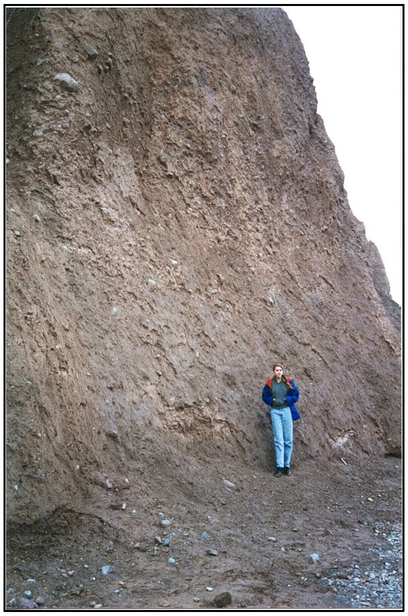
# CONTROLLING COASTAL BLUFF GROUNDWATER



At the mention of coastal erosion, many people will think of stormwaves eating away at dunes or undercutting the base of coastal bluffs. Consequently, much time, money, and effort is expended fighting coastal erosion at the water s edge. Unfortunately, often erosion continues even after the toe of slopes are protected by the construction of bulkheads, seawalls, and revetments. This is because the stability of many coastal bluffs often depends upon the amount and action of groundwater within the bluff and upon surface water action over the face of the bluff as much as it does upon the action of waves at the toe of the slope. Erosion of bluffs due to surface runoff and groundwater seepage is often slower than that resulting from wave action and may therefore tend to be invisible to landowners over the short term. Over long periods of time, however, the damage can be equal to or greater than that from wave attack.

Excess groundwater can weaken even formerly stable slopes and result in significant, sometimes startling, amounts of erosion. Groundwater carries with it the potential for sudden, major, catastrophic occurrences, such as slumps, mudflows and landslides which can move significant amounts of soil almost instantaneously. Uncontrolled surface water runoff can also result in substantial amounts of soil being moved downslope.

## SURFACE RUNOFF

Surface runoff on the unprotected face of a coastal bluff can be an important cause of erosion. When raindrops strike the face of a slope, particles of soil are disturbed. The flow of water over the face of the slope can then move those dislodged soil particles down the slope toward the shore. As the amount or velocity of runoff is increased, the amount of soil moved and the size of the individual soil particles moved will both be increased. Surface erosion is most noticeable and even spectacular during major events such as intense thunderstorms. The long-term effect of surface erosion caused by less-intense rains may not be as spectacular in the short-term, but the amount of soil lost can be significant over time.

Surface runoff can take place whenever there is more water on a slope than the soil can absorb. Factors which can influence the amount of soil moved downslope by surface runoff include the steepness of the slope, the roughness of the surface, the size and angularity of the soil particles, the strength of the impact of the falling rain that is dislodging those particles, and the amount and type of vegetative cover holding the soil in place. The erodibility of the soil is based on the physical characteristics of the soil. The faster water can infiltrate into a soil and the higher the organic content of the soil, the more resistant the soil will be to erosion. Sand, sandy loam and loam-textured soils are generally less erodible than silt, very fine sand, and clay-textured soils.

