Understanding, Living With, & Controlling

Shoreline Erosion

A Guidebook for Shoreline Property Owners

Third Edition

Tip of the Mitt Watershed Council

Acknowledgments

This guidebook was made possible by a grant from the U.S. Environmental Protection Agency through the Great Lakes Commission's Great Lakes Basin Program for Soil Erosion and Sedimentation Control. Martha Kupka, Charlevoix and Emmet Conservation Districts; Phil Naegele, Charlevoix and Emmet Conservation Districts; Dan Sikarskie, Huron Pines Research Conservation and Development Council; Diane Rekowski, Northeast Michigan Council of Governments; Perry Smeltzer, Cheboygan Conservation District; and Pepper Bromelmeier, Antrim Conservation District served on the project advisory committee. In addition, Laura Grantham, Conservation Resource Alliance; Keith Martell, Charlevoix and Emmet Conservation Districts; Linda Koon, Charlevoix and Emmet Conservation Districts; Will Brune, Little Traverse Conservancy; John Gannon, U.S. Geological Survey; Brad Wilkins, Michigan Department of Environmental Quality; Martha Lancaster, private citizen; Debbie Messer, Watershed Council Board President; Kathy Bricker, Center for Marine Conservation; and Richard Brown, Meridian Township made valuable contributions by providing information and/or reviewing and editing draft versions. Special recognition goes to Watershed Council staff members Ann Baughman, Wil Cwikiel, Gail Gruenwald, Michelle Gilliam, Jan Wilkins, Lauren Tepper, and Scott McEwen for their assistance. Josephine O'Brien created the artwork, except for Figures 24 and 25 which were drawn by Matt "Mojo" Staley. Kate Melby produced some of the figures and did the typesetting. Jeremy Hamel provided some of the photographs. Lewis and Jody Hopkins and the Linnenberg Family allowed the biotechnical erosion control demonstration project to be constructed on their properties. Wendy Johnson verified the accuracy of names, addresses, and phone numbers in the appendices.

Project funded by a grant from the U.S. Environmental Protection Agency
through the Great Lakes Commission's
Great Lakes Basin Program For Soil Erosion and Sediment Control

426 Bay Street, Petoskey, MI 49770
phone: 231.347.1181 fax: 231.347.5928 e-mail: info@watershedcouncil.org
website: www.watershedcouncil.org

ISBN 1-889313-01-7

Cover Photo— Erosion at the base of this steep streambank is resulting in stream widening, excessive sand sedimentation, and loss of shoreline vegetation.

Table of Contents

The Tip of the Mitt Watershed Council is the voice for Northern Michigan's waters. We are dedicated to protecting our lakes, streams, wetlands, and ground water through respected advocacy, innovative education, technically sound water quality monitoring, and thorough research. We achieve our mission by empowering others and we believe in the capacity to make a difference. We work locally, regionally, and throughout the Great Lakes Basin.We were formed in 1979 and have a history of working closely with lake associations and shoreline property owners on water resource management issues.

Over the years, it has become clear that shoreline erosion is one of the biggest water resource issues and one of the greatest concerns of shoreline property owners. To address the issues and concerns associated with shoreline erosion on inland lakes and streams, we applied for, and received, funding for a project from the Great Lakes Commission.

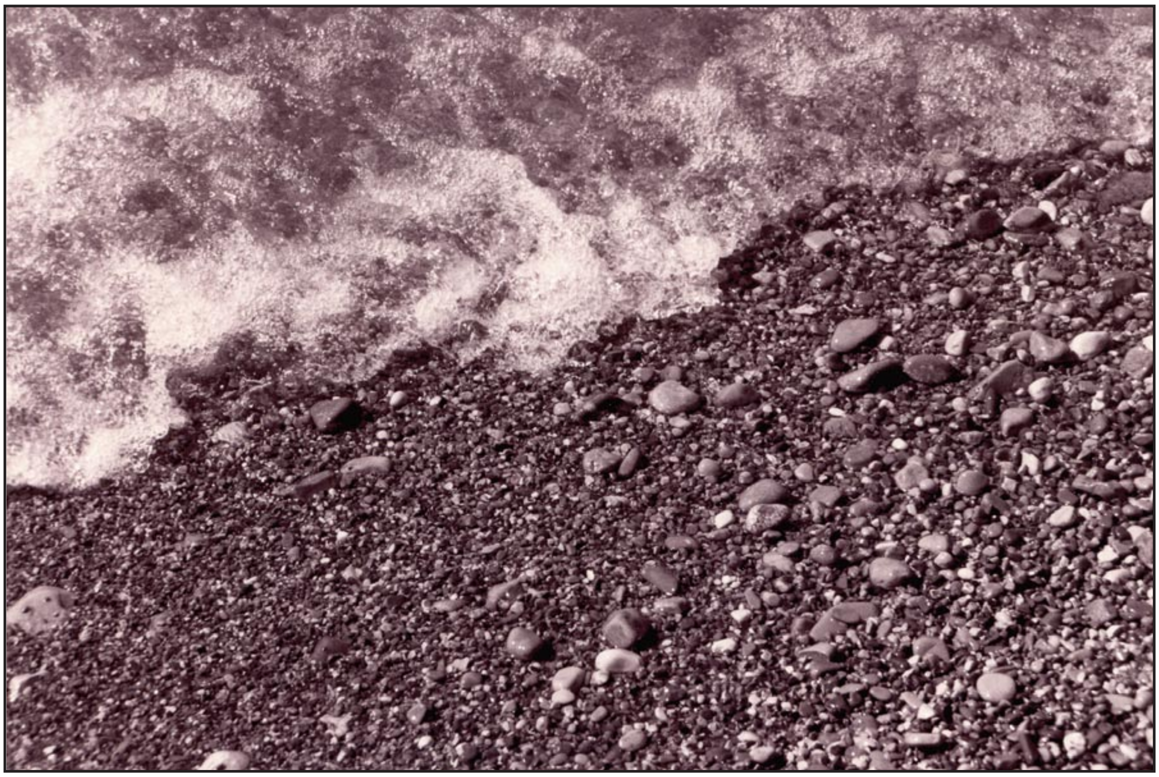
The five phases of the project were:

1. Research state-of-the-art practices for controlling shoreline erosion;
2. Develop educational materials (brochure and guidebook) on shoreline erosion control;
3. Work with individual landowners to implement a shoreline erosion control demonstration project;
4. Develop and provide an erosion control consultation service to shoreline property owners; and
5. Work with other environmental organizations throughout the Great Lakes basin to help them better address this topic.

This guidebook was developed from a Northern Michigan perspective.It is the hope of the Watershed Council that it will result in better understanding and actions by shoreline property owners in the Tip of the Mitt region, throughout Michigan, and around the Great Lakes Basin.

Section One

Introduction to Shoreline Erosion



Waves gradually expend their energy on this sloping gravel shoreline helping to protect shoreline soils against erosion.

Shorelines do not exist in an unchanging condition… Unfortunately, nature's dynamic equilibrium and human efforts to control it are often a poor mix.

Erosion is the wearing away of the land surface by the action of wind, water, ice, or gravity. Sedimentation is the deposition of eroded soils in waterways or other locations.

Shorelines do not exist in an unchanging condition. Erosion and the transport and deposition of sediments are natural processes along shorelines. There is often a net balance between the amount of shoreline eroded and the amount of new shoreline created by sedimentation – a condition known as dynamic equilibrium.

Natural erosional pro-cesses typically proceed very slowly, on a geologic rather than a human time scale. The plants and animals that live along the shoreline can adjust to these slow changes, maintaining a stable, healthy, productive ecosystem. In fact, some species have adapted to live in erosional areas. For example, bank swallows nest in steep, eroding bluffs and wood turtles lay their eggs in eroding sandy streambanks. Studies have revealed that preventing natural shoreline processes can upset overall ecosystem stability. Trying to eliminate all shoreline change is like trying to still the very waves and currents that cause it.

Emergent marsh plants, such as this hardstem bulrush (Scirpus acutus), have disappeared in many areas following shoreline development, exposing the shore to greater erosive forces.

Human activities or disturbance along shorelines and throughout watersheds can bring about changes that greatly accelerate the natural erosional process, often with profound environmental or economic impacts. Accelerated erosion can lower the stability and productivity of aquatic habitats and may have serious implications for landowners.

Large scale efforts to control accelerated soil erosion and sedimentation, from both inland and shoreline sources, have been ongoing by a variety of state and federal agencies since the dust bowl conditions of the 1930's. In the past, much of the focus of shoreline erosion and its control has been on the coastlines of the oceans and the Great Lakes, where erosion has the potential to be most severe and have catastrophic consequences. The approach has often been one of pure structural engineering, without considering the influence of, or impact to, ecological systems.

Information pertaining specifically to inland lakes and streams has been slow to develop, has been largely unavailable to shoreline property owners in an understandable form, and has generally not taken an ecosystem approach. As a result, some accelerated erosion problems have gone unnoticed or unchecked, and many erosion control projects which have been constructed are either inappropriate or ineffective for inland waters.

The trend in recent decades for shoreline living, coupled with shoreline development patterns, has contributed to accelerated erosion. Natural shoreline erosion is also now perceived as a problem, whereas on previously undeveloped shorelines subtle changes in shoreline configuration were rarely noticed and not considered a situation that needed controlling. Some lakeshore developments do away with the natural shoreline in favor of bulkheads or other erosion control structures as a matter of course. Quite often these structures are not needed.

Many people in our society do not accept the moveable nature of shoreline property, but rather seem to expect that shorelines will be permanently fixed in perpetuity and recorded as such in land titles, similar to other surveyed property boundaries. Unfortunately, nature's dynamic equilibrium and human expectations as well as our efforts to control it are often a poor mix.

This guidebook focuses on the erosion and sedimentation caused by the energy of streams and inland lakes acting on their shorelines. Its goal is not to help shoreline property owners make their shoreline unchanging, but rather to inform about shoreline processes and help guide actions to control nature in a way that is not utterly futile or environmentally harmful. It attempts to present an unbiased overview of the pros and cons of different methods. However, it seems clear to Watershed Council staff that one method, biotechnical erosion control, provides the most cost-effective, environmentally friendly and aesthetically appealing alternative to controlling accelerated shoreline erosion.

Understanding shoreline erosion and developing effective protection strategies is a complex subject. The information in this guidebook is the result of an extensive literature search, discussions with experts on this topic, and the experience of the Tip of the Mitt Watershed Council staff with conditions and residents of northern Michigan lakes and streams. Research on this project revealed that there is no overall recipe for a successful erosion control project, and there are many contradicting pieces of advice.

New methods and refinements of old methods are constantly being developed. Each site involves a unique set of circumstances and generally requires a customized solution.

Even though there have been numerous studies and publications on this topic, there are no manuals with generic plans for shoreline protection projects which are guaranteed to work. However, by utilizing the information contained in this guidebook and following an organized plan to assess problems and evaluate the pros and cons of potential solutions, the likelihood of choosing an appropriate and successful action will be improved.

Section Two

Understanding Shorelines and Shoreline Erosion

Beaches have been called one of the most effective defense structures in the world. Sand or gravel beaches can resist forces that tear apart rigid structures after a few seasons.

Excessive sand bedload plagues many trout streams.

Shorelines are areas of unending conflict between the land and the natural forces of wind, waves, gravity, and currents. There is a connection between the shoreline and the adjacent water body. What happens in the water affects what happens on land, and vice versa. It is important to understand this relationship in order to manage erosion and sedimentation problems.

Shoreline Types

Among the most important factors influencing shoreline erosion on both lakes and streams are the features of the shoreline, particularly the materials composing the shoreline and the type of shoreline formation.

MATERIALS

Shoreline materials are derived from adjacent surface sediments, deterioration of rock cliffs, sediments transported long distances and deposited by flowing water, the disintegration of shells, and the production of organic soil (a soil composed of partially decomposed plant materials) in marshes and other wetlands.

The composition of the land surface in the Great Lakes basin has been modified by a series of glaciations over the last million years, the last of which ended 10 to 12 thousand years ago. In addition, various postglacial stages of the Great Lakes modified many areas of the landscape. As a result, most areas are covered by erodible deposits ranging from pure sand to pure clay to a mixture of different soil particles called till. However, bedrock outcrops are found in some areas. Nearly all the natural lakes in the Great Lakes basin were formed by glacial action. Therefore, glacial deposits are the most available source of shoreline materials.

The erodibility of a shoreline is a function of the amount of erosive energy reaching the shore versus the resistance of the shore material. There are six basic types of shoreline materials: rock, gravel, sand, silt, clay, and organic material. Each type has a different ability to resist erosion. **Figure 1** portrays the erodibility of five of the different types of shoreline materials by current velocity.

Rocks and gravel are heaviest, and may require large amounts of energy to move. Sand, silt, and organic materials (not shown in figure) are the most erodible. Clay is not very erodible because the tiny particles stick to one another (termed cohesiveness). The root systems of woody vegetation greatly augment the strength of all types of soils.

FORMATIONS

There are four basic forms of shorelines on both lakes and streams: 1) cliffs and bluffs, 2) gently sloping plains and beaches, 3) dunes, and 4) wetlands. A combination of these may occur at a single location.

Cliffs and Bluffs

Cliffs and bluffs are high, steep banks at the water's edge. Cliffs are primarily composed of rock, while bluffs are composed of unconsolidated materials.

The rock types composing cliffs may have originated from sediments deposited on the beds of ancient seas (i.e., sedimentary rocks such as limestone or sandstone), or rocks forged in the intense heat of the earth (i.e., metamorphic or igneous rocks like quartzite or granite). Although all rock cliffs are relatively resistant to rapid erosion, sedimentary rocks are most erodible.

The erodibility of bluffs is variable, depending on their particular physical characteristics. Bluffs may consist of the same materials throughout (such as sand or silt), a mixture of different materials deposited by glaciers (glacial till), or distinct layers of different materials.

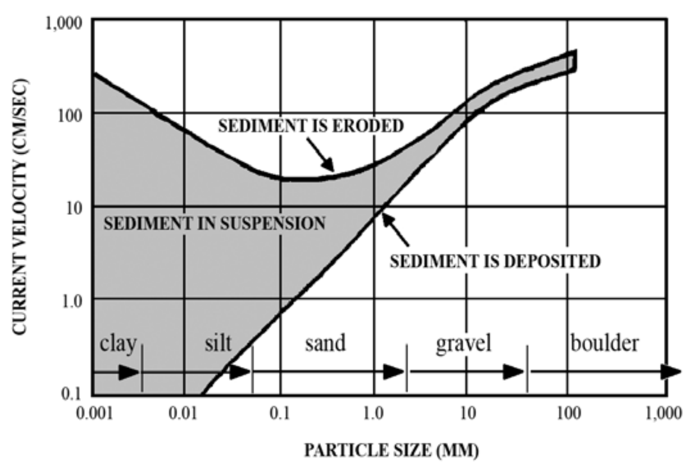


Figure 1: *Erodibility of different shoreline materials by streamflow.*

Bluffs are most susceptible to erosion when the waves or currents erode the base (toe) of the slope. The steeper the face of the bluff, the more susceptible it is to erosion. High bluffs (over 20 feet) are more likely to experience erosion problems than low bluffs due to the weight of the bluff itself and the potential energy of runoff flowing down the bluff face. Steep, high bluffs can collapse suddenly in a landslide (also known as mass wasting, bluff slumping, falls, or debris flows) due to soil instability or human alteration.

The discharge of ground water makes any area of the land surface more erosion-prone because it moves soil particles away from the point of discharge. However, ground water discharge from bluffs presents a more serious threat to soil stability than in flatter areas. This is especially true when layers of different soils are present because the discharge of ground water can be concentrated in a small area, intensifying its effect. **Figure 2** shows a conceptual drawing of a shoreline bluff.

Plains and Beaches

Sloping plains and beaches are the most common shoreline forms. They are composed of loose sediments, ranging from silt to boulders, which slope gently up to and away from the water's edge. A beach is the zone of sediment that extends from the low water line to the beginning of permanent vegetation. Most of the beach is dry during calm weather. During windy weather on lakes and some large rivers, waves approach from offshore, breaking and surging up the face of the beach. Beaches are the product of erosive forces, sediment supply and movement, and the near-shore land profile.

Beaches have been called one of the most effective defense structures in the world. Sand or gravel beaches can resist forces that tear apart rigid structures after a

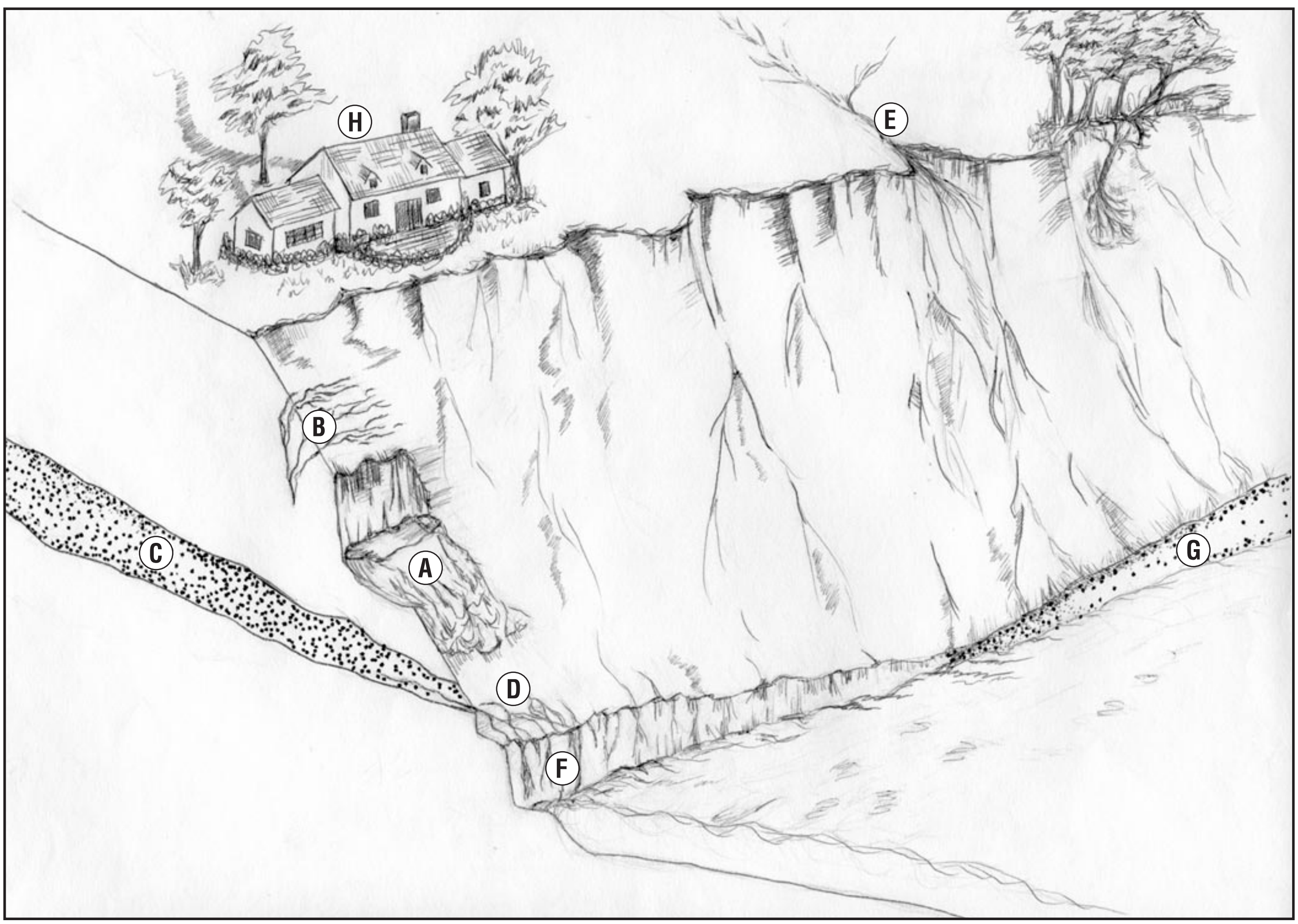


Figure 2: *A conceptual drawing of a shoreline bluff. A—bluff slump, B—stress cracks, C—sand layer, D—seepage, E—overland erosion and gully, F—eroding toe, G—toe partially protected by beach, H—heavy structure in disturbed area.*

few seasons. Sand is the most common beach material. It is the only sediment which can build lakeward as well as erode landward. Shoreline recession rates are usually low or nonexistent wherever there is a wide beach.

