SURFACE WATER AND GROUNDWATER ON COASTAL BLUFFS:

A GUIDE FOR PUGET SOUND PROPERTY OWNERS

Sponsored by:

SHORELANDS AND WATER RESOURCES PROGRAM
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Olympia

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Forward

During the weeks following Christmas, 1994, we received numerous telephone calls from coastal property owners concerned about recent landsliding on their bluffs. Residents reported large and small slides, damaged stairways and bulkheads, old trees that had been undermined, and settling of yard areas near the bluff edge. On further discussion, we found that most of these slides occurred during two short periods of heavy rain in late December.

In each case it appeared that problems had been exacerbated by poorly designed or improperly constructed drainage systems. Although property owners were often aware of potential problems, they did not fully appreciate the relationship between drainage and slope stability and they often did not understand the operation nor the limitations of their existing drainage system. In many cases, it appeared that simple measures might have greatly reduced the amount of damage.

Coastal slopes on Puget Sound are inherently unstable areas. Our experience suggests that careful management of site drainage is probably the most cost-effective approach to minimizing bluff hazards. Even where circumstances dictate significant structural stabilization efforts, such as shoreline bulkheading or regrading of slopes, site drainage remains an essential component of the solution.

At Ecology, we would like to encourage both safe and environmentally sound shoreline development. Dealing with drainage wisely has little adverse impact on our beaches and shorelines and bears few of the environmental consequences associated with extensive shoreline bulkheading or major clearing and grading of coastal slopes.

Hugh Shipman
Washington Department of Ecology

USING THIS PUBLICATION

Surface Water and Groundwater on Coastal Bluffs provides coastal property owners with general information concerning the management of water on coastal slopes The publication introduces the relationships between coastal geology, water, and slope stability. General criteria for evaluating site drainage and potential drainage control techniques are presented in this booklet. The information presented can guide a successful drainage control program specific to a coastal slope area.

This publication is the third in a series of Washington Department of Ecology booklets focusing on specific slope management practices for Puget Sound coastal property owners. Other publications in the series are entitled *Slope Stabilization and Erosion Control Using Vegetation: A Manual of Practice for Coastal Property Owners* and *Vegetation Management: A Guide for Puget Sound Bluff Property Owners.*

The Ecology property owner booklet series presents a range of slope maintenance techniques designed to prevent accelerated erosion and landslide failures along Puget Sound coastlines. Each property owner may use the publication series differently to assist in their unique slope management needs and decision-making.

An informed and coordinated approach to site planning, drainage control techniques, low-impact slope stabilization, and vegetation management around your slope can help you avoid many of the typical slope failure scenarios repeated along Puget Sound waterways. Additionally, when you generally understand your plans and goals, you can communicate your issues to other individuals or to a local permitting agency

COASTAL LAND OWNERS

Property owners can use this publication to help plan drainage control improvements for their property. Readers can use this information to effectively communicate their goals to a contractor and participate in the design, construction, and maintenance of their system. This information may also help readers avoid some of the common pitfalls of drainage control practices along coastal slopes.

For problematic sites, you should seek professional assistance. This booklet contains basic water management information necessary to make initial site evaluations and reasonable improvements to site drainage. Information in this booklet should be used with other applicable resources.

Contractors

Contractors should find some of the subjects in this publication useful in presenting information on drainage control to property owners who are unfamiliar with different approaches to drainage problems. Techniques and practices presented in this publication should help emphasize to property owners the need to maintain at least minimum installation and material standards to achieve successful performance from a drainage system.

Real Estate Agents

Real estate professionals can use this publication to address some typical questions of potential property purchasers when they visit coastal properties and are uncertain about slope drainage. Clients who are new to coastal slopes may be interested in the general drainage control approaches for their property.

Governmental Permit Agencies

Agencies that review permit requests or inspect construction projects should find this publication helpful in assessing proposed or installed structures that may affect the stability of private properties or public resources. Some traditional upland drainage control techniques can be ineffective and may contribute to the slope stability problems of coastal properties. Consequently, many stability and erosion control problems could be avoided if guidance is made available to landowners and contractors.

Professional Assistance

To locate technical experts such as experienced registered engineers specializing in geotechnical and/or drainage projects, use local telephone directories or call the Seattle or Kitsap branch of the American Society of Civil Engineers (ASCE) for membership references. The ASCE branches serve both sides of Puget Sound.

Additionally, some local public works offices maintain lists of engineering design professionals that practice in your area. When hiring any professional, you should get information on their qualifications and experience in specific technical areas.

GETTING STARTED WITH DRAINAGE CONTROL

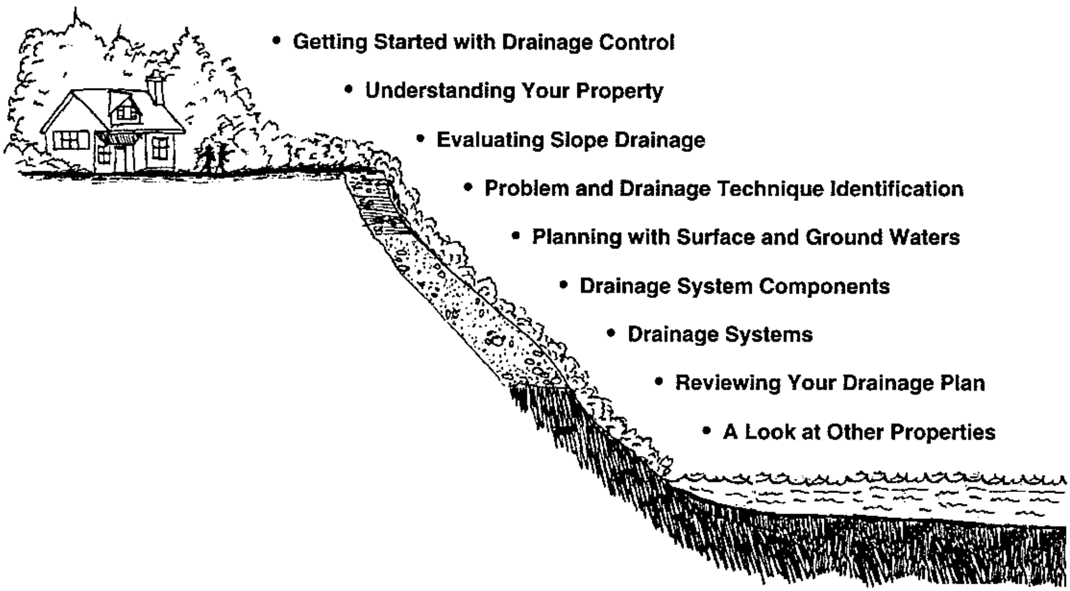


Figure 1. Sections of this booklet.

Drainage and erosion are 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 publication 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. Refer to the booklet section *For More Information* on page 61.

The main booklet 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 booklet 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.

Understanding Your Property

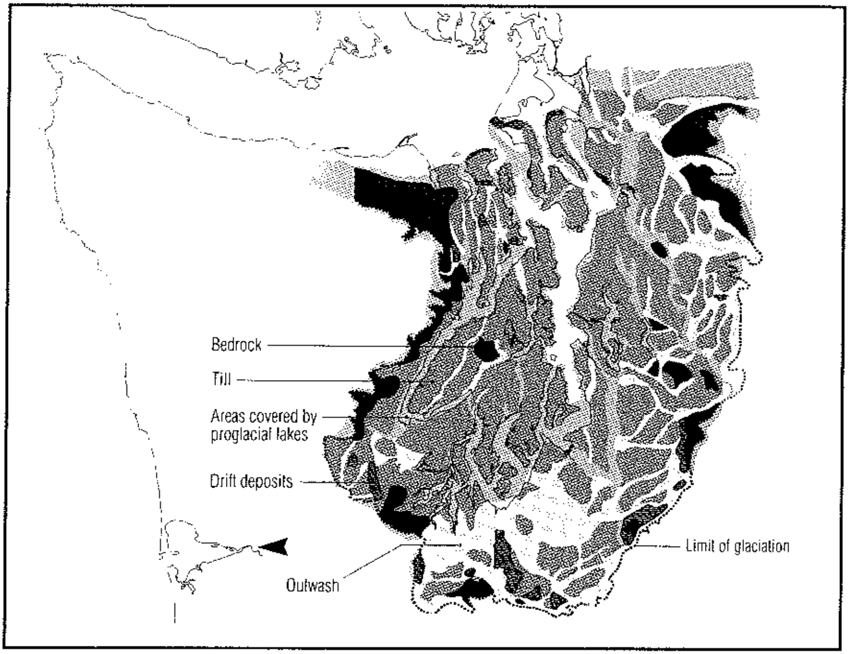


Figure 2. Glacial sediments in the Puget Sound lowlands *(from Downing, 1983. Used with permission of the Washington Sea Grant Program).*

In the construction industry, glacial till is frequently referred to as hardpan because it is very dense, making it difficult to dig. Hardpan is a mixture of clay, silt, sand, and gravel. Water infiltrates through this soil very slowly and consequently water will often accumulate or "perch" above the glacial till during and after wet weather periods.

Puget Sound Geology

Most of the Puget Sound geology that influences coastal slope drainage and stability is a result of past glaciations. *Figure 2* shows the general geology of the Puget Sound area. The glaciers deposited the soil layers that make up your slope. A common soil layer sequence found along coastal slopes is shown on *Figure 3*. The layers consist of glacial till, sand and gravel, and silt/clay. Your shoreline bank or bluff could be composed of one or more of these soil layers. Some isolated areas of Puget Sound shorelines consist predominantly of rock instead of soil.

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.

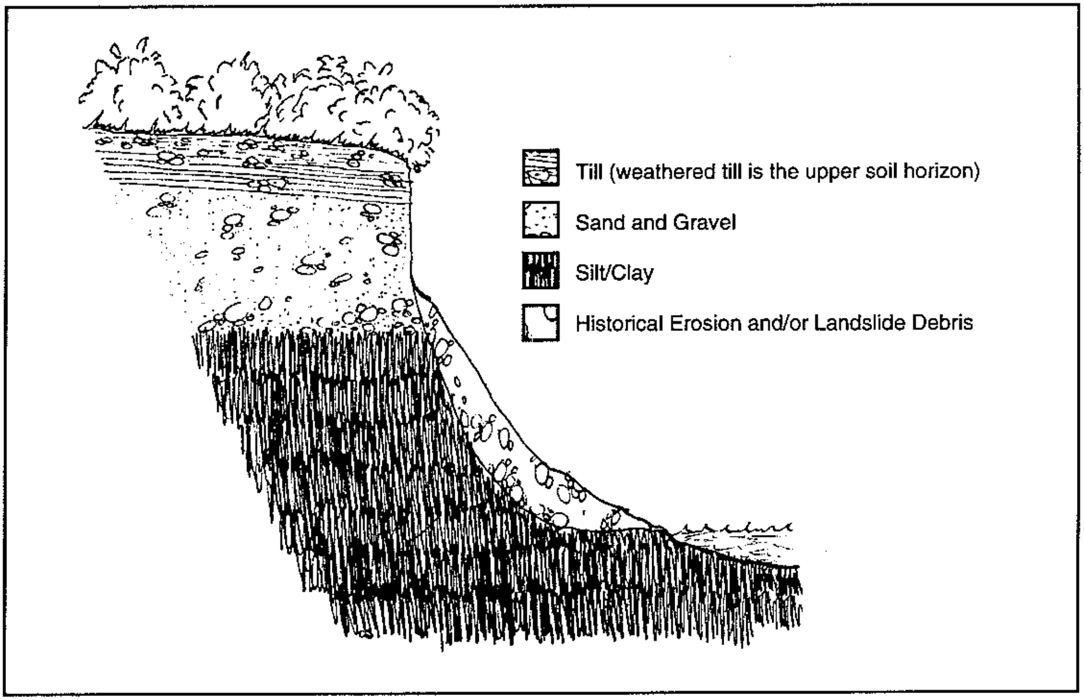


Figure 3. Common soil layer sequence found along coastal slopes.

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 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.