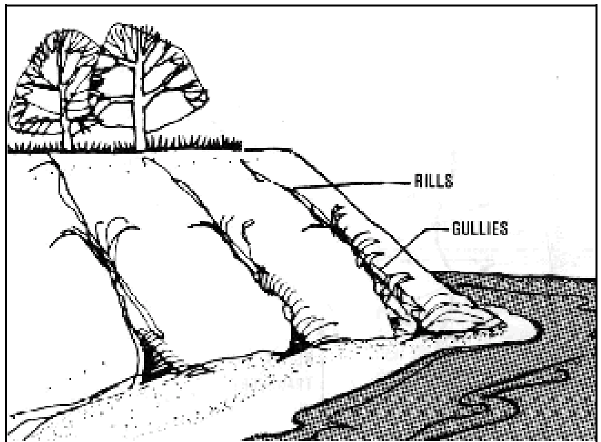


Figure 1

Sheetwash is the unconfined flow of water over the surface of the ground during and after a rainfall. It usually is quite uniform across a slope and is usually not noticed until a good deal of soil has already been lost. As sheetwash progresses, the runoff may become concentrated, and small, well-defined grooves or rills will begin to form (Fig. 1). Runoff in rills can attain higher velocities than sheetwash and can dislodge and carry away larger soil particles. Over time, with continued runoff, rills can become gullies. This occurs most on slopes with little vegetation and which are steep and less stable. The soil moved downslope by surface erosion from the face of a coastal bluff is usually deposited at the toe of the slope, making the overall slope less steep and more stable. The next cycle of storm waves can remove this material from the toe of the slope, making the slope steeper and less stable and restarting the cycle.

## GROUNDWATER SEEPAGE

The degree of stability of coastal bluffs depends on many different factors including the steepness of the slope; the size, shape, and cohesiveness of the soil particles; the amount of moisture in the soils of the slope; actions of humans; and natural forces that tend to disturb the soil. Even when a slope may be stable under normal circumstances, excess groundwater can render it unstable and result in significant, sometimes startling, amounts of erosion.

As water soaks into soil, it fills in the minute spaces between soil particles. In general, soil with uniformly small particles will have small spaces between those particles, and the speed at which the water moves downward will be slow. In coarse-grained soils, the interparticle spaces will be larger and the water will flow faster. It s normal for even very dry soils to have at least surface layers of moisture surrounding the individual soil particles.

Some coastal bluffs are made up of glacial till, a random, unsorted mixture of sand, silt, clay, and rocks deposited by the glaciers that once covered most of the state. Other bluffs have separate layers of sand, silt, and/or clay that were deposited by ancient streams, lakes, or wind. The composition of coastal bluffs varies widely depending upon the geographic region of the state under consideration. A specific bluff's internal composition may not be uniform throughout, but may range from unsorted particles near the top, overlaying layers of sand and clay, on down to a bedrock till base. Along Lake Ontario, glacial drumlins are made up of mixed sand, silt, and gravel along with clay lenses, large cobbles, and boulders.

Layers of clay (or hardpan) in a bluff are very dense and form barriers to water that would otherwise seep downward through the soil (Fig. 2). Such barrier layers may extend for miles underground before being exposed at the face of a bluff. When groundwater meets one of these barrier layers, its downward movement is blocked and it will flow along the top of the barrier. Water flowing along the layer causes the wet top of the layer to act as a lubricated slide beneath the overlying materials. In addition to lubricating the top of the barrier layer, excess moisture no longer has an easy escape route and will tend to fill in the spaces in the overlying soil. This moisture lubricates the soil particles, making slippage more likely, and adds extra weight to the bluff, forming a zone of instability in the saturated soil.

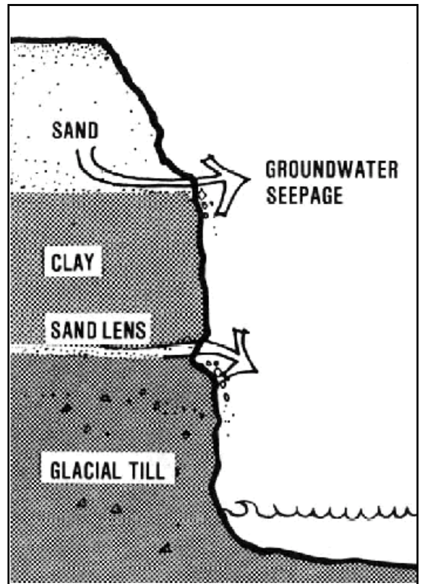


Figure 2

Disturbance of the slope, such as by construction activities, vibration from traffic, overloading the top of the slope with buildings and swimming pools, or undercutting of the toe by wave action (Fig. 3) can trigger slides (large amounts of unconsolidated material moving in a disorganized manner down the slope) or slumps (whole blocks of soil moving as a unified body) of large sections of the destabilized slope (Fig. 4). When the moisture content exceeds certain