Dunes

A dune is a hill or mound of loose, wind-blown material, usually sand. Although some dunes could also be considered bluffs, bluffs typically have steeper sides than are possible with sand dunes. Dunes are normally associated with oceans and the Great Lakes, but on some large inland water bodies wind may blow beach sand into small, low dunes. Dunes are harsh environments due to rapid sand movement, wide temperature fluctuations, drought, and low nutrient levels. The sparse vegetation, which helps to build and stabilize dunes by slowing wind velocity and trapping windblown sediment, can be damaged by excessive foot traffic or other types of disturbance. If vegetation disappears, the dune can be blown away, eliminating an important shoreline feature and a potential source of sand for beach nourishment.

Wetlands

Wetlands usually occur in combination with a low plain. They develop in areas where the water table is high enough during the growing season that the vegetation community is dominated by plant species tolerant of wet soil conditions. Some wetlands develop in areas protected from wave action, such as by an offshore bar. If conditions change so that waves attack this type of wetland, rapid erosion and wetland loss may result. Other types of wetlands develop in front of sand beaches in the presence of wave activity and nearly continuous inundation. These wetlands, often vegetated with rushes, function to diminish wave energy on the shore, and trap and hold bottom sediments. Their loss may result in beach erosion.

Streams and Streambanks

A stream is a body of water flowing in a more or less uniform direction along a path of least resistance from a higher elevation to a lower elevation within a catchment area or watershed. Some ecologists consider a stream's ecosystem (a functioning system consisting of living organisms interacting with nonliving components) to include its entire watershed. This is because many features and conditions in the watershed influence stream characteristics. These include geology, hydrology, land use, climate, soils, topography, and vegetation. In addition, conditions which occurred in the distant past, such as glacial meltwater and logging, have had lasting effects on stream characteristics.

WATER FLOW

The water flowing in streams originates from precipitation in the watershed. The water gets into the stream channel by direct precipitation, overland runoff, throughflow (water which flows briefly through the upper layers of the soil), and ground water discharge. Direct precipitation and runoff reach stream channels rapidly, throughflow reaches the channel after a moderate lag time (hours or days), and ground water flow has a long delay (months or even years).

Watershed Drainage

Each watershed is different in the way water moves through it to the stream channel. The way precipitation is routed through the watershed has a great impact on stream level fluctuation, water temperature, and the biological character of streams. In watersheds where the precipitation is drained rapidly, streams typically have higher flood peaks and lower base flows. In watersheds where the precipitation is drained slowly, streams have steadier flows and less extreme flooding.

Ground water flow characteristics depend on the porosity of the soil along with the slope of the water table. This means that watersheds with sandy soils and large elevational differences are most likely to have high amounts of ground water input. One way to illustrate a stream's flow regime is to plot the discharge over time. This is called a hydrograph. **Figure 3** compares the hydrograph of streams in watersheds with rapid and slow drainages.

Physics of Stream Flow

To properly manage streams, it is essential to understand the basic concepts of how water moves through channels. This is a complex topic. In fact, much of our knowledge of these concepts comes from carefully controlled laboratory studies, which may have

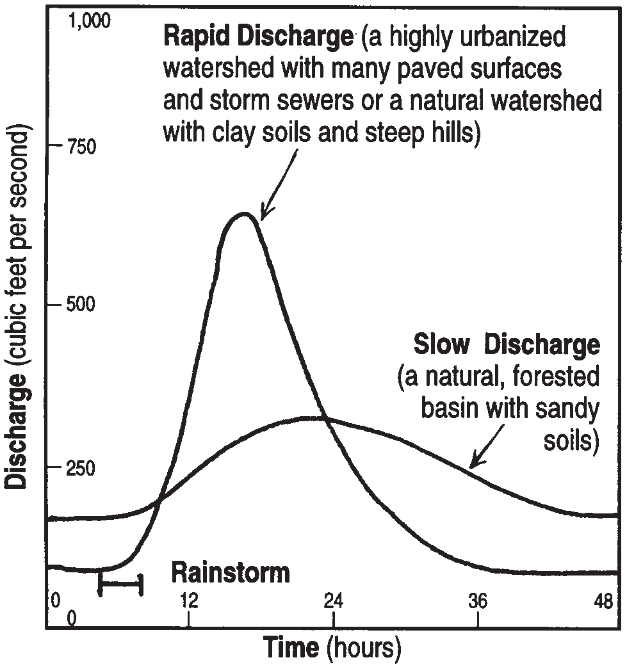


***Figure 3:** Idealized hydrograph of two similarly sized streams in watersheds with fast and slow discharge following a rainstorm.*

limited applicability to field situations. However, better understanding and application of these concepts can be achieved by careful observation of the stream under a variety of conditions.

Velocity

Given a steady discharge volume, the velocity of the water in a stream may change over the length of the stream in response to different channel characteristics. A narrow, deep, evenly contoured section of channel is likely to have greater velocity than a section with a wide, shallow, convoluted streambed. Velocity is greatest in areas with steeper streambed slope (called gradient and usually measured in feet of elevation drop per mile of stream channel). A smooth section of stream channel will have greater velocity than one with rough surfaces. Rough surfaces may be due to conditions such as a large amount of woody debris or many large boulders. The velocity of a stream can be classified into three flow categories:

1) Subcritical (or tranquil) flow - This is found in relatively deep, low velocity (slow) streams. If externally generated waves (such as those created by a rock thrown into the water) can travel upstream, then subcritical flow is present. The flow in most streams is subcritical.

2) Critical flow - This occurs at the point where the force of the moving water is equal to the force of gravity. Externally generated waves travelling upstream remain stationary over the bottom.

3) Supercritical (or rapid) flow - An area of high velocity found in rapids or where water pours over ledges. Externally generated waves travelling in an upstream direction will actually be swept downstream relative to the bottom. Supercritical flow may produce internally generated standing waves caused by a "rebound" of turbulent water. Standing waves are different than externally generated waves.

Power

Mechanically speaking, power is defined as the rate at which work is done. In the case of a stream, power is evident as the ability of the stream to erode its bed and banks and transport sediment. Examples of stream power would be a stream’s ability to transport one cubic yard of sand an average of 10 feet downstream in a day (low power) or move large boulders during a flood (high power). The higher the stream’s velocity, the greater its power.

Stream power can be subdivided into two components: total stream power and specific stream power. Total stream power is the product of the combination of channel gradient and total discharge. Specific stream power expresses stream power per unit of streambed area. Small streams with a steep gradient have high specific stream power, but low total power. Their banks might erode, but they probably will not undermine a house located some distance away in the foreseeable future. On the other hand, large rivers in flat terrain have low specific power but high total stream power. Their current may not usually sweep you off your feet, but they can move large amounts of sediment and meander large distances over the course of a lifetime.

Shear Forces

Water velocity is not evenly distributed throughout a stream channel. Highest velocities are usually found more or less in the centers of channels because of frictional drag on the channel margins. However, bends in the stream, and rocks, logs, and other objects can deflect water and alter current velocities. When there is a large difference in water velocity across the stream channel, shear forces (relatively swiftly moving water masses sliding past others of slower speed) are induced. The shear forces create turbulence (swirling flow) which exerts erosive force on the stream banks and beds. In areas of great turbulence, a current contrary to the mail flow (called an eddy) may develop.

The location of shear forces are greatly influenced by channel shape. In narrow, deep stream channels, shear forces are greatest on the channel sides. In wide shallow channels, shear forces are greatest on the streambed. The higher the shear force, the greater the erosion potential. Figure 4 shows examples of the distribution of shear force in several types of stream channels.

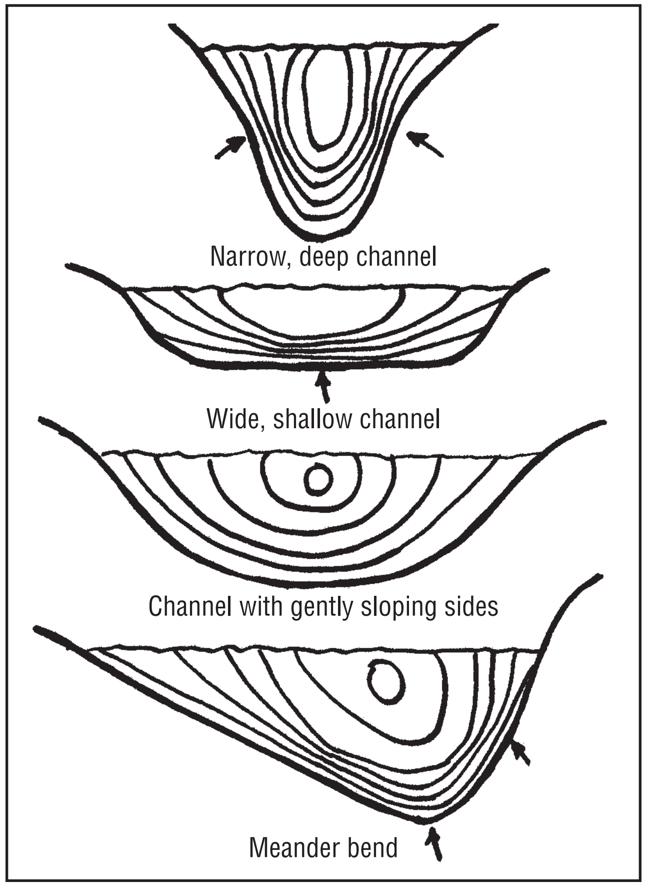


Figure 4: *Distribution of shear forces in several types of stream channels. Lines show areas of equal current velocity, with highest velocity always near the center of the channel. Arrows indicate areas of greatest shear force and turbulence.*

SEDIMENT TRANSPORT

All streams transport sediment from the headwaters to the mouth. This occurs as suspended sediment and bedload.

Suspended Sediment

Suspended sediment usually consists of light organic material or tiny particles of silt and clay carried in the water column by turbulent streamflow. If the suspended sediment levels are high enough, the water may appear muddy. The amount of suspended sediment can be measured relatively easily by filtering a known volume of water and weighing the material trapped by the filter.

Bedload

Bedload consists of larger or heavier sediment particles which are transported by rolling, sliding, or bouncing along the streambed. Even though the stream water may appear crystal-clear, excessive bedload (usually sand) may be present which can decrease bank stability and degrade aquatic habitat. It is difficult to quantify the amount of bedload without specialized equipment and detailed studies.

The term for sediment deposited by a stream is alluvium. Channels which are composed of sediments originally deposited by the river are termed alluvial channels. This is in contrast to streams which flow through bedrock channels.

Balance of Erosion and Deposition

Although there is almost always change occurring within stream channels (erosion in some areas and deposition in others), a stream is considered well balanced (or stable) if the following three conditions are present:

1. The power of the water and the resistance of the channel are in equilibrium;
2. The streambed remains at a relatively constant elevation; and
3. The material swept downstream by the current is replaced by an equal amount of material carried from upstream.

When the equilibrium of a stream is upset, the stream will compensate in some way to bring the system back into balance. The basic factors which upset stream equilibrium are changes in water supply or discharge volume; sediment input or sediment load; channel width, depth, slope, and roughness; water velocity; and distribution of shear forces. The most common compensating actions are streambank erosion, bed scouring or incising, and buildup of bed and banks.

In cases where the streambed is being scoured, the banks become steeper. This may cause them to lose their base of support and begin the erosion process. When streambeds buildup due to erosion and sedimentation upstream, the channel volume may be decreased. Subsequent flood events may exceed the channel capacity, and the power of the flood waters may erode the banks.

ANATOMY OF A STREAM

The portion of a stream channel that virtually always contains water is termed the low flow or base flow channel. The active (or bankfull) channel is a broader area that contains flowing water frequently enough that it lacks significant vegetation. The floodplain may occupy a very broad area which is occasionally inundated, but which is covered with permanent terrestrial vegetation.

On streams which carry a large amount of suspended sediment, a ridge called a levee may be deposited along the edge of the bankfull channel during flooding. Levees afford some degree of natural flood protection. As a result, artificial levees have been constructed in many areas which lack a natural levee. The size of these stream channel features may differ greatly between streams, depending on watershed characteristics **(Figure 5)**.

Channel Type

In nature, water flow can never be perfectly uniform within a channel. Instead, the current swings from side to side, exerting unequal erosive forces against the banks. As a result, stream channels which flow through alluvial deposits are almost never straight.

Sinuous/Meandering

Some streams can develop a highly sinuous (S-shaped) curving pattern, termed meandering. Meandering typically occurs in broad, flat valleys with a low gradient. When the current flows through a bend in the channel, the portion of the current with highest velocity hugs the outside of the bend. Shear forces and turbulence erode the streambank there. The greatest erosion usually occurs just past the midpoint of the curve. As the main portion of the current then

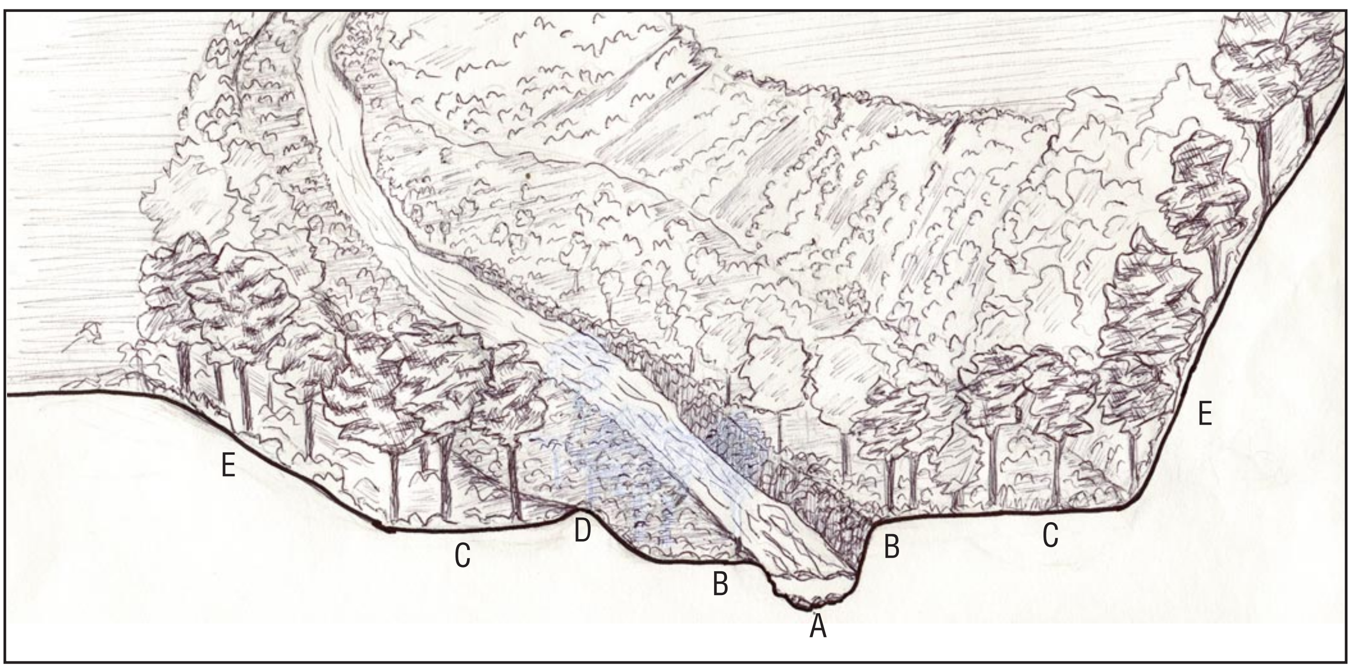


Figure 5: *Basic characteristics of a stream channel and valley. A—low flow channel, B—bankfull channel, C—floodplain, D—levee, E—upland.*

current then swings out and crosses to the next bank, the current along the side of the river which was just eroded slows and sediment is deposited, usually just downstream from the midpoint of the next curve.

This ongoing pattern of erosion and deposition causes meanders to progress slowly downstream year by year. The meanders tend to be spaced at regular intervals—5 to 7 stream widths apart. **Figure 6** shows the pattern of erosion and deposition in meandering streams.

Braided/Anastomosing

Strongly depositional streams with unstable beds may develop a "braided" pattern with many shifting channels and islands. Braided streams with islands which become stable and vegetated are called anastomosing. Figure 7 shows the five basic types of stream channels.

Riffles and Pools

Some streams form a series of alternating shallow and deep areas along the streambed—a kind of vertical, underwater counterpart of meanders. The shallow areas are known as riffles and the deep areas as pools. Streams with moderate (10 to 30 feet per mile) gradients are most prone to developing alternating riffles and pools. Streams with high gradients (greater than 30 feet per mile) may develop a staircase pattern with abrupt drops over logs and boulders into areas of deep, still water.

Although the reasons for their formation are not clearly understood, riffles often form where the main portion of the current crosses from one bend to another. In meandering streams, the riffle-pool locations correspond to meander locations and progress downstream with them **(Figure 6)**. In streams with nearly straight channels, the riffle-pool sequence develops as the current swings from side to side. However, in nonmeandering streams the riffle-pool sequence does not normally migrate.