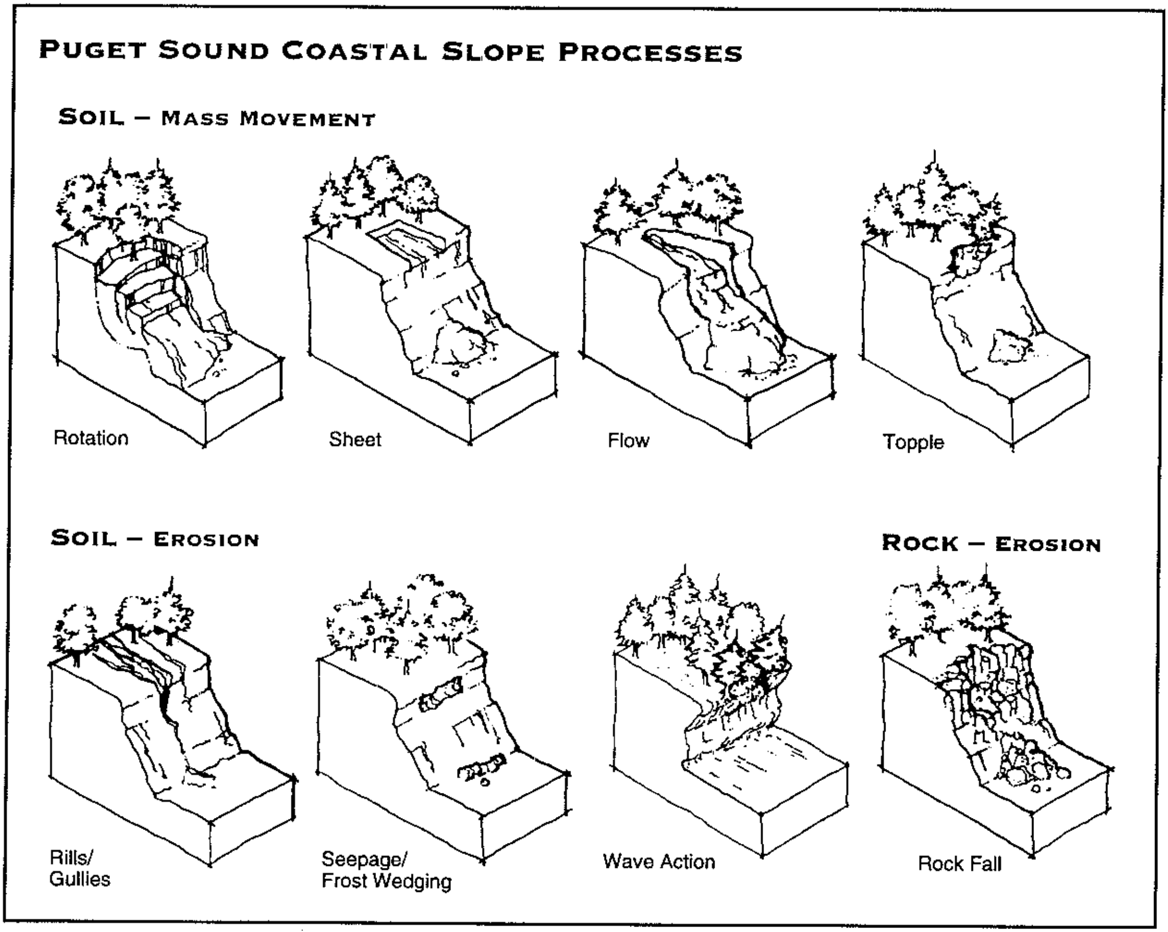


Figure 4. Typical Puget Sound Coastal Slope Processes.

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 groundwater 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.

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 booklet you can generally evaluate your slope drainage and identify measures that can be taken to improve slope stability and erosion.

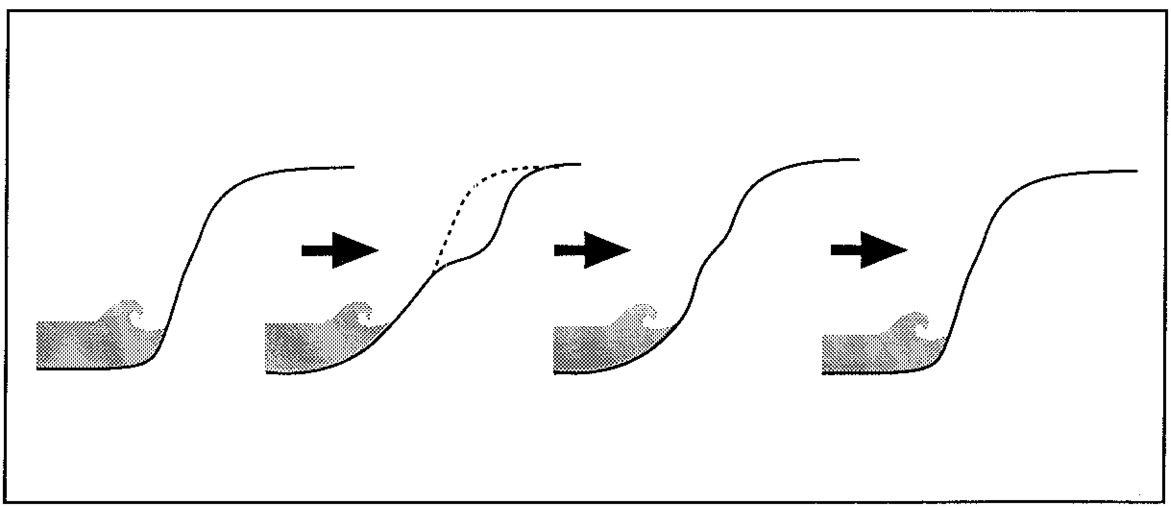


Figure 5. Change of a bluff face

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.

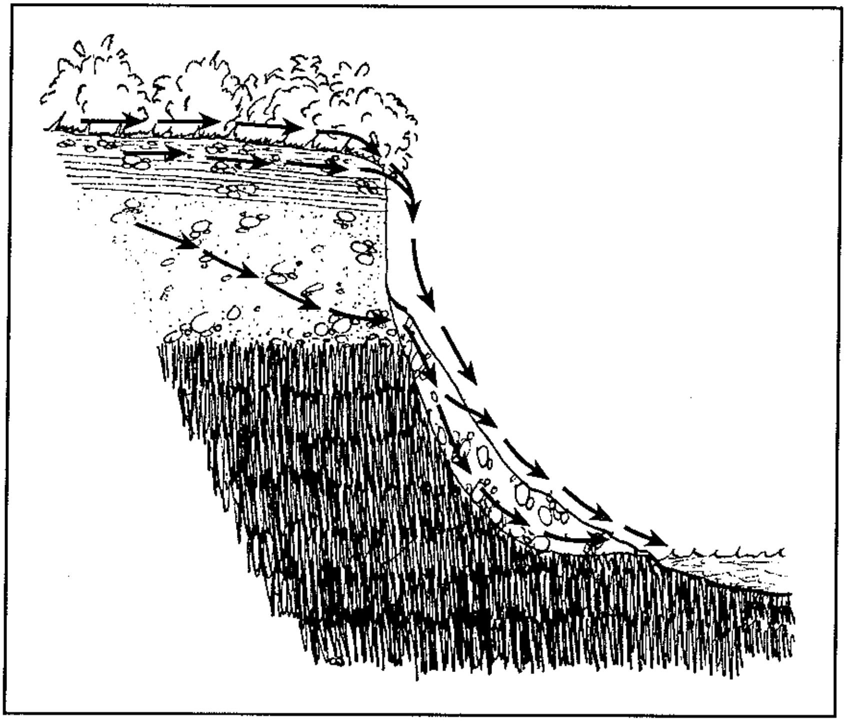


Figure 6. General surface water and groundwater movement down coastal slopes.

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.

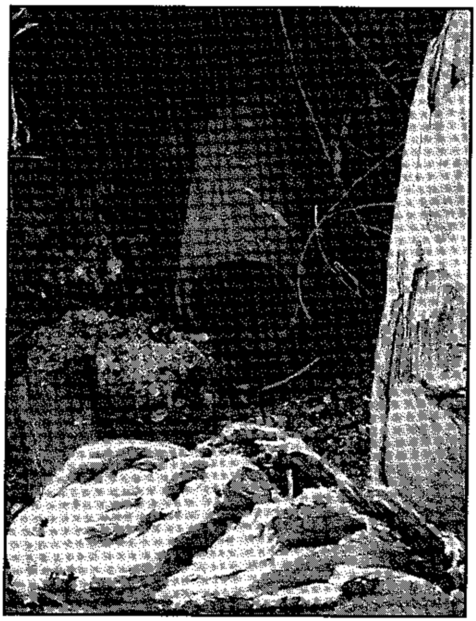
Slope Stability and Drainage

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.



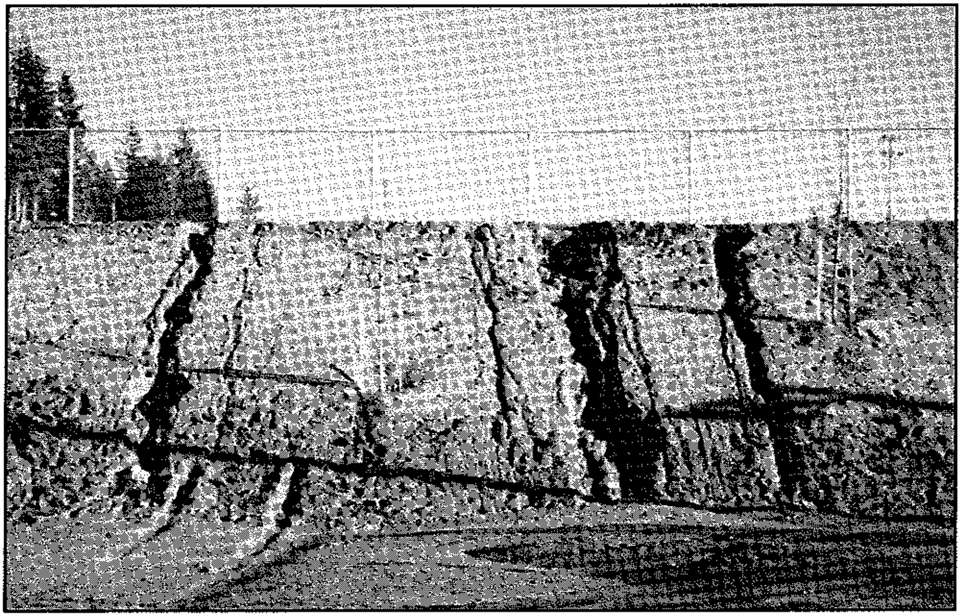
Pipe erosion caused by broken pipe.

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.



Rill and gully erosion on constructed 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 section *For More Information*).

Evaluating Slope Drainage

As you now know, 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* at the end of this section 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* 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 ground-water while digging into the soil on your site.

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.

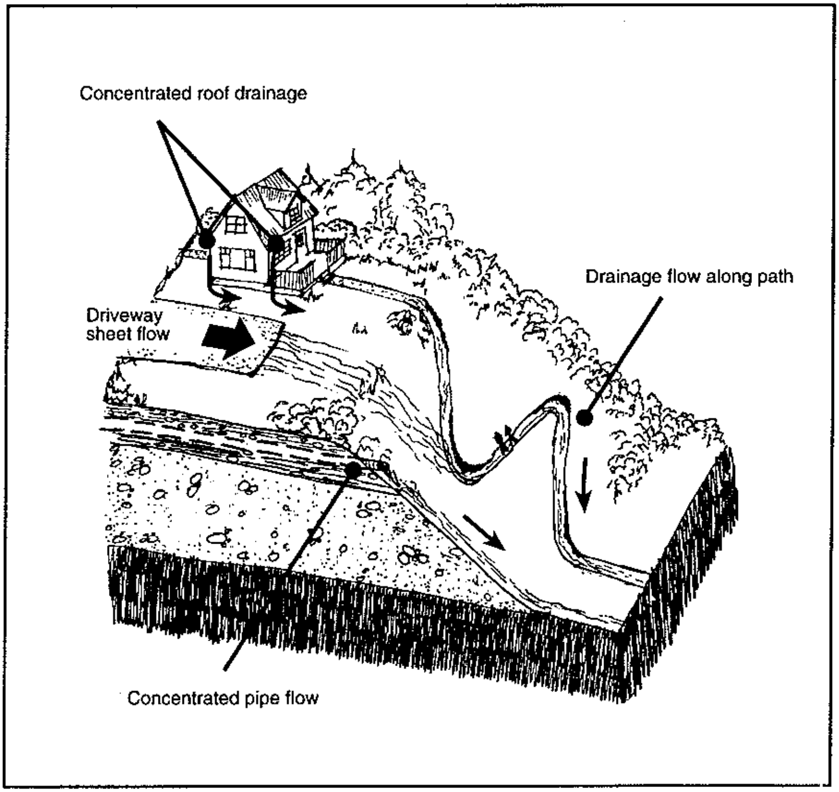


Figure 7. Common surface water problems.

Horsetail

Skunk Cabbage

Salmonberry

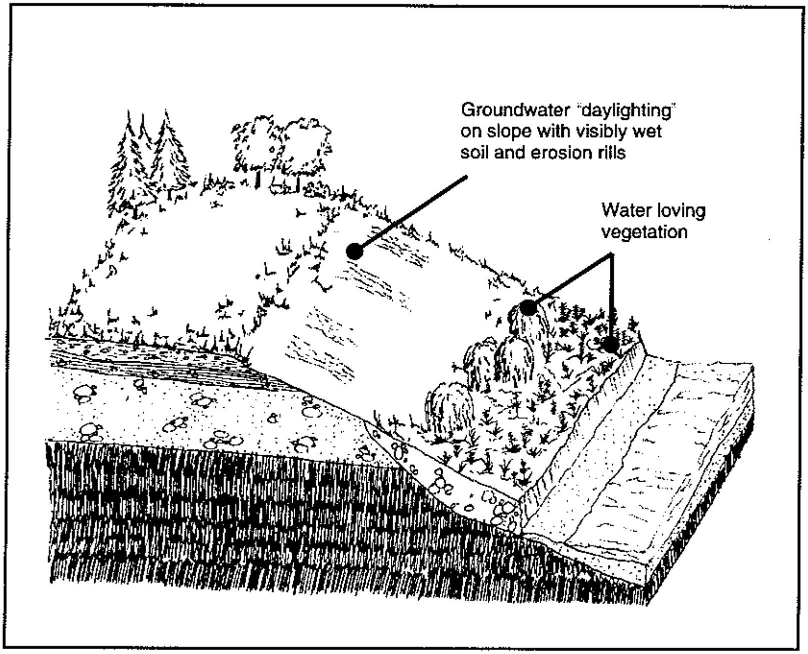


Figure 8. Typical groundwater evidence on slope.

