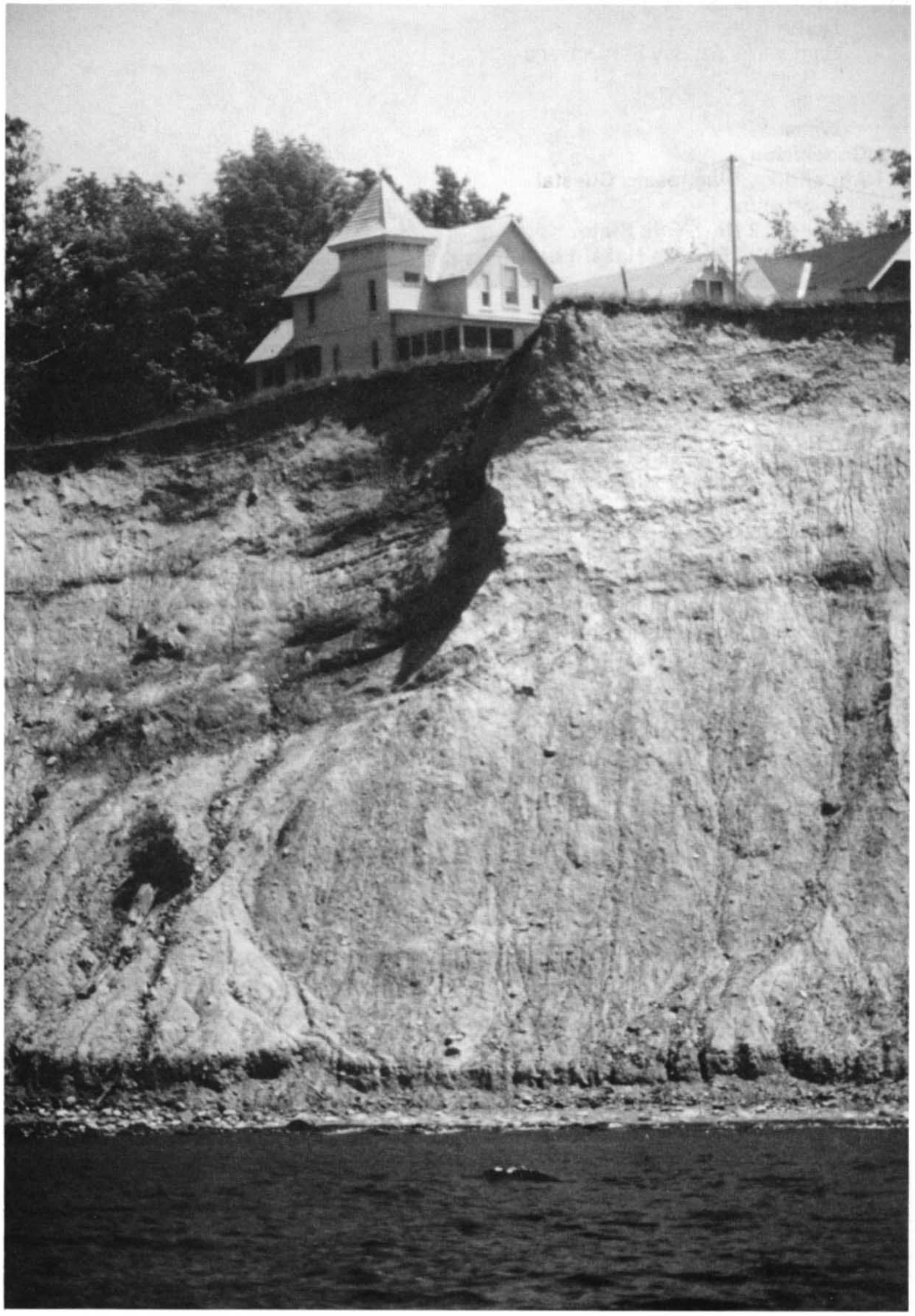
A Guide to Coastal Erosion Processes

Charles R. O'Neill, Jr.

Information Bulletin 199

A Cornell Cooperative Extension Publication



Contents

Charles R. O'Neill, Jr., is a regional specialist in the NYS Sea Grant Extension Program, SUNY College, Brockport, NY 14420.

The author would like to express his deepest appreciation to Michael Duttweiler for his continued support and encouragement during the writing of this bulletin and to the following individuals for their review and criticism of the end result: Dr. Robert Adams, Chairman, Department of Earth Sciences, State University of New York College at Brockport; Sandra Brennan, Bureau of Mineral Resources, New York State Department of Environmental Conservation; Arthur Lieberman, Landscape Architecture Program, Cornell University; Stephen Murphy, Coastal Processes/Management Program Advisory Committee; and Jay Tanski, New York Sea Grant Extension Program.

Introduction

Many areas of New York's coast are naturally subject to shoreline erosion. In many of these areas, particularly where there are homes, businesses, and other structures, the erosion becomes a problem.

The coast is a dynamic area in which erosion and deposition are constantly taking place. The forces that cause coastal erosion and deposition are natural phenomena that have been taking place for centuries and will continue to do so indefinitely. Viewed in this manner, it is not the erosion and deposition that are the problem, but their impacts upon human-made coastal features.

Too frequently, the natural processes behind coastal erosion are poorly understood and are ignored when shoreline development is being planned and implemented in erosion-prone and erosion hazard areas.[1] Many of the actions then undertaken to try to cope with the ensuing erosion "problem" either fail to work as intended, do not last long enough to realize a practical or financial benefit to their owners, or may even compound the problem for that site or for neighboring areas of the coast.

This Information Bulletin is intended to give coastal landowners, developers, and government officials a better understanding of natural coastal processes that cause shoreline erosion. Natural erosion control features of the coast, such as barrier beaches and dunes, are also discussed. Finally, the impacts of various human activities upon shoreline erosion are examined. The reader will be able to use this information to make better decisions when planning and permitting new development along erosion-prone areas of the state's coast.

A second Information Bulletin (IB 200), *Structural Methods for Coastal Erosion Management,* takes a detailed look at the various ways in which coastal erosion might be dealt with, including guidelines for constructing and maintaining a range of erosion control structures. A third Information Bulletin (IB 198), *Vegetation Use in Coastal Ecosystems,* covers the functions and uses of vegetation in coastal erosion control.

Coastal Processes

Coastal erosion is the loss or displacement of land along the coastline due to the action of wind, waves, currents, tides, wind-driven water, waterborne ice, runoff of surface waters, other impacts of storms, or groundwater seepage.

Coastal erosion is a long-term occurrence, measured in decades and centuries. When viewed on a day-by-day basis, a segment of the coast may not appear to be eroding badly at all. In some years, almost no erosion may be evident. However, other years may show several feet of erosion. An erosion rate of 1 foot per year may not sound like very much, but when looked at over longer periods of time, the total footage is significant. For example, a house that today is 25 feet back from the shore would be only 15 feet away in a decade. And that assumes an average of 1 foot per year; think of the impact if a major storm happened during year six and cut away 5 feet of the shore all at once!

The primary natural causes of long-term coastal erosion—rising sea levels, tidal fluctuations, naturally fluctuating lake levels (on the Great Lakes), wind, waves, and natural deficiencies in the amount of sediment being transported in nearshore currents—can be considered as uncontrollable by humans.

Waves are one of the main driving forces of coastal erosion along the marine and Great Lakes coasts of New York. Waves are generated by winds blowing over water and by the passage of boats and ships through the water. In most areas, wind-driven waves are by far the more important of the two.

Wind can cause erosion in coastal areas where an abundance of loose sand is exposed and is available to be moved into and out of dunes. This occurs mainly in areas where the wind is not restricted by vegetation, landforms, or human-made structures and the sand is fine-grained enough to be transported by the wind.