Influence of Streambed Characteristics

When streambeds are composed of sand, the configuration of the bed may change rapidly in response to changes in flow. This can result in downstream

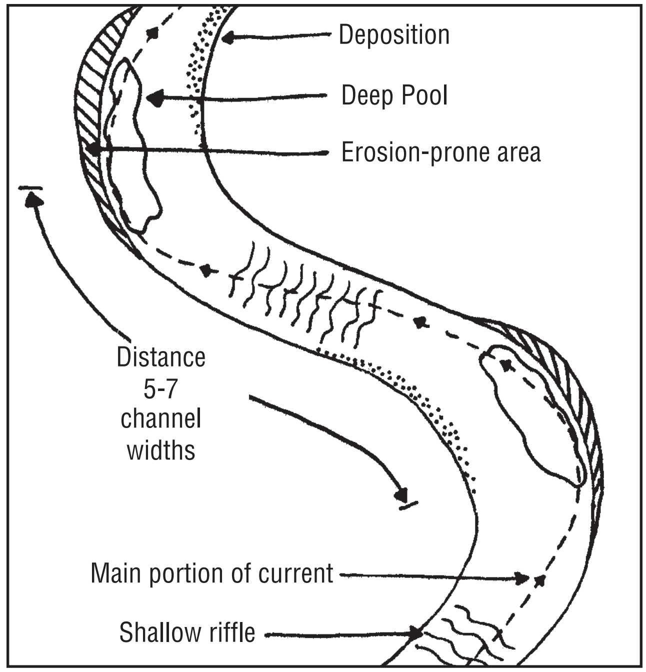


Figure 6: *Meandering, erosion and deposition, and riffle-pool patterns in streams.*

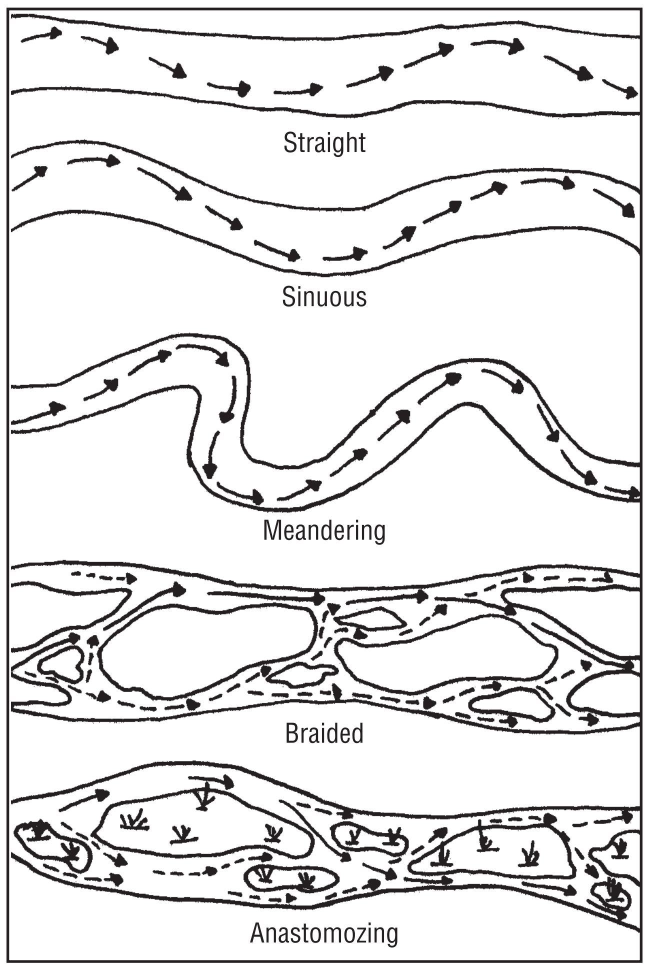


Figure 7: *The five basic types of stream channels.*

movement, scouring, or buildup of sediment. Streams with sand beds tend to be wide and shallow. Riffle-pool development does not normally occur in sand bed streams. Streams with channels flowing through silt or clay deposits tend to be narrow and deep. Gravel beds are relatively immobile, and sediment transport usually occurs only during flood events. Riffle-pool sequences occur most commonly in gravel bottom streams.

Lakeshores

A lake is a body of water isolated from the sea with an area of open, relatively deep water and a wave–swept shore. Lakes are differentiated from ponds, which are shallow (often having vegetation growth reaching the surface throughout) and are not large enough to develop waves larger than ripples.

CHANGING SHORELINES

From a human perspective, most natural lakeshores may appear unchanging from year to year, but lakes and lake basins are by no means static and permanent. Compared to rivers, lakes are much more temporary geologic features of the landscape. Most lakes can be expected to become completely filled in by geologic and biologic processes by the time they are several tens of thousands of years old.

Modifications of shore outline and lake depth are ongoing as the result of erosion and sedimentation occurring from both inside and outside the lake. This process is working toward an equilibrium in which the shoreline irregularities are smoothed—headlands washed away and bays filled in with sediments eroded from headlands. However, complete shoreline smoothing is rarely achieved because this process is slower than the overall basin filling process.

LAKE CHARACTERISTICS AND EROSION

The rate and extent of erosion are dependent on the size of the lake, the size and direction of waves, the strength and direction of currents, the characteristics of ice, the depth of the water near shore, and the shape and composition of the shoreline. Although these processes are best understood and observed in very large systems like the oceans and the Great Lakes, the same processes occur on inland lakes of all sizes, although on a smaller scale.

Waves

Wind blowing over water sets the surface into motion and eventually creates waves. Waves can also be created by moving watercraft.

Waves, coupled with the subtle currents (at least compared to those in rivers) they generate, are the primary forces responsible for shaping and modifying lakeshores. In most lake basins, waves are constantly adjusting the shoreline, although the rate of change is usually slow and may not be apparent from year to year.

The physics of waves are quite elaborate. A great many variables influence their characteristics, and textbooks filled with complex equations have been written to describe waves in dozens of different circumstances. However, for the purposes of this guidebook, the discussion of the physical behavior of waves on lakes will be greatly simplified.

Wave Characteristics

Waves are typically described by measurements of wave height, wavelength, and wave period. Wave height is the vertical distance between trough (low point) and crest (high point). Wavelength is the distance between successive crests. Wave period is the time it takes two successive wave crests to pass a stationary point. Figure 8 shows the characteristics of waves.

Waves From Wind

On inland lakes, the size of waves created by wind depends primarily on two factors: wind speed and fetch (the over-water distance across which the wind blows). Wind duration and water depth also influence wave size, but are major factors only on the oceans and very large lakes. Wave energy is roughly proportional to the size of the wave (specifically to the square of the wave height).

At any given time and location on a lake, waves of many different sizes are present. This is because not all waves start at the same point, but are being created continuously across the water surface. In addition, different waves move at different speeds. When one wave catches up to and becomes superimposed with another, a single wave of greater size than either of the original two is briefly created.

Table 1 shows the average height of the highest one-third of the waves which are generated for different wind speed and fetch conditions in deep water. This is termed significant wave height. The calculation of significant wave height can be a complicated matter, and a number of different methods exist. The information in **Table 1** was derived from monographs presented in **Reference 8**.

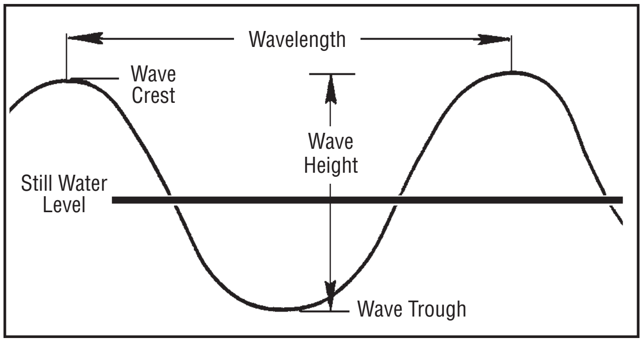


Figure 8: *The characteristics of waves.*

Waves From Boats

Much of the power expended in propelling a boat results in the creation of waves. A boat moving through the water is accompanied by at least three pressure disturbances on each side, resulting in several groupings of waves diverging outward from the direction of travel. The size of waves created by boats is a function of the volume of water displaced by the boat and the speed at which the boat is traveling. However, the wave size does not always increase with boat speed. Many boats are designed to skim across the water surface at high speeds (called planing), and therefore displace less water.

Boat-generated waves are of a different physical nature from wind-generated waves and contain more energy than a wind-generated wave of equal size. Wave heights of up to three feet have been reported from large boats operating on inland lakes. The operation of large, high-speed boats on small water bodies can create waves greatly exceeding the size and erosive energy of any occuring naturally. Although the wave train generated by the passage of a single boat is of short duration, intense boating activity can result in nearly constant wave action.

Water Depth and Waves

As a wave moves through deep water, its basic characteristics do not diminish. However, when the water depth becomes shallower than half the wavelength, the wave motion begins to encounter friction from the bottom. The wave speed slows, with a corresponding decrease in wavelength and a slight increase in height, creating a steeper wave.

The depth at which this usually occurs is often indicated by the formation of ripple marks on the lake bottom (in areas with sandy sediments). When the water depth is less than 1.3 times the wave height, the wave can steepen no further, and it collapses (breaks) in a cascade of foam. Although much energy is lost in this near-shore "surf zone," diminished waves continue to move shoreward.

As each remnant wave hits the shore, water surges up the face of the beach (termed run-up or swash) and the remaining energy is expended. Run-up distance depends on beach slope, the roughness of the beach surface, and wave size.

Average Sustained Over-Water Wind Speed (MPH)

Fetch (Miles)	10	20	35	50
1.0	0.30	0.60	1.05	1.50
2.0	0.40	0.85	1.45	2.15
5.0	0.70	1.35	2.35	3.30
10.0	0.90	1.90	3.30	4.75
15.0	1.20	2.35	4.10	5.80
20.0	1.35	2.70	4.70	6.75

Table 1: *Simplified chart to estimate significant wave heights for different conditions of wind speed and fetch.*

Longshore Currents

Longshore currents are weak currents which often develop in the surf zone. They form when waves strike the beach at an angle and bend, pushing and holding water on the shore. As this water tries to seek its original level, a current develops which flows parallel to the shoreline in the general direction of the wave movement. This is termed the downdrift direction. The power of the current is proportional to wave energy.

Waves, Currents, and Erosion

The energy of waves breaking on or near the shore and the swash action may result in the erosion and transport of shore materials and the suspension of sediments in the surf and near-shore zones. Although longshore currents are relatively weak, they may be powerful enough to transport sediment stirred up by breaking waves. The movement of sediment by longshore currents is often referred to as longshore drift.

Unless waves strike the beach at a perfectly perpendicular angle, beach sand and gravel are carried up the beach slope at an angle by the in-rushing wave, and then straight down by suction created as the water slides back down the beach face. This process is repeated with each new wave, causing sand grains to move down the beach in a sawtooth pattern. Waves can also move sediments by forcing air into crannies and crevices (called quarrying), and "sand-blasting" the shore with suspended sediments.

After wave turbulence suspends sand, the current may move it only a short distance before it settles out. However, subsequent waves then provide additional turbulence for additional movement. On the other hand, sediment particles which are smaller and lighter than sand may stay in suspension a long time and move great distances. Figure 9 illustrates the pattern of sediment transport by waves and longshore currents.

Because of changes in wind and wave directions from day to day, the direction of longshore transport of sediment switches back and forth. However, the wind usually blows prevalently from one direction, resulting in a net sediment transport in one direction. Longshore currents may carry wave-stirred sediments to some point and then drop them, creating a spit. This usually occurs at an area of indentation or embayment. If a spit develops across the embayment, then it is called a bar.

When deep water is found near shore, larger waves with more erosive energy can reach the shore than in areas which are shallow near shore. Points, headlands, and promontories may be subject to particularly strong wave energy due to refraction, or bending, of the waves and exposure to winds from several directions.

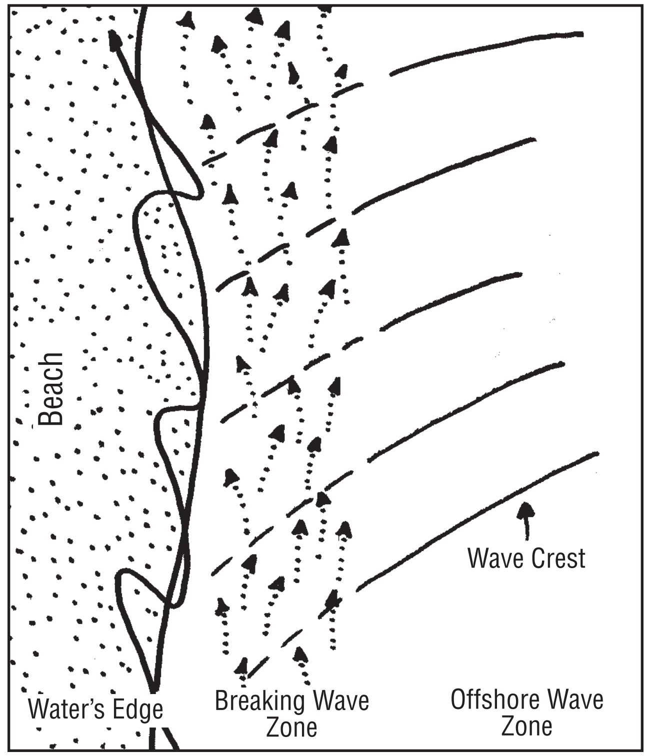


Figure 9: *Pattern of sediment transport by waves and longshore currents. Suspended sediment (dotted arrows) moves with the longshore current, and beach sand (solid arrow) moves down the beach in a sawtooth pattern.*

Lake Level

The greatest erosion usually occurs during highest lake levels, because larger waves may be able to break closer to the shore. If the lake level is high enough above normal, more easily erodible materials (not well-washed and sorted by previous waves or protected by a beach) may be exposed to wave action. Conversely, when lakes are at low levels, beaches are widest and are able to better absorb the energy of waves. In lakes with a gently sloping shore, a small change in water level may result in quite large horizontal changes in shoreline position.

Factors Determining Lake Level

The level of a lake is determined by its surface storage capacity coupled with water inputs and losses. Cumulatively, this is referred to as a lake's water budget or water balance. Water sources for lakes are the same as for streams, although the delivery to the lake may be modified somewhat by the presence and variable nature of tributary streams. Water is removed from a lake system by the surface outflow of streams, the subsurface outflow of ground water, evaporation, and possibly by consumptive human use.

Lakes generally experience a much slower change in water level in response to precipitation in their watershed than do rivers. This is due to a greater lag time of water movement through the watershed. The range in water level variation is also much less, due to the large storage capacity on the lake surface.

Seasonal Variation

The seasonal variation of most inland lakes follows a distinct pattern, most commonly with a low point in late winter, a rapid rise to a high peak in spring, and falling or fluctuating levels in between. However some lakes, such as those having no inlet or outlet (termed ground water seepage lakes) and reservoirs, may have drastically fluctuating water levels throughout the seasons or years. In natural lakes, seasonal variation is probably the result of long-term climate trends rather than recent events. The level of reservoirs may be primarily the result of human manipulation.

Wind Setup

During times of high winds, short-term rises of lake level may occur on the shore toward which the wind is blowing. This is known as wind setup or storm surge. It is caused by winds piling up and holding water against the shore.

The amount of wind setup may be significant on some inland lakes, up to a foot or more. The amount of wind setup depends on wind speed, fetch, and average water depth. A diagram is presented in Figure 10 for determining wind setup on lakes.

Ice

Ice can both protect against and cause shoreline erosion. In northern latitudes of the Great Lakes Basin, lakes may be frozen for five months of the year, preventing the formation of waves or longshore currents. Beach soils may freeze, giving added strength to the shore.

Ice expands and contracts as it warms and cools, causing small fractures to form. As water seeps into these fractures and freezes, the entire ice sheet expands during the course of a winter. This can result in the ice pushing into the shore with great force (up to 10-12 tons per square foot)—enough to push back the shoreline. In fact, most northern lakes have developed a permanent feature called an ice-shove ridge caused by millennia of ice expansion. Most ice expansion occurs in late winter, when wide temperature fluctuations occur and insulating snow cover is absent.

As the lake "breaks up" in the spring, large sheets of ice can be blown around by the wind. If a strong wind blows a large sheet of ice (many acres or even square miles in size) across a considerable distance of open water, its momentum can cause it to slide up onto the shore, scouring the beach.

Freeze-thaw cycles in unvegetated lakeshore soils can cause displacement of soil particles (called ice heaving). Ice can actually result in a small but permanent loss of beach sand each season when sand is "captured" in shorefast ice which then blows offshore and melts.

ANATOMY OF A LAKESHORE

When erodible materials along shorelines are first exposed to waves (primarily at the time of lake formation), they are washed and sorted, with fine material (silt, clay, and organic matter) being carried away and the coarsest materials (coarse sand, gravel, and rocks) being left at the waterline. This erosional process results in the formation of a flat to gently sloping terrace on the periphery of the lake. The underwater portion of the terrace is called a littoral shelf. The lakeward end of the littoral shelf is a feature familiar to many bathers and is often known as “the drop-off.”

The exposed portion of the terrace is called a beach. The beach typically terminates inland in a wave-cut ledge, which may range in size from a tall bluff to a small ridge cut into the beach sand (called a beach arp). Lakeward of the wave-cut ledge the beach is generally unvegetated because it is routinely subjected to swash. This area is known as the foreshore. Inland from the crest of the beach scarp, the beach is usually vegetated along most inland lakeshores. This area is known as the backshore. The features of the backshore are variable. It may be very narrow or relatively wide. It may have a low, flattened profile, rise abruptly to an upland area, or be a low sand dune. In very large lakes, the backshore may be sparsely vegetated due to the surging of occasional large storm waves. **Figure 11** shows a typical profile of a lakeshore.

The coarsest sediment occurs in the surf zone. Progressively finer sediments are found both inland and lakeward of the surf zone. Beaches are generally narrower and steeper during and after storms due to the transport of fine sand offshore by wave and current energy. This transported sand may be deposited as offshore bars, which cause waves to break further offshore. During fair weather, the sand bars may migrate landward and meld once again with the beach.

As explained previously, waves and currents keep littoral materials constantly moving downwind with a net transport usually in one direction. As long as ransported material is replaced with equal quantities carried from upwind locations, the shoreline remains relatively stable -- a condition called dynamic equilibrium.

However, if significant amounts of upwind sediments are suddenly prevented from moving or the supply of new material is cut off from naturally eroding areas, the shoreline may retreat. Even coarse material may disappear from the beach in some lakeshore areas of high energy.