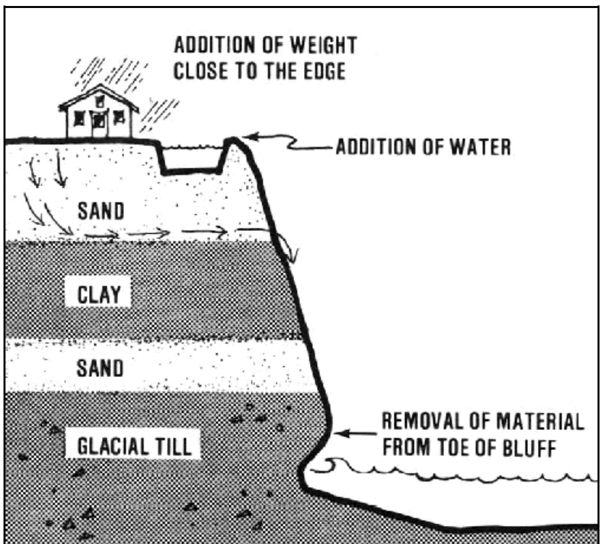


Figure 3

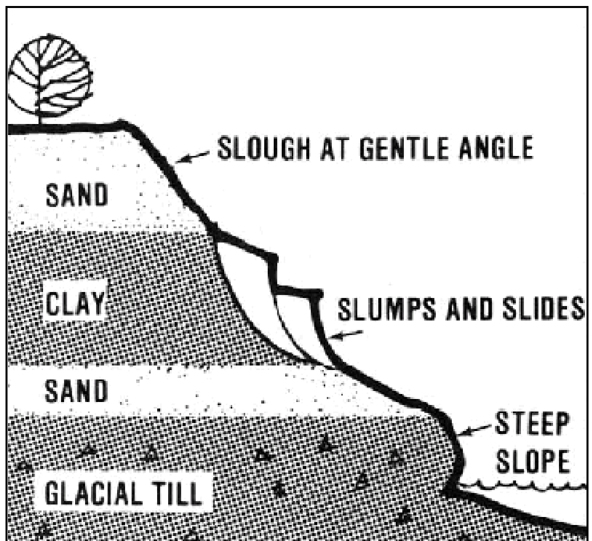


Figure 4

maximum natural tolerances, the soil may even begin to flow from its own weight (and that added by the water). In such cases, major amounts of land can be lost in relatively short periods of time. Different materials act in different ways. Silt and sand tend to erode in thin layers from the face of a slope, whereas glacial till and clay will form larger slump blocks. Both are susceptible to slides. Clayey soils tend to be prone to mudflows.


Figure 5

The effects of groundwater seepage are not always as spectacular as slides and slumps. A slower long-term deformation, often with multiple sliding surfaces and exhibiting viscous movement is called creep. Where a barrier layer meets the face of a slope, seep zones (which can be seen as bands of dark moist soil, running nearly horizontal along the face of a bluff [Fig. 5]). Particles of soil can be washed away from the face of a bluff along such seep zones. The water flowing from seeps can cause rill and gully erosion along the face of the slope below, and can undercut areas on the face of the slope well above wave under-cutting that might be taking place at the toe of the slope. Seeps are often active during the early spring. Ice and frost that build up on the face of a slope in the fall and winter act as a dam to retain groundwater until a thaw. When this dam of frozen earth melts, water stored within are released.

Natural precipitation is not the only source of groundwater in coastal bluffs. Septic-system leach fields can add tremendous amounts of water to the soil. Home roof drains, lawn sprinklers, and runoff from paved driveways, parking lots, and roads also add water to the soil.

Another factor contributing to surface erosion is the removal of vegetation. This reduces the amount of water used from the soil and may increase soil water levels, increasing soil pore water pressure and destabilizing the soil. Loss of stabilizing roots can also increase erosion. While deep-rooted vegetation can help to prevent sheet and rill erosion, surface vegetation does little to prevent slides and slumps and is often carried down the bluff with the eroding materials.