Silt, sand, and gravel are kept in nearly constant motion in the nearshore area of the coast. At any time, sediment may be transported away from any given point of the shore at the same time that it is being deposited on that same location. As long as the supply of materials entering the system is at least as great as the amount of sediment leaving the system, there will be no net erosion. If the sediment transport out of the system is greater than that entering, then erosion will result. Certain development actions, such as armoring an eroding shoreline with bulkheads or constructing groins or jetties out from the shore into the water, can cut off the supply of sediment to an area, perhaps increasing erosion at that site.

Some beaches show seasonal differences in the rate of erosion. The most-common occurrence of this phenomenon is a cycle of winter erosion and summer building-up of marine beaches.

Figure 1. *Waves are one of the primary causes of coastal erosion. They can move material onto, off, and along a shoreline.*

It is estimated that the sea level is rising at a rate of 9 to 11 inches per century. As the level of the water is increased, so too is the amount of coastal land that is inundated. Further, storm waves can now reach farther inland than previously, eating away at dunes and bluffs that heretofore had not been threatened.

Shorter-term changes in water levels can also influence coastal erosion. Along New York's marine coast, erosion is usually greater at times of high tides (daily and semimonthly) as the water reaches farther inland. If a storm should occur at a time of a high tide, storm waves will do additional damage. Along the Great Lakes, water levels fluctuate between a midwinter low and midsummer high, reflecting differences in seasonal precipitation and evaporation patterns as well as ice effects. As with marine tides, high lake levels can result in increased amounts of erosion.

Barometric pressure differences over the water can also result in water level differences, causing higher water levels in areas of low pressure and lower levels under high pressure areas. Storm winds and waves can "pile up" water on the shore (storm setup), resulting in temporarily high water levels. On the Great Lakes, when the storm is over and the winds abate, water from the higher level area flows back to where the level had been temporarily lowered. The water level may actually change several times (to ever-decreasing amounts) similar to waves sloshing in a bathtub. This bathtub effect is called *seiching,* and the increased water levels associated with it carry with them the same potential for increased erosion as any elevated water levels do.

Causes of Coastal Erosion

Waves

Wind-driven waves (fig. 1) can move material onto, off, and along the shore depending upon their height, length, period, and the direction at which they are striking the shore. Wave height is the vertical distance between the crest and trough of a wave. Period is the time between successive wave crests passing the same point. Wavelength is the distance between successive crests. (See fig. 2.) Wave height, length, and period depend upon the distance that the wind blows over open water (the *fetch*), the length of time during which the wind blows, the speed of the wind, the depth of the water, and the distance that the wave travels after leaving the area where it was generated by the blowing wind. In general, long fetch, strong wind, and long duration result in the largest waves.

Waves are generally steeper and closer together the nearer they are observed to where they were formed. Thus, waves caused by a storm wind blowing onshore will be "choppier" than waves that have traveled a great distance before reaching shore. Generally speaking, the maximum fetch, or the longest distance of open water over which wind can blow, is the main controlling factor in wave height. Also important is the average depth of the water over which the wind blows. Deeper water means larger waves because the amount of bottom friction is reduced.

When wind generates waves, it imparts a portion of its energy to those waves. Much of a wave's energy is spent during the process of breaking. A wave breaks when it reaches water too shallow to support its height (generally, when the wave height is 80 percent of the depth of the water—a 4-foot wave will break in 5-foot-deep water). Breaking waves release their energy, creating turbulent water. The turbulence disturbs the bottom sediments, and the moving water of the broken wave can then move those sediments.

If the water immediately offshore is deep with a steeply sloping bottom, waves will break closer to the shore and can be expected to cause more erosion than if the slope of the bottom is gradual with shallow depths immediately offshore. Short, steep waves (such as those from an onshore storm near the coast) generally remove materials from the beach. On the other hand, longer-period, less-steep waves (swells) tend to move sediment back onto the beach, thus building the beach up.

The actions of storm waves can erode the shore much faster than swells replenish the shore. Therefore, a number of major coastal storms occurring over a short period of time can result in major coastal erosion, for there is little time for longer-period swells to reverse the damage caused by the storm waves. Along some areas of the coast, this building up and tearing down of the shore may be seasonal, with summer swells making "deposits" and winter storms making "withdrawals." Along other sections of the coast, such patterns may be cyclical with replenishing taking place for several years followed by several years of erosion (fig. 3).

Sediment Transport

The term *littoral* is used when something pertains to the shore. Hence, the movement of sediments in the nearshore area by wave action and currents is termed *littoral transport.* The material moved by the waves is called *littoral drift.* This transport can be perpendicular to the shore (onshore-offshore) or parallel to the shore (longshore). Sediment eroded from a coastal bluff is often deposited *downdrift,* maintaining a beach.

Both types of transport can result in either erosion or deposition depending upon the physical characteristics of the

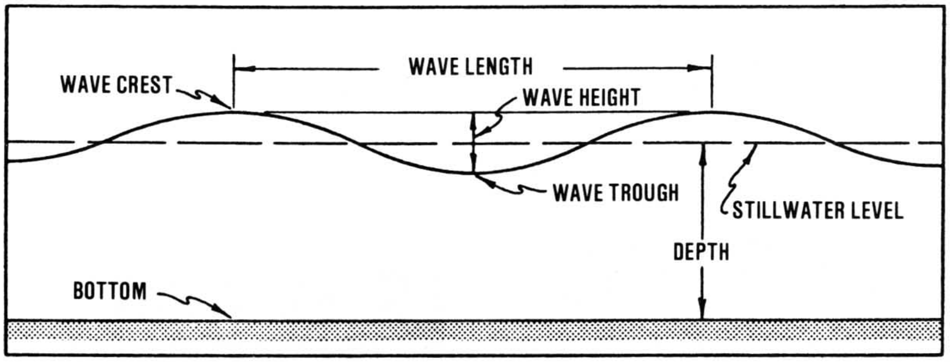


Figure 2. *Wave length, height, and period can control the direction of sediment transport along a shoreline. Adapted from U.S. Army Corps of Engineers 1977.*