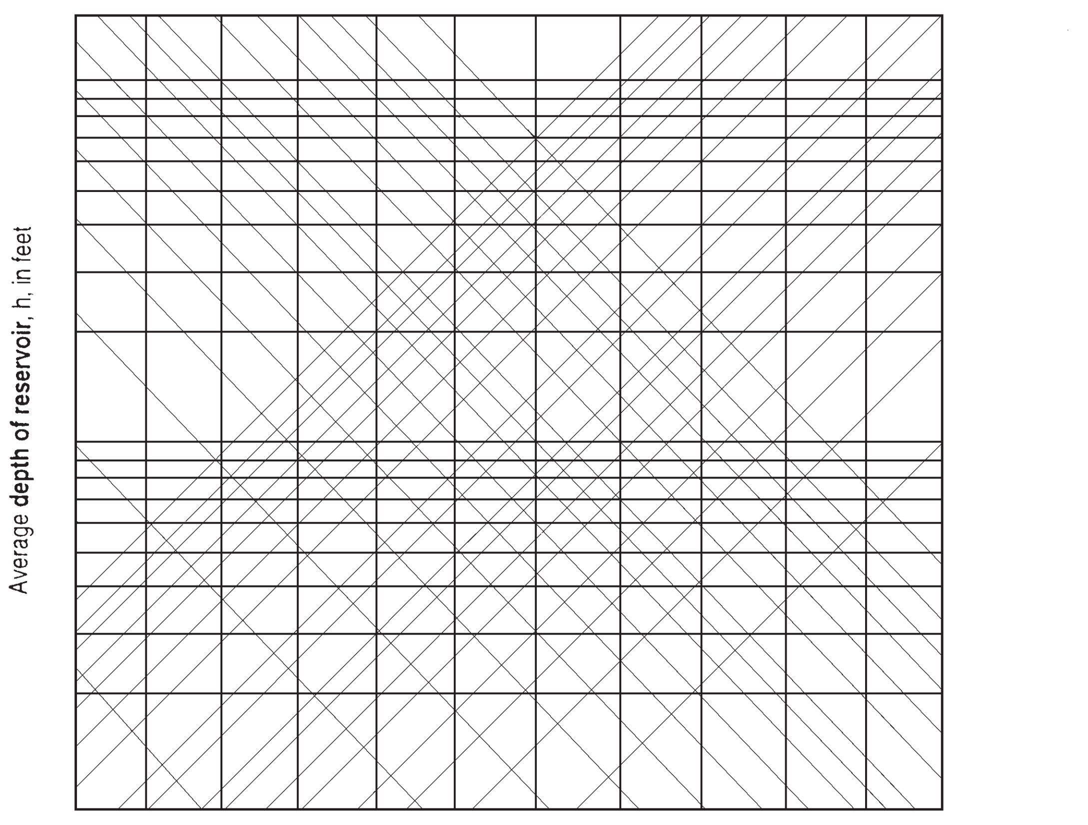


Figure 10: *Diagram for determining wind setup on lakes. For example, (   ) a wind of 40 mph blowing across a lake with an average depth of 20 ft. and a fetch of 10 mi. would result in a wind setup of about 0.6 ft.*

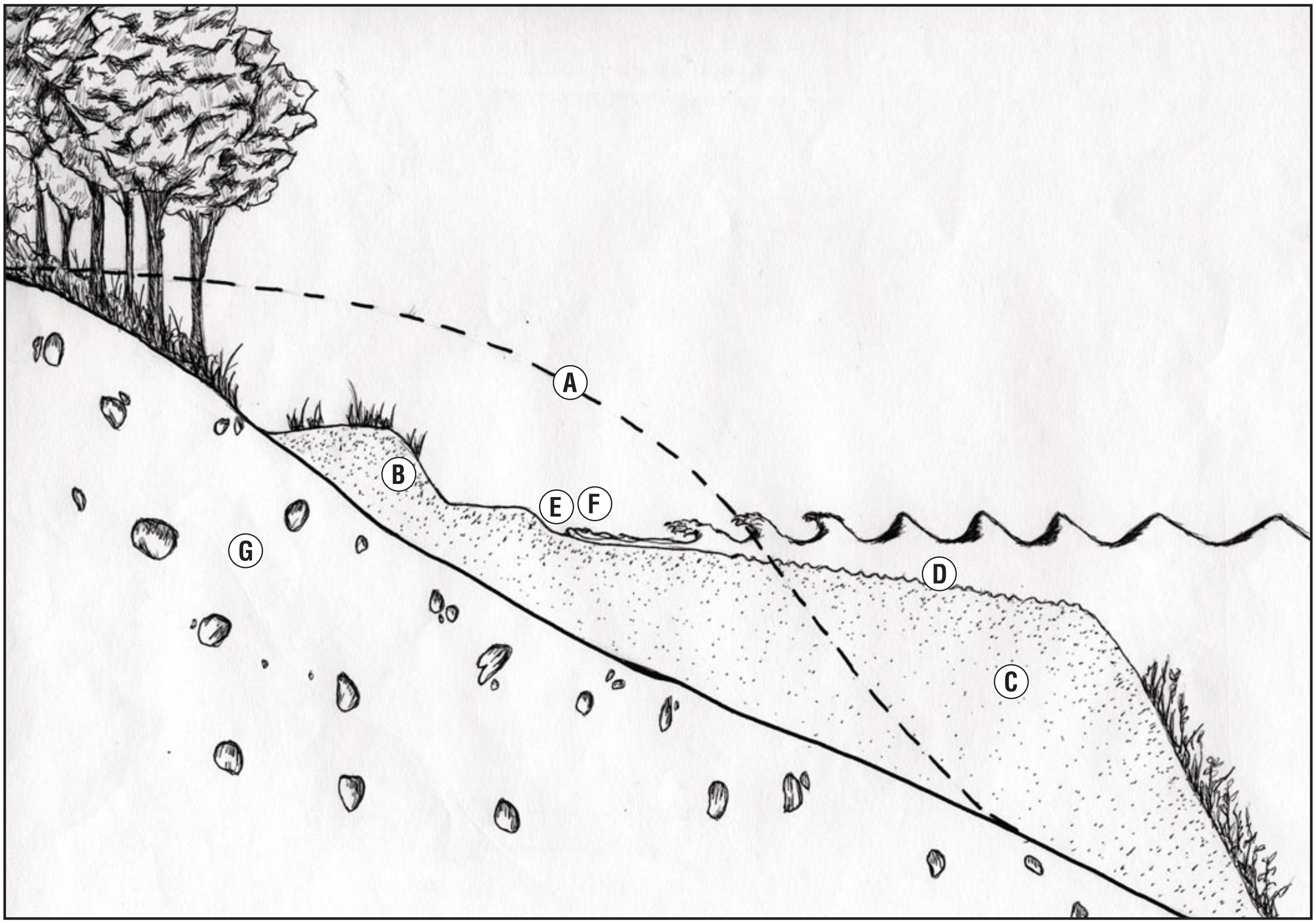


Figure 11: *Typical profile of a lakeshore. A—original shoreline, B—dune, C—littoral shelf, D—ripple marks on sand, E—beach scarp, F—foreshore, G—glacial till.*

The creation of new reservoirs, or raising the level of an existing lake by damming, can result in rapid, extensive erosion of shorelines. This occurs as the lake shoreline readjusts by the formation of a new wave-cut ledge, beach, and underwater terrace. Many natural lakes in the Great Lakes Basin which had their outlets dammed early in the century are still in this rapid readjustment phase. Studies on Europe's Lake Geneva showed that average erosion rates increased from an immeasurable amount to about three inches per year after impoundment.

Section Three

Impacts of Shoreline Erosion

It is estimated that over one billion tons of sediment pollute the waters of the United States each year.

Sediment from shoreline erosion can impact fish populations and ultimately decrease fishing success.

One of the most obvious impacts, and perhaps that of greatest concern to many shoreline property owners, is the loss of valuable waterfront property. Given the high value of shoreline property, recession of just one foot of shore along a 100-foot lot can represent a loss of more than $9,000 on a cost-per-square-foot basis. This does not take into account the potential damage to, or loss of, near-shore buildings and other structures. Erosion and sedimentation in aquatic environments can also result in a number of other economic impacts, as well as serious water resource problems.

Sediment Pollution

Sediment is considered a pollutant when excessive levels result from human activities. It is, by volume, the greatest water pollutant in the United States. It is estimated that over one billion tons of sediment pollute the waters of the United States each year. Although much of this comes from overland erosion (from rainfall and snowmelt runoff in inland areas), shoreline erosion contributes a significant share. A visible color plume in surface water, deposition in shallows, or shoal formation in lakes or streams can indicate that sedimentation is occurring.

Loss of Vegetation and Shoreline Habitats

Shoreline erosion may result in the loss of shoreline vegetation, which provides aesthetic beauty and valuable habitat for wildlife. On streambanks, the loss of vegetation can expose formerly shaded waters to direct sunlight, resulting in excessive water warming (termed thermal pollution). If the vegetation loss is extensive enough, the erosion rate may increase, in turn causing more vegetation loss in a continuing and escalating cycle of degradation.

Thermal Pollution

Thermal pollution can be particularly serious for cold-water stream ecosystems. For instance, trout cannot tolerate water warmer than 65 degrees Fahrenheit for extended periods of time. In a stream which has marginal water temperature conditions for supporting trout, erosion and sedimentation may cause enough warming to reduce trout productivity, or even cause the stream to completely lose its ability to support trout.

Interference with Light

Suspended sediment particles diminish the amount of sunlight which penetrates into the water. The utilization of sunlight by plants is a key ingredient in photosynthesis and forms the basis of the food chain in most lakes and streams. If sunlight penetration is diminished, so is the productivity. This translates into fewer pounds of fish per acre. If there is enough suspended sediment, the water takes on a brown or muddy appearance. When this happens, more solar energy is absorbed compared to clearer water conditions, also resulting in increased thermal pollution.

Release of Nutrients

Soil particles, especially the smallest sizes like silt and clay, may have chemically bonded nutrients attached. In some instances, depending on the source of the soil, heavy metals or other potential pollutants may also be bonded to the soil. When sediment is suspended in water, the chemical bond may be broken and substances associated with the soil may become dissolved in water and be available for uptake by both microscopic algae and rooted aquatic plants.

Nutrients liberated in this manner stimulate increased plant growth. Besides being a nuisance and unsightly, excessive weed and algae growth can eventually lead to oxygen depletion, mucky bottom deposits, and changes in the fish community. If toxic substances are present, they may be taken up by microscopic plants, travel throughout the food chain, and result in a human health hazard.

Stressed Fish and Wildlife Populations

Many fish common to waters of the Great Lakes Basin (such as pike, bass, and trout) rely heavily on sight for successful feeding. Turbid water may hinder their ability to see, lowering feeding rates and slowing growth. This can eventually translate into poorer angler success and harm to the economy of areas and businesses dependent on the sport fishing industry. Turbid water may also negatively impact other fish-dependent wildlife such as loons, eagles, and otters.

Oxygen Depletion

If the sediment levels become high enough, soil particles and associated substances from shoreline erosion may kill some sensitive organisms by depleting oxygen, interfering with gill function, or smothering eggs.

Loss of Under-Water Habitat

The physical filling of the bottom by sediment degrades aquatic and near-shore terrestrial habitats, negatively impacting birds and animals which depend on aquatic habitats. A permanent loss of fish spawning habitat may result.

If sedimentation amounts are very high, or exist over an extended time period, a water body may actually fill in to a large extent. The original basins of some impoundments are now so filled with sediment that dam operation and recreational use are impeded. These accumulated sediments can be especially problematic for dam removal/stream restoration projects. On many northern trout streams, excessive sand deposits from a century of erosion have filled in deep areas of the channel and even caused some streams to overflow their banks, flooding adjacent terrestrial areas.

In lakes, firm bottoms can become covered with soft sediments, diminishing their recreational attractiveness. Navigation channels and boat slips may become too shallow to accommodate boat traffic, necessitating costly and environmentally damaging dredging.

Section Four

Assessing Lakeshore and Streambank Erosion

Wind-driven ice comes ashore with great force on this northern lake, dislodging shoreline soils and structures.

Erosion may be caused by a condition at the site, or by a systemic problem (from widespread factors throughout the watershed, generally beyond human means of control). Additionally, the forces causing erosion may be either natural or of human origin.

Identifying the Causes

The most basic prerequisite to managing shoreline erosion is to identify the forces which are causing it. This is often difficult because the processes responsible are not directly observable and only their aftermath is evident.

Any change which occurs on the shoreline will affect the equilibrium of the entire lake or stream system. To understand what is causing erosion, it may be necessary to examine conditions up and down the shoreline in addition to those at the site. Researching events which occurred in the past and anticipating likely future events can help in understanding problems and designing solutions. It can be a waste of time and money to try site-specific fixes for problems which are widespread throughout the lake or stream system (called systemic problems).

Signs of Trouble

The best way to identify and assess erosion problems is to check shorelines regularly and be observant of changing conditions. Warning signs of accelerated erosion problems include:

- A large area of bare soil along the shore, especially on a steep, high shoreline bank;
- Large or small gullies caused by overland runoff along the shoreline;
- A noticeable recession of the shoreline over a period of time;
- Leaning or downed trees with exposed roots on the shoreline;
- Large patches of unusually cloudy (turbid) water near a lakeshore, or unusually high stream turbidity, especially during periods of high water;
- Excessive deposits of sand or other sediments on the streambed, or very wide, shallow areas of a stream.

However, there is no absolute criteria for separating "normal" erosion from "accelerated" erosion. Oftentimes, the presence of accelerated erosion can be determined by comparing developed shorelines with adjacent undeveloped areas. It is important to remember that factors of both natural and human origin can result in shoreline instability. Examples of natural factors are a large tree uprooted during a windstorm, or a flood resulting from a torrential rainstorm. Human disturbances include the removal of natural vegetation along the shoreline, dredging, or construction activities.

Most erosion is likely to occur during periods of high water or high winds. Watching what happens on a shoreline during these times and comparing it to normal conditions or water levels can be insightful.

Erosion Rates

An assessment of erosion rates (number of feet per year) can provide valuable insight on the need for erosion control. However, the erosion rate is probably not constant, but rather occurs in a series of starts and stops over the years, usually corresponding to storm events. The highest priority for erosion control is at sites with rapid recession rates (more than 1 foot per year).

For example, a steep unvegetated bank which is the result of frequent landslides indicates a high erosion rate and should be considered for corrective action in the near future. However, a similar bank which has not receded in many years but which has not become revegetated for some other reason may not be in need of immediate attention. In areas with expansive lawns and low banks, the rate of recession may be rapid but inconspicuous because of the absence of reference benchmarks or large areas of bare soil.

Try to determine if the shore is actually eroding or if the condition is merely static. Over a period of time, measure the distance to the shore from a prominent, immovable object. Old photographs (either snapshots or aerial photos) can help determine where the shore was in the past. A simple (but accurate) map of the shore and adjacent features can help document conditions and bring them into perspective.

Severity Indexes

Although assessing the severity of erosion is often somewhat arbitrary, some erosion severity indexes have been developed. Appendix 2 shows two examples of erosion severity indexes for lake and stream conditions.

Characteristics of Erosion

Erosion may be caused by a condition at the site, or by a systemic problem (from widespread factors throughout the watershed, generally beyond human means of control). Additionally, the forces causing erosion may be either natural or of human origin. The following pages discuss the most common causes of shoreline erosion. Remember, there may be a number of causes at a single erosion site.

Site Specific Causes

Overland Runoff and Erosion

If rainfall (or snowmelt) is intense or of long duration, the water flows over the ground surface rather than soaking in. This is called runoff. Runoff picks up and carries soil particles. As runoff velocity and volume increase, rills (small channels) and deep gullies can be cut into the soil surface.

In shoreline areas where excessive runoff or bare soils are found, overland erosion may result. In this case, the toe of an eroding bank may be stable, with rills or gullies present on the upper bank. Both natural conditions (slope, soil type, drainage pattern) and human activities (impervious surfaces, vegetation removal, construction in progress) may increase the volume or velocity of overland runoff. Runoff may originate quite a distance away from a shoreline erosion site. Overland erosion is also started when raindrops fall on bare or sparsely vegetated ground and detach soil particles.

Ground Water Seepage or Springs

Ground water seepage occurs where the water table intersects the land surface. It may appear as a wet spot or layer in a steep bank face, or as a definite flow of water. The discharge of ground water can loosen and transport soil particles. Saturated conditions can also weaken soils. Freeze and thaw cycles in natural soils can cause the ground surface to heave and buckle, dislodging chunks of soil. If the bank is composed of layers of differing texture, one layer may slide over another, resulting in bank failure. Seepage is generally a natural condition.

Stream Obstacles

Objects which fall, or are placed, in or across a stream channel can deflect or constrict streamflow. When a channel is constricted, the velocity increases, increasing sheer forces and the erosive power of the water. If the current is deflected from the main part of the channel toward the bank, erosion may result.

Stream deflection or constriction may result from either natural events or human activities. Examples include a large tree falling into the channel and deflecting the current into the bank or a road crossing culvert constricting the stream, increasing velocity and causing downstream erosion.

Stream Channel Alteration

Dredging, straightening, removal of large woody debris, activities of beaver (as well as suppression of beaver activity), and clearing for recreational passage are all forms of stream channel alternation which upset the dynamic equilibrium of a stream. Many stream channels are "smoother" than they were historically due to clearing of obstructions, and so have higher velocity. Channel dredging may cause a streambed erosion condition which progresses steadily and continuously upstream from the point of dredging until equilibrium is restored (called headcutting). When streams become straightened, the channel gradient increases, thereby increasing the velocity and erosive power of the stream. Most problems associated with stream channel alteration are of human origin.

Bank Failure

The sloughing-off of a large mass of soil from a bluff face is termed bank failure. Bank failure can be caused by a decrease in soil strength. Soil swelling (due to water absorption by clay), pressure from ground water, slow "creeping" of the soil, or an increase in sheer stress (due to changes in channel shape; increased weight, such as buildings, on top of the bank; or a rapid drawdown of water) are examples

These boaters are creating waves much larger than would naturally occur on this river, greatly increasing erosive forces on the shoreline. Years of such activity prompted the construction of bulkheads, which are now failing.

of processes that decrease soil strength. Cracks on the face, or along the top, of a bank are indications of impending bank failure. Bank failure is caused by both human activities and natural conditions.

Removal of Vegetation

The root systems of woody shoreline vegetation augment the strength of all types of soils. The conversion of shoreline vegetation from forest to lawn has occurred in many areas of development. Many shoreline erosion problems occur simply because too much natural woody vegetation has been removed, decreasing the strength of the shoreline soils.

Tree trunks, limbs, and other woody material, as well as emergent rushes and floating-leaved aquatic plants are often abundant in the water along natural shorelines. These materials take the brunt of wave and ice energy and bind and protect bottom sediments, helping to protect the shore. They also provide valuable aquatic wildlife habitat. However, they are often removed along developed shorelines, exposing the shore to more erosive energy.

Tree trunks and other plant stems in a floodplain add a “roughness factor,” which slows the velocity of flood waters due to friction. When trees are removed from a river’s floodplain, roughness decreases, resulting in greater velocity and stream power.

Bank trampling and soil compaction by cattle, humans, and vehicles is also an important cause of vegetation loss and shoreline erosion.

Powerboat Waves

Boating activity has increased on most water bodies in recent years. The nature of boating has also changed, with larger and more powerful boats in use. Accelerated erosion is often associated with recreational boating, especially on smaller lakes, protected bays and channels, and many rivers.

Obstruction of Longshore Current and Sediment Transport

A channel dredged perpendicular to the lakeshore can intercept and trap sediments transported by longshore currents. The placement of a permanent structure, such as a jetty, can deflect longshore currents out into the lake, causing sediments to be deposited in deep, offshore areas. The result in both instances is sediment starvation and erosion in downdrift areas.

Undercutting Toe of Steep Bank

Undercut banks are a natural feature and provide an important habitat on streams. However, instances where they form rapidly or excessively may indicate a problem condition. Undercutting is often related to vegetation loss or to systemic factors of both natural and human origin. If vegetation can persist at the waterline of an undercut streambank, the relative erosion severity is low.

Disturbance of Shoreline or Bottom Materials

On many shorelines, rocks have been removed for use in rock gardens, stone masonry, landscaping, etc. In some other areas, sand has been removed for fill, channels have been dredged for boat navigation, or woody debris removed to enhance recreational use. The original shoreline developed a dynamic equilibrium in the presence of these materials, and their removal results in instability in the immediate vicinity and possibly far up and down the shoreline.

Dams

Dams on streams act as traps, preventing the downstream flow of sediment. Downstream of the dam, sediment continues to be eroded off the streambed without being replaced. In this situation, the elevation of the bed may be lowered significantly (a process known as incision).

During subsequent floods, the velocity of the current is greater in the deeper, narrower channel. The stream banks become steeper and less stable and begin to erode, eventually causing the channel to be widened.

Sedimentation

Widespread deforestation and associated logging activities early in the century caused massive sand sedimentation in some streams. In many areas with low gradient, more sand accumulated on the streambed than could be transported downstream. This sand bedload has caused extensive habitat degradation. In addition, in some instances, it has caused river beds to build up, water to spill over the bank, and braided channels to develop.

Contemporary sources of sediment include road-stream crossings, tilled cropland, many types of construction activities, as well as some types of logging practices. If sedimentation is widespread (although sometimes inconspicuous), it may also be considered a systemic cause.