## IMPROVING SURFACE DRAINAGE

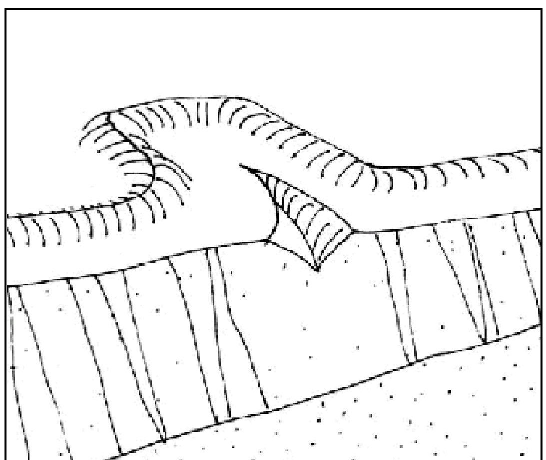


Figure 6

Surface erosion can be minimized by collecting and diverting runoff from the face of a slope, by minimizing hard-surfaced areas, which tend to shed rainwater more rapidly than natural ground surfaces, and by proper use of vegetation to slow runoff and provide a less-compact soil surface. Water collected from a dwelling s roof through the use of rain gutters and downspouts should not be allowed to flow over a bluff s face. Instead, the water should be piped to an area where it can be discharged without causing erosion. Water flowing over the ground s surface can be controlled with earthen berms (Fig. 6), embankments and diversion swales. Soil can be banked into low ridges (berms) and seeded with grass. Properly located shallow ditches (swales) can carry water away from the bluff face to an appropriate discharge area.

## IMPROVING SUBSURFACE DRAINAGE

By improving subsurface drainage, you can remove excess water from within the bluff and increase the bluff s more stable, and minimize seepage erosion of its face. This will also help lower the bluff's permanent water table, thereby increasing the bluff s capacity to absorb groundwater during periods of heavy precipitation.

To identify seepage zones in the soil of a coastal bluff, look at the bluff face after a rainfall and note the level at which water seeps out (this may be seen as horizontal dark bands of soil or as actual flowing moisture). Alternatively, test holes could be dug into the top of the bluff to determine the depth of the impenetrable barrier layer over which the water is moving (this is not an option if the first barrier layer is much deeper than six to eight feet).

Excess groundwater must be intercepted before it seeps out of the bluff face. This is done by installing subsurface drains (artificial underground channels that collect and discharge excess water at an appropriate location) using perforated conduits buried beneath the surface of the ground (Fig. 7). These drains offer less resistance to water flow than does the soil around them the groundwater flows into the conduit rather than through the ground. The drains direct the collected water to a discharge point away from the bluff.

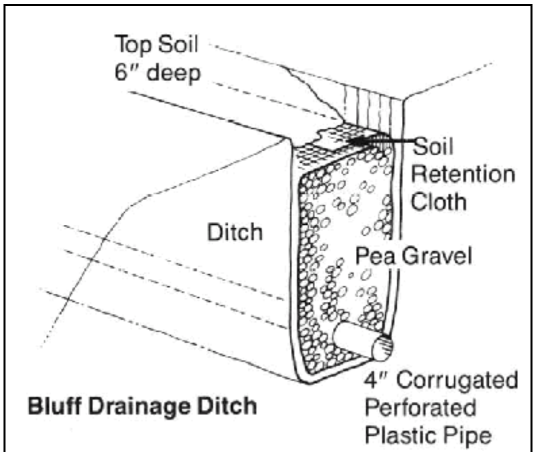


Figure 7

### Subsurface Drainage Materials

Two types of conduit are available: clay (or concrete) tile and plastic tubing. The choice of drainage conduit material depends upon local soil conditions. Although prices vary among materials, the difference in costs is usually minor. Drainage conduits are usually at least four inches in diameter, although larger diameters (up to 12 inches) can be used where soil conditions or groundwater quantity dictate. An experienced local drainage contractor or consulting engineer can help guide a landowner s choice in conduit type and size.

### Clay or Concrete Tile

Baked clay has been used for drainage tiling for several hundred years; concrete is a newer form of tile, but performs similarly to clay. Clay or concrete tile comes in sections of one or two feet in length and diameters of four to 24 inches. Individual tile segments butt up to each other with water entering the pipe through the spaces at these joints. In sandy soils, the butted joints should be covered with filter fabric to prevent the tiles from becoming clogged with sand. Since the tiles are rigid, they do not require soft bedding material in the trench beneath them provided the trench base is stable and is dug on a uniform slope. Rigid tiles are generally resistant to deformation due to uneven ground and backfill pressures.

