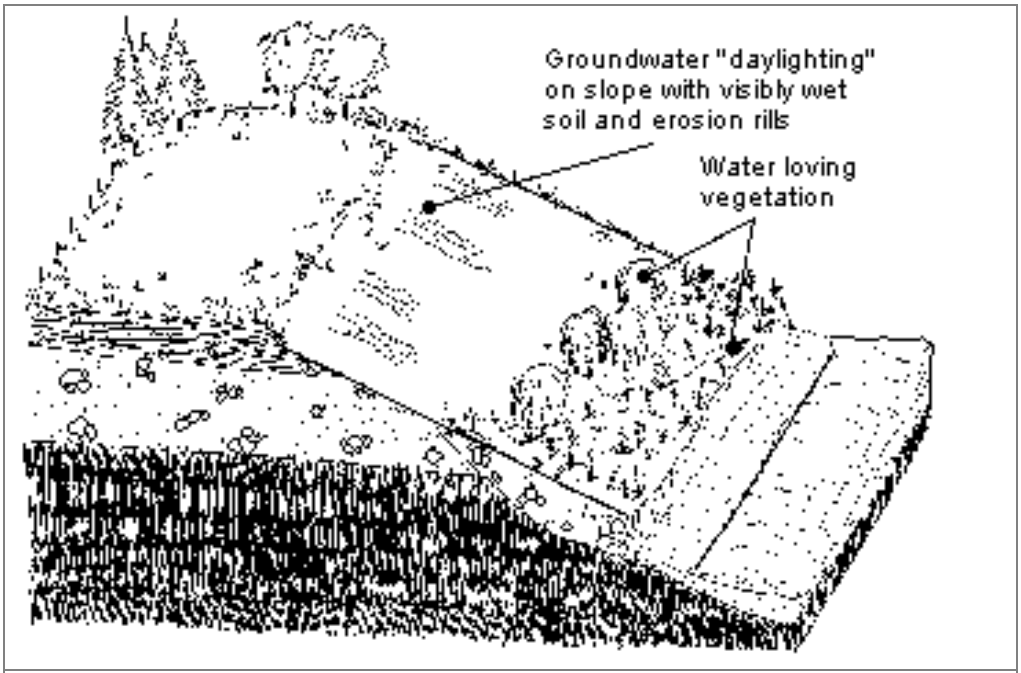

Figure 8. Typical groundwater evidence on a slope.

Changes to Slope Drainage Characteristics

Previous site development grading and landscaping on your property may have significantly changed natural drainage patterns. If your property is undeveloped, site development will significantly affect existing slope surface water and groundwater flow. Modifications to slope drainage that can impact your property include the following actions:

Routing new or existing drainage sources to an existing natural drainage course, catch basin, pipe, or culvert or routing drainage directly onto a neighbor's property. Routing drainages to areas that are not able to accommodate the flows can cause erosion and/or slope stability problems.

Site grading that changes the slope and contour of the site. Site grading can cause surface water to channelize or sheet flow to flow to a different location which can lead to erosion and/or slope stability problems.

Converting permeable surfaces to impermeable surfaces such as roof, driveway, parking, or compacted earth areas. These development features cause an increase in stormwater runoff (compared to rain that falls on native vegetation). This increases the potential sheet and concentrated flows that can cause erosion and slope stability problems.

Slope cutting or filling and vegetation removal for views and beach access. Cutting and filling on a slope can impact slope stability and can also alter existing drainage paths. Removing vegetation can significantly reduce slope stability. The companion documents Slope Stabilization and Erosion Control Using Vegetation and Vegetation Management: A guide for Puget Sound Bluff Property Owners should be referenced for further information on slope vegetation management practices and erosion control.

Source Control
Reduction or prevention of surface water runoff should be the first and is often the least expensive approach to reducing drainage problems. Problems are typically created by collecting rainfall from large impervious areas and discharging the flow to adjacent pervious areas. The rapid addition of runoff to the discharge location exceeds the discharge area's capacity to dissipate the flow. Consequently, the runoff moves across your site as an uncontrolled surface flow with the ability to cause slope stability and erosion problems.

To minimize surface water flow try to reduce the amount of impervious surface around your property. If you do collect water from impervious areas, try to reintroduce the water over a large area which does not affect slope stability. A slow release of the water from a detention storage facility may also be appropriate for some properties which do not have suitable discharge areas. You should contact an engineer to investigate this option for you.

Minimizing the degree of site modification to your property may also help avoid some of the slope stability problems associated with site development. Modifications to property include: conversion of native vegetation areas into landscaped zones; driveways which alter drainage flow paths; removal of vegetation along a slope; beach access construction; regrading a property; disturbing/compacting native soils; ineffective drainage control systems; pipe discharges onto a slope; unstable earth fills; and technically unjustified bulkheading.

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.

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 below. 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.

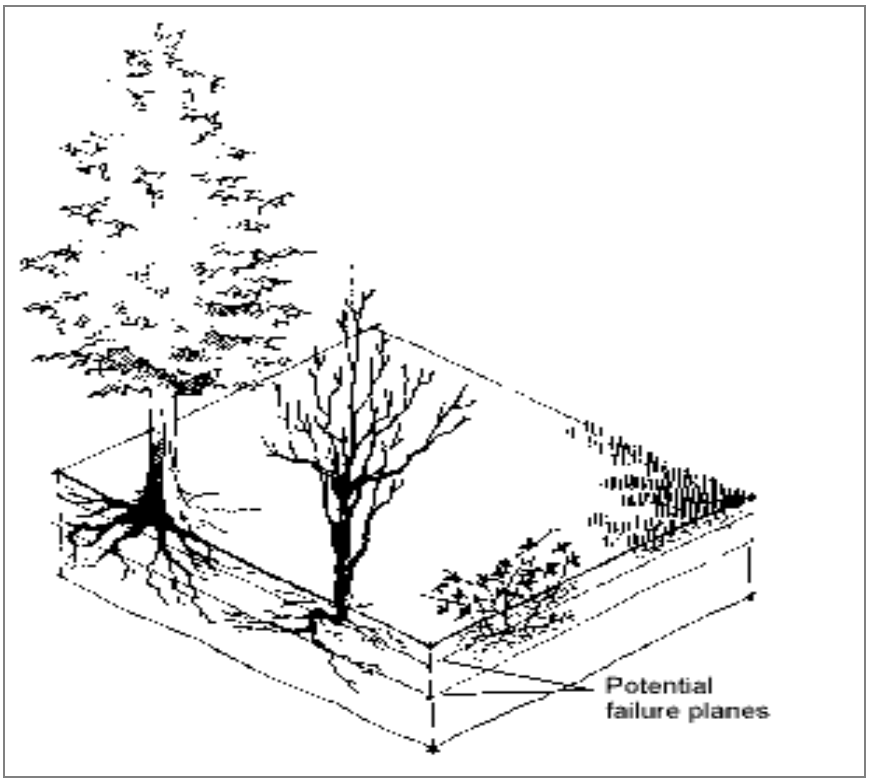

Figure 7. Root Reinforcement of a Slope

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 strengthen 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 site 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 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 propagating. 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 (11/2- 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.