Systemic Causes

Powerful Currents

Flowing water tugs at soil particles and may remove those at the surface of the streambed and move them along with the streamflow. Although currents may cause erosion almost anywhere, locations of high stream velocity; super critical flows; high shear forces; high specific stream power; and deep, narrow channels have the highest potential for erosion.

Stream currents are greatest at the outside of a stream bend, and erosion is most likely to occur there. The sharper the bend, the more erosive the current force.

On the other hand, the current is least at the inside of the bend, and deposition of sediments is likely to occur there. Currents are, of course, a natural condition but subject to human influences.

Powerful Wind-Generated Waves

As waves expend their energy on the shore they can dislodge soil particles. Although even small waves may cause erosion under the right conditions, the larger the water body, the larger the potential wave, and the greater the erosion potential. If erosion is in an area of the lake subject to more wave forces than other areas of the lakeshore (points, areas with great fetch, or deep water near shore), then waves may be a primary cause of the erosion. Although wind generated waves are not greatly influenced by human activities, the extent to which they influence erosion can be (i.e., shoreline vegetation removal).

Ice

On streams which freeze, spring breakup can cause ice-jams, or send large chunks of ice downstream at high speed. This can cause erosion from flooding or by impact and abrasion of the bank. On inland lakes, ice may subject shorelines and structures to crushing forces and abrasion. In some areas, this may require a different approach to erosion control techniques than in areas not subject to ice action. Ice is largely a natural condition, but the effects may be intensified on streams by obstructions.

Stream Meander

On streams flowing through highly erodible sediments, erosion and deposition often results in pronounced meanders which migrate downstream over time. Streams with meandering channels are recognized by a prominent, repeating S-shaped pattern. Most efforts to control stream meandering have been unsuccessful, merely postponing the unstoppable forces of time and gravity. Whether or not a stream meanders is predisposed by watershed conditions.

Streambed Instability

If a streambed is vertically unstable (either building up or cutting down), the dynamic equilibrium will be upset and streambank erosion will result. However, this condition is difficult to determine. It is usually done by comparing survey information over time, or surveying along the length of alluvial stream channels and looking for sharp elevation differences (called nick points).

Sometimes, extensive bedload indicates that the bed is rising. However, it is hard to know whether the bedload sediment is the cause of eroding streambanks or if eroding streambanks are the source of bedload sediment. In situations where the streambed is unstable, standard bank protection practices may be ineffective. Some water resource managers do not attempt to control streambank erosion without first addressing the cause of streambed instability.

Increased Lake Water Level

The shorelines of new reservoirs undergo dramatic readjustment and severe erosion is usually widespread. Even impounding natural lakes by as little as one or two feet causes the shoreline to undergo readjustment from the altered forces of waves and currents. Shoreline readjustment is still occurring after more than 100 years in some impoundments in the Great Lakes Basin.

If increased water level is expected to be a temporary condition (for instance, extraordinary rains may raise the water to a level which will occur only once a decade), then any resulting erosion will also likely be temporary and of relatively low severity.

Oftentimes, controlling the seasonal fluctuations of a natural lake is proposed as a solution to erosion problems. However, there are usually other environmental or socioeconomic implications associated with artificial lake level control which make doing so inadvisable or impractical. All proposals to control lake level must be well researched before implementing.

Increased Stream Discharge From Urbanization

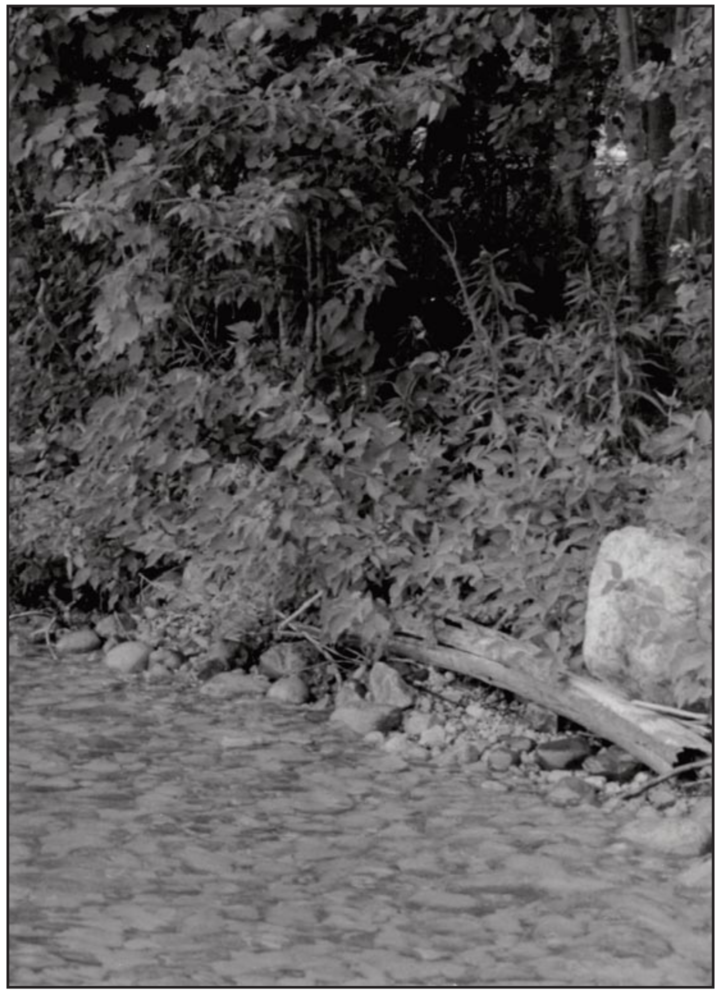
As urbanization in a watershed increases, there is much greater runoff due to the increase in impervious surfaces. In addition, the runoff is often delivered to streams much faster due to storm sewer systems. This can lead to higher, more frequent floods as well as an increased average annual stream discharge.

Streams with increased discharge must adjust their beds and banks to accommodate the extra water and establish a new dynamic equilibrium. In this case, it is unlikely that any erosion control practice will be completely successful until the stream channel has finished adjusting to major changes in its hydrology.

Section Five

Methods of Preventing Shoreline Erosion on Inland Lakes and Streams

Protecting wetlands on private property and supporting strong local, state, and federal wetland protection programs are some of the best means to prevent erosion caused by flooding.



Most undisturbed, well vegetated shorelines with rocky beaches are able to resist the erosive forces of waves, currents, and ice are relatively stable.

As previous sections have explained, some soils and shoreline types are more erosion-prone than others. In addition, certain activities or conditions can stress almost any shoreline area to the point where erosion increases. In these situations, special protective precautions can help prevent erosion. The popular saying that an ounce of prevention is worth a pound of cure is definitely true when it comes to shoreline erosion. The following section describes measures that can help prevent both natural and human-caused erosion.

Access Control and Protection

Intense foot traffic, especially on steep slopes or in sensitive cover types (such as wetlands or dunes), can kill vegetation and stress soils, leading to accelerated erosion. In these situations, installing access control structures or protecting the soil surface against the pounding of feet can help prevent erosion. These actions may also facilitate the safe use of a site. It should be recognized that some sites are not suitable for shoreline access but are more appropriately used for other activities, such as scenic viewing from a distance.

One type of access control structure is an exclusionary barricade, such as a fence or hedge. Exclusionary barricades can serve to keep people completely out of an area, or simply to direct them to the most appropriate areas. In some instances, thorny plants such as blackberry, black locust, or hawthorne have been used as an additional disincentive against entry. The importance of sand dunes as stabilizers of shorelines is widely recognized in Holland, and people there are actually excluded from some areas by barbed wire to ensure dune protection.

Construction of stairs on steep slopes which cannot be avoided is one way to protect the soil against the stress of foot traffic. There are two basic stairway designs: spanning the ground surface using posts and rails or creating a series of small terraces excavated into the hillside.

Designs which span the surface are generally considered to be easier and less disruptive than terraced construction, which can exacerbate erosion problems if not designed and constructed properly. However, depending on site conditions and project goals and objectives, there may be situations where terraced steps are preferable. Boardwalks, seasonal docks, or even paved walkways in special instances are other means of protecting shoreline soils.

Rock Preservation

Naturally occurring rocks serve an important erosion control function. Unfortunately, because shoreline rocks are highly visible and accessible they are frequently removed from shorelines for a variety of reasons. Significant removal or even disturbance of naturally occurring shoreline or nearshore rocks will upset the dynamic equilibrium of the surrounding area. As such, no more than a few rocks should ever be removed from any one spot in the beach or near shore area. Instead, rocks should be collected from upland, inland areas for rock gardens, masonry projects, as a source of rocks for an erosion control project, etc. Rocks are usually readily available from gravel pits or landscaping businesses. Sometimes, farmers are glad to have rocks which have been removed from, and piled alongside of, farm fields hauled away.

Ice-Shove Ridge Protection

If a well-vegetated ice-shove ridge exists, it is probably a relatively stable feature after years of being subjected to ice forces. However, many property owners grade the ice-shove ridge away in order to achieve a flatter landscape. Altering this ridge (including removal of trees and shrubs) should be avoided because it may result in increased erosion as the ice seeks to establish a new dynamic equilibrium. The ridge also helps prevent excessive surface runoff and can serve as a source of material for beach nourishment.

Building Setback

One reason that high bluffs are unstable is that the weight of the bluff itself causes the soils comprising it to be relatively unstable. Adding weight to the bluff from construction projects can add to the instability of the bluff. To avoid stressing soils with excessive weight and creating a potential erosion casualty, keep new construction as far back from the edge of the bluff as possible.

Careful Watercraft Operation

Increased boat activity on many water bodies is resulting in shoreline erosion. Boats should be operated so as not to produce waves larger than those which naturally occur on that portion of the water body. On small water bodies, this generally means using small boats, or operating large boats at slow speeds. Special watercraft regulations in these areas, such as banning motors or restricting speeds to slow-no-wake, can be instituted with strong local support.

Shoreline Vegetation Preservation and Management

The importance of preserving a strip of natural, diverse vegetation for preventing erosion cannot be over-emphasized. This is a voluntary measure that everyone can easily practice along their shoreline. In addition, local zoning ordinances can be adopted which require that a strip of natural vegetation remain in place along shorelines.

The recommended minimum width of a vegetated buffer strip (also known as a greenbelt) is 35 feet. However, a good rule of thumb is that the wider the buffer strip, the better. Vegetated buffer strips should contain a mixture of trees, shrubs, and herbaceous ground cover. Selective, limited trimming and removal of vegetation for access and view corridors can be incorporated into a buffer strip without jeopardizing its integrity.

On well-vegetated, undeveloped shorelines, intensively managing vegetation can help further strengthen a shoreline against erosion. Examples of intensive vegetation management include removal, trimming, or thinning of existing species; coupled with planting of selected additional native vegetation. The goal of such actions is to develop the healthiest, most extensive woody root systems, and the most durable woody stems to protect against ice scouring. Typically, a young successional stage seems to work best to accomplish this.

Oftentimes, a vegetated buffer strip is viewed as a good place to dump lawn clippings, leaf rakings, or woody yard debris. However, this can smother living vegetation which is functioning to hold the soil in place. Avoid dumping of these materials in vegetated buffer strips, especially on steep slopes. Instead, dispose of such materials by scattering them widely in an inland area, or better, by composting them in a designated inland area.

Large trees (more than six inches in diameter) which lean out toward the water more than 30 degrees from vertical deserve special attention. In these situations, the force of gravity or the wind can more easily overcome the strength of their roots or the soil, and the trees may suddenly be uprooted. Sudden uprooting can subsequently lead to rapid soil loss and decreased bank stability. Leaning trees on high, steep bluffs have a greater potential for causing problems than trees on low bluffs, or flat to gently sloping shorelines. In some instances, cutting down large leaning trees on shorelines can help reduce the potential for erosion.

Of course, while these trees are alive and upright they are benefitting shoreline erosion control. In addition, large shoreline trees can be a treasured property amenity, and a decision to cut them is not always an easy one. When considering cutting, the property owner must weigh the ultimate erosion control benefits of cutting against other disadvantages, such as loss of aesthetics, wildlife habitat, etc.

A guideline for management of large leaning trees is to immediately cut only those which appear to be in imminent danger of uprooting. For others, monitor them closely over an extended period. If their degree of lean increases measurably and steadily, or if soils start to become exposed around the base, strongly consider cutting to prevent uprooting.

Even when a tree is cut, its root system remains and continues to function to strengthen soils for awhile. For special trees, pruning, supporting with cables, and other innovative methods may effectively prevent or delay uprooting. Consulting with an arborist (a specialist in the planting and maintenance of trees) is suggested for these types of actions.

By the time the roots of felled trees start to decompose, new woody vegetation will hopefully have been planted or begun to grow naturally to take its place. The root systems of many deciduous trees which are cut actually continue living and new shoots often sprout from the base of the stump.

Wetland Protection

One of the primary functions of wetlands is flood control. By some estimates, the Great Lakes Basin has lost two thirds of their original wetlands. Protecting wetlands on private property and supporting strong local, state, and federal wetland protection programs are some of the best means to prevent erosion caused by flooding.

Some wetland forests are especially susceptible to disturbance. This is because trees are shallow-rooted in soils with a high water table. Creating openings can expose remaining trees to more wind forces, and cause uprooting.

In the past, emergent wetland plants growing along shorelines have often been regarded as a hindrance to swimming and other water-based recreation, and have been eliminated. If reeds, rushes, or other wetland plants grow along the shore, they should be preserved to the greatest extent possible.

Control Overland Runoff, Erosion, and Sedimentation

As more land becomes urbanized, runoff rates increase. However, there are techniques available to ensure that post-development runoff rates do not exceed pre-development rates. For example, keep impervious surfaces to a minimum and promote the infiltration of runoff rather than conveying it directly to the lake or stream via a drain pipe. Many local governments are beginning to adopt ordinances which require efforts to manage storm water properly.

Use proven techniques to prevent overland erosion which may be occurring due to construction activities, or from permanent conditions, such as roof discharge or long, sloping driveways. The five basic principles of overland erosion and sediment control are:

1. Plan the development to fit the topography, soils, drainageways, and natural vegetation of a construction site.

2. Expose the smallest practical area of land for the shortest practical time. This may mean completing large projects in stages.

3. Implement soil erosion control practices as a first line of defense. Good erosion control will reduce the amount of sediment which must be controlled later. These techniques include:
- The use of special grading methods (roughen surfaces, flatten steep slopes, preserve vegetation),
- Temporary and permanent vegetation plantings, mulching, and maintenance,
- Diversion dikes and ditches coupled with proper discharge structures,
- Reduction of runoff volume and velocity,
- Use of retaining walls, and,
- Careful removal and stockpiling of topsoil for later use.

4. Apply sediment control practices to prevent off-site damage. These techniques include:
- Diversion dikes and ditches coupled with proper discharge structures,
- Sediment traps and filters,
- Vegetative filters, and,
- Sediment basins (these are the most effective sediment control).

5. Implement thorough inspection, evaluation, and maintenance of control structures.

In some areas, erosion control permits are needed for earth change activities near shorelines. Be sure to obtain the proper permits for all construction activity near the shoreline and take precautions to avoid overland erosion.

Progressive Watershed Management

An important focus of local land use planning and zoning regulations should be environmental and watershed protection. Regulations can help keep development out of erosion-prone areas or restrict the type of development that could result in erosion problems. Make sure your local government officials know that you support watershed protection at the local level.

Section Six

Selected Methods of Controlling Shoreline Erosion on Inland Lakes and Streams

Biotechnical erosion control enhances natural appearances and improves wildlife habitat along the shoreline.

The shallow roots of these upright sedges (Carex stricta) are not enough to prevent the organic and silt soils of this streambank from eroding.

Although there have been numerous erosion control methods and materials developed over the years, many have proven ineffective or inappropriate for one reason or another. The following section contains a number of methods which the Watershed Council believes are environmentally appropriate and effective for certain situations on inland lakes and streams. In addition, several methods in common use, but which are not generally recommended for inland lakes and streams, are discussed.

BIOTECHNICAL EROSION CONTROL
(Applicable to both lakes and streams)

General Description

Prior to development, diverse vegetation communities covered the shorelines of lakes and streams throughout the Great Lakes Basin. As discussed previously, vegetation protects against erosion in several ways. The removal of native vegetation has been a major factor in accelerating shoreline erosion in most instances.

Reestablishing a diverse vegetation community is one of the simplest and most effective techniques for controlling shoreline erosion. A modest investment in vegetation reestablishment can avoid a serious erosion problem in the future which may ultimately be very expensive to control.

Erosion control which primarily relies on the use of vegetation (both living and nonliving) is most commonly known as biotechnical erosion control (BEC). BEC brings together biological, ecological, and engineering concepts to produce a living, functioning system to prevent erosion. There are a number of variations of this term in use, including bioengineering, hydrobioengineering, soil bioengineering, biotechnical slope control, and biogeotechnical erosion control.

Although BEC techniques have been used for at least 150 years, they have only recently gained widespread recognition by resource professionals and engineers for their effectiveness and come into common use. Unfortunately, BEC has yet to be widely accepted by shoreline property owners. Although studies have shown that most riparians prefer the look of a well-vegetated shoreline, on an individual basis they appear reluctant to give up shoreline lawns, 180-degree viewing vistas, and conventional structural erosion control methods such as bulkheads or rock revetments. One reason seems to be the misconception that BEC will preclude beach access and eliminate scenic lake views. However, by using well-planned or innovative landscaping techniques, a well vegetated shoreline need not preclude acceptable levels of desired property uses.

BEC is suitable for a wide range of erosion problems. However, it is best suited to relatively low energy situations where a subtle shift in the balance between erosive energy and shoreline resistance can restore stability to the shoreline—exactly the situations most prevalent on streams and inland lakes. In relatively high energy situations, it may be necessary to couple vegetation with more extensive structural techniques.

BEC is a low-cost method achievable by most shoreline property owners. It is generally an easy method to install (even by do-it-yourselfers), although it can be a very labor-intensive technique and require a lot of attention immediately following installation. It enhances natural appearances and improves wildlife habitat along the shoreline.

In addition to erosion protection, living vegetation can also protect water quality by removing nutrients and reducing runoff. It is one of the best methods to use where the shore is subject to occasional ice scouring because the vegetation can rebound quickly on its own following disturbance. However, the band of vegetation needs to be wide enough so that it is not completely removed by ice action.

BEC is durable, self-renewing, and requires minimal maintenance once established. If BEC techniques fail, they will not intensify the erosion problem as other techniques might. Also, compared with other techniques, there are fewer requirements for heavy equipment.

On the other hand, BEC may not be appropriate for every problem situation. For instance, it usually has limited effectiveness for bluff slumping caused by seepage. Vegetation alone probably will not work on urban streams with "flashy" runoff hydrographs (see Figure 3). Its effectiveness may be limited by site characteristics such as steep slopes, poor soils with droughty conditions, and shorelines exposed to powerful wave and current energy. It is susceptible to damage where foot and vehicular traffic may be intense, and suitable plants are sometimes difficult to obtain. BEC has a more limited construction season than some other methods, can be labor-intensive, and professional expertise on the subject is not widely available.

The use of plants alone has limitations and cannot be considered a suitable substitute for all structural methods. To overcome these limitations, vegetation is often used in conjunction with, or as a supplement to, other methods. For instance, in areas of high boat traffic, structural wave breaking techniques may also be needed. There is a wide variety of variations combining living and dead vegetation and structural components. The following section describes some of the basic techniques.