## Corrugated Plastic Tubing

This state-of-the-art material, made of polyethylene or polyurethane corrugated tubing, comes in diameters of four to 12 inches and in lengths of up to 250 feet. Water enters the pipe through small holes or slits molded into the plastic. The corrugations help provide some additional strength to prevent flattening, but the tubing will yield to uneven ground pressures and may be crushed if it is not placed on a well-prepared, carefully shaped bed backfilled with a uniformly sized porous material. Filter fabric is needed around the tubing to prevent fine sand or silt from entering and clogging the drainage system. Such filter material can be purchased in 200-foot rolls and is easy to install. Plastic tubing is much easier to handle than is clay or concrete tile and allows for more feet of tiling to be laid in the same amount of time than with clay tile. Plastic tubing is widely available, relatively low in cost and weight, and is easily connected to additional lengths of tubing or to solid-walled pipe for carrying the water gathered to a suitable discharge location.

## Construction

The conduits are laid in trenches, six inches to a foot in width, excavated parallel to the top edge of the bluff, five to ten feet back from the edge, cut down to the top of the impermeable barrier layer (Fig. 8). The actual distance from the edge of the bluff to the trench will vary with location of buildings and shrubbery. The depth of the trench is dictated by the depth from the surface of the ground to the impermeable layer acting as a barrier to groundwater movement. This layer could be just a few feet beneath the surface or as deep as commercial backhoes can dig. If the barrier layer is too deep, drainage conduits may not be feasible.

Figure 8

The bottom of a drainage trench is shaped to accept the curvature of the conduit being used. The trench is lined with filter fabric (Fig. 9. This step can be left out if the tile is wrapped in filter fabric). The conduit is laid in the trench, and the trench is backfilled with a uniform porous material, such as washed or bank-run gravel, to within about four inches of the top. The final four inches is filled with topsoil and planted with grass seed. It is important that the conduit be laid at a slope of at least two inches of vertical drop for every 100 feet of horizontal run in order for the water to flow properly. An uneven conduit or one laid without the necessary grade can cause water to flow slowly, reducing the conduit s carrying capacity and possibly resulting in the buildup of silt, eventually clogging the conduit.

Figure 9

Trees near drainage trenches should be cut off at ground level to stop their roots from growing into and damaging the drainage conduits. Stumps and roots should be left in the ground to act as soil binders to strengthen the bluff.

### Drainage Outlet

Without an adequate outlet for the excess surface or groundwater collected by a drainage system, drainage will not be effective. In some locales, excess groundwater can be discharged into nearby streams. This should be done in a way which will not create an new erosion problem where the water is discharged. The discharge conduit is usually made of metal or rigid plastic and should have bars or screening to keep out animals. It should be the same diameter as the drainage conduit.

If a site lacks natural drainage channels, collected water can be discharged through the bluff face. A metal or plastic pipe is used to carry water from the end of the collection conduit down the face of the slope to be discharged into the waterbody. The mouth of the pipe needs to be barred or screened to prevent entry by animals. In Great Lakes coastal areas, the outlet pipe must have adequate protection against ice damage or be located above expected ice levels. Also, outlet pipes must not be exposed to storm waves which could damage the pipes or push sediment into the pipes, clogging them. Drainage water should not be released directly down the face of a bluff.

### Limiting Costs of Drainage Projects

Professional land improvement contractors perform most of the drainage system installation work in New York State. Employing a contractor who knows about drainage slopes, maintenance of constant grades, and acquisition of appropriate materials is usually worth the extra initial cost over a general contractor not specializing in such projects. The cost of drainage projects is generally figured based upon the length and depth of the trenches to be cut, and the type of equipment used. Money can be saved by planning multi-property installations. Damaging underground utilities such as telephone, gas, water, sewer, and cable can be costly. Utilities should be located before excavation begins. Shallow trenches can be dug by labor-savvy property owners who wish to undertake such projects on their own to limit costs. However, incorrect grades or installation could render a do-it-yourself project far less effective than a professionally designed, professionally installed project.

### Limitations of Drainage Projects

Drainage improvements do not provide protection to areas adjacent to but not part of the project, nor do they protect against erosion resulting from direct action of waves at the toe of a slope.