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 groundwater 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.

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 develop ment 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.

Special Needs Areas

Should you recognize or suspect that your property or adjacent properties contain any of the following, you should contact the suggested resources for assistance or information.

1. Historical or recent landslides based on your observations or from Coastal Zone Atlas Mapping [A,F,J]
2. Groundwater seepage located more than 10 feet below the crest of slope with landsliding or significant erosion of the slope [F]
3. Your site drainage will affect adjacent properties [A,F,I]
4. Your septic system discharges or seeps onto the slope [A,E]
5. Surface water flows from off-site sources affect your property [A,I]
6. You need to understand and implement erosion control techniques for property development [A,B]
7. Pipe outfalls located below ordinary high water elevation of Puget Sound [A,B]
8. Site ponds, streams, or wetlands [A,B,C,H]
9. Coastal marine erosion [A,D,F,G,K]
10. Habitat for endangered, threatened, rare animal species (e.g. bald eagle or osprey nests/alternate nests/perch trees) [D]

A - Local Planning Office and Engineering Department

B - Washington Department of Ecology – Water Quality Program

C - Army Corps of Engineers, Seattle District

D - Washington Department of Fish and Wildlife – Habitat Division

E - Local Health Department

F - Geotechnical Engineer

G - Coastal Engineer

H - Wetland Professional

I - Civil Engineer specializing in drainage

J - Washington Department of Natural Resources – Geology and Earth Resources Division

K - Washington Department of Ecology – Shorelands Program

Coastal Property Owner Slope Drainage Checklist

Slope Characteristics

Slope Height:

- ☐ less than 10 feet
- ☐ 10 feet to 50 feet
- ☐ greater than 50 feet

Slope Angle:

_____ degrees (see discussion in *Slope Stabilization and Erosion Control Using Vegetation*)

Slope Vegetation:

- ☐ bare soil areas
- ☐ vegetation cut, removed or cleared
- ☐ mature vegetation (trees, shrubs and groundcover)
- ☐ water loving plants (horsetail, skunk cabbage, willow, salmonberry, etc.)

Slope Geology:

- ☐ sand or sand and gravel
- ☐ glacial till
- ☐ silt/clay
- ☐ rock

Landslide Indicators:

- ☐ recent slide
- ☐ bowl-shaped slope configuration
- ☐ hummocky ground
- ☐ leaning trees or bowed trunks
- ☐ areas of low brush (blackberry) /bare areas

Coastal Zone Atlas:

- ☐ landslide area
- ☐ unstable
- ☐ intermediate stability
- ☐ stable

Beach Access:

- ☐ stairs
- ☐ wide path/road
- ☐ tram
- ☐ narrow path

Site Surface Water

Surface Water Features:

- ☐ stream channel
- ☐ ponds/wetlands

how far from crest of slope? ____________________

- ☐ flows down/over the slope
- ☐ tightline down slope
- ☐ erosion evidence: rills, gulleys, etc.

Surface Water/Storm Water Flows:

- Sheet flow from:
  - ☐ driveway
  - ☐ parking area
  - ☐ lawn
  - ☐ other
- Roof downspouts empty:
  - ☐ onto ground
  - ☐ into buried pipe
  - ☐ other
- Outlet for downspout pipe:
  - ☐ into soil or on surface of slope
  - ☐ tightlined down slope
  - ☐ unknown (test with hose)
- Other pipe/culvert discharges:
  - ☐ onto slope
  - ☐ tightlined down slope
  - ☐ other
- Areas where surface water disappears into ground?

  ☐ Yes ☐ No
- Seepage/water noticed along beach access path?

  ☐ Yes ☐ No

Site Groundwater

Groundwater observation:

- ☐ seepage on slope: crest, face, or toe?
- ☐ wet soil zone: crest, face, or toe?
- ☐ vegetation indications of wet soil: crest, face, or toe?

Location of observed groundwater:

- ☐ Near-surface soil seepage 1 to 3 feet below crest of slope
- ☐ Groundwater seepage 5 to 10 feet below crest of slope
- ☐ Groundwater seepage on slope face more than 10 feet below crest or at slope toe

Other Site Features

Location of:

- Septic system
  - ☐ between house and slope
  - ☐ behind house
  - ☐ N/A
- Irrigation system
  - ☐ any leaks
  - ☐ summer use only
  - ☐ control valve off and lines drained in winter
- Downspout infiltration system
  - ☐ between house and slope
  - ☐ behind house
  - ☐ not applicable
- Landscape yard drains
  - ☐ tightline down slope
  - ☐ discharge onto slope
  - ☐ unknown (test to find out)
- Landscape pools/ponds/fountains
  - ☐ between house and slope
  - ☐ behind house
  - ☐ not applicable
- Hot tub(s)/swimming pools
  - ☐ between house and slope
  - ☐ behind house
  - ☐ not applicable
- Where are tub/pool/pond/fountains drained?
  - ☐ into a tightline drainage system
  - ☐ onto slope
  - ☐ below slope
  - ☐ onto ground
  - ☐ unknown (test to find out)

Distance of site features from slope crest:

____

____

____

____

____

____

____

____

Other Resources:

Have you reviewed other information from Ecology in this booklet series to help you?
(See section *For More Information*)

____

____

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Problem and Drainage Technique Identification

Now that you have identified the general drainage characteristics of your property, it is important to get an idea of whether you should consider your drainage observations as problematic to slope stability and erosion control. If you note any changes in your slope geometry or surface characteristics during wet weather, it is very likely that drainage is driving the failure. Consequently, it is important to know the initial condition of your property in order to assess any changes. Should you have concerns, get some technical assistance. Once you've identified problem areas, appropriate drainage techniques in *Table 1* can be reviewed which may address your drainage problem. One or more of these techniques can be chosen to make up your drainage system. Refer to the section on drainage systems for more details on each technique

Drainage Technique	Drainage Characteristic		
	Shallow groundwater less than 10 feet below slope crest	Deep groundwater more than 10 feet below slope crest	Surface water
Interceptor Drain	●		●
Relief Drain	●		●
Strip Drain	●		●
Interceptor Swale	●		●
Stormwater Detention Storage	●		●
Slope Drains	●		●
Horizontal Drains, Well Systems Drainage Blankets	●	●	●
Contour Wattling	●		●
Revegetation	●		●
Toe Drainage	●	●	●
Erosion Control	●		●

Table 1. Drainage characteristics and potential applicable drainage control techniques.

PLANNING WITH SURFACE AND GROUND WATERS

After spending time evaluating the drainage characteristics of your property, completing the checklist and locating potential problem areas, you may feel ready to start taking action on your drainage issues. However, before you go forward you should take advantage of published information, public agency guidance, and opinions from technical experts in specific areas (see section *For More Information*) Seeking additional resources and guidance will allow you to clarify or modify your checklist notes on your property. You should resist jumping from your initial property observations directly to the installation of drainage control elements If you spend just a little time with site planning, you may be able to pull the pieces of your drainage observations into a coordinated system which can help you avoid relocating problems from one area to another.

CREATING A PROPERTY DRAWING

Making a plan (drawing) is the best way to organize your drainage control system and is certainly the best way to communicate your approach to others *Figure 9* shows an example drawing. Nearly everyone feels comfortable with pictures. Your drawing will help everyone associated with your property clearly know the nature and extent of your proposed work. Governmental agencies that may be involved in project permit approval usually request if not require a property drawing or plan. The drawing may be part of a more formal submittal to an agency usually called a drainage control plan. The plan may include a drawing of your property and some written descriptions of the project. Regardless of the different reasons for a plan, it is in your interest to create a drawing because of the following:

- A drawing helps you cost-effectively coordinate and locate your planned improvements in relation to other property features;
- A drawing helps you clearly communicate your drainage control goals to potential contractors which should help you obtain good work proposals and accurate cost estimates;
- A drawing helps avoid damage to property;
- A drawing helps form a basis of communication between property owners, contractors, and agencies that is clear and positive; and
- A drawing can be used to record locations of constructed drainage improvements.

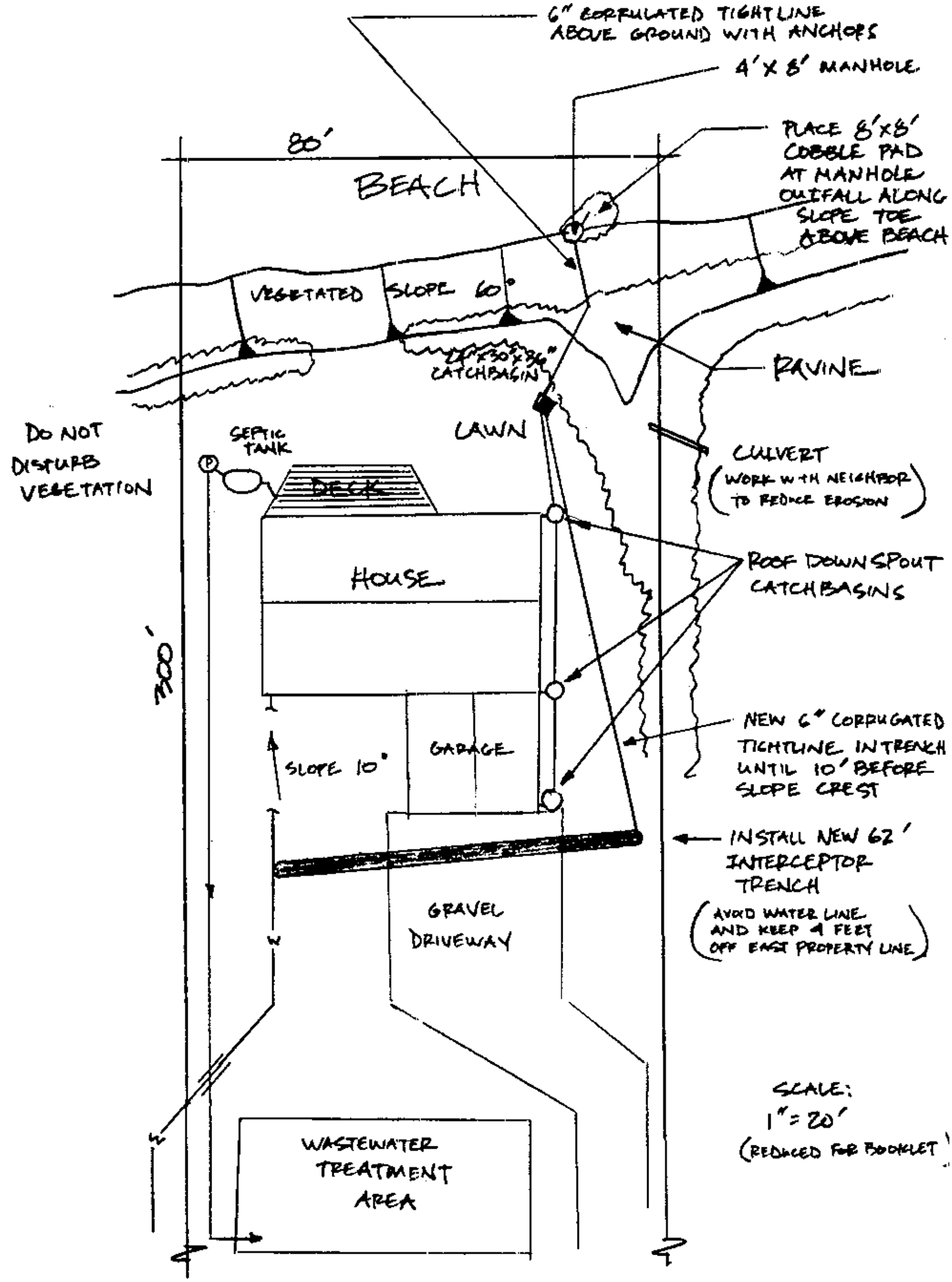


Figure 9. Example of a drawing.

Elements of the Drawing

There are three primary types of information you are likely to put on your drawing: general topography, existing features, and planned features. Each of these pieces of information is fairly easy to acquire. For topography you have the choice of either hiring a professional surveyor to do a boundary and topographic survey or generating portions of the plan yourself.

If the planning area is small with the topography contours and boundary lines easily established, you may decide to undertake the work yourself. To begin the drawing, you must identify the locations of your property corners and general property dimensions. You will need a pencil, a protractor, straight edge and an engineer's scale or ruler in order to sketch the configuration of your property on a large sheet of paper. Using a scale of one inch on paper equals 20 feet on your property usually works fine for most sites where the planning area is restricted to under an acre. Otherwise, you can use a scale of one inch equals 30 feet or greater.

Setting topographic contours or grades in a small open area of roughly a couple hundred feet square can be performed measuring or estimating the vertical drop per 100 feet. The feet dropped in 100 feet equals the average slope angle in percent (i.e. 2 feet in 100 feet equals 2 percent). On steep slopes, you may be able to only approximate the grade but still be sure to identify the locations of your observed features.