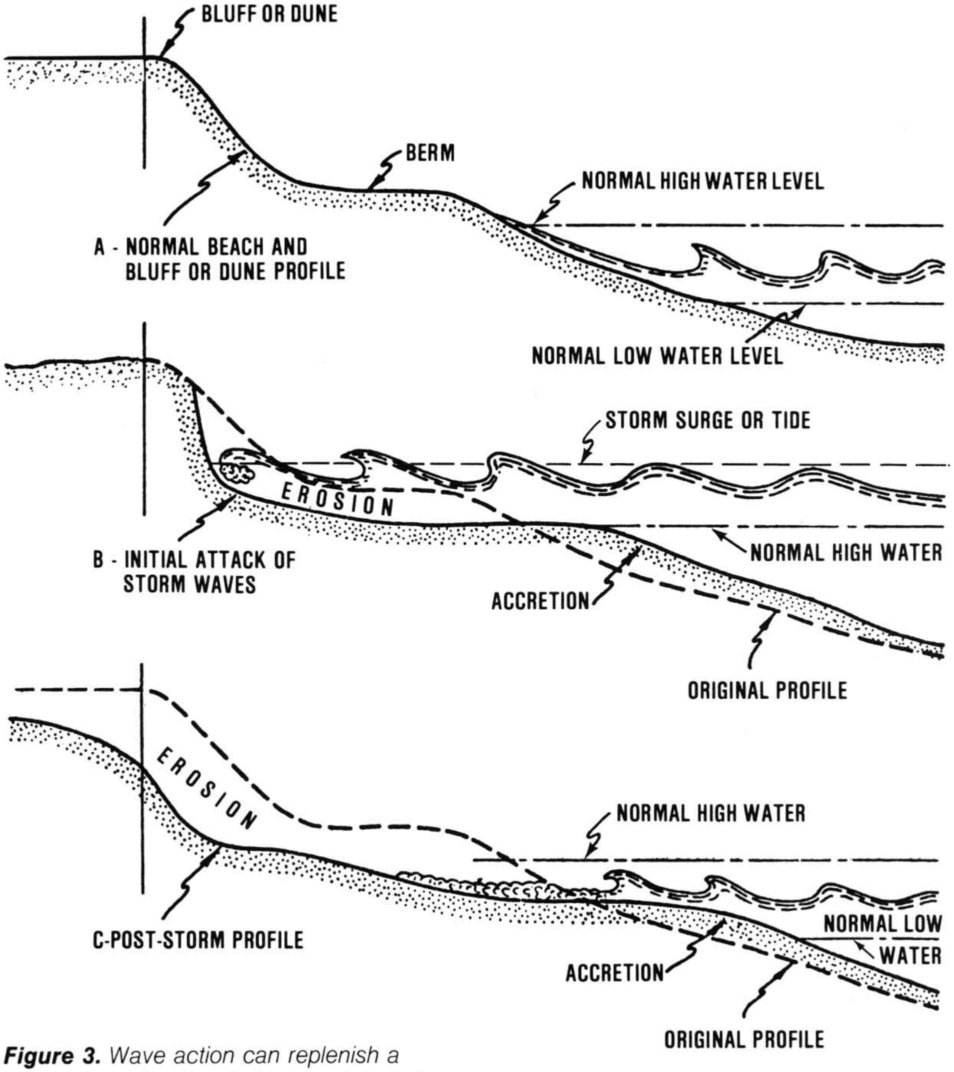


Figure 3. *Wave action can replenish a beach, as well as erode it away. Adapted from U.S. Army Corps of Engineers 1977.*

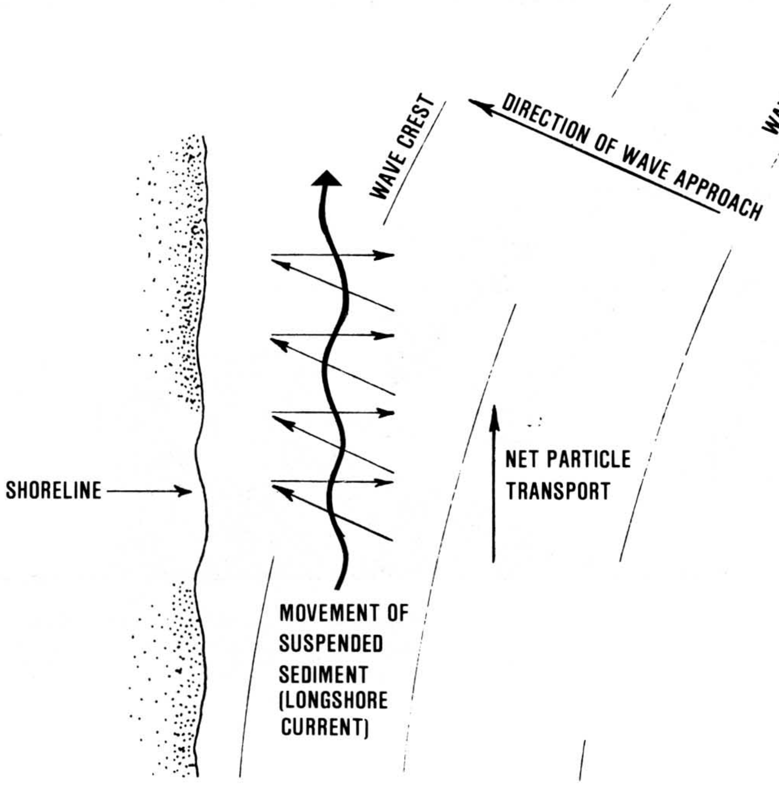


Figure 4. *When waves strike a beach at an angle, they move sediment onto the beach at an angle; that material then washes back off the beach in a direction parallel to the backrush of the wave (following gravity downhill). This zig-zag movement results in a net longshore current in the direction of the prevailing waves. Adapted from U.S. Army Corps of Engineers 1981.*

shore and the waves. In general, steep, short-period waves transport sediment offshore, whereas less-steep waves with longer periods tend to move sediment onshore.

When waves break, as already explained, the water stirs up bottom sediments. These sediments are then moved up the face of the beach with the water until its energy is expended and it begins to rush back offshore. The water moves offshore in response to gravity and, therefore, usually does not follow the same path as it took up the beach unless it struck the beach precisely head-on. Therefore, sediment is moved downdrift in a zig-zag manner, not just forward and backward. (See fig. 4.)

A longshore current is set up in the breaker zone moving generally parallel to the shore. This current is generated by waves breaking at an angle to the shoreline (fig. 4). It is not a permanent current in regards to either direction or strength. As wave energies and directions change, so do the direction and strength of the longshore current. Along the ocean coast, tidal currents are also present, but are not usually strong enough to cause erosion problems except at bay mouths where the current velocities are highest.

Longshore transport takes place when breaking waves suspend sediments in the water. These sediments can then be moved for short distances downdrift by the longshore current before they settle back to the bottom. As they are resuspended by subsequent waves, these sediments are moved farther along the shore by the current. Storm waves, having greater energy, tend to move more sediment through longshore drift than do lower, longer-period waves.

The longshore and onshore-offshore transport of sediment depends heavily upon wave direction and strength. At some times there can be deposition; at other times erosion may take place. Longshore currents may even reverse. Therefore, sediment transport must be looked at as two distinct components: (1) gross transport (that is, the total amount of sediment passing a given point during a year's time, regardless of the direction in which it is moving) and (2) net transport (for example, if 200,000 cubic yards of sediment are transported east-to-west along the shore and 75,000 cubic yards west-to-east, the net amount of sediment transported at that point is 125,000 cubic yards east-to-west).[2] Understanding the net direction and amount of transport and the net and gross transport rates is important both in understanding the process of erosion taking place along a shoreline site and in planning for appropriate erosion-control measures should they be desirable and environmentally sound. Determining these amounts and rates will usually require the services of a professional coastal engineer or researcher.

Surface Runoff

Surface runoff on the unprotected face of a coastal bluff or beach 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. Other factors that can affect the amount of soil transported downslope by surface runoff include the steepness of the slope, the roughness of the surface, the size and angularity of the soil particles, and the strength of the impact of the falling rain that is dislodging those particles.

Sheetwash is the unconfined flow of water over the surface of the ground after a rainfall. As sheetwash progresses, the runoff may become concentrated, and grooves or rills will begin to form. Over time, with more runoff, rills can become gullies. Runoff in these flow channels can attain higher velocities than sheetwash and can dislodge and carry away larger soil particles. (See figs. 5 and 6.)

It is believed that most of the erosion on coastal bluffs during the summer is due to sheet, rill, and gully erosion. This occurs after the toe of a bluff or beach has been cut away by wave action during the winter and the spring, removing vegetation and making the slope steeper and less stable. Surface erosion then removes a substantial amount of soil from the face of the slope, carrying it to the toe where it is deposited. The next cycle of storm waves can remove this material from the toe, and the process repeats itself.

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.