### Effects of Drainage Projects on Coastal Processes and the Environment

Drainage improvements may result in a decrease in fine sediments in the littoral system by reducing the amount of sand, silt or clay being eroded away from a slope. This could potentially increase the amount of erosion in downstream locations. No significant environmental effects result, except if turbidity of water immediately adjacent to the project is decreased as a result of removing clay and silt from the system, in which case water quality and fish habitat at that location may be improved.

### Advantages of Drainage Projects

Drainage improvements do not affect the use of fronting beaches for other uses and a relatively low cost compared with their effectiveness at controlling bluff erosion.

### Drawbacks of Drainage Projects

Drainage improvements may not be the sole solution to coastal bluff erosion in cases where the problem is exacerbated by wave attack at the toe of the bluff (Fig. 10). While simply installing toe protection is not a total solution (Fig. 10a), in such cases, drainage improvement should be considered as part of an overall erosion control strategy, along with structural improvements at the bottom of the slope (Fig. 10b). Drainage improvements may also not be the total solution in situations where slopes are too steep to be stable even when excess water has been removed. In such cases, reshaping of the bluff to a more stable angle may be necessary in conjunction with drainage improvement and, perhaps, structural toe protection.

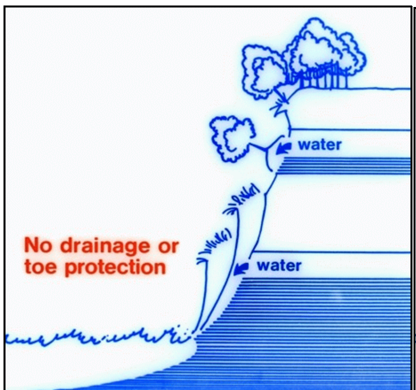


Figure 10

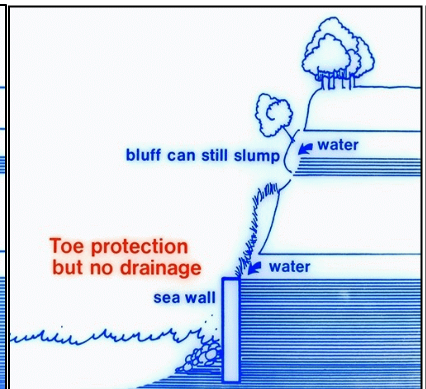


Figure 10a

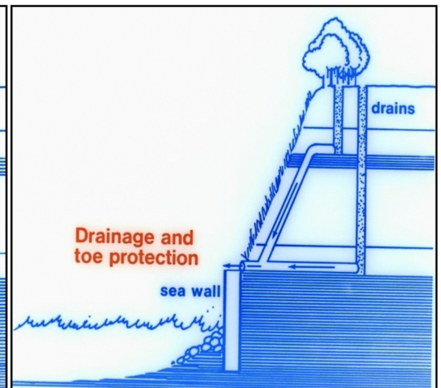


Figure 10b

## COASTAL SLOPE RESHAPING

When a coastal slope is steeper than the angle at which the soil particles will remain naturally in place, the potential for erosion is dramatically increased, particularly if the surface of the slope is devoid of vegetation, which would normally hold the soil in place.

Provided there is sufficient room at the top of the slope, a coastal bluff could be regraded to a flatter angle to increase its stability. Regrading by itself is not a solution to surface erosion, but instead must be performed as part of an overall restabilization project, including revegetation of the slope. If there is a problem with undercutting at the toe, a structural control measure such as a bulkhead may also be necessary.

Vegetation is essential to the surface stability of a slope. Most plants are difficult or impossible to establish on slopes steeper than a ratio of 1:1 (that is, one foot vertical rise per every one foot of horizontal run), or about 45 degrees (Fig. 11). When regrading a slope, the ideal angle to aim for, provided there is room at the top of the slope to do so, is 1:3 (18 degrees). Since this gentle a slope can result in the loss of substantial property depth at the top edge of a bluff, where there are existing structures close to the bluff s edge, a slightly steeper 1:1.5 (33 degree) slope may be a viable alternative. For situations where it is impractical or too expensive to regrade a bluff to even a 1:1.5 ratio, the use of railroad tie, gabion, or stone terracing may be an alternative method of reducing the effective slope of the bluff, while providing horizontal steps to hold vegetation and stabilizing the vertical sections mechanically.