For most sites there are enough complex issues or enough area to cover that it helps to hire a surveyor to do a topographic site plan. The surveyor can also locate any existing features on your property that you identify. The locations of roads, houses, landscaping, outbuildings, the top and bottom of slopes, existing drainage features, and septic systems can all be included in your topographic survey work. Remember to check any survey against what you actually observe on your property. Typically, you will need to add more detail to your plan than what is shown

Now that you have most of the information shown on your plan, the last remaining bit of information is to identify features that are part of any planned construction. With your plan showing existing site information you can now locate potential drainage improvements on your site. Review this booklet along with other references before choosing the final location any proposed drainage system improvements.

The Department of Ecology Water Quality Program as part of the Puget Sound Water Quality Management Plan suggests that both small and large parcel construction projects put together an Erosion and Sediment Control Plan. The Water Quality Program identifies small parcels as properties having: individual, detached single family residences and duplexes; created or added less than 5,000 square feet of impervious area (driveways, parking lots, roof area, etc.); and land disturbing activities of less than one acre. Your plan may satisfy all or part of any erosion and sediment control plan.

Check with your local public works department for more details on specific drainage or drainage plan requirements. A typical drainage plan package submitted to your local building and planning office usually includes the following basic information: location of property and physical description of the property; a scaled plan (drawing) of the property showing accurate locations of existing and proposed structures and topography; locations of drainage system(s) and erosion control measures; limits of site disturbances; locations of any required setbacks and critical areas; and identification of the final points or areas of water discharge.

Regulations and Ordinances

The state Hydraulics Act, designed to protect fish and their habitats, requires that an HPA (Hydraulics Project Approval) be obtained for any work that occurs in state waters. An HPA will typically be required for shoreline bulkheading, placement of drainage outfalls below the ordinary high water line, or any modification of the beach.

Coastal bluffs are sensitive ecological areas and may be identified as critical habitats or may support rare or protected wildlife species. Heron rookeries and trees used as eagle nest sites are examples of protected habitat areas. Contact your local planning office or the Department of Fish and Wildlife's Habitat Division.

The Shoreline Management Act (SMA) applies to many activities that occur within 200 feet of the shoreline. Each local government administers the SMA through its Shoreline Master Program and each jurisdiction may regulate activities differently. Contact your local planning office to see what activities require a shoreline substantial development permit and which are exempt on your particular shoreline.

Local jurisdictions may require permits or approvals for some types of drainage work. In general, individual property owners are not subject to permit requirements for stormwater control and discharge. Outfalls from subdivisions larger than 5 acres may be required to obtain an NPDES (National Pollution Discharge Elimination Standard) permit. Contact your planning and public works departments or the Ecology water quality program staff at the Permit Coordination Center for more specific information that affects your property.

Drainage System Components

There are several drainage components that are fairly common in most drainage systems. This section introduces some basic components that are part of the drainage systems described in the following section – *Drainage Systems*. Successful construction involves selecting the appropriate materials for the collection, conveyance, and discharge requirements of your system. Attention to proper capacity and durability of each drainage material is critical. The performance of your system will be improved by using good construction techniques and by performing routine periodic maintenance.

Drainage Materials

The quality and availability of drainage products vary greatly from area to area. However, with a couple of weeks of preplanning, any material can be delivered to your site at a reasonable cost. Consequently, do not settle for poor quality materials when you can have any item you need with just a phone call.

• Drainage Pipe

Drainage pipe is available in rigid wall and flexible wall lengths. On individual lots most applications require fairly small diameter pipe (4 inches to 12 inches). Generally, plastic pipe is used by contractors based on cost, ease of installation, and availability. The walls of pipe vary from thin and corrugated to thick and solid. Each pipe type has some degree of flexibility over the length which has many advantages in slope applications and some disadvantages. The biggest disadvantage is that the installer must check the grade of the pipe to confirm there are no reverse slopes or low points along the length of pipe which may reduce the performance of the drainage system.

A variety of solid and perforated pipes shown with a strip drain

The least expensive pipe selection is usually the thin corrugated pipe which is available at most home centers and discount stores. The pipe is very flexible and is sold in coils of one hundred feet or greater. This pipe may be satisfactory for very shallow installations without significant backfill or backfill compaction, but it can fail easily by being crushed during installation with heavy equipment and by the weight and compaction of soil backfill. It may also be susceptible to degradation by ultraviolet light. Finding watertight connections (couplings) can be a problem with thin corrugated piping. Duct tape is not a long-term connection solution. Using corrugated pipe with thicker walls and watertight connections can help avoid the crushing and leaking problems common with thin-walled pipe installations

Other plastic pipe is available including corrugated pipe with smooth interior walls, rigid pipe, light duty and heavy duty pipe, and perforated and non-perforated pipe. Aluminum culverts and concrete cylinder pipe are available for surface water routing under road surfaces and down slopes. Culvert pipes are usually purchased in diameters of 12 inches or greater.

Plastic drainage pipe are produced from different materials but are commonly made with polyvinyl chloride (PVC), polyethylene (PE), and high density polyethylene (HDPE) material.

Rigid pipe is sold in short lengths of approximately 10 to 20 feet and requires good connections at each end. Pipe sold in coils requires fewer connections which is a benefit but may have a low strength for wall crushing or buckling depending on the pipe manufacturer's specifications. Ask your pipe supplier about pipe details.

Perforated pipe allows water to enter or exit through small openings along a length of a pipe. The openings can be circular or slots. The more opening space per foot of pipe, the greater the capacity of the pipe to collect and move water. Slotted pipes have an advantage over pipes with small holes because they tend to reduce the amount of fine soil particles that get pulled into a drainage system and discharged downstream. Solid pipe has no openings in the walls and is commonly referred to as tightline pipe in drainage applications.

• **GEOTEXTILE**

A geotextile is a permeable fabric material made from synthetic polymers. Geotextiles are used in many engineering applications. The primary functions of a geotextile in drainage applications are filtration and drainage. Simply, the geotextile retains the soil while water passes through the fabric and into the drainage collection system. Geotextiles used in drainage applications can be woven or nonwoven fabrics. The woven geotextiles have a weave pattern while the nonwovens are formed from a random pattern of fibers bonded together.

Typical drainage applications include interceptor drain construction, drainage blanket installation and geotextile wraps for pipes. For interceptor drains, the geotextile is used to line the trench prior to backfilling with gravel drain rock to limit the migration of the adjacent soil into the gravel backfill. For drainage blankets, the geotextile is used in a similar manner, except it is more commonly placed on a slope or a more horizontal location. Sometimes, the geotextile is wrapped directly around pipes for ease of construction at difficult locations.

Geotextiles can be obtained from local distributors. Each distributor represents multiple manufacturers of geotextiles. The geotextiles can be picked up directly or shipped from the distributor to the buyer. The geotextiles are commonly sold by the roll, with few distributors willing to sell smaller quantities cut from a roll. The common roll width is 12.5 feet with a typical total square yardage per roll ranging from 500 to 600 square yards (sy). The cost to buy quantities less than a full roll varies depending on distributor.

It is important to differentiate between landscape fabric available at local hardware and garden centers and appropriate geotextiles for drainage applications. Typically, landscape fabric is not durable and will eventually clog which can lead to serious slope stability issues. See the section *For More Information* for geotextile material sources.

• Catchbasins and Manholes

Drainage systems need a method to collect and concentrate water flow at a location. Catchbasins and manholes allow pipes coming from different directions and elevations to converge at specific locations. They can convert surface flow to subsurface pipe flow. Catchbasins and manholes can trap larger sediment and debris allowing only drainage with fine sediments to enter pipes. Also, they can provide a drop in elevation down a slope and dissipate the energy of pipe flows. Catchbasin and manhole structures are commonly constructed of concrete or polyethylene and have a number of lid options ranging from open grates to watertight construction.

• Pipe Couplings

A pipe coupling connects one length of pipe to another without leaking. They are sold as rigid or flexible connections. Improper or poorly retrofitted connections on drainage pipes are very common failure locations. It is important to use a good connection system or couplings specifically manufactured for your pipe. The couplings should have a watertight gasket seal. When pipe is placed above ground on a slope and is not anchored correctly or has too much flow resistance, you will likely see a coupling failure in the future. By planning ahead, you can minimize the number of couplings by ordering longer lengths of pipe.

• Pipe Anchors

Pipe anchors should be used for pipes on steep slopes. Pipe bends should be adequately supported. Water flowing downhill can place tremendous forces on pipe connections and bends. Do not underestimate the need to resist these forces by anchoring and supporting the pipe. Pipe anchors are not purchased but are built in place. Pipes should be anchored above grade as well as below grade. *Figure 10* illustrates a number of anchoring systems.

• Drainage Gravel

Drainage gravel should be rounded rock ranging in size from $^3/_4$ inches to $1^1/_2$ inches in diameter. The gravel provides a uniform bedding for drain pipes to create a consistent pipe slope and provide a free draining material adjacent to perforated pipes. Water moves through the spaces between the gravel before entering a pipe or other means of conveyance. This material is usually delivered to your property by a gravel supply company

Installation Considerations

Always mark the locations of utilities before you begin construction. You can call the Utilities Underground Location Center "1-call" at 1-800-424-5555 for a free service that will locate the utilities that service your property. Utilities can include power, telephone, water, gas, cable, and others. There may be some utilities and underground features that only you know about (power to an outbuilding, drainage lines, buried tanks). Be sure to also locate these utilities prior to construction.

Drainage system installation should be done during dry weather periods except in emergency situations. Excavations can quickly be flooded with water making proper construction difficult and dangerous. If there is a lot of water present while excavating soil, you will have sediments accumulating in the gravel openings, on the geotextile, in pipes and catchbasins, and in marine waters where the drainage will eventually discharge.

Avoid construction when the ground is wet. Your system will perform better with dry weather construction and not cause sedimentation in other areas.

Before you complete the installation of your system check to make sure pipes have not been crushed by heavy equipment. Make sure each connection is solid and not leaking. Check the slope of pipe runs. It is a common practice to water test your drainage system before covering it with soil (backfilling).

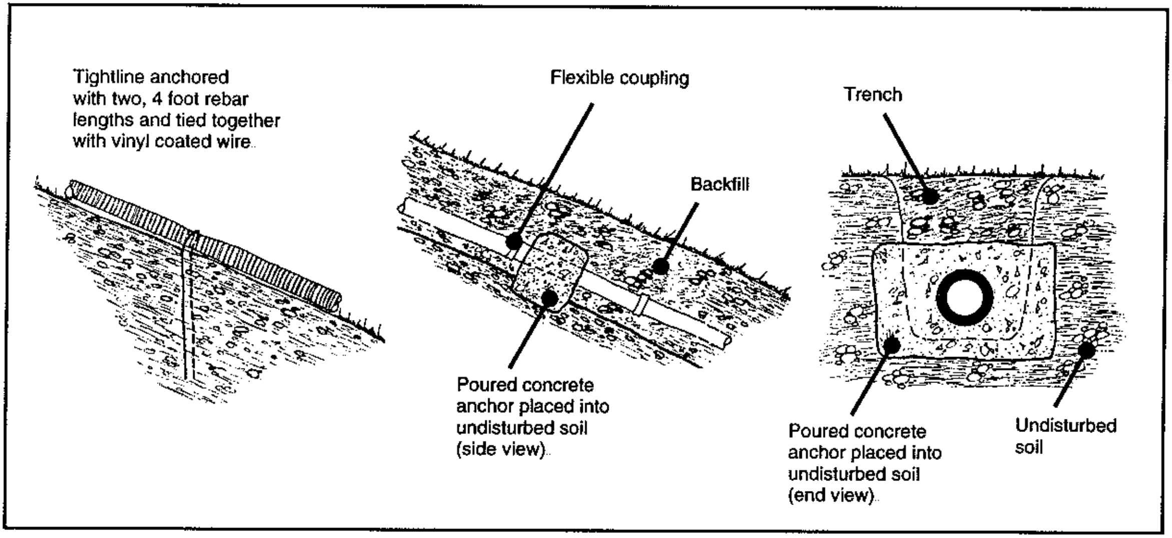


Figure 10. Anchoring Systems

Water must move downhill so double check to see that water moves to your planned locations. If you do not do the installation yourself at least observe your construction so you can help troubleshoot any future problems. Make a photo record of the work if you have a camera handy.

During construction you should take your plan drawing and sketch onto the plan what actually was installed. Important items such as locations, depths, sizes, and problems will help you improve or expand your system later. A system "as-built" will also help you or a future property owner avoid damaging the system during other site improvement work.

Care and Maintenance

Every drainage system needs some periodic inspection to see that the system performs properly. Surface features like yard drains, roof drain catchbasins, manholes, swales, above ground pipes and couplings, pipe anchors, and discharge areas can be quickly checked. Catchbasins and manholes are usually designed to capture debris and heavier sediments and will require the removal of a few buckets of material from time to time to prevent pipe clogging and discharge of material into water bodies.

Below ground drainage features like pipes, strip drains, couplings, and overall system performance should be checked regularly for signs of failure during rainfall events. Overflows, leaks, wet areas, flow bypassing your system, and discharge interferences can be noted and immediately repaired if you detect the problems early.