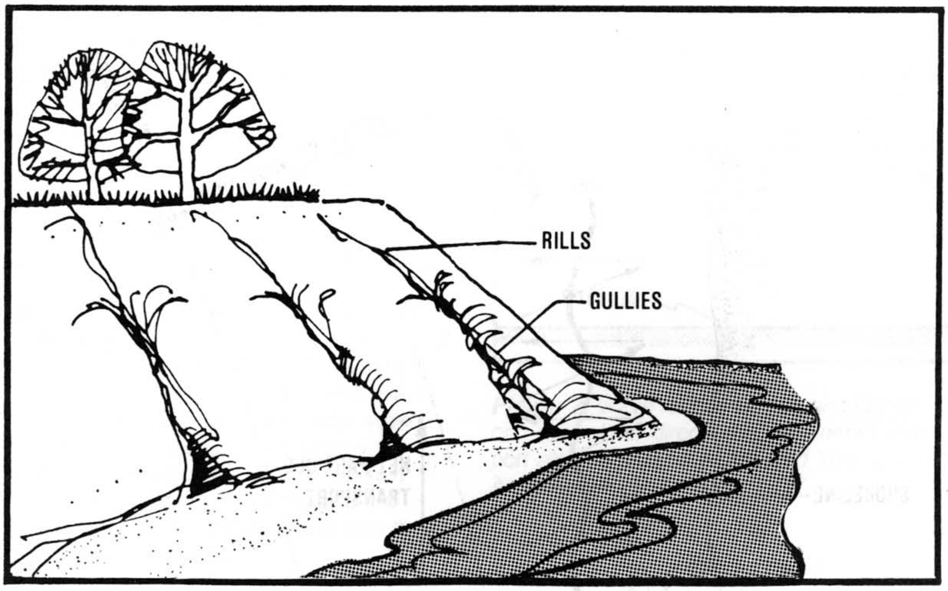


Figure 5. *Surface runoff of rain (and other) water can cause rills, which later are deepened into gullies. Adapted from Great Lakes Basin Commission 1977.*

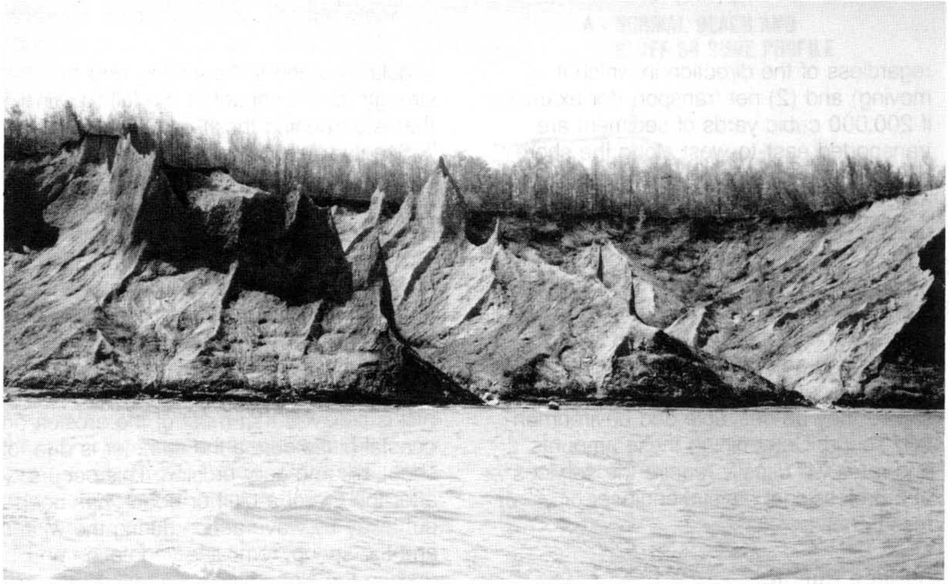


Figure 6. *Large amounts of soil can be carried away by surface erosion, only to be deposited along the toe of a slope and carried away again by wave action.*

Even when a slope may be stable under "normal" circumstances, excesses of groundwater can render it unstable and result in significant, sometimes startling, amounts of erosion.

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.

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.

New York's coastal bluffs are made up of two main types of sediments (fig. 7). The first, glacial till, is usually a random mixture of sand, silt, clay, and rocks deposited by the glaciers that once covered most of the state. The second type has separate layers of sand, silt, and/or clay that were deposited by ancient streams, bodies of water, or wind. The composition of coastal bluffs varies widely depending upon the geographic region of the state under discussion. A specific bluff's internal composition may not be uniform throughout, but may range from layers of sand and clay at the surface down to a bedrock or glacial 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 a barrier to water that would normally seep downward through the soil. (*Note:* In some areas, these layers could be rock such as sandstone or shale.) When groundwater meets one of these barrier layers, its downward movement is stopped, and it will seek low ground by flowing along the top of the barrier (fig. 8). The effect of the water flowing along this layer is that the wet top of the layer acts 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 and adds extra weight to the bluff, forming a zone of instability in the saturated soil. Disturbance of the slope, such as by construction activities, vibration from traffic, overloading the top of the slope with build-

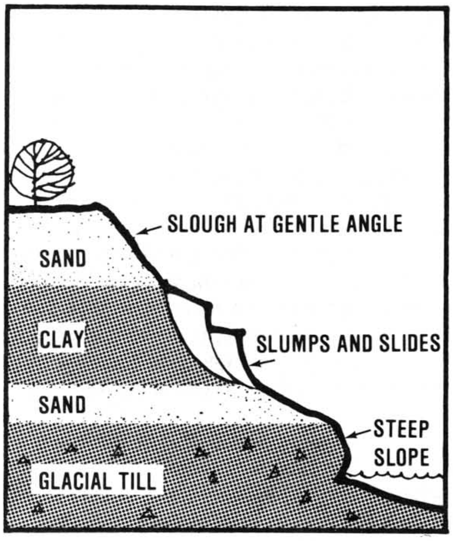


Figure 7. *New York's coastal bluffs are made up of glacial till and layers of sand, silt, and clay. Silt and sand tend to slough off a slope at relatively gentle angles; more cohesive clays and tills will usually slump or slide. Adapted from Great Lakes Basin Commission 1977.*

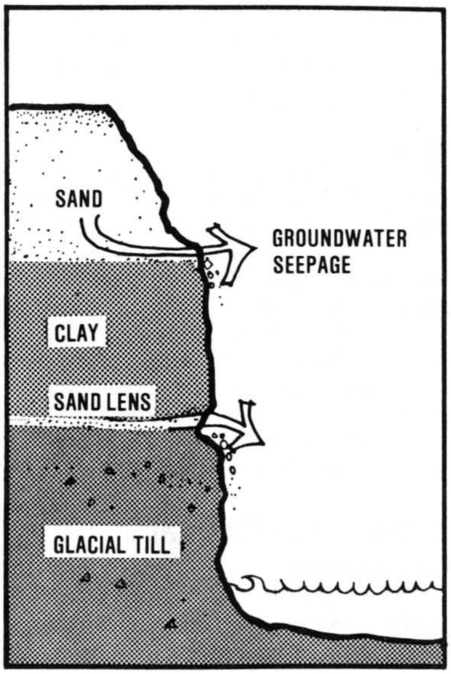


Figure 8. *Layers of clay or sand can result in groundwater seep zones. Adapted from Great Lakes Basin Commission 1977.*

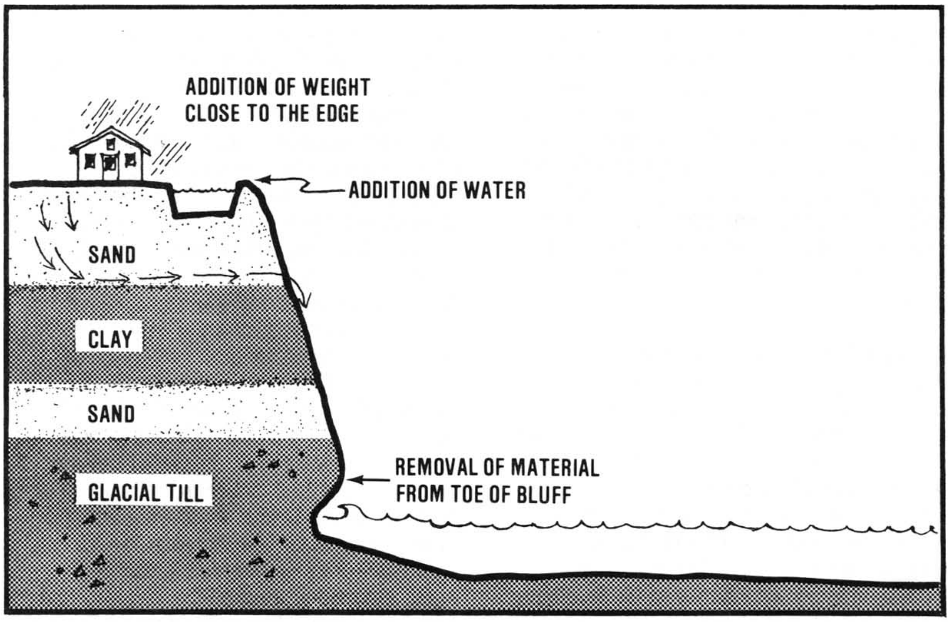


Figure 9. *Extra weight at the top of a bluff, water added from roof drains, septic systems, or swimming pools, and various human actions can result in an unstable slope. Adapted from Great Lakes Basin Commission 1977.*

ings and swimming pools, or undercutting of the toe by wave action (fig. 9), 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 slope (fig. 10). When the moisture content exceeds certain 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 be eroded 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 (fig. 7).