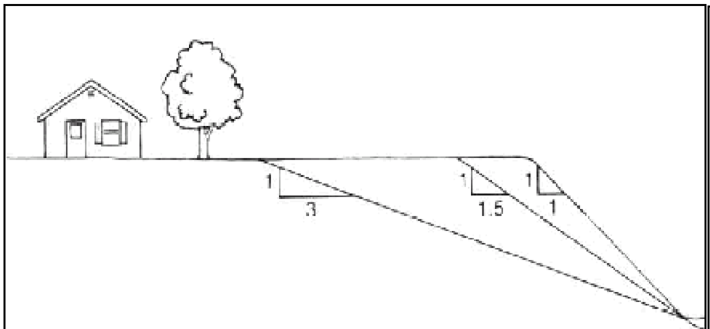



Figure 11

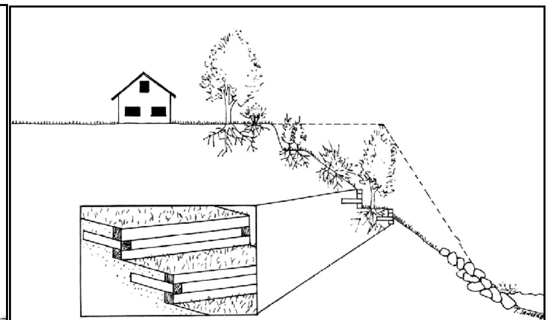


Figure 12

### Limitations of Slope Reshaping

Slope reshaping does not provide protection to adjacent areas, nor does it protect against erosion resulting from direct action of waves at the toe of a slope.

### Effects of Slope Reshaping on Coastal Processes and the Environment

Slope reshaping may result in a decrease in fine sediments in the littoral system by reducing the amount of clays or silts being eroded away from a slope. This could potentially increase the amount of erosion in downstream locations. No significant effects result, except if turbidity of water immediately adjacent to the project is decreased as a result of removing clay and silt from the system, water quality and fish habitat at that location may be improved.

### Advantages of Slope Reshaping

Slope reshaping can improve access to the shore and normally does not have any impact on other uses of fronting beaches. A disadvantage of slope reshaping is that it reduces the amount of usable flat land at top of the slope.

## VEGETATIVE STABILIZATION

Once excess groundwater has been controlled through improved drainage and, if necessary, the slope has been regraded, vegetation can be planted on the bluff s face. This will help to reduce rain-induced surface soil erosion and the plants  roots will help bind the soil particles together.

Although it may seem counterintuitive, the removal of inappropriate vegetation on a bluff is also desirable. Trees growing near the bluff s edge place large weight burdens on this area, especially during windy periods. Cutting trees off at ground level keeps them from falling during storms and taking with them a piece of the bluff. Leaving the roots from the cut trees in place will act as a soil binder.

For information on the use of vegetation to control coastal erosion, consult the Cornell University Shoreline Conservation Series Information Bulletin 198, Vegetation Use in Coastal Ecosystems (available, with other coastal erosion publications on the World Wide Web at: http://www.cce.cornell.edu/seagrant/gl-levels/publications.html).

## INFORMATION SOURCES

New York Sea Grant erosion control information is available from the following locations:

New York Sea Grant Extension
Morgan II, State University College
Brockport, NY 14420
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Fax: (585) 395-2466
E-mail: sgbrockp@cornell.edu

New York Sea Grant Extension
146 Suffolk Hall
State University of New York
Stony Brook, NY 11794-5002
Voice: (631) 632-8730
Fax: (631) 632-8216
E-mail: sgstonyb@cornell.edu

New York Sea Grant Extension
62B Mackin Hall
SUNY College at Oswego
Oswego, NY 13126-3599
Voice: (315) 312-3042
Fax: (315) 312-2954
E-mail: sgoswego@cornell.edu

Lake Champlain Sea Grant Extension Project
101 Hudson Hall
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