Drainage Systems

Approaches to drainage issues will usually fall into two general types of solutions which incorporate drainage minimization solutions and drainage control system solutions. Each group of solutions helps manage slope stability and slope erosion at your property. The practices introduced in this section are general and cover basic drainage management techniques around coastal slopes. Consequently, any single technique by itself may not sufficiently address the broad range of drainage issues occurring on your property. Nor may this publication discuss in sufficient detail the application of each technique to the unique characteristics of your property. Therefore, it is always a good practice to reference other information sources before making the final selection of your drainage system.

General slope shapes for Puget Sound shorelines used in this publication are shown in *Figure 11*. Use *Figure 11* to approximate some of the slope shapes that are familiar to you. When you identify your general shape(s), you can match drainage control techniques with your property characteristics identified in your

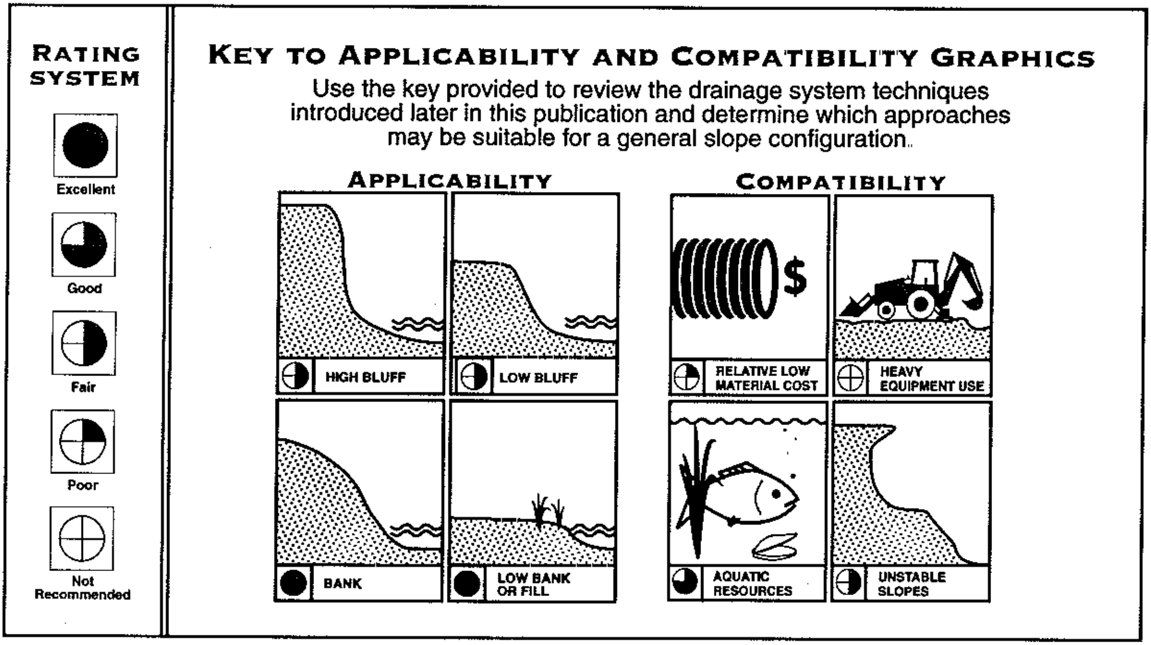


Figure 11. Indicates general applicability of a drainage system technique for typical slope shapes and compatibility of drainage system approaches with existing shoreline issues. The degree of general applicability or compatibility ranges from *Not Recommended* ⊕ to *Excellent* ● and is indicated accordingly in the graphics window.

planning efforts. You then can implement a number of drainage control measures presented in this section.

Drainage improvements on a coastal property can be located in any of the following areas: above the slope crest, on the slope face, and near the slope toe. In each of these slope zones, a variety of construction techniques can be applied. Nevertheless, some generalizations can be made about each group of techniques based on their locations. The compatibility of each group in different slope areas is summarized on *Table 2* located on page 37.

Above Slope Crest

Managing surface and groundwater before flow reaches a slope is usually the most prudent approach to improving slope stabilization soil and erosion control. Improving drainage at the top of the slope typically requires an integrated approach to drainage control instead of a single, large-scale approach which may be seen on the slope face and along the slope toe. In a system there can be many different drainage control elements including: groundwater interceptor and relief drains, surface water interceptor swales, tightlines, catchbasins, landscaping yard drains, and detention storage. The construction approaches for systems with these components are similar.

Slope Face

Designing and installing drainage control systems on slope faces can be risky for both the slope and for slope workers. Make sure that you and other people are secure on the slope and that you are not working in unstable areas. Drainage control on slope faces typically addresses issues such as groundwater seepage from the slope and surface water erosion control. Depending on the geometry and characteristics of your slope, you can consider different control techniques. Construction disturbance risks to your slope should always be weighed against the potential gains in slope stability. A number of the construction practices are low impact techniques while others may require heavy equipment.

Below Slope Toe

Slope drainage in Puget Sound has been historically modified by the construction of retaining walls and bulkheads near shorelines. Wall designs should have adequate drainage to keep water pressures from developing behind walls. Presently many bulkheads and wall systems around Puget Sound are in varying conditions of failure and consequently are not performing as designed. Should you suspect that drainage at your slope toe accumulates behind structures, you should seek technical assistance to assess your site conditions before performing improvements in this high risk area.

General Compatibility of Drainage Control Techniques in Different Areas of a Slope

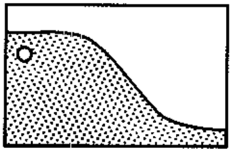
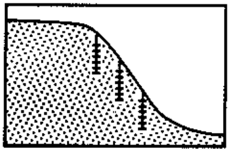
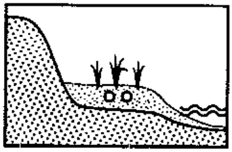
Compatibility	 Slope Crest Modifications	 Slope Face Modifications	 Slope Toe Modifications
Drainage Goals:			
Increases Slope Stability: Less water in/on slope	●	●	
Decreases Slope Erosion	●	●	●
Environment Impact: Potential improvement in water quality	●	●	●
Environment Impact: Potential degradation in water quality	●	●	●
Environment Impact: Significant ground surface disturbance		●	●
Relative low-cost construction	●		
Relative low-impact construction	●		
Reduces slope toe undercutting by waves			●
Drainage Systems:			
Trenching Systems: Installation with heavy equipment	●		●
Relief Drains: Groundwater control	●	●	●
Strip Drains: Seepage control		●	
Swales and Tightlines: Surface and ground water control	●	●	●
Contour wattling: Surface water control	●	●	●
Revegetation: Surface water control	●	●	●
Drainage Source Control: Avoidance of flow concentrations	●		
Additional Drainage Control Techniques	●	●	●

Table 2. General compatibility of drainage control techniques in different areas of a slope

Groundwater Interceptor Drains (Curtain and Trench Drains)

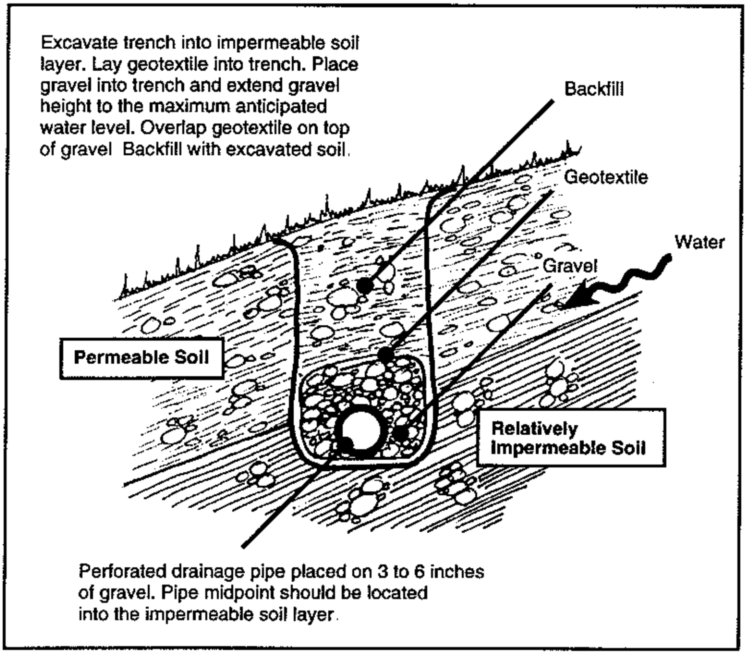


Figure 12. Interceptor drain.

An interceptor drain is a gravel trench that is excavated into a relatively impermeable soil layer and installed to collect and remove groundwater as it flows across the impermeable layer as shown in *Figure 12*. The trench is typically placed across a contour of a slight to moderate sloping area to intercept groundwater prior to influencing slope stability. Generally, trenches are constructed 2 to 3 feet wide and are lined with a quality geotextile that does not clog. There is a one to two foot overlap of the geotextile above the gravel and below the backfill in the trench. Water carried by the trench pipe should be conveyed to a tightline (solid pipe) which transfers water down the slope to an appropriate discharge point. Trenches can be excavated with curves and bends to prevent cutting tree roots and hitting underground utilities.
It is wise to confirm utility locations before you dig. Trenches can be covered with topsoil and replanted to conform to your existing ground conditions. Do not forget about safety during construction. Trenches over four feet deep (on level ground) should be protected against collapse.

- **Limitations:**

Trenches should not be greater than 4 feet deep without shoring to hold up the sidewalls and protect workers in the trench. Shoring is typically provided by a "trench box." Alternatively, the side of the trench could be sloped back to a flatter, more stable configuration. Trenches should be set back at least 20 to 30 feet from the slope crest. Technical assistance should be obtained where trenches are deeper than 5 feet below grade and within areas closer than a distance equivalent to the slope height measured horizontally from the slope crest. Additionally, if you can stand over the proposed trench location and look upslope and see the slope at your eye level within 20 feet (about 4H:1V), you should obtain technical assistance to evaluate the slope stability consequences of trenching at different depths and locations. You should not consider trenching until you are into a dry weather period and slope conditions reflect the dry conditions. Also, you must be aware of the location of wastewater treatment systems so you do not inadvertently collect incompletely treated wastewater effluent.

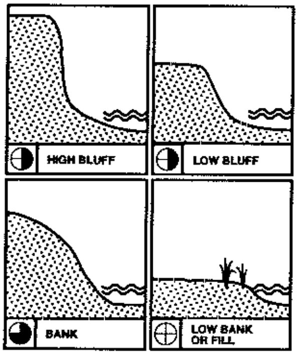
Getting heavy equipment onto a slope face is usually risky and impractical without significant disturbance to existing soils and vegetation. To reduce the potential for initiating a landslide, limit the length of trench open at any one time. If you have a 10 foot high slope behind the trench and you open a trench ten feet deep you essentially have 20 feet of overburden that may fall into the trench opening. This situation is dangerous and should not be taken lightly. Get technical assistance when trenching on slopes.

• **ADVANTAGES:**
Good option to intercept groundwater which is perched above a relatively impermeable soil. Good coverage technique. Construction technique is widely practiced.

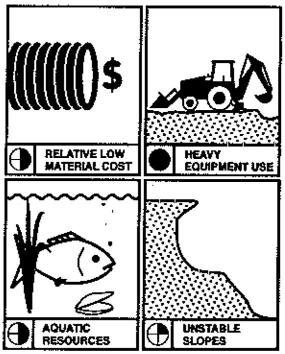
• **DISADVANTAGES:**
Pipes in the system are often undersized. Must be able to slope pipe in trench. If not properly backfilled and compacted, surface water can flow into trench and cause additional problems for the slope and drainage system. The tightline trench which connects with the interceptor trench should be adequately sealed and compacted to prevent water from moving down the trench to the slope face.

French drains are sometimes confused with interceptor drains. However, French drains generally use large gravel without a pipe and the trench itself conveys the water across and down the slope. Consequently, the trench must be sloped. These drains must still convert trench flow to pipe flow in order to get drainage down the slope. French drains are not generally the system of choice for slope applications.

APPLICABILITY



COMPATIBILITY



Relief Drains (Tile Drains)

Relief drains are installed similarly to interceptor drains except in a designed pattern arranged to artificially lower the groundwater elevation in the slope soils to a specific elevation. They can also be constructed to intercept surface water drainage if placed at the surface. *Figures 13* shows a number of grid patterns. Typically, they are shallower trenches sloped to drain to a collection tightline pipe. Groundwater continues to flow below the drains because these drains are not typically excavated into the impermeable soil.