The effects of groundwater seepage are not always as spectacular as slides and slumps. Barrier layers may slope (underground) toward the face of a slope. Where the barrier meets the face of the slope, seep zones (which can be seen as bands of dark, moist soil, usually running nearly horizontal along the face of a bluff) and sometimes even springs may occur (fig. 11). Particles of soil can be dislodged and washed away from the face of a bluff along such seep zones. The water flowing from seeps or springs can cause rill and gully erosion along the face of the slope below. The effect can be to undercut areas on the face of the slope. The overhang will then collapse, resulting in more loss of land.

Ice

Significant ice formation takes place each winter along New York's Great Lakes' shoreline. The thick, relatively narrow band of ice that freezes immediately adjacent to the shore forms an ice foot anchored to the lake bottom. During winter and prethaw spring storms, this ice foot can serve as a natural erosion-control structure, protecting beaches or the toe of bluffs from direct wave attack. As the ice thaws and breaks into thick, free-moving flows, storm winds and waves can drive it onto the shore, scouring away beaches and bluffs and damaging human-made erosion control structures.

Ice and frost can form impermeable dams along or within coastal bluffs, preventing the unimpeded flow of groundwater through the bluffs. Frost cracks form on the surface of the land behind the top edge of a coastal bluff, usually roughly parallel to the face of the bluff (fig. 12). As a cycle of freezing and thawing takes place, more moisture enters these cracks, wedging them farther open. This allows additional water to seep into the soil. These

Figure 10. *This tree used to be at the top of the bluff before the land beneath it slumped.*

Figure 11. *Dark, moist bands indicate groundwater seep zones.*

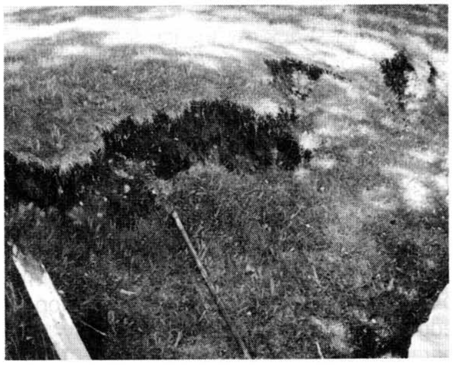


Figure 12. *Frost cracks can form unnoticed under the turf layer and then cause large sections of the top of a slope to break off.*

cracks also reduce the strength of the bluff. When these "dams" thaw in the spring, major slumps and slides often take place along the cracks.

Wind

Wind is an especially important cause of erosion in areas of sand beaches and sand dunes. Wind is responsible for the building of dunes and can erode them as well. Where natural vegetation has been destroyed or where the surface of dunes or beaches have been seriously disturbed, wind can move the unprotected grains of sand, causing cuts or gaps (blowouts) through the dunes or decreasing the depth of sand on the beaches (fig. 13). Sandy bluffs can also be eroded by wind.

Erosion and Coastal Landforms

New York has a varied coast. There are low, gently sloping coastal plains, sand beaches, bluffs, cliffs, cobble beaches, and various types of wetlands. It's not unusual for a stretch of the shore to be made up of a combination of two or more landforms, such as a low bluff with a cobble beach at its toe or a coastal plain with a sandy beach. Some coastal landforms serve as natural erosion protective features, minimizing the amount of coastal erosion to land and structures behind them.[3] These include beaches and dunes, bluffs, barrier islands, bay barriers, offshore bars, spits, and shoals, and coastal wetlands and the vegetation on them. The type of landform and the materials that make up the landform play important roles in determining both the rate of erosion as well as the type of erosion situation that may develop.

Coastal Plains and Beaches

Low, gently sloping coastal plains (and sand beaches) are made up of erodible unconsolidated sand and gravel. Near river mouths, which provide large amounts of sediments recently eroded from upland areas, silt and clay may also be part of beach sediments or mudflats, but are quickly sorted out by wave action and moved offshore where they settle in quieter waters. Sloping gradually up from the shore, coastal plains and beaches usually are no higher than 10 feet above the water level and are, therefore, also very susceptible to flooding by storm waves (and tides along the marine coast).

Beaches and low coastal plains can act as natural protective features by standing between waves and the toe of coastal bluffs and cliffs. The wider and higher the beach or plain, the more wave energy it can absorb and the more protection it affords to the land behind it. In addition to absorbing and deflecting the energy of waves, beaches also serve as a source of sediment particles for littoral transport and dune, sandbar, or shoal building.

A coastal plain or sand beach comprises an area that is normally covered by the uprush and backrush of waves (the *foreshore*) and an area that is reached only by storm waves (the *backshore*). Waterward of the foreshore is the *nearshore* or *littoral zone,* which extends from the foreshore out to or beyond the breaker zone (defined by the action of nearshore currents). (See fig. 14.)

At the normal upward limit of the wave runup on the beach, a crest is formed. Behind this crest is a flat berm which is not impacted by normal wave action. Waves from severe storms, however, do rush up over this crest and berm, and frequently form a scarp inland from the beach berm. An inland berm may be formed behind this scarp. If dunes are formed, they are typically behind the storm scarp and berm.

Offshore Bars

Offshore bars are formed from offshore sediment or from materials carried away from a beach during times of high wave activity or higher-than-normal water levels (fig. 14). If an offshore bar is built up sufficiently, incoming waves will break in the shallower water over the bar, farther out from the beach than they broke before the bar was formed. This reduces the energy of the waves when they finally do reach the shore and helps to reduce the amount of erosion on the shore behind the bar.

Of course, the action of waves breaking over the bar causes some erosion of the bar itself. When the amount of sediment being contributed to the bar from the beach equals the amount of sediment being eroded away from the bar by the breaking waves, the system remains in equilibrium. Long swells (low waves spaced far apart) may carry sand back onto the foreshore and backshore from the bar, building up the beach. Bars may actually migrate shoreward, sometimes "welding" onto the front of a beach. However, a major storm could erode the bar and carry that sediment so far offshore that it is effectively removed from the system. In this case, the beach once again becomes open to more-direct wave attack. Areas affected by only major storm waves, but not exposed to swells, will not be built back up by this replenishing action, and storm erosion will usually be permanent.

Dunes

Dunes are another type of landform composed primarily of sand. Located immediately behind the beach, primary dunes are closest to the beach and are generally only lightly vegetated (frequently with beachgrass). Secondary dunes are found landward of primary dunes and may be either well colonized with grasses, shrubs, and even trees or unvegetated. Unvegetated dunes are more prone to migration than vegetated dunes.

Like beaches and offshore bars, dunes are a natural erosion protection feature. During periods of high water or severe storms, primary dunes provide a major barrier to storm surges and act as a reservoir for sand to replenish that which is carried off the beach by wave or wind action. A higher, more-vegetated dune is more effective in providing erosion protection than a lower, bare dune. When primary dunes are breached, secondary dunes provide the same type of protection to landward areas.