Detailed Design Criteria—Living Vegetation

Selecting Appropriate Species

Environmental conditions are important factors to consider when selecting species for planting. The most important conditions to consider are soil wetness and texture, soil and water chemistry, light levels, general and micro climate conditions, and land use activities.

Some species of plants can tolerate a wide range of environmental conditions while others have a narrow tolerance. For instance, northern white cedar prefers an alkaline pH and will not tolerate full shade. Determine the conditions present on-site and prepare a list of common or available species in the region which are suited to the same conditions.

Native species growing nearby the project site are the best choice for vegetation reestablishment. Nonnative species or ornamental hybrids commonly used for urban landscaping are usually a poorer choice because they may spread uncontrollably and displace native vegetation, or they may not be as well adapted to life on the shoreline.

Quickly reestablishing good ground cover in areas where the soil has been disturbed is a first priority. The Natural Resources Conservation Service (NRCS) has developed general guidelines for species composition of seeding mixtures for ground-cover reestablishment (see Appendix 3). Appendix 4 lists some common plants of the Great Lakes Basin which are suitable for final landscaping in a variety of shoreline conditions.

Obtaining Plants

There are three methods for acquiring plants:

1) Purchase–Many suitable shoreline erosion control plants are available at local nurseries, lawn and garden stores, or farm co-ops. Soil and Water Conservation Districts throughout Michigan offer seedlings for sale in spring and fall at bargain prices **(Appendix 7)**. If plants are not available locally, there are a number of mail order suppliers of native upland and wetland plants. A listing is given in **Appendix 5**. Most have catalogs and price lists available upon request. Suppliers closest to your region are most likely to have plants that are adapted to conditions in your location.

Advantages of purchasing plants include low requirements for labor and expertise in plant identification/collecting skills, and a better chance of availability when needed. Several companies now manufacture pre-planted vegetation rolls and pallets which can be moved to the job site. These are especially good in weak, non-cohesive sand soils.

2) Collect wild plants–Plant identification skills are needed if you plan to use this method. **Appendix 4** contains a list of plant identification/natural history guidebooks. Only common, abundant species should be collected. Even then, only a limited number should be carefully removed from a particular area in a way that will not cause erosion or other environmental damage. Before collecting, obtain a listing of protected plants and make sure that they are avoided. Collect from private property only with permission (or in the case of public land, only under permit from regulatory agencies).

Collecting can be a low-cost technique. The plants are more likely to be adapted to local conditions than purchased plants, and they will probably be subject to less stress if handled properly and planted quickly after collection. If not dormant, plants must be handled very carefully.

3) Propagate and grow–Plants can be grown from seeds, bulbs, cuttings, etc., either on-site or in specially prepared beds, ponds, or greenhouses. This may require more planning, but depending on the quantity needed, may also be low cost and avoid the potential environmental impacts of collecting.

Planting Techniques

Seeding or rooted planting

These are methods which are probably familiar to everyone to some degree. The basics are no different from growing a garden or planting a tree purchased from a local nursery.

All types of vegetation may be established with this method, including wetland plants whose roots may grow in soil covered by up to two feet of water (reeds, rushes, sedges, cattails). Seeding is usually the best way to establish thick vegetative cover after soil disturbance **(Appendix 3)**, although sod is an option where immediate results are needed.

Of course, it may be impractical to try to establish some types of plants from seeds. Trees and shrubs grow slowly, and erosion control needs may be too urgent to wait. Some seeds are difficult to obtain and germinate. In addition, some species spread primarily vegetatively rather than by seeds.

Cuttings/live stakes

In areas where seeding or rooted planting is impractical (such as large areas, sites where nurturing is not feasible, or where financial or human resources are limited), living vegetation can be established by other means. Some species of woody plants have the ability to root and grow from cuttings, willow being the best example. Live stakes can be incorporated into structures. They can even be installed through rock revetment, although special equipment is usually needed **(Figure 12)**.

It is best to collect cuttings when dormant. The cuttings should be soaked fully to hydrate and to wash off naturally occurring substances secreted by many plants to inhibit adventitious rooting.

Brush bundles

These are bundles of long cuttings from living woody plants which are tied together (for both physical & biological reasons), placed in shallow trenches, and covered with soil (although the branch tips may be left exposed). The technique is also known as live fascines, brush layering, or wattling.

Brush bundles are primarily used on sparsely vegetated or barren high, steep, eroding slopes. They reinforce slopes several ways: the branches add to soil stability (which increases as roots sprout and grow), protruding tips capture debris and slow runoff, and infiltration properties of the soil are improved. **Figure 13** shows an example of using brush bundles. **References 20 and 57** is a good source of more information about this technique.

General Planting Guidelines

Timing

The best time for rooted plantings is during dormancy just before growth starts in the spring. **Appendix 3** provides guidelines for seeding dates.

Site Preparation

Topsoil is a precious resource and should be managed wisely during construction activities. Carefully remove and stockpile topsoil from areas to be disturbed and replace it afterward. Importing topsoil mined from another site should be done only in areas where the original topsoil has been lost and which are subject to conditions where vegetation would otherwise be difficult to establish. The soil should not be compacted or contain large stones or clods of roots.

It is difficult to establish vegetation on slopes steeper than 1:1.5 (vertical distance:horizontal distance). If slopes are steeper than that, evaluate the feasibility of slope flattening. **Figure 14** shows a simple slope measuring device constructed with a piece of wood, protractor, string, and weight.

Even if a few trees are present on the slope, it may bebest in the longterm to remove them if it will facilitate slope flattening. New, and potentially

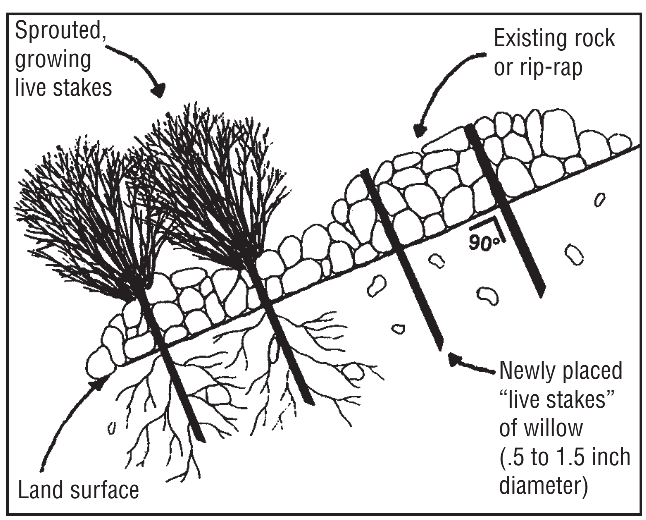


Figure 12: *Live stakes installed through rock revetment.*

healthier, trees will grow back, but soil lost to erosion on a chronically eroding slope is irreplaceable.

In addition to the aforementioned guidelines, it is necessary to prevent excessive surface runoff. Grassed swales, berms, detention basins, and drop structures are all methods which may be used to control surface runoff. Any existing erosion channels, either small rills or large gullies, should be smoothed.

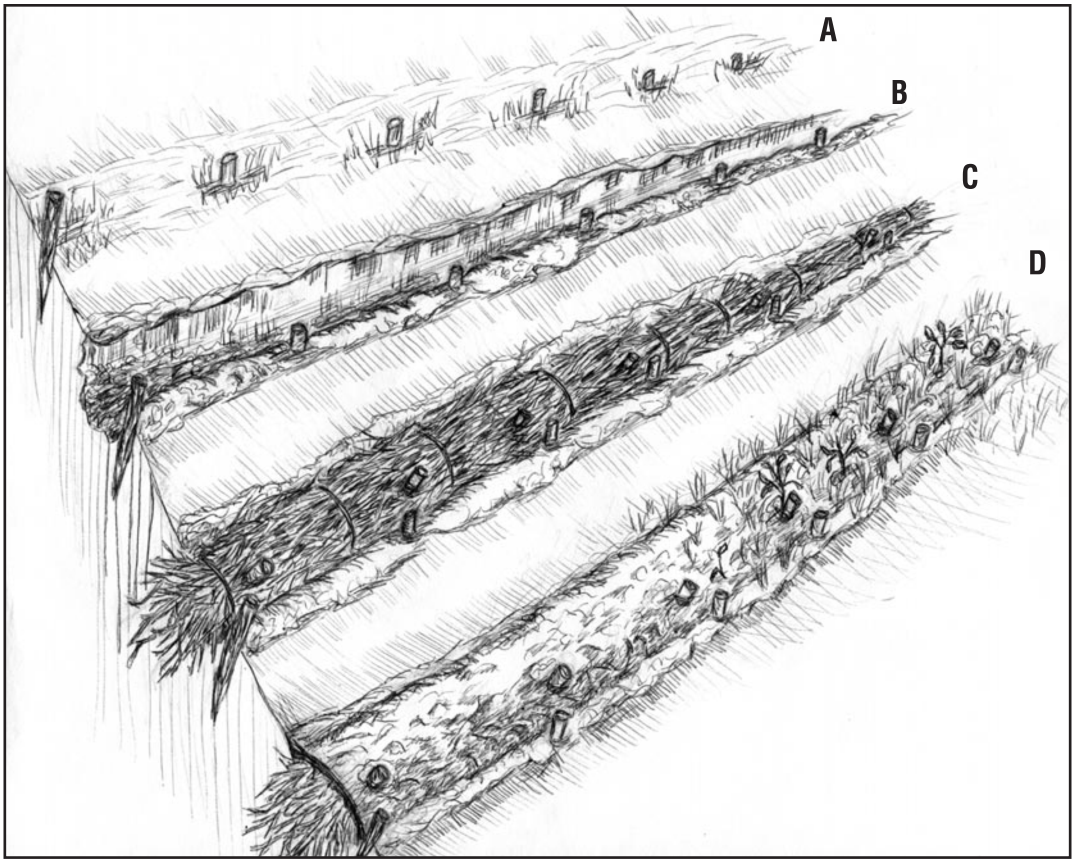


Figure 13: *Installation of brush bundles on a steep slope. A–elevation contour staked for trenching, B–excavate trench, C–install and stake brush, D–cover with soil.*

Planting Density/ Spacing
Different species have different density/spacing requirements. Appendix 3 gives application rates for seeding mixtures. Approximate spacing for tree, shrub, and herbaceous seedlings should be 6' X 6', 3' X 3', and 6" X 6" respectively, with seedlings staggered in adjacent rows. Seeding and planting by hand is most practical on small sites and is usually the only alternative on steep slopes.

Fertilizing
Apply lime & fertilizer appropriate for vegetation requirements and soil conditions. A soil test, available in the U.S. through the local Cooperative Extension Service office, can determine nutrient availability and needs.

Without a soil test, apply 10-0-10 (or similar low phosphorous fertilizer) at a rate of 12 pounds per 1,000 square feet for seedings (the three numbers refer to the percent composition of nitrogen, phosphorus, and potassium.) For tree and shrub seedlings, apply about 1/8 pound of 10-10-10 per plant spread in a band 8 to 10 inches from the plant. The fertilizer should be covered with soil or mulch to prevent runoff into the lake or stream.

Mulching
Mulch is a protective layer placed on the ground to prevent erosion, drying, freezing, consumption by animals, or the growth of competing species. Most commonly it consists of straw, woven fiber blankets, or soil tackifiers (commonly called hydroseeding). It is most important to use mulch if there will be a large area of bare soil, and when planting on steep slopes.

Maintenance
Follow-up maintenance includes watering during drought and on hot, dry sites; inspecting for overland erosion; replacing individual plants which die or reseeding large areas where needed; and protecting plantings from disease, insect pests, browsing by herbivores, and other destructive forces.

Figure 14: *Determining the slope of a site targeted for erosion control. A 1:1 slope has an angle of 45°, 1:1.5=33°, 1:2=27°, and 1:3=18°.*

Detailed Design Criteria—Nonliving Vegetation

Tree Revetments

Anchoring dead, cut trees along an eroding streambank is an effective, inexpensive method which was developed for controlling streambank erosion in Missouri. Trees placed in this manner greatly slow the current along the eroding bank, decreasing erosive energy and possibly even resulting in the deposition of silt and sand. New tree growth and other vegetation may take root naturally under and behind the revetments, or vegetation can be planted in conjunction with tree placement.

The vegetation will provide additional, long-term shoreline stability. Hopefully, by the time the tree revetments degrade, the living vegetation alone will provide stable conditions. Tree revetments can also provide excellent fish and wildlife cover. The goal of tree revetments is to get living vegetation established. If living trees are already present but falling in, then tree revetments may not help the situation in the long term.

Evergreen trees make the best revetments, because of their conical shape and the high number of limbs and fine branches. Freshly-cut trees are best for use as revetments, because they are more flexible and will last longer. Large trees are preferable because they cover more streambank per unit installation effort.

Placement of tree revetments should begin at the downstream end of the eroding streambank. The butt end should be pointed upstream and the pointy end downstream. The tree is placed tightly against the bank and anchored to the streambank at both ends with metal cables (3/16" steel aircraft cable is recommended) and cable clamps. The next tree is moved into place overlapping the butt of the first tree in a fishscale fashion.

The type of anchoring system will depend on the soil type and its inherent strength. Screw anchors, duckbill brand anchors, and metal T-posts have all been used successfully. Whatever system is used must be able to withstand the tremendous forces of the current against the trees. It is very important that the trees be attached firmly against the bank. If there is any slack, the trees may move violently in the current, either breaking free or allowing (or even aggravating) continuing erosion behind them.

The revetment must always begin and end at a point on the bank which is not eroding. The trees must be placed at the toe of the eroding bank. If the toe is more than 2.5 feet below the waterline during usual water levels, tree revetments may not be practical.

Tree revetments are most effective on bends of small to medium sized streams which have become unstable because the original cover of trees has been removed. They are not recommended for areas with bank heights greater than 12 feet. **Figure 15** illustrates the concept of tree revetments.

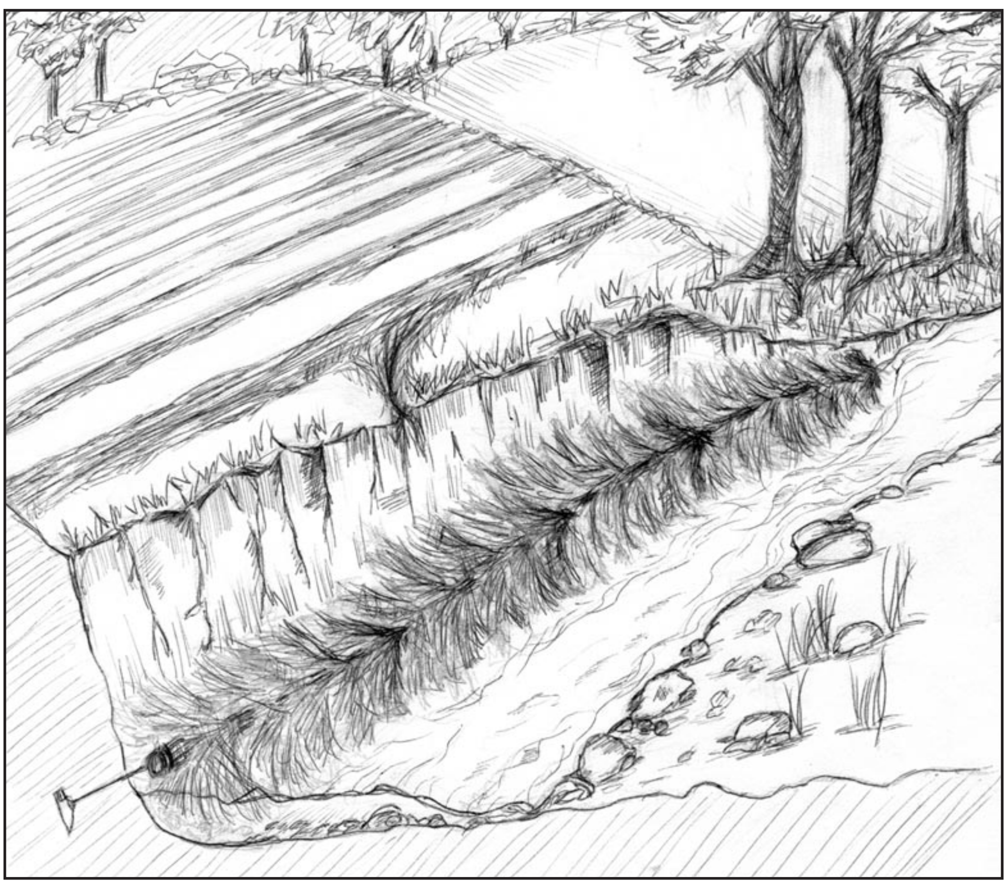


Figure 15: *A revetment of trees anchored against the toe of an eroding streambank.*

Brush Layer/Mattress

This method is similar to tree revetments, but consists of a thick mattress-like layer of dead brush placed on streambanks or broad areas of slopes generally devoid of vegetation. However, brush should not be simply dumped into deep eroding gullies on slopes which are caused by concentrated volumes of overland runoff because erosion will simply continue beneath the brush. In this situation the runoff problem should be corrected.

The goal of brush mattressing is to capture debris and sediment, slow current velocities and runoff, promote infiltration, and give the surface a more hospitable micro-climate for revegetation. The covering layer should be anchored with stakes, wire, twine, etc.

Brush mattresses are best used in conjunction with establishment of living vegetation. On slopes, they consist of long branches alternated with layers of soil on terraces. On streambanks, layers of brush are placed in an overlapping pattern progressing upstream (similar to placing tree revetments).

Coconut Fiber (Coir) Bundle Revetment

Coir is the term for the fibers from the outer husk of the coconut. It is rot resistant, has high strength, and provides nutrients for plant growth. Coir can be woven into a variety of forms, including the fuzzy brown doormats found at many homes. Recently, it has come into use for stabilizing shorelines and providing hospitable conditions for plant growth. It is compacted and bound into long bundles of varying diameters and placed in areas of high wave and current energy.

Coir bundle revetments have proven effective, when used alone or in combination with other techniques, for both streams (current velocity up to 12 ft./sec.) and lakeshores (wave height up to 4 ft.). The coir bundle physically buffers the shore against wave and current energy. It is very flexible, thus very resistant to damage and failure. It provides a better growing medium than dead brush bundles, and is more durable, providing stability up to decades.

Roots of vegetation planted in and adjacent to the coir bundle eventually replace coconut fibers and form a living, self-renewing form of revetment. Sediment is often trapped and deposited behind the coir bundle.

Coir bundles are usually placed along an existing shore or, in some circumstances, in a location to redefine a new bank. They are secured in place with 2-inch diameter stakes driven 3 feet deep at twelve-to eighteen-inch intervals along both sides of the bundle.

Coir is light and buoyant at first (which facilitates handling and positioning), but quickly becomes waterlogged and sinks. Hand tools are needed to make cut and fill adjustments beneath the bundle so that it lies evenly at the correct elevation. The upper surface should protrude above the normal water level several inches.

Butted ends can be laced together using 1/8-inch diameter rope for extra security. The terminal ends should be buried several feet laterally into the bank.

The coir can be seeded, or planted with small rooted plants. Rooted plantings in the coir should be spaced at about six-inch intervals. On lakes, rock toe protection is often used to prevent scouring at the toe of the coir bundle. Figure 16 shows a coir bundle revetment in place on a shoreline.

ROCK REVETMENTS

(Applicable to both lakes and streams)

General Description

A rock revetment (also called riprap) is an armor facing on a slope to protect it and the adjacent land from scouring by waves and currents. The concept for an engineered rock revetment came from observations of natural shoreline areas where rock and gravel deposits on gently sloping shorelines result in the most stable shorelines.