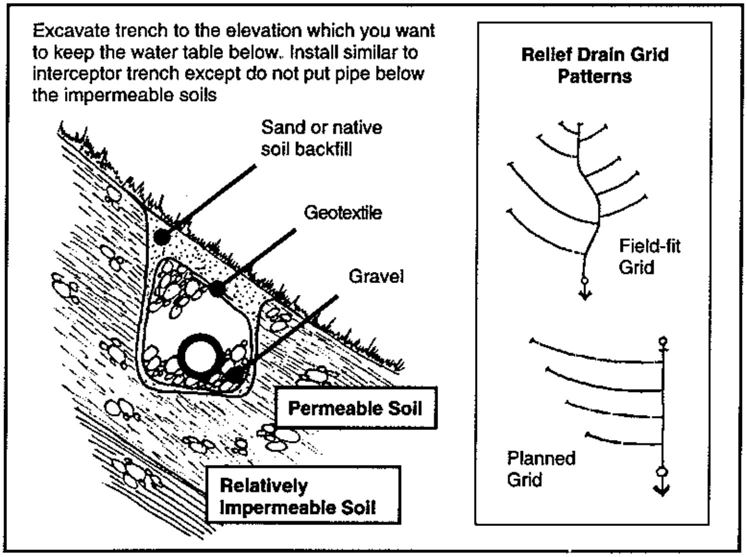
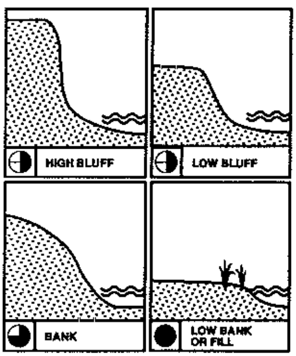
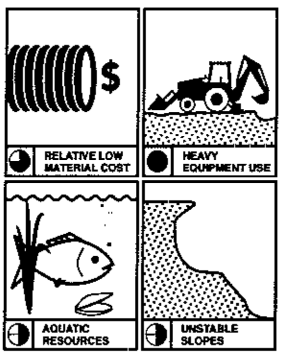


Figure 13. Relief drain and example grid patterns

Applicability



Compatibility



- **Limitations:**

System requires complete coverage of the project area to be effective. May not be feasible in areas where there is vehicle traffic loading on pipes. Previous property development may limit extent of system.

- **Advantages:**

Flexible design layout. Can be used to keep groundwater from daylighting on slope face. Can be used in conjunction with geotextile wrap (sock) around pipe instead of gravel in different areas.

- **Disadvantages:**

Trenches open at surface can accumulate fine grained soil reducing the system capacity for surface water capture. Requires some maintenance.

Strip Drains

Strip drains are thin rectangular conduits which can be placed into narrow 4 inches trenches which minimize the degree of disturbance to the slope soils and vegetation. Typical dimensions range from one to two inches wide to 8 to 12 inches high and are pre-wrapped with a geotextile. The strips are used like relief drains described earlier.

However, they address low volume flows like groundwater seepage issues. There are fabricated end connections which convert the rectangular drain to conventional circular pipe dimensions. *Figure 14* shows a strip drain in a trench.

• Limitations:
Limited flow capacity. Must be installed across a slope contour instead of down a slope.

• Advantages:
Easy to get material rolls onto the slope. Limits the degree of slope disturbance to soil structure and vegetation root systems. Good in highly variably, disturbed areas with limited flow.

• Disadvantages:
Not commonly available at the discount centers. Must call pipe supply center.

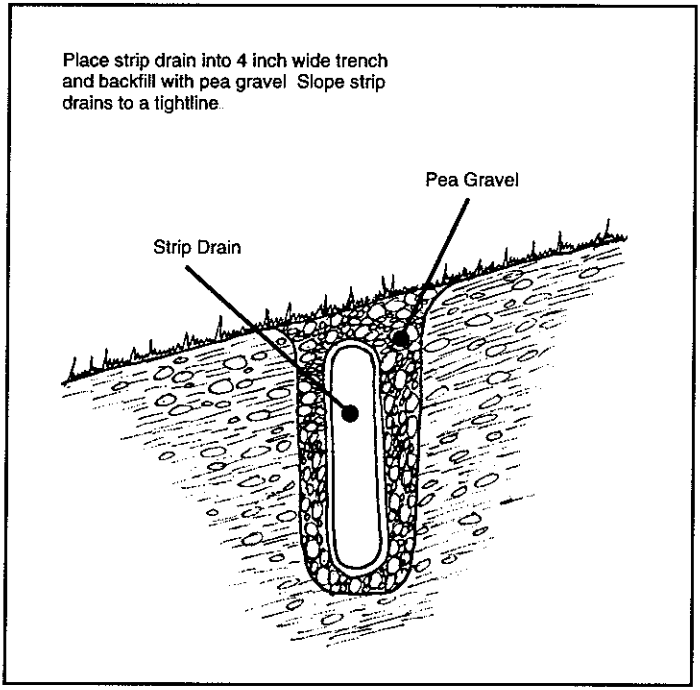
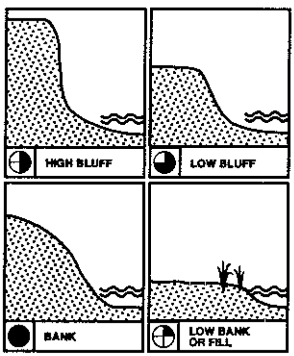


Figure 14. Strip drain system.

Applicability



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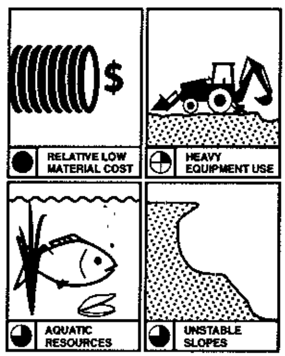


INTERCEPTOR SWALES

Interceptor swales capture uncontrolled surface water flows above steep and unstable slopes and convey flow to a stable discharge point. Swales can be excavated to form a channel and then seeded with a hearty erosion control grass mix. It is a very economical drainage technique that can also be used as a temporary erosion control measure. *Figure 15* shows a typical swale system.

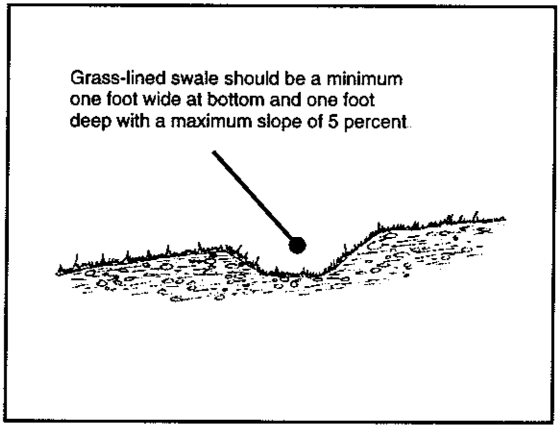
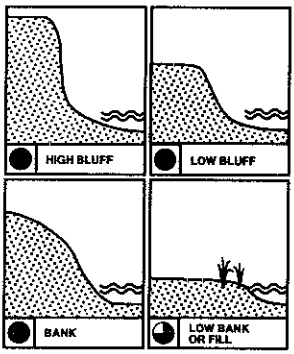


Figure 15. Typical swale system

APPLICABILITY



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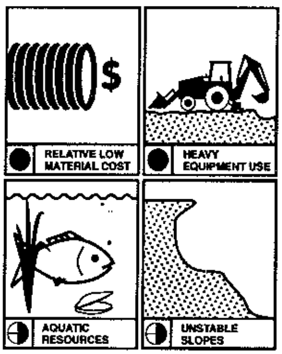


- **LIMITATIONS:**
Swales should not be sloped greater than 5 percent. Needs a minimum 1 foot width at the bottom with 1 foot minimum depth and 2H:1V maximum side slopes.

- **ADVANTAGES:**
Available construction materials and inexpensive construction. Easy to place many swales at different locations. Easy to landscape around.

- **DISADVANTAGES:**
If permeable (sand and gravel) soils are crossed by the swale, conveyed water could infiltrate into the soils adding to local groundwater.

Stormwater Detention Storage

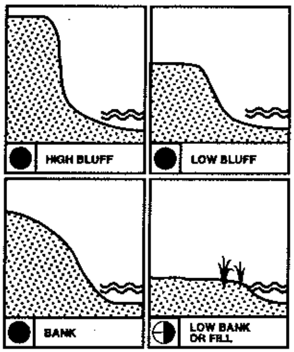
Detention storage holds collected stormwater and releases it at a controlled rate. Storage facilities can be either constructed above ground as a pond or placed below ground as a vault. Surface systems can be designed as either dry or wet features during dry weather periods. Buried vaults can be prefabricated concrete, corrugated aluminum, polyethylene, or fiberglass structures.

• Limitations:
The controlled release structure should be designed by an engineer. Buried systems are relatively expensive and surface systems consume land when water depths in the detention pond are kept shallow. In slope areas surface features should be lined to prohibit infiltration in the soils. Buried storage areas should slowly discharge to tightlines. Consequently, drywells which allow infiltration into soils near slopes are not recommended.

• Advantages:
Surface features can be a landscape amenity. Detention facilities can keep existing drainage system from exceeding capacity. Buried storage is not visible. Reduces erosion potential to slope or beach areas. Excellent application for very small or space limited lots.

• Disadvantage:
For buried storage the cost per 100 cubic feet is relatively expensive. Depending on storage volume required, surface water features need a dedicated space on the property (away from slope crest). Systems require maintenance.

Applicability



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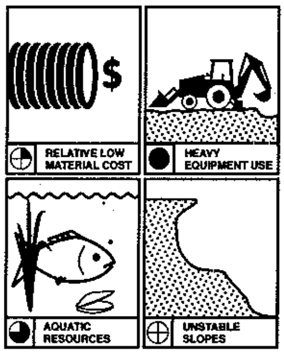
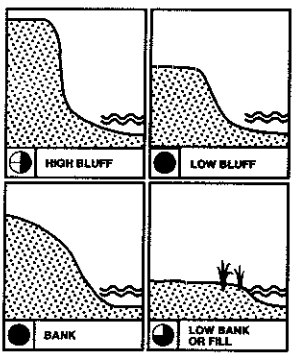


Slope Drains (Tightlines)

Slope drains in this publication are solid wall pipes which carry collected water down a steep slope gradient without exposing the slope face to soil saturation and channel erosion. These drains are usually combined with some energy dissipating structure at the discharge point such as a rip rap pad (apron) or manhole. It is critical that the slope drains be anchored properly along the slope face. If pipes are not buried, it is important that along steep bluff faces or along unstable landslide zones you should not have pipe connections which could fail and create serious stability problems. Use a continuous length of pipe in these locations.

Applicability



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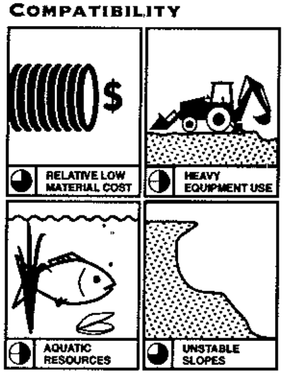


For situations where the pipe cannot be supported underneath, use smooth interior wall pipe (instead of corrugated wall inside and out) which increases the flow capacity of the pipe and reduces the flow friction on the pipe. Remember using smooth pipe will increase the flow velocity and forces acting on the pipe coupling and bends at the slope toe. Therefore, it is critical to support bends in pipes, anchor pipe lengths, and minimize the number of couplings.

• Limitations:
Hard to support pipe along vertical bluff faces. May require special anchoring and flow energy dissipation along length. Erosion gullies can start along pipe trenches if not properly compacted and stabilized.

• Advantages:
Conveyance system does not place water on the slope Good steep slope technique.

• Disadvantages:
Piping is commonly undersized. If failures occur the effects on slope stability and erosion control can be rapid and serious. Without proper energy dissipation such as manholes and rip rap aprons at the slope toe, the discharges cause erosion at the slope toe and beach.

Additional Drainage Control

There are a number of additional drainage control techniques that can be applied to some sites in cases where there is an unacceptably high level of risk to existing structures and there are limited alternatives available to your slope. Each technique requires a geotechnical engineering evaluation and involves using specialized construction equipment and installation practices. Generally, these techniques are very expensive to implement and are intrusive to slope soils and vegetative cover. Most importantly these drainage control alternatives can be devastating to slope stability if poorly applied or constructed.

• Horizontal Drains

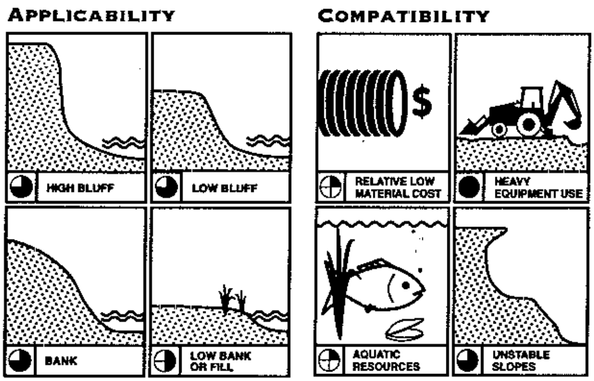
Horizontal drains are small diameter wells drilled almost horizontally into a slope face to remove groundwater and seepage before discharging onto the slope face. These drains are primarily used for stabilizing slopes although they can be used in emergency situations to provide immediate relief of adverse groundwater and seepage on problem slopes. Installation of wells requires that a construction platform is cut into the slope.

• Well Systems (Vertical Wells & Relief Wells)

Well systems are used for improving groundwater conditions in troublesome slopes. Wells are typically drilled vertically into a slope and provided with a discharge pipe at the bottom of the well which drains water freely to a collection pipe or pervious soil material. Well systems require multiple installation in an area to effectively lower the groundwater elevation. In extreme cases, pumps are included in the design layout. The term "chimney" drain is sometimes misapplied to coastal slope drain design. Traditionally, its use is confined to earth dam construction.

• Drainage Blanket

Drainage blanket is a layer of free draining granular material placed on the face of a slope to help stabilize shallow soils and reduce erosion. Blankets should be specified by geotechnical engineer to help avoid increasing your stability problems.