Wind-deposited dunes can take months or years to form, but may be entirely removed by a single major storm. If the vegetation on dunes is destroyed, the sand can be more easily moved by both wind and waves, and the erosion control potential of the dunes is reduced.

Barrier Islands, Bay Barriers, and Spits

Barrier islands, also called barrier beaches, are offshore bars, roughly parallel to the beach, that have grown so large as to be above the normal high water level (at its crest). Barrier islands, like dunes, may be bare or vegetated and perform similar protective functions. Barrier islands also provide very important ecological functions, worthy of protection.

Bay barriers, or baymouth bars, extend partly or completely across the mouth of a bay and perform the same general erosion protection and ecological functions as do barrier islands (fig. 15).

Spits are narrow shoals or points of land attached to the shore and extending out into the water. Like bay barriers and barrier islands, spits may or may not be vegetated and serve both erosion protection and ecological functions.

Barrier islands, bay barriers, and spits serve as sand reservoirs in the same way that dunes do and are all quite fragile. Disturbance of their dunes and the vegetation growing on their sands will lead to erosion of these landforms and a reduction in their effectiveness as natural erosion control features. Obstruction of littoral transport that provides sand to them can also result in their destruction.

Figure 13. *Disturbance of a sand dune can result in blowouts.*

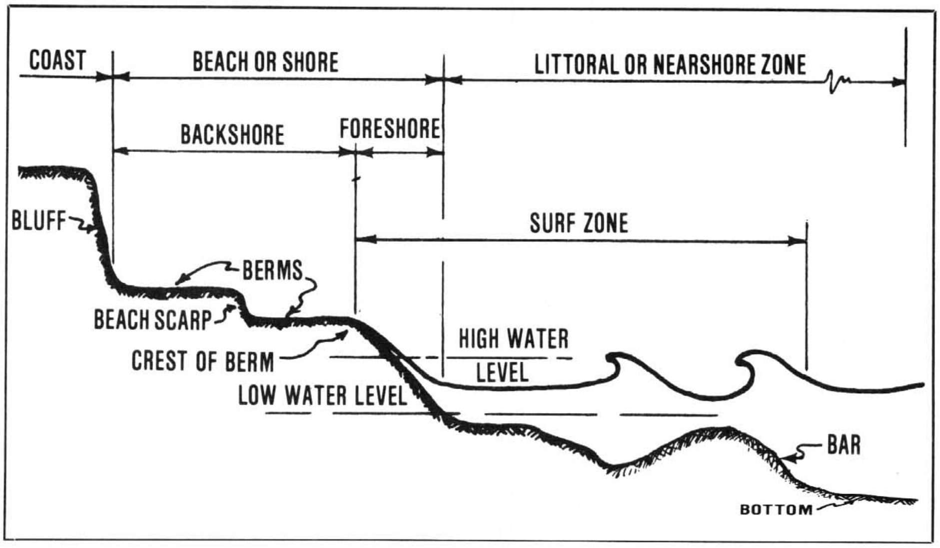


Figure 14. *Makeup of a beach. Adapted from U.S. Army Corps of Engineers 1977.*

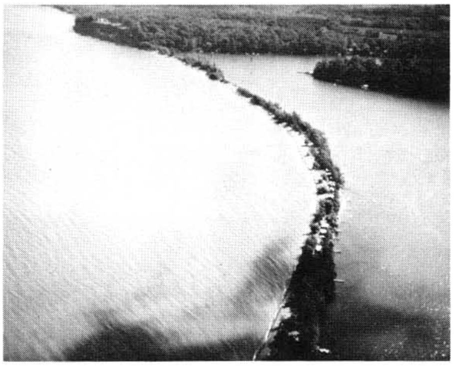


Figure 15. *Bay barriers are important natural erosion protection features.*

Figure 16. *When a slope exceeds 45 degrees, erosion rates increase dramatically with increased slope angles.*

Figure 17. *Wetlands help hold soils together, reducing erosion. They are also important natural buffers from coastal storms.*

Bluffs

New York's coastal bluffs are made up of various erodible sediments such as sand, silt, clay, and gravel. Rock, such as shale or sandstone, may be exposed at the base of a bluff, or the sand, silt, and till may extend on down below the water's edge. The causes of erosion on coastal bluffs (toe erosion, surface runoff, groundwater seepage), combined with the varied composition of coastal bluffs, result in average long-term annual recession rates from less than 1 foot per year to 5 feet per year or even more!

Along the Great Lakes, in areas where coastal bluffs are composed of cohesive sediments, slides and slumps tend to be as prevalent as damage directly attributable to wave erosion. In such cases, wave action at the toe steepens the bluff, triggering mass movements of entire segments of the bluff. This material, which is then deposited at the toe of the bluff, is removed by wave action, the steepness of the slope being retained thereby. Even if the toe of the bluff were to be protected from wave attack (such as by a naturally developed beach or by a human-made erosion control structure such as a bulkhead), these bluffs would most likely continue to erode until they reached more stable angles of repose (the angle of slope at which a bluff will be stable depends upon various factors, including particle characteristics and moisture content).

In coastal areas where bluffs are greater than 6 meters (20 feet) high, recession rates increase with increasing bluff height. Similarly, when the slope of a bluff is steeper than 45 degrees (the actual angle depends upon the physical characteristics of the bluff), the greater the slope, the greater the rate of erosion (fig. 16).[4]

For coastal bluffs at angles gentle enough for a vegetative cover to establish (generally less than 45 degrees), erosion rates are lower. This is due to the vegetation's roots "tying" the top layers of the soil together, breaking the force of falling raindrops, slowing surface runoff, and removing moisture from the soil during growth.

Bluffs provide a substantial amount of sediment to littoral transport, allowing for the buildup of beaches and offshore bars. During times of storm waves, bluffs protect inland areas and coastal development from direct wave attack and flooding, unless, of course, the development is located too near the edge at the top of an eroding bluff, in which case serious problems may develop.

Wetlands

In the coastal zone, wetlands (swamps, marshes, bogs, and similar areas) are usually found in areas of beaches and low coastal plains. They are inundated or saturated most of the year and are vegetated with plants suited for such an environment (fig. 17).

Salt and freshwater wetlands serve important ecological and erosion protection functions. They serve as huge sponges, absorbing and then slowly releasing seasonal high waters or flood waters, while providing a buffering effect to surrounding lands. The roots of wetland plants help to hold the soil together, reducing surface erosion. The wetland plants themselves filter large amounts of silt from runoff water, depositing it in the wetland. Pollutants such as fertilizers are removed by the vegetation before they can reach the open water of the coast. And finally, the biomass, once dead and rotted, combines with the deposited silts to form a cohesive bottom, which resists surface erosion.

Conclusion

As stated in the introduction to this paper, coastal erosion is a natural process that becomes a problem only when it threatens human-made structures or land deemed as valuable by society. When erosion is a problem, a thorough understanding of the physical processes causing it (and the geographic and geologic factors fostering it) is invaluable for planning its control. In some cases, various alternatives may present themselves; in others, erosion control may prove to be physically impossible, environmentally unsound, or economically impractical.

A practical approach to coastal erosion control would be to (1) identify the problem (see appendix 1, "Diagnosing Coastal Erosion"); (2) identify all practical control alternatives; (3) identify environmental and socioeconomic impacts of control; (4) select an alternative and prepare a plan; (5) identify and apply for all required permits or approvals; (6) select a contractor to perform the work; (7) construct the project; and (8) perform routine inspection, maintenance, and repair on the final product. (Items 2-8 are addressed in the Cornell Cooperative Extension Information Bulletin 200, *Structural Methods for Coastal Erosion Management.*)

Appendix 1
Diagnosing Coastal Erosion

Before designing a coastal erosion control structure, before selecting the type of erosion control structure desired, in fact, even before determining whether an erosion control structure is desirable for a specific site and problem, it's important to identify what the exact causes of the erosion are. Professional help may be needed in many situations and is available from New York Sea Grant Extension, the USDA Soil Conservation Service, county Soil and Water Conservation Districts, the New York State Department of Environmental Conservation, and private coastal engineering consultants.