Revetments are comprised of three components: the armoring layer, base apron, and filter layer. The armor layer must be stable against the wave or current energy expected at the site. Either angular quarried rock or the rounded stones found in glacial deposits (fieldstone) may be used. The base apron keeps the revetment from sliding or being undermined. The filter layer keeps the original soil in place beneath the revetment. **Figure 17** shows a typical cross section of rock revetment.

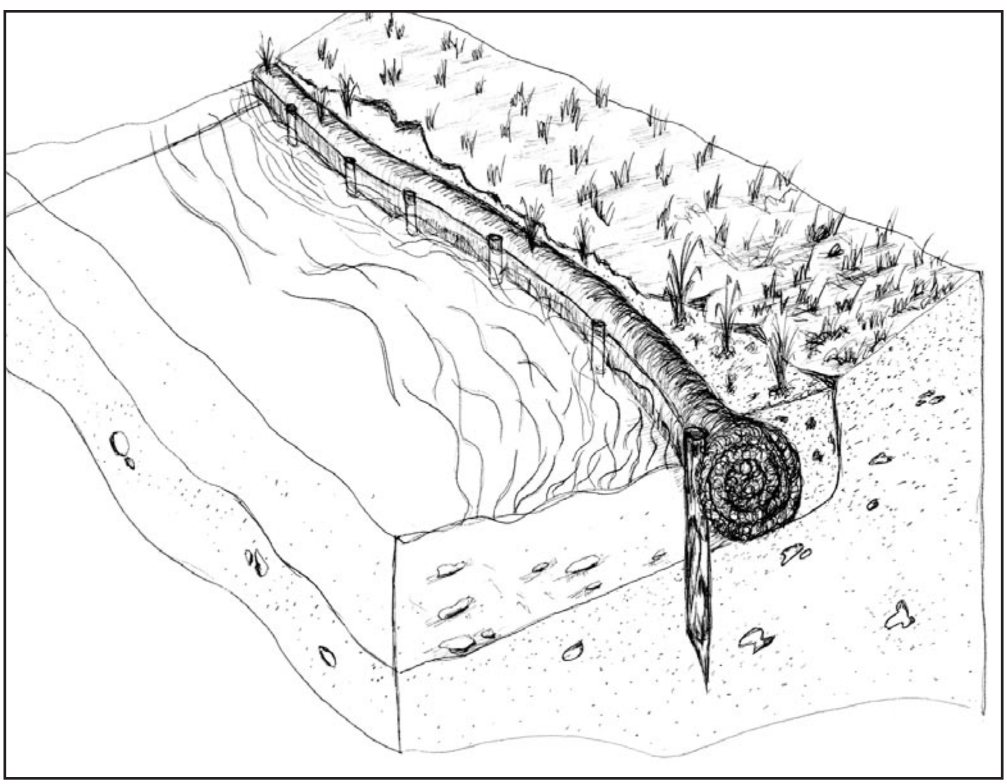


Figure 16: *Coir bundle revetment.*

The terminal ends of the rock revetment must be well tied in to the shore and blend in with the adjoining shore at a gradual angle. Failure to pay attention to this detail may result in an ineffective structure, disruption of longshore currents and sediment movement, and possibly even accelerated erosion on neighboring properties.

Other types of armoring materials are sometimes used in revetments. They include gabions (rock-filled wire baskets), cement filled bags or other containers, and reinforced concrete slabs. While these materials may all be appropriate for some situations where halting erosion is imperative, such as urban areas, emergencies (especially where structures are immediately threatened), high-energy situations, or limited working space, they are generally inappropriate for small projects on private property for one or more of the following reasons:

- there is usually no way to incorporate vegetation,
- they are less flexible or inflexible,
- they are less durable than rock,
- they are more costly,
- they need more sophisticated engineering,
- they are less effective,
- they can degrade water quality, and
- they are less aesthetically appealing.

Materials such as concrete blocks, broken chunks of concrete from street or sidewalk demolition (especially that which contains exposed steel reinforcing rod), tires, and crushed auto bodies should not be used in revetments. Therefore, rock is the only nonvegetative revetment material recommended and described in detail in this guidebook.

Rock revetments are time tested, highly durable, and often the most economical method where stone is available (as it is in most areas of the Great Lakes Basin). They are somewhat flexible, and so do not become ineffective if shoreline settling or slight structural damage occurs. If damaged, spot repairs are easily made.

Construction is simple, although it is important to follow basic design criteria in most instances. Because of its rough surface, rock revetment experiences less wave run-up (and therefore does not have to be as tall) as smooth-faced structures. The rock size needed on inland waters can usually be placed by hand without heavy equipment. Rock revetments are useful for protecting bluffs which are unstable due to erosion at the toe. However, if bluff instability has some other cause, they are ineffective. Rock revetment can provide habitat for aquatic organisms.

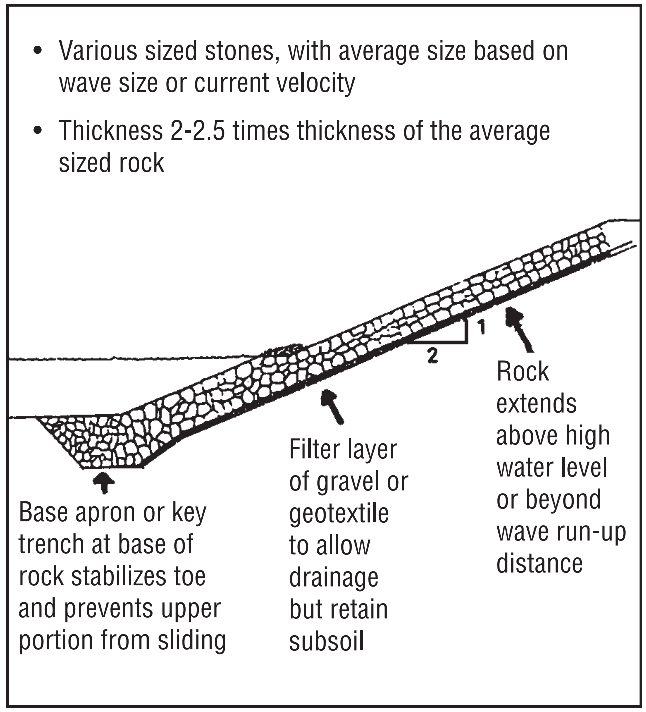


Figure 17: *Typical cross section of rock revetment (riprap).*

As with all techniques, rock revetment has some drawbacks and is not appropriate in all situations. The rocks used in a revetment can be out of character with the natural shoreline, resulting in adverse aesthetic impacts. Rock revetments have steep, uneven surfaces and can limit recreational accessibility. Without proper design and construction, the shore may be subject to continuing or intensified erosion at the terminal ends of the revetment. Rock revetments may accelerate erosion in specific areas by reflection of energy, although the potential is less than with bulkheads (see section on bulkheads for a more detailed description of this). It may be counter productive in high-energy streams, or when overuse results in total armoring of both banks, because erosion problems are simply transferred downstream. It may actually limit a stream's ability to create trout habitat by undercutting banks.

Avoid using rock revetments on streams with high power, steep gradients, flashy hydrographs, or within theflood plain of meandering streams (because the meander will eventually move through the revetment, see **Figure 18**). However, rock revetments have been used with excellent results on streams with low total stream power, flat gradients, stable flows, or where stream meanders occur outside the flood plain. Streams of this nature are found throughout much of the Great Lakes Basin.

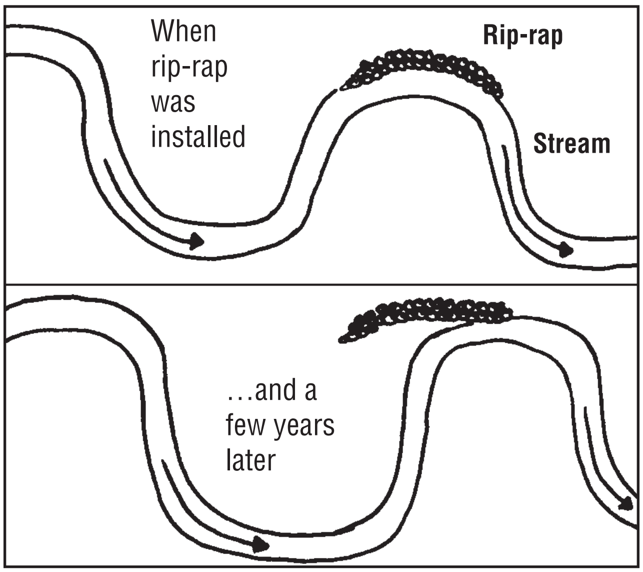


Figure 18: *Fate of rock revetment on the bank of a meandering stream.*

The following design criteria were adapted from information developed by the Natural Resources Conservation Service and the U.S. Army Corps of Engineers (ACOE). For more detailed information on designing rock revetment structures, please refer to **References 6, 8, 16,** and **57** in **Appendix 1**.

Standard Design Criteria for Lakes

When designing a rock revetment for lakes, design criteria which need to be addressed include median, maximum, and minimum rock size (weight or diameter), slope, location of upper and lower limits, thickness, and type of filter or bedding.

Rock Size

Rock size is determined based on wave size. The larger the expected waves, the larger the rocks must be so they are not moved about by breaking waves.

Table 1 is a simplified chart to estimate significant wave heights for different conditions of wind speed and fetch. Please refer back to the discussion of wave characteristics in Section 2 for more information on this topic.

Table 2 shows median rock sizes (in both weight and diameter) recommended by engineers to withstand the forces of various significant wave heights. Median rock size means that about half the rocks are larger and half are smaller, which is somewhat different than average rock size. Some engineering manuals recommend that rock size for revetments be based on significant wave heights generated by an "average sustained" wind speed of 50 miles per hour (MPH).

Significant wave height (feet)	Rock Weight (Pounds)	Rock Diameter (Inches)
0.5	1	2.0
1.0	10	4.5
1.5	20	6.5
2.0	50	9.0
2.5	100	11.0
3.0	160	13.0
4.0	390	18.0
5.0	750	26.0
7.0	2,100	48.0

Table 2: *Recommended median rock sizes for various significant wave heights.*

However, practical experience and observations seem to indicate that using this criteria overestimates the needed rock size, resulting in revetments with uncharacteristically large rocks in contrast to surrounding shoreline areas. This may be because sustained wind velocities of 50 MPH are rare in most areas of the Great Lakes Basin.

In fact, terms such as "average sustained," maximum sustained," or "continual overwater" wind speed seem to be poorly defined. No such data is available from National Weather Service (NWS) or Federal Aviation Administration weather stations. Instead, wind speed data is most frequently obtained from a 2- to 5-minute period of observation approximately 10 minutes before the hour.

Wind speed is reported as mean speed, fastest (average) speed over the period of observation, and peak gust in the Normals, Means, and Extremes Table in the Local Climatic Data Summary (tables of data developed at each "first order" weather station see **References 8 and 16**). Climate data is available from the National Climatic Data Center in Asheville, North Carolina (704) 271-4800.

Studies have shown that the fastest wind speed observations typically result from short-duration events, such as squall lines or thunderstorms. Although the fastest average speed measurements from weather station data tables or summaries best represent "maximum sustained" wind speeds, they probably overestimate the wind velocity upon which rock size should be based in that area. Alternatively, some engineering manuals present a rather complicated method of calculating duration-averaged wind speed from weather station data tables.

An examination of data tables and summaries from several weather stations in Michigan seems to verify that sustained wind velocities of 50 MPH are rare. At the NWS office in Traverse City, Michigan over a 6-year period with 48,005 wind observations, winds greater than 32 MPH occurred only 0.8% of the time and the peak recorded wind speed was 40 MPH. The NWS office in Alpena, Michigan reports that although the peak observed gust for a period of observation of more than 35 years was 60 MPH (in 1988), the fastest observed 2 minute wind speed was only 37 MPH.

For the Great Lakes Basin, rock size determinations based on significant wave heights generated by a 35 MPH "average sustained" wind seem more realistic. It is the recommendation of this guidebook that a 35 MPH wind be used as the standard design criteria for rock revetments in this region.

Another factor to consider when determining rock size is that the size of waves in the near-shore region may be less than the significant wave heights offshore. This is especially true in areas with gently sloping beaches. Another simple method is available to estimate the size of the wave likely to actually hit the beach.

1. Measure the water depth 50 feet from the lakeshore;

2. To this depth, add the distance between the present lake level and the normal yearly maximum lake level (the maximum level may be determined by official records, or, if none exist, by reliable personal observation);

3. Finally, multiply this total depth by 0.8 to find the maximum design breaking wave height.

We recommend calculating wave height using both methods, and then choosing the smaller of the two calculations to use for significant wave height when designing rock revetments.

The rock used in a revetment should be of varying sizes, instead of all the rock being close to the recommended median size. To calculate size range, multiply the recommended median size by 1.5 to determine maximum, and 0.5 to determine minimum. For example, at a shoreline site with a 5-mile fetch, the significant deep water wave height with a 35 MPH wind speed would be 2.35 feet. Based on this, the median rock size should be about 11 inches in diameter, with a size range of 5.5 to 16.5 inches.

The various sizes should be evenly distributed throughout the revetment, and placed so that gaps between the individual rocks are minimized. In the case of large median rock sizes (greater than 9 inches), adding additional rock smaller than the recommended minimum will help fill gaps. This will result in maximum stability and minimize the movement of wave energy through the revetment.

Rocks used in revetments should be squarish or rounded in shape. Avoid using flat, platelike rocks which are more easily moved by the waves. Angular quarry stone is reported to be most stable because of its interlocking characteristics. However, fieldstone may be more readily available, cheaper, and blend into the surrounding environment better. If care is used in size selection and placement of the rock, the use of fieldstone will be adequate on inland lakes.

Slope

Rock revetments depend on the soil beneath them for support, and should therefore be built only on stable slopes. The revetment should be absolutely no steeper than 1:1.5 (vertical distance:horizontal distance), although a 1:2 or flatter slope is a better goal. If the original land contour is too steep, it can be flattened by grading. If this is not a practical option because of nearby structures or great bluff height, then enough rock should be placed so it results in a suitably flat slope. The final slope of the revetment face must be determined before determining its upper and lower limits.

Upper and Lower Limits

The upper limit of the structure (vertical height above ordinary high water mark) must be greater than the height of the wave run-up. The flatter the slope, the less vertical wave run-up. If the significant wave height is known, **Table 3** can be used to estimate wave run-up heights for different construction techniques and slopes. Some water bodies have the potential for significant wind setup, which should be considered in addition to run-up. Refer to **Figure 8**, and add the wind setup height to the calculated vertical wave run-up height.

The lower limit (toe) of the revetment should extend 1 to 1.5 times the significant wave height below the ordinary high water level, if possible, to prevent undercutting. However, this may be both impractical and undesirable in some shallow, slightly sloped beaches. Excavating a base apron (a slight trench-shaped depression at the base of the rock) before rock placement will also help prevent undercutting and sliding of the rock.

Thickness

Recommended thickness of the rock throughout the length and width of the revetment is about two times the median rock diameter.

Filter Layer or Bedding

The interface between the soil and the revetment is probably one of the most important design details, but is one of the most neglected and is responsible for many project failures. In most shoreline areas, ground water flows from the land to the lake. No matter how carefully the rock is placed, water from breaking waves seeps into the soil and then flows back to the lake. In addition, high velocity jets of water from waves also penetrate the spaces and stir up underlying sediments. When rocks are placed on a slope without an underlying filter layer or bedding, water exiting the soil behind the rocks carries small soil particles with it. Since the spaces between the rocks are so much larger than the largest soil particles, they pass practically unhindered through the rock. In this way the bank can erode from behind the rocks (although probably at a somewhat slower rate than before).

However, with a properly designed filter layer of woven or nonwoven synthetic or natural cloth (often termed "geotextile") or gravel, soil particles are prevented from washing out. This happens because at least some soil particles are larger than the pores in the overlying filter. As water flow passes out of the soil and through the filter layer, coarse soil particles block the pores in the filter preventing continued washout of soil. Although water continues to pass through the filter layer (in both directions), the soil particles cannot. Additional benefits of the underlying filter layer are to support the armor against settlement and allow ground water drainage through the structure.

Woven geotextiles tend to be stronger and, because of uniform mesh sizes, generally function better than nonwoven geotextiles. Synthetic geotextiles hinder the growth of plants through the revetment. Where plant growth is desired, gravel or biodegradable jute geotextiles may be more suitable. Biodegradable geotextiles are not as durable as synthetic, but they function long enough to allow vegetation to become established and act as a living filter layer.

There are many different types of filter layer products from which to choose. Sources are included in the list of manufacturers and suppliers of shoreline erosion control products in **Appendix 6**.

Geotextiles are generally available in one hundred-foot-long rolls, 12 to 18 feet wide. Pores in geotextiles should be sized to match the size of the soil particles to be retained. If not properly installed, geotextiles can work partially loose. The ends should be securely buried within the rock revetment or the underlying soil to avoid visual impacts, debris hazard, and wildlife entanglement. It is important to cover the geotextiles thoroughly, because they can degrade in the presence of sunlight. Overlap should be 8 to 12 inches with pinning at 2- to 3-foot intervals using staples or stakes of steel, wood, or other materials.

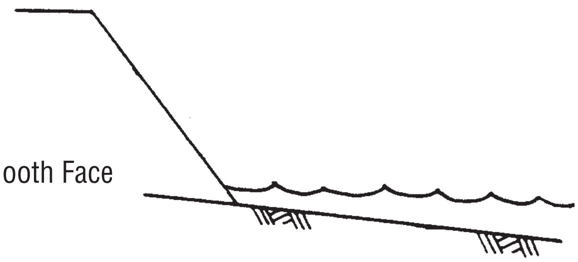
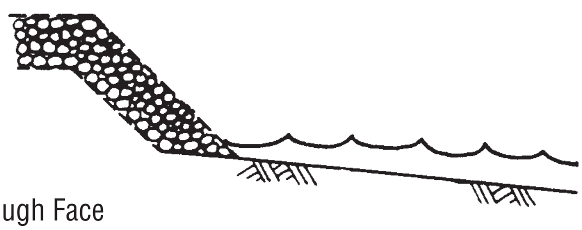
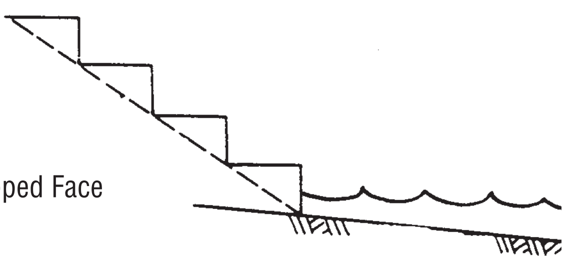
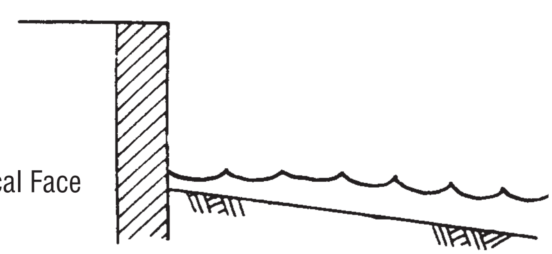
	Shoreline Slope	Wave Run-up Factor
 Smooth Face	1.5:1 2.5:1 4.0:1	2.25 1.75 1.50
 Rough Face	1.5:1 2.5:1 4.0:1	1.25 1.00 .75
 Stepped Face	1.5:1	2.00
 Vertical Face	—	2.00

Table 3: *Chart for estimating wave run-up. (Multiply the significant wave height by the wave run-up factor.)*

The recommended minimum thickness of gravel bedding material is 6 to 9 inches. Even when using geotextiles, it is best to use an intermediate layer of small stone over the fabric to help evenly distribute the load and to prevent rupture of the geotextile from sharp rock edges.