CONTOUR WATTLING

Wattling system can be used as slope drains when angled slightly across a contour. Contour wattling is an erosion control planting method which can also be used to stabilized very shallow soil structure against landsliding.

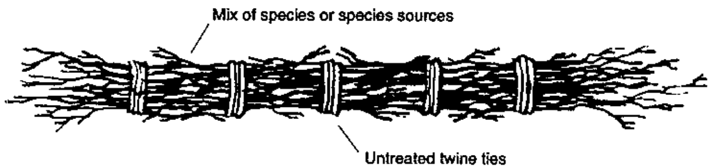


Figure 16. Wattle detail.

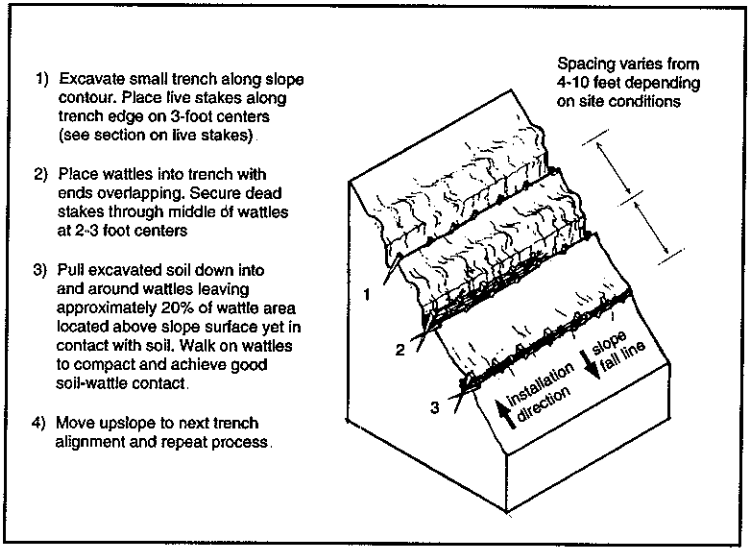


Figure 17. Contour wattling

The method involves packing lengths of woody plant material into cables or bundles (sometimes called live fascines) about 8 to 10 inches in diameter as shown in *Figure 16*. The bundles are laid continuously along slope contours as shown in *Figure 17*. 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.

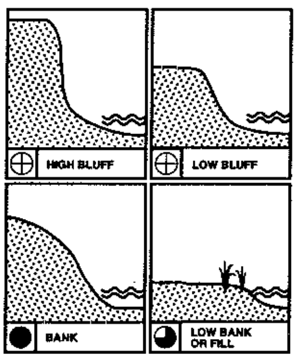
Woody plants which are particularly suitable to contour wattling are willow, red-osier dogwood, and snowberry. Wattling is generally considered good for slopes of 1.5H:1V or less. The installation of wattles along slopes requires a greater degree of planning prior to installation. Generally, wattles 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. The Ecology booklet *Slope Stabilization and Erosion Control Using Vegetation* describes wattling techniques in detail.

• **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 may be initially necessary.

• **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. Routed drainage must be collected into stable swales at slope toe.

APPLICABILITY



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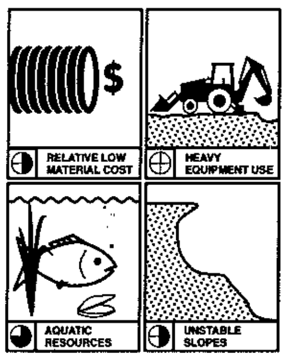


Revegetation

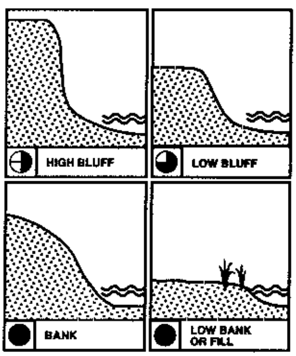
Plant materials do modify soil moisture by removing water from the soils through the root network. Root networks of both woody plants and herbaceous ground covers help stabilize slopes against shallow landsliding and surface erosion. Techniques use native plan species and are widely accepted. Refer to the Ecology documents *Slope Stabilization and Erosion Control Using Vegetation: A Manual of Practice for Coastal Property Owners* and *Vegetation Management: A Guide for Puget Sound Bluff Property Owners* for additional information.

• **LIMITATIONS:**
Soil types and moisture conditions must be appropriate for each species selected. Native plant materials are inconsistently available in different areas. Twice a year *Hortus Northwest* publishes a directory of suppliers of native plant materials such as seed mixes, bare root stock, cuttings, container plants, etc. (see section *For More Information*).

• **ADVANTAGES:**
Plants also strengthen surface soils. Aesthetics. Techniques conducive to many slope configurations. Does not require heavy construction practices and associated slope disturbances. Can be used with other drainage control techniques.

• **DISADVANTAGES:**
Installation should be done in late fall or early spring. Requires a relatively long time on the slope to perform installation of container plants.

APPLICABILITY



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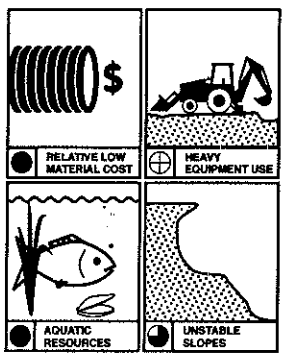


Slope Toe Drainage Control

Many developed properties on Puget Sound have some form of shore protection (bulkheads, alternative soft protection, etc.) on the beach or at the toe of the slope. These structures have earth pressures which try to slide the construction forward and/or overturn them. Consequently, it is critical that adequate drainage control is placed behind these structures to reduce water pressure buildup and water piping failures.

Water collected from upslope areas should not be introduced into soils behind structures. Impermeable walls have more potential problems than permeable systems such as revetments and biotechnical protection systems. Should marine waters also flood backfill behind these structures, the drainage control system must be able to quickly drain the material to prevent potential failures. Providing excess drainage capacity and weep holes in walls is very important to the long-term performance of coastal structures.

Tightlines that extend down a slope and end near marine waters, should have an erosion prevention device that slows and spreads the collected water along the area above the beach without eroding beach sediments. Manholes, rip rap aprons, rock spillways, and rock channels are commonly used for different slope situations to dissipate flow energy. The discharge force of water leaving a pipe is high for smaller pipes so it is important to anchor or encase the pipe with concrete and/or large rock.

• Limitations

Shoreline areas tend to be dynamic and change configuraton constantly from soil creeping down the slope, from landslides, and from coastal erosion. Consequently, drainage control must be flexible enough to adapt to these continuing changes. Must be careful working at the toe of unstable slopes.

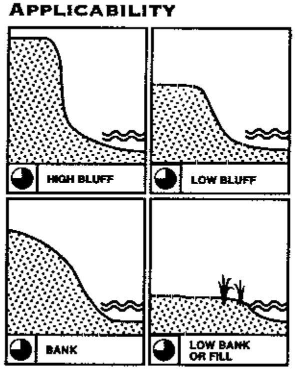
• Advantages

Helps reduce piping of fine-grained soil away from slope. Reduces static water pressure in slope debris material and in wall backfills.

• Disadvantages

Can be expensive construction. Work may require slope stability analyses.

Applicability



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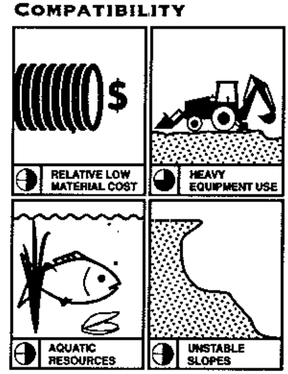


Erosion Control Techniques

The primary purpose of erosion control is to reduce the erosive effects of surface water runoff on exposed soil. As a reminder, reducing the source of the surface water runoff can provide a significant improvement to erosion problems and should be the first step taken.

How erodible exposed soil is to surface water runoff depends on several factors such as type of soil, steepness of the slope, and height of slope. Erosion control techniques tend to focus on ways to reduce the magnitude of these factors.

Some techniques are more appropriate during temporary earthwork activities during construction rather than more permanent site conditions. For example, exposed cut and fill slopes during construction are commonly covered with plastic sheeting (visqueen) to limit the erosion of these soils. The plastic sheeting is replaced with vegetation for a more long term solution. Plastic sheeting has found its way to residential properties with its use commonly extended to longer time frames. Plastic sheeting should be considered a temporary solution rather than a permanent one.

There are many techniques available for erosion control. During construction, they include mulching, matting, covering with plastic sheeting, silt fences, settling ponds and protective berms. Your local public works department can provide more information on best management practices for erosion control. More permanent controls include installation of vegetation or other slope protection materials and slope recontouring. Vegetation can be established through seeding, container or bare root planting. Vegetation used in contour wattling and brush layering can also reduce slope lengths, thereby reducing the erosion potential on the slope. The Ecology manual *Slope Stabilization and Erosion Control Using Vegetation* should be referenced for more information on vegetative techniques.

There are also a number of erosion control blankets available that can be used to protect the exposed slope while the vegetation is getting established. These blankets range from mats of non-biodegradable materials to biodegradable jute netting.

For areas where vegetation cannot be established, e.g. steep slopes or high volume of runoff, hard surfacing such as large, angular rock (4 to 6-inch diameter) can be used to protect underlying erodible soil. Placement of a geotextile between the underlying soil and the rock surfacing would reduce the amount of soil that would move through the voids in the rock surfacing.

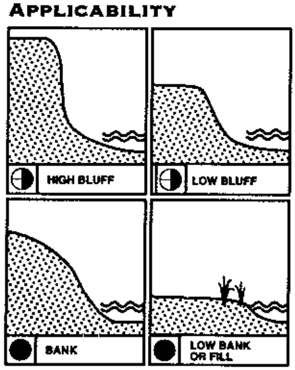
Slope recontouring (terracing or flattening) involves modifying the slope configuration on a large scale to improve slope stability. This should only be done with the guidance of a geotechnical engineer. Without proper review of the slope conditions, slope recontouring could make slope stability conditions worse.

• **LIMITATIONS:**
Difficult to impossible to maintain erosion control on steep slopes and on slopes subject to wave action.

• **ADVANTAGES:**
Techniques can be done by hand and can be relatively inexpensive. Erosion control can be done using vegetation that enhances the landscaping of the property.

• **DISADVANTAGES:**
Establishing vegetation takes planning and time.

APPLICABILITY



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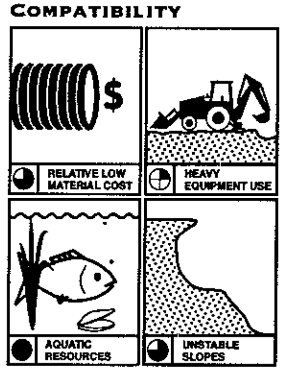


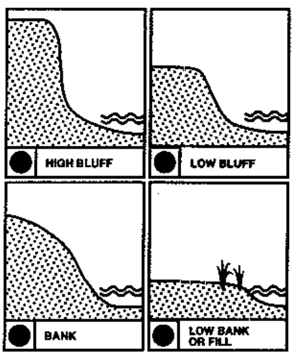
Source Control

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.

Applicability



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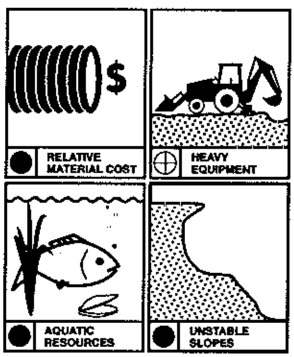
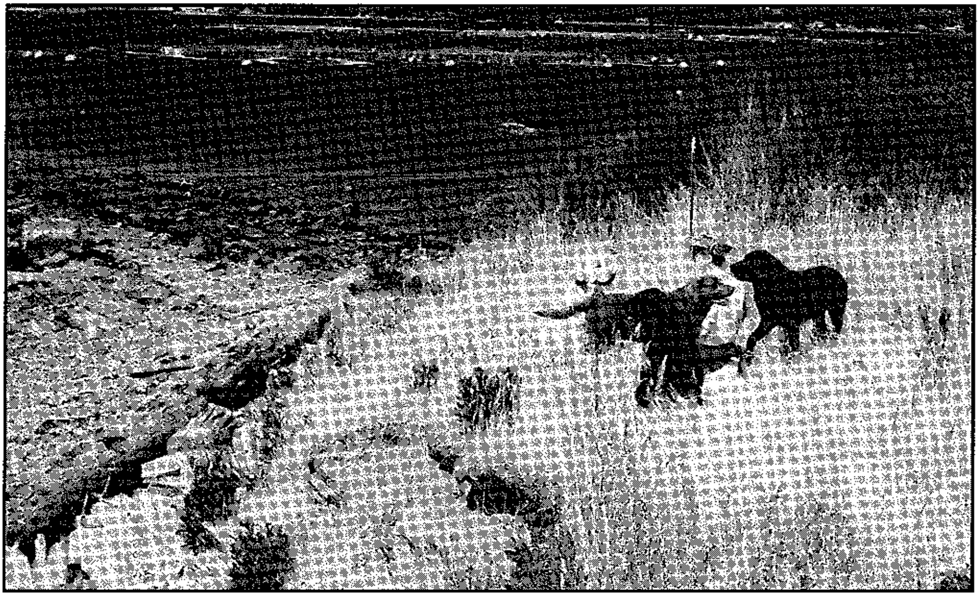


General Retail Material Costs for Drainage Control Component

Material	Unit of Measure	Range of Cost per Unit, $	Extra Items Required	Local Availability
Plastic Drainage Pipe				
Corrugated solid wall 4"	per foot	0.30 – 0.50	✔	✔
6"	per foot	0.90 – 1.10	✔	✔
Corrugated perf. wall 4"	per foot	0.30 – 0.50	✔	✔
6"	per foot	0.90 – 1.10	✔	✔
Rigid solid wall 4"	per foot	0.50 – 0.70	✔	✔
6"	per foot	1.30 – 1.50	✔	✔
Rigid perf. wall 4"	per foot	0.55 – 0.75	✔	✔
6"	per foot	1.20 – 1.50	✔	✔
Corrugated solid wall 12"	per foot	3.50 – 5.00	✔	
Aluminum Culvert				
12"	per foot	6.50 – 7.50	✔	✔
18"	per foot	10.50 – 14.50	✔	✔
Strip Drains 2" x 12"	per foot	1.75 – 2.25	✔	
Yard Drains 12" x 12"	each	50 – 175		✔
Manhole				
concrete 4' x 6'	each	900 – 1400		
polyethylene 4' x 6'	each	1000 – 1600		
Catchbasin				
concrete 24" x 30" x 36"	each	120 – 250		
polyethylene 24" x 30" x 36"	each	180 – 400		
Buried Detention Storage	per 100 ft^3	400 – 800	✔	
Geotextile	per yd^2	0.60 – 0.80		
Gravel Drain Rock	per yd^3	12.00 – 19.00		✔
Native Woody Plants	gal container	2.50 – 10.00		✔

Table 3. General retail material costs for drainage control components.