The following checklist will enable a coastal landowner or local government permit official to perform a simple do-it-yourself evaluation of an eroding shoreline site and to make a preliminary determination as to what the primary cause(s) of erosion are. It cannot be stressed enough, however, that coastal erosion control engineering and design are complex and difficult and the potential impacts far-reaching. Coastal erosion control projects, beyond simple slope regrading and vegetative plantings, should usually not be undertaken by nonprofessionals. For detailed information on coastal erosion control, refer to the Cornell Cooperative Extension Information Bulletin 200, *Structural Methods for Coastal Erosion Management.*

Three major causes of coastal erosion (wave action, surface runoff, groundwater seepage) are presented, along with questions regarding readily observable physical factors. A predominance of yes answers in any section is a good indication that that particular cause of erosion may be one, if not the primary, cause of erosion at that site.

Wave Action

1. Is the site a headland that juts out, unprotected, into the water? Yes______ No______
2. Is there a long fetch (stretch of open water) in front of the site over which the wind can blow and generate large waves? Yes______ No______
3. Does the site face prevailing winds and waves? Yes______ No______
4. *a)* Is there a beach along this section of shoreline? Yes______ No______
   b) If yes, is the beach often covered by waves, particularly during storms? Yes______ No______
   c) If yes, can you see a decrease in the size of the beach after it has been covered by storm waves? Yes______ No______
5. If the shoreline is a bluff, is there evidence of wave action (such as undercutting of the slope) at the toe of the bluff during storms? Yes______ No______
6. Is the site subject to flooding during storms? Yes______ No______
7. *a)* Is there already an erosion control structure at this site? Yes______ No______
   b) At an adjoining site? Yes______ No______
   c) Is the structure being flanked (that is, is the erosion cutting around the end of the structure and encroaching into the site)? Yes______ No______

Surface Runoff

1. Is the face of the slope unvegetated and unprotected from the action of rain and flowing water? Yes______ No______
2. During a rainfall, can you see a sheetlike flow of water over the surface of the slope? Yes______ No______
3. *a)* Are there rills (tiny channels) cut into the surface of the slope? Yes______ No______
   b) Are there gullies (larger channels) cut into the surface of the slope? Yes______ No______
4. *a)* Does the lawn (or other large, flat area) at the site slope toward the face of the slope? Yes______ No______
   b) Is the runoff from that area allowed to flow uncontrolled over the face of the slope? Yes______ No______
5. *a)* Does the runoff from the roof of any building on the site run directly off the roof and over the face of the slope? Yes______ No______
   b) Does any driveway or parking lot runoff go directly over the face of the slope? Yes______ No______
   c) Is there any lawn sprinkling or irrigation taking place at the top of the slope? Yes______ No______

Groundwater Seepage

1. *a)* After a rainfall or in the spring, can you see seep zones (dark, wet-looking layers of soil) along the face of the bluff? Yes______ No______
   b) If yes, are they still there after the rest of the face of the slope has dried up? Yes______ No______
2. *a)* Is there active slumping or landsliding taking place on the bluff? Yes______ No______
   b) Are there any mudflows or springs along the face of the slope? Yes______ No______
3. *a)* Does the runoff from any roof drains discharge into the soil at the top of the slope? Yes______ No______
   b) Does driveway or parking lot runoff soak into the soil at the top of the slope? Yes______ No______
   c) Is there any lawn sprinkling or irrigation taking place at top of the slope? Yes______ No______
   d) Is there a septic system leach field near the top of the slope? Yes______ No______

Appendix 2
New York State Coastal Erosion Hazard Law

Readers in New York State should be aware that certain coastal lands are classified as Coastal Erosion Hazard Areas by the state's Coastal Erosion Hazard Areas Act. Some coastal terms have very specific legal definitions for purposes of implementing that law. Some of these legal definitions follow. Readers wishing to know more about this law should consult Article 34 of the Environmental Conservation Law, the Coastal Erosion Hazard Areas Act, Part 505 of the New York Codes, Rules, and Regulations, the Coastal Erosion Management Regulations, or their local office of the New York State Department of Environmental Conservation for details.

1. Under this law, BEACHES are defined as the zone of unconsolidated material that extends landward from the mean low-water line to the place where there is a marked change in material or physiographic form or to the line of permanent vegetation or to the seaward toe of a dune, whichever is most seaward. Beaches are considered to be natural [erosion] protective features.
2. The seaward limit of a BLUFF is considered to be the landward limit of its contiguous beach or, where no beach exists, the mean low-water level. The landward limit is considered to be 25 feet landward of the bluff's receding edge. Bluffs are considered to be natural [erosion] protective features.
3. COASTAL EROSION HAZARD AREA: Under state law, an area of the coastline which is *(a)* subject to erosion and located landward of shorelines having an average annual recession rate of 1 foot or more per year (inland boundary is a horizontal distance 40 times the long-term average annual recession rate landward from the receding edge of a bluff and perpendicular to the shoreline); or *(b)* a natural [erosion] protective feature.
4. NATURAL [EROSION] PROTECTIVE FEATURE: Under state law, beaches, barrier islands, barrier beaches, bay barriers, bluffs, primary dunes, secondary dunes, spits, wetlands, and the vegetation thereon that afford protection to inland areas from coastal erosion are considered to be features that protect inland areas from erosion. These features are shown on the state's Coastal Erosion Hazard Areas maps.
5. PRIMARY DUNE: The most seaward major dune where there are two or more parallel dune lines within a coastal area. Where there is only one dune present, it is the primary dune. Smaller dunes formed seaward of the primary dune are considered to be part of the primary dune. The seaward limit of a primary dune is the landward limit of its fronting beach. The landward limit is 25 feet landward of its landward toe.
6. RECEDING EDGE is the most landward line of active erosion, or where there is no discernable line of active erosion, it is the most seaward line of permanent vegetation.
7. SECONDARY DUNE: The major dune immediately landward of the primary dune. Its seaward limit is the landward limit of its fronting primary dune; its landward limit is 25 feet landward of its landward toe.

Notes

1. In New York, under the Coastal Erosion Hazard Areas Act of 1982 (Environmental Conservation Law, Article 34), erosion hazard areas are identified as areas of the coast where the average recession rate caused by erosion is 1 foot or more per year. In this bulletin, the term *coastal erosion hazard area* will be used to refer to areas as identified in this law. The term *erosion-prone areas* will refer generically to areas susceptible to erosion, but not necessarily covered by the law.
2. Along the Atlantic coast of Long Island, the net rate of transport may range to near a million cubic yards of sediment per year. Along Lakes Erie and Ontario, this net transport would not usually be expected to exceed 100,000 to 150,000 cubic yards per year.
3. New York's coastal erosion management regulations define natural protective feature areas as "land or water area[s] containing [the abovementioned] natural protective features, the alteration of which might reduce or destroy the protection afforded other lands against erosion or high water."
4. Drexhage and Calkin 1981.

Glossary

Note: The terms presented in this glossary come from various sources, but were culled mainly from U.S. Army Corps of Engineers, *Shore Protection Manual*, volume 3, 3d edition, U.S. Army Coastal Engineering Research Center, Fort Belvoir, VA, 1977.

ACCRETION. The buildup of a beach by the natural (windborne or waterborne) or human-induced deposition of sand or other sediments.

BACKSHORE. That portion of a beach or the shore lying between the first major inland change in topography and either the crest of the first (seaward or lakeward) berm or the upper limit of wave wash at high tide. The backshore is affected by waves only during severe storms, especially when they are combined with very high water. This area is also called the BACKBEACH.

BARRIER ISLAND. An embankment of sand, gravel, or other unconsolidated material built in shallow water upon the floor of a lake or the sea by waves and currents, running roughly parallel to the shore and extending above the normal high water level. Also called BARRIER BEACHES and OFFSHORE BARRIERS.

BAY BARRIER. A submerged or emerged bank of sand, gravel, or other unconsolidated material built in shallow water on the floor of the sea or a lake by waves and currents and extending partly or entirely across the mouth of a bay. These are also called BAYMOUTH BARS.

BEACH. The area of unconsolidated sediments extending landward from the low water line to the place where there is a marked change in either material or landform or to the line of permanently established vegetation. A beach is the area between the most inland limit of storm waves and the mean low water line. Beaches are made up of a foreshore and a backshore.

BEACH BERM. A nearly horizontal part of a beach formed by the deposit of material by wave action at the high water line. Some beaches may have several berms, others none at all.

BLOWOUTS. Areas where wind has "blown out" notches or gaps in a beach or dune. This occurs where there is no vegetative cover to hold the sand.

BLUFF. A high, steep bank or cliff composed of erodible materials.

COAST. The strip of land, of indefinite width (up to several miles), that extends from the shoreline to the first major change in topography.

COASTAL EROSION HAZARD AREA. Under New York State law, an area of the coastline which is *(a)* subject to erosion and located landward of shorelines having an average annual recession rate of 1 foot or more per year (inland boundary is a horizontal distance 40 times the long-term average annual recession rate landward from the receding edge of a bluff and perpendicular to the shoreline); or *(b)* a natural [erosion] protective feature.

CURRENT. A flow of water.

DOWNDRIFT. The direction of predominant movement of littoral materials.

DUNE. A ridge or mound of loose, windblown material, usually sand.

EROSION. The loss or displacement of land along the coast due to the action of waves, currents, tides, wind-driven water, waterborne ice, or other impacts of storms; or the direct action of wind, runoff of surface water, or groundwater seepage.

FETCH. The area of open water over which a wind with constant direction and speed blows, generating waves.

FORESHORE. That portion of a beach or the shore lying between the crest of the seaward berm (or upper limit of wave wash at high tide) and the ordinary low water line. The foreshore is normally traversed by daily and tidal waves. This area is also called the BEACH FACE.

GROUNDWATER. Water within the soil that supplies wells and that comes to the surface as seepage or in springs.

LITTORAL. Of or pertaining to the shore.

LITTORAL CURRENT. Any current in the zone extending seaward from the shoreline to just beyond the breaker zone.

LITTORAL DRIFT. The material moved along the shore by waves and currents.

LITTORAL TRANSPORT. The movement of littoral drift along the shore by waves and currents, both parallel to the shore (longshore transport) and perpendicular to it (offshore transport).

MEAN HIGH WATER. The approximate average of the high water level for a given body of water at a given location.

MEAN LOW WATER. The approximate average low water level for a given body of water at a given location.

NATURAL [EROSION] PROTECTIVE FEATURE. Under New York State law, a nearshore area, beach, bluff, primary dune, secondary dune, or wetland and the vegetation thereon that afford protection to inland areas from coastal erosion.

NEARSHORE. An indefinite area extending seaward from the shore to beyond the breaker zone and identified by the presence of nearshore currents.

OFFSHORE BAR. A submerged or emerged bank of sand, gravel, or other unconsolidated sediment built in shallow water upon the floor of a lake or the sea by waves and currents.

PRIMARY DUNE. The most seaward major dune where there are two or more parallel dune lines within a coastal area. Where there is only one dune present, it is the primary dune. Smaller dunes formed seaward of the primary dune are considered to be part of the primary dune.

RILL. A tiny drainage channel cut in a beach or bluff face by the seaward flow of surface water.

RECESSION RATE. The rate, expressed in feet or meters per year, at which an eroding shoreline moves landward.

SECONDARY DUNE. The major dune immediately landward of the primary dune. Its seaward limit is the landward limit of its fronting primary dune.

SEICHE. An oscillating wave in an enclosed body of water that continues its motion (similar to the swinging of a pendulum) after the termination of the driving force (usually wind or barometric pressure differences). On the Great Lakes, any sudden rise in water level in a harbor or bay is also called a seiche, whether oscillating or not.

SHORE. The narrow strip of land in immediate contact with the water, including the area between high and low water lines. This encompasses the backshore and the foreshore.

SPIT. A small point of land or a narrow shoal projecting into a body of water from the shore.

SWELL. A long, low wind-generated wave that has traveled out of the area in which it was generated.

TOE. The lowest point on the slope of a bluff or a dune.

UPDRIFT. The direction opposite that of the predominant movement of littoral materials.

WETLAND. Lands and submerged lands, commonly called marshes, swamps, sloughs, bogs, and flats, supporting aquatic or semiaquatic vegetation that depends upon seasonal or permanent flooding or sufficiently water-logged soils to give them a competitive advantage over other plants.

Bibliography

DeYoung, B., and L. Brown. 1979. *Controlling bluff groundwater along the Great Lakes.* New York Sea Grant Extension Fact Sheet. Cornell Univ., Ithaca. 6 pp.

Drexage, T., and P. E. Calkin. 1981. *Historic bluff recession along the Lake Ontario coast.* New York Sea Grant Institute, Albany. 133 pp.

Freese, J. H., and F. H. Kulhawy. 1983. *General planning considerations for small-scale coastal structures.* Coastal Structures Handbook Series, New York Sea Grant Institute, Albany. 124 pp.

Great Lakes Basin Commission. 1975. "Shore use and erosion." Appendix 12 in *Great Lakes Basin framework study.* Ann Arbor, MI. 111 pp.

Great Lakes Basin Commission. 1977. *The role of vegetation in shoreline management: A guide for Great Lakes shoreline property owners.* Ann Arbor, MI. 32 pp.

Michigan Sea Grant. 1982. *Proceedings of workshop on bluff slumping.* Ann Arbor. 136 pp.

N.Y.S. Department of Environmental Conservation. 1983. *Coastal erosion management regulations.* 6NYCRR505. Albany. 41 pp.

U.S. Army Corps of Engineers. 1966. *Shore protection, planning and design,* Tech. Rep. no. 4, 3d ed. Coastal Engineering Research Center, Ft. Belvoir, VA.

______.1973. *Help yourself: A discussion of erosion problems on the Great Lakes and alternative methods of shore protection.* North Central Division, Chicago, IL. 24 pp.

______.1977. *Shore protection manual.* Coastal Engineering Research Center, Ft. Belvoir, VA. 964 pp.

______.1981. *Low cost shore protection. . .a guide for engineers and contractors.* Washington, DC. 173 pp.

______.*Monthly bulletin of lake levels for the Great Lakes.* Detroit District, MI.

Wiegel, R. L. 1953. *Waves, tides, currents, and beaches: Glossary of terms and list of standard symbols.* Council on Wave Research, The Engineering Foundation, Univ. of California, Los Angeles.

The New York State College of Agriculture
and Life Sciences is a statutory college of
the State University, at Cornell University,
Ithaca, N.Y. 1985.
Produced by Media Services at Cornell
University

Cornell Cooperative Extension—Helping You Put Knowledge to Work

This publication is issued to further Cooperative Extension work mandated by acts of Congress of May 8 and June 30, 1914. It was produced with the cooperation of the U.S. Department of Agriculture, Cornell Cooperative Extension, New York State College of Agriculture and Life Sciences, New York State College of Human Ecology, and New York State College of Veterinary Medicine, at Cornell University. Cornell Cooperative Extension offers equal program and employment opportunities. Lucinda A. Noble, Director.