REVIEWING YOUR DRAINAGE PLAN



One of the many moments spent along Puget Sound.

Having a basic understanding of how drainage (both surface water and groundwater) flows through and on your slope is the first step in trying to identify and solve drainage problems.

Once you've identified these problems, you can reduce or eliminate the causes of these problems through source reduction and control. If source control is not possible, then you can use one or more of the drainage techniques discussed to limit the adverse impacts of drainage on your property. Proper drainage system planning, installation and maintenance can reduce the risk of slope instability. When you have questions or concerns regarding your plan, remember to contact experts or refer to additional sources of information. Ultimately, you will continue to enjoy living with one of the most unique coastal environments in North America – our Puget Sound.

A LOOK AT OTHER PROPERTIES

BAINBRIDGE ISLAND, KITSAP COUNTY

- **SITE CONDITIONS:**
  Clay soils, daylighting groundwater 20 feet below the top of the slope. Slope is about 25 feet high but house is located only 5 to 10 feet back from the crest of the slope.

- **SITE DRAINAGE FEATURES:**
  Large driveway area draining to a catch basin near the top of the slope. However, little water reaches the catch basin. Observation of driveway sheet flow shows water disappears into the joints between the driveway concrete slabs. Wood originally between the slabs had rotted away. Downspout discharges and other site drainage are routed to a tightline system that discharges below the slope. However, a leak is present within the tightline system.

- **RESULTING PROBLEM:**
  Recent landslide just below existing residence. Landslide on slope was caused by groundwater and uncontrolled surface water flows (tightline leak).

- **SOLUTION:**
  Repair of the slide area using a retaining wall with good backfill drainage, repair of tightline leak, perform regular monitoring of the tightline system for possible future leaks, and place a flexible joint sealant between concrete driveway slabs.

HANSVILLE, KITSAP COUNTY

- **Site Conditions:**
  Sand at top of slope underlain by clay, groundwater daylighting at the sand/clay boundary located about 10 feet below the top of the slope. Slope is greater than 50 feet in height and house is over 80 feet back from the top of the slope.

- **Site Drainage Features:**
  All site runoff from roof, driveway, and foundation drains routed to a tightline system that appears to be functioning without leaking. Septic field located between the residence and the crest of slope, about 30 to 60 feet from the crest.

- **Resulting Problem:**
  Slope erosion and recent landslide. Landslide originated at the top of the slope near the sand/clay boundary.

- **Solution:**
  Construct an interceptor trench to collect the groundwater before it reaches the face of the slope and route the water collected in the trench via a tightline system down to the bottom of the slope. Location of the cutoff trench would be best between the slope and the residence but must be set well back from the crest of the slope. However, the septic system location creates a planning conflict. Even if there was sufficient room for the trench setback from the top of the slope, a cutoff trench too close to the septic system could pick up untreated or inadequately treated wastewater.

  Two alternatives remain: 1) Relocate the septic system to an area behind the house (away from the slope) and construct the cutoff trench in the area previously occupied by the septic system; or 2) locate the cutoff trench behind the house. Alternative 1 is more expensive but would provide a greater level of drainage control for the slope by intercepting groundwater closer to the problem area. Also, by locating the septic system behind the residence the septic system wastewater flows are further from the crest of the slope.

GRAPEVIEW, MASON COUNTY

- **SITE CONDITIONS:**
  High bluff, glacial till soils. The owner cut a sloping path from the residence to the stair system at the top of the bluff. At the bluff crest the path was notched into the bluff about 10 feet.

- **SITE DRAINAGE FEATURES:**
  No control of site surface water. All surface water allowed to flow towards the top of the slope. Most of the site surface water drained down the path.

- **RESULTING PROBLEM:**
  Serious erosion from the concentrated surface water flow undermined the stair foundations resulting in stair damage and loss of vegetation from the slope.

- **SOLUTION:**
  Reroute site surface water flows where they originate at the house downspouts (tightline) and lawn (surface swale). Capture and route the water down the bluff in a tightline system. Capture as much of the site runoff before it gets near the path As a backup system construct a swale and catch basin that captures and routes any water flow on the path before it reaches the bluff crest. Tightline the captured flow down the slope. Note that it would have been best not to have "notched" the bluff in the first place.

KINGSTON, KITSAP COUNTY

- **SITE CONDITIONS:**
  Construction of a new residence in a previously undeveloped area. Area is mapped in Coastal Zone Atlas as Historic Old Slide Area. Soils are sand over clay. There is evidence of groundwater seepage with water loving vegetation on a portion of the slope. The site slope shows indications of past sliding: leaning and rounded trees and hummocky ground.

- **SITE DRAINAGE FEATURES:**
  None constructed prior to site development. Natural groundwater daylighting on the slope.

- **RESULTING PROBLEM:**
  Development triggers slide activity.

- **SOLUTION:**
  Do not develop the site or do so with extreme caution. Develop only with the input and engineered designs by professional geotechnical and civil/drainage engineers experienced with development in slide areas. Recognize that development on known slide areas contains inherent risk, even with the best of engineering design.

FOX ISLAND, PIERCE COUNTY

- **Site Conditions:**
  Development of a 10 acre subdivision in a previously undeveloped and heavily vegetated area. Extensive slope clearing, grading, cuts, and fills performed.

- **Site Drainage Features:**
  None prior to development. Few erosion control measures incorporated into the construction or final site configuration. No engineering performed to evaluate fill placement on steep slope. Drainage system poorly laid out and not effective in intercepting and routing surface water flows.

- **Resulting Problem:**
  Site development without adequate construction or permanent stormwater, leads to heavy site erosion and landslides.

- **Solution:**
  Install drainage control measures including swales, detention, and tightlines down to the base of the slope. Provide erosion control and revegetation of the site. Reengineer the fills by recontouring, removing, reinforcing, or constructing a retaining wall.

  Given the level of damage to the site and cost for repair, the developer would have been better off spending the money up front for adequate engineering and site construction erosion control measures.

LUMMI ISLAND, WHATCOM COUNTY

- **SITE CONDITIONS:**
  A shallow undeveloped waterfront lot has known drainage and slide problems. The only site vegetation is a narrow strip along the top of the bluff. Owner contacts someone for input on site development.

- **SITE DRAINAGE FEATURES:**
  None on undeveloped lot. Recommended input on site development includes a deep interceptor trench within several feet of the bluff edge.

- **RESULTING PROBLEM:**
  Proposed trench construction so close to the bluff crest would remove almost all vegetation from the top of the bluff. Also, excavating a trench so close to the edge could actually cause rather than prevent a failure at the top of the slope.

- **SOLUTION:**
  Do not construct a trench close to the top of the bluff crest.

When retaining someone to provide you with technical input for drainage design and slope stability improvement be sure they are State of Washington licensed civil engineers with education and experience as a geotechnical engineer and/or drainage engineer. Don't be afraid to ask questions and clarify recommendations that don't make sense to you. When in doubt get a second opinion.

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

Individual Drainage
Product Representatives
Use telephone to locate specific materials.

For geotextile call regional distributors at:

- CSI Geosynthetics
  Vancouver, WA
  1-800-426-7976
- Enspec
  Seattle, WA
  (206) 623-9508
- Northwest Lining
  Seattle, WA
  (206) 872-3872
- Charles Watts
  Seattle, WA
  (206) 783-8400

Permit Assistance Center
Washington Department of Ecology
(360) 407-7037

Hortus Northwest
Pacific Northwest Native Plant Directory
P.O. Box 955
Canby, OR 97013
(503) 266-7968

Washington DOE
Shorelands Publications:

Vegetation Management: A Guide for Puget Sound Bluff Property Owners. Publication: 93-31

Slope Stabilization and Erosion Control Using Vegetation: A Manual of Practice for Coastal Property Owners. Publication: 93-30

Coastal Erosion Management Studies in Puget Sound, Washington: Executive Summary. Publication: 94-74

Management Options for Unstable Coastal Bluffs in Puget Sound, Washington. Publication: 94-81

Coastal Zone Atlas of Washington, Volumes 1-12. (Out of print; consult your local library or Planning Department)

To order Ecology publications write:
Publications Office
Dept. of Ecology
P.O. Box 47600
Olympia, WA 98504

Other Publications:

Downing, John. 1983. *The Coast of Puget Sound: Its Processes and Development.* University of Washington Press, Seattle.

Washington DOE Water Quality Program Urban Nonpoint Unit Brochures:

Stormwater Quality Programs in the Puget Sound Basin
WQ-R-93-010 Report 1 of 5

Selecting Best Management Practices for Stormwater Management
WQ-R-93-011 Report 2 of 5

Stormwater Erosion and Sediment Control for Small Parcel Construction
WQ-R-93-013 Report 3 of 5

Stormwater Erosion and Sediment Control for Large Parcel Construction
WQ-R-93-013 Report 4 of 5

Source Controls to Protect Stormwater Quality
WQ-R-93-014 Report 5 of 5

Glossary

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.

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.

Catch Basin
A structure usually buried, where surface water is captured and conveyed into pipes and/or where piping (often of different sizes) is connected.

Cliff
A high, very steep to perpendicular 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.

Culvert
A pipe or concrete box structure that conveys flow from open channels, swales, or ditches under a roadway, driveway, fill soil, or surface structure.

Curtain Drain
Drainage trench that is excavated into an impermeable soil layer to collect groundwater that is perched on that layer. Trench is backfilled with drain rock (gravel) that is enclosed in a geotextile. A perforated pipe is placed within the drain rock backfill to collect and convey the groundwater to a suitable discharge point.

Detention Facility
A structure or ground surface feature that temporarily stores water and releases it at a controlled rate.

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 channels and piping systems.

Drain Rock
Rounded gravel ranging in diameter from 1½ to 3" with no fine particles, used in drainage trenches

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.

Extreme High Water (EHW)
The average height of the highest tidal waters reached during the year over a 19-year period.

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.

GEOTEXTILE
Synthetic fabric used to return soil while allowing water to pass through the soil and fabric into drainage collection system.

GROUNDWATER
Water collected or flowing underground usually in the interstices of soil or rock fractures. Typical soils containing groundwater are relatively permeable soils such as sand and gravel

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

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

HUMMOCKY
Having an uneven, jumbled or erratic appearance characteristic of landslide movement.

IMPERMEABLE
Having a structural density 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.

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

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.

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.

PERFORATED "PERF" PIPE
A pipe with small slots or holes typically used to either capture and route groundwater to a tightline drainage system or release captured water from a drainage collection system to the local soils.

RELIEF DRAINS
Series of drainage trenches laid out in a pattern to lower water levels to a specific elevation. Construction is similar to an interceptor drain.

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 ground floor, drains, or sewers.

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

SHEET FLOW
A thin layer of water moving across a surface without the formation of concentrated streams of water.

SHORELINE
The intersection of a specified plane of water with 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.

SLOPE EROSION
The wearing away of rock or soil from a slope crest, face, or toe due to water, wind, ice, or gravity. Typical slope erosion from water results in RILL or GULLY erosion features

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

Strata
A layer of soil.

Surface Water
Water standing, ponding, or flowing on the ground or other surface feature.

Swale
Shallow open earth channel used to intercept and route surface water flows to a discharge location.

Tightline (solid pipe)
Typically used to describe a solid wall, rigid or flexible pipe used to transport water from one location to another, either buried or positioned along the ground surface. A tightline does not have slots or holes like a perforated pipe.

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.

Trench
In drainage applications, temporary ditch excavated in the ground to install drainage system components

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.

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)".