"Light" Rock Revetment Design Criteriafor Lakes

In some areas of accelerated erosion, the erosive forces overcome the resistance of the shoreline by only a very small margin. In these circumstances, the installation of a rock revetment according to the aforementioned standard design criteria may be a more extreme measure than is needed to restore the stability of the shoreline. Although the identification of these circumstances is not clear cut, they are likely to occur when one or more of the following conditions are present:

- The significant wave height is less than 2 feet.
- The recession rate is three inches per year or less.
- There is some reason to believe that removal of the original shoreline rocks (the natural rock revetment) has occurred in the past.
- There is not room for placing a standard revetment structure. For example, the mouth area of a small stream, where the slope required for standard design criteria would nearly fill in the stream mouth without extensive bank reshaping.
- The shoreline is generally stable, but only small "spot treatments" are needed.
- The shoreline's offshore slope is very slight.

In essence, light armoring attempts to restore the original shoreline and, when coupled with BEC methods, may be enough to solve the erosion problem. In addition, it can be very inexpensive and blend in perfectly with the natural shoreline. After installation, if careful monitoring shows that this method is not adequate to control erosion, then a more sophisticated structure can be installed at a later date with few unacceptable consequences. Where reconstruction of the natural stone armoring seems appropriate, the following guidelines are suggested (some of which are the same as for standard design criteria):

- Collect fieldstones from an inland, upland site, not from other areas of the lakeshore. The stones should be of various sizes, with maximum size about 8 inches or similar to that found in adjacent undisturbed areas of shoreline. Round or squarish rocks should be used rather than flat, thin shapes.

- First place a gravel "filter layer" under the area where the fieldstones are to be placed. The gravel should be shoved up under any undercut banks. Although synthetic filter fabric may also be appropriate, its use may unnecessarily complicate the light revetment option.

- Place stones one to two layers thick, extending from at least several feet offshore to what appears to be the normal extent of the wave run-up. The stones should be hand-placed so that they fit together well and do not contain large voids.

- Examine other natural shoreline areas for guidance on how densely the rocks should be placed to remain in character for the shoreline. Try to duplicate the conditions found in adjacent areas, where the shoreline is relatively erosion free.

- If ice moves the stones (usually by impacting them into the bank) it will probably be futile to move them back into their original position because the ice will likely move them again in subsequent years. Rather, let the virtually unstoppable forces of the ice move them about until a more or less stable position is achieved. If more armoring is needed along the waterline (both to protect soils and achieve an appropriately flat slope), add more stones as needed. Although "touch up" maintenance may be necessary on an ongoing basis, eventually the rock armoring and shoreline vegetation will reach a more or less stable equilibrium with the ice forces.

Standard Design Criteria for Streams

Rock revetment retards the natural erosion process on streams and attempts to lock the stream into a preferred course. Many of the basic design concepts for rock revetment are the same as those described above for lakeshores. However, on most streambanks currents are the main erosive force rather than waves, and the criteria for determining median rock size is based on overcoming the powerful pulling forces of the current.

banks currents are the main erosive force rather than waves, and the criteria for determining median rock size is based on overcoming the powerful pulling forces of the current.

The energy developed by currents and flow patterns is more complex than that developed by lake waves. A number of complicated formulas have been developed which relate rock size to discharge, and channel slope and size. **Figure 19** shows a relatively simple method designed by the Natural Resources Conservation Service for determining median stone sizes based on current velocity and side slopes.

Other references recommend much more general rock sizing criteria. One ACOE publication recommends that a well distributed mix of stones weighing from 20 to 200 pounds will be suitable for all applications where the maximum stream velocity is less than 10 feet per second. Michigan Department of Environmental Quality (MDEQ) guidelines indicate that a standard rock size for streams should be 8 to 18 inches (or about 40 to 400 pounds).

Accurately determining stream velocity at the proposed rock revetment site is another complex matter, one which should be obtained by measurements using a current meter at both horizontal and vertical intervals. However, a rough estimate of stream velocity can be obtained with the following technique using common household materials.

Using a tape measure, measure 50 feet or so along the stream bank at the site of the proposed rock revetment. Toss a slightly buoyant object (such as an apple, orange, or block of wood) into the main portion of the current at the head of the measured stretch and record how many seconds it takes to travel the measured distance. Do this several times and calculate the average time. Divide the distance traveled by the average travel time to calculate stream velocity in feet per second. Velocity is best determined during periods of high water.

Excavating for a base apron (a.k.a. key trench) may be more difficult and environmentally disruptive in flowing waters than in lakes. Often, a good alternative is to place extra-heavy rocks at the base of the rock revetment. Their weight will serve the same function as a base apron, and scouring by the current may cause them to settle into place in much the same way as would an excavated trench. It is most crucial to establish a good base apron on streams with unstable bottoms (silt) or one which appears to be subject to strong scouring forces.

As with lakeshores, hand placement of rock is best because it ensures that the rock interlocks well. However, swift currents and steep drop-offs may make work of this nature difficult in some streams. Simply dumping the rock over the bank is another option for placement. However, this is only feasible where there is adequate bank access for vehicles. If rock must be dumped, care should be taken to ensure stable, well-vegetated portions of the bank are not damaged, and that sorting does not occur during dumping, but that the different sized rocks remain well mixed.

MISSING Graph

***Figure 19:** Determination of stone size based on current velocity and slope.*

A method sometimes used on medium to large rivers is to pile rock on the bank. As it erodes, the rocks fall in, armoring the slope. If possible, hand place at least the crucial surface layer.

A filter layer may be placed beneath rock revetment along streams, but it is not as crucial as in lakeshores because of the different nature of the erosive forces (pulling shear forces, rather than impact or suction). Some erosion control specialists prefer to use gravel rather than geotextiles because it is more conducive to vegetation growth.

The revetment should extend from the base of the slope to bankfull level (see Figure 5), or up to the level of healthy vegetation growth, whichever is less. Existing obstructions such as logs or brush, may need to be removed before placing rocks so the integrity of the armor blanket is not breached. However, if living trees and shrubs within the revetment can be preserved, they will enhance its strength.

BULKHEADS
(Applicable to both lakes and streams)

General Description

A bulkhead is a wall whose purpose is to hold or prevent the sliding of soil. They are also called retaining walls. Bulkheads are also often constructed to provide some protection from wave action. There are three basic types of bulkheads: thin structures penetrating deep into the ground (i.e., sheet piling), deeply driven posts supporting a primarily above-ground wall, or massive structures resting on the ground surface (i.e., concrete wall).

The term bulkhead is often used interchangeably with seawall or breakwall. However, seawall is the term more correctly applied to massive structures constructed in the water at the shore or offshore to protect shorelines from wave action (see section on breakwaters). Massive seawalls are not normally appropriate on inland waters, especially in private property situations.

Bulkheads are only suitable for areas where there is, or needs to be, an abrupt rise to an elevated surface feature. The most appropriate uses for bulkheads are for toe protection of eroding bluffs, where deep water along shore is needed for docking structures, and where bottomland filling is deemed essential.

Bulkheads have numerous disadvantages. When placed in the water or at the water's edge, the vertical faces of bulkheads can reflect and transfer wave energy, causing increased bottom scouring in front of the structure and accelerated shoreline erosion beyond its end. The loss of a sand beach is often the result. Bulkheads are aesthetically unattractive and degrade shoreline habitat. They are rigid structures and cannot adapt to minor landscape movements. This means that they are usually doomed to eventual massive failure from the enduring forces of nature. They create access problems unless stairs are provided. They require heavy equipment and open accessibility at the site, and the installation can be noisy and disruptive.

The popular action of attaching a cosmetic facing of treated lumber to a sheet piling bulkhead has water quality implications because toxins can leach out of treated lumber in direct contact with water. Although the use of modern treated lumber in such situations is acceptable to the MDEQ, the U.S. Environmental Protection Agency does not allow its use in drinking water reservoirs. It is best to avoid using treated lumber in direct contact with water whenever possible.

Bulkheads are most environmentally acceptable on inland lakes and streams when used to protect the toe of an unstable bluff which is normally inland somewhat from the high water level, but which may be subject to erosive forces during periods of extremely high water. The use of bulkheads which permanently stand in the water should be avoided, especially on water bodies which have high water quality and support valuable or unique fisheries, or in areas which contain habitats which have not been previously degraded. Bulkheads have relatively high initial costs, although they have very little maintenance after installation (at least until massive failure begins). **Figure 20** shows general design details for bulkheads.

Detailed Design Criteria

Post and plank bulkhead construction is accomplished by driving a series of support posts backed by wood planking to form a retaining wall. The posts are typically either thick (4.0 inches minimum) wood posts or steel pilings driven in at least two times the above-ground height and sometimes anchored from behind.

Anchoring devices usually consist of a timber or concrete “deadman,” or duckbill or screw-type earth anchors. If anchors are used they should be connected to the outside of the pilings. Connecting hardware, cables, etc. should have better corrosion protection features than plain carbon steel (i.e., galvanized or wrought iron). Post and plank bulkheads are more susceptible to toe scouring and undermining, and rock toe protection should always be used.

Although some types of wood (such as northern white cedar and black locust) are rot resistant, structures built with untreated wood will generally be more susceptible to rotting than those built using lumber treated with preservatives. However, as explained earlier, treated lumber placed in direct contact with water can leach toxins. Therefore, post and pile bulkheads should only be used in locations inland somewhat from the high water level, but which may be subject to erosive forces during periods of extremely high water.

Sheet pile bulkheads are supported primarily by ground penetration (called cantilevered construction), but may be supported additionally by anchors or braces. Sheet piling should be driven to a depth of 2 to 3 times the vertical height above ground. If anchors are used, they should be connected to horizontal beams on the outside of the sheet pile near the top to evenly distribute loads and help ensure straight alignment.

Steel sheet pile can be driven into soft and hard soils, as well as some types of soft rock. Aluminum and timber sheet pile is suitable only for softer soils (sand, silt). Suggested minimum thicknesses for sheet piling are: 0.109 inches for metal, 2.0 inches for wood planks. Since there are concerns with using treated wood in contact with water, wood sheet pile bulkheads are not recommended for bulkheads standing in water.

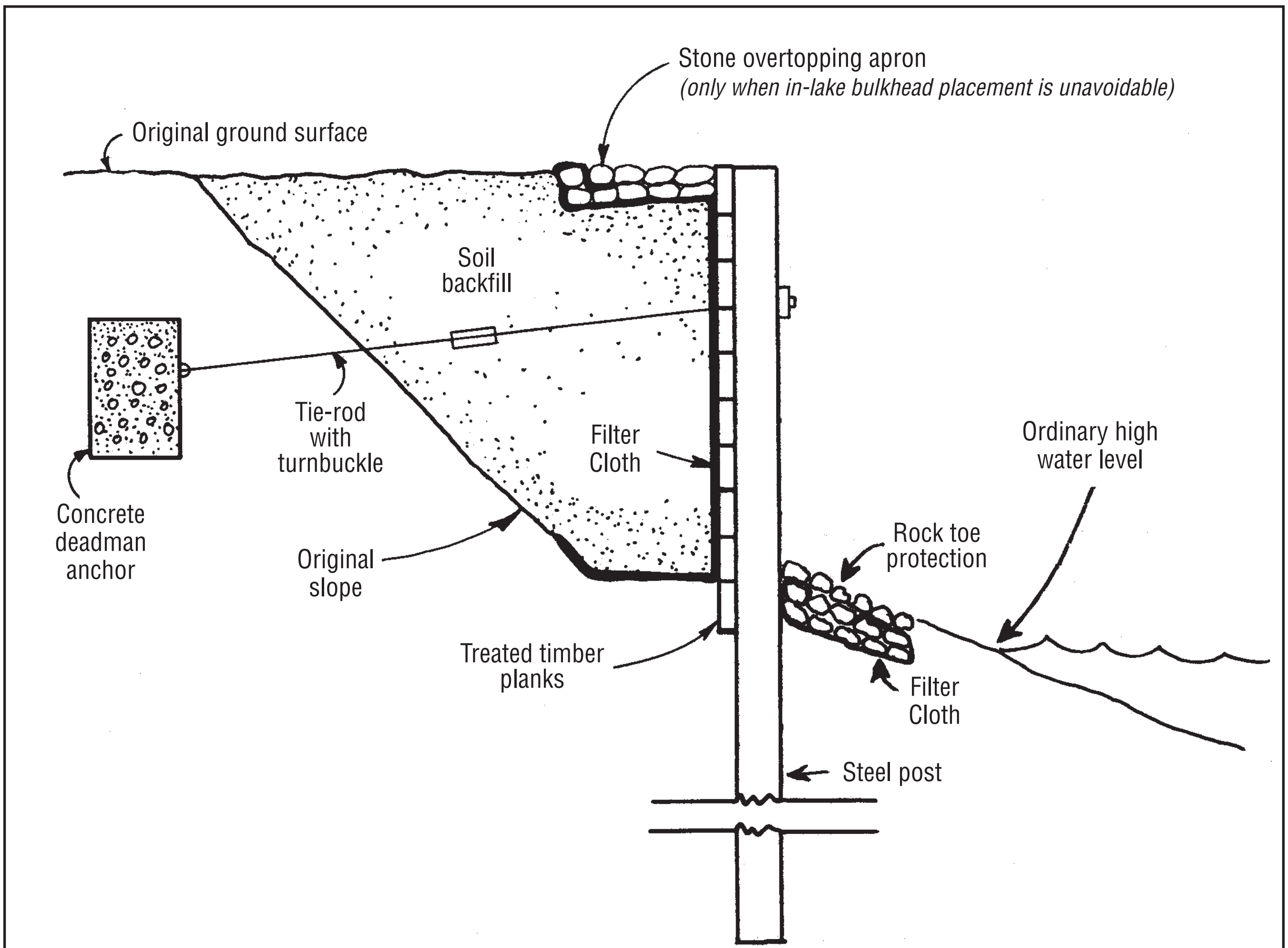


Figure 20: *Bulkhead design features.*

Steel and aluminum piling are interlocking and form a tight fit. Joints between wood planks should be as tightly fitted as possible. Of the three basic bulkhead types, sheet pile bulkheads probably function best in areas subject to continual wave action.

Massive above-ground construction is usually only advisable when a shoreline bluff rests on bedrock, making the installation of deeply driven structures impractical. Otherwise, this technique is much more subject to failure by settling and/or undercutting than other types of bulkheads. No design details are provided here. It is best to consult with an engineer in special cases where massive above ground structures are suitable.

All types of bulkheads must be high enough to avoid overtopping by the waves. The same technique described for rock revetment may be used to determine wave run-up height **(Table 3)**.

A geotextile filter layer should be used behind all bulkhead structures. Coarse granular material should be used for backfill. Supplemental drain holes through the face of the bulkhead are recommended to ensure that the structure does not retain excessive amounts of water in the soil behind it.

It is likely that wave and current energy will be intensified at the ends of bulkheads, increasing the erosion potential. The terminal ends of the bulkhead should blend into adjacent shorelines at a gradual angle to prevent erosion from progressing beyond, or starting behind, the end of the structure (termed flanking).

Placement of rock revetment or installation of bio-technical erosion control can help protect against flanking. Bulkheads should not protrude out beyond the normal shoreline because disruption of longshore transport of sediment can result. Bulkhead flanks should be monitored to detect accelerated erosion at an early stage.

GROINS
(Applicable to lakes only)

General Description

Groins are structures constructed perpendicular to the shore and extending out into the water. Their purpose is to trap sand or retard its longshore movement both for erosion protection and beach enhancement. Groin structures themselves do not inherently protect the shoreline. Instead they work to diminish longshore transport of sediment by changing alignment of the beach. Sand accumulates on the upcurrent side of the groin. Once sand fills the area in front of the groin, it moves around the end of the structure and once again begins moving down-drift, although at a slower overall rate. **Figure 21** shows the effect of a groin.

The functional behavior of groins is complex and difficult to predict. Groins are only effective where there is a high net transport rate of sand in one direction. If substantial longshore drift of sand is not occurring, sand accumulation will not occur and groins will neither protect a shoreline from erosion or build a beach. If there is a high amount of transport, if the movement is equal in both directions, groins will do little.

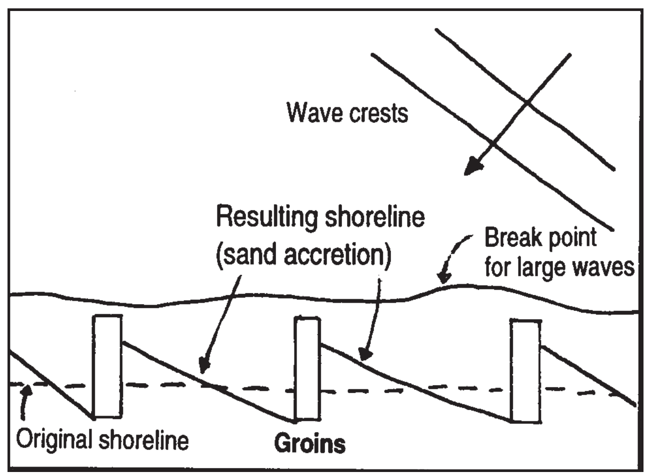


Figure 21: *Effects of groin construction.*

Even where conditions are suitable for groins to function, a problem is often created whereby the retarded movement of sand accelerates erosion and diminishes beach size on the downdrift side. Another drawback to groins is that they can hinder foot travel along the beach.

Groins are suitable on inland lakes only in a few circumstances where restricting sand movement will have no affect on neighboring properties and where erosion is actively impacting the upper beach zone. In Michigan, groins are only rarely permitted in inland lakes by regulatory agencies because there are not enough available sediments for their successful function. Generally, they are only applicable to the Great Lakes or sea coasts, and even then the problems often outweigh the benefits.

General Design Criteria

In the past, groins were commonly constructed on inland lakes by creating a long pile of cobble- and boulder-sized rocks collected from the beach. This practice upsets dynamic equilibrium in two ways (interrupts longshore drift and disturbs lake bottom) and is not recommended.

Groins are more properly constructed of imported fieldstone or quarrystone, timber-rock cribs, or sheet piling. If groins are to be constructed, filling behind them initially with sand, pea stone, or gravel from an off-site source can help minimize sediment starvation problems downslope. Groins must be massive and strong enough to resist displacement by waves, currents, ice action, etc.

Groins must never be built offshore to the extent that sand which moves around the end is forced into such deep water that it cannot be returned to the downdrift beach. This has often been the case when long piers constructed of permanent fill (which f unction somewhat as groins) have been constructed on lakeshores.

There are other important design considerations necessary for groins to function as intended, such as height, length, and spacing. However, since groins have such limited applications in inland lakes, detailed design criteria are not presented here.

BEACH FILLS
(Applicable primarily to lakes)

General Description

Beach fills are attempted for two basic reasons. Fill is often placed in an attempt to provide a buffer zone against erosion. It is also commonly used to create or enhance a recreational swimming beach. However, filling is often a futile, environmentally destructive action and should only be pursued after careful study and planning.

If a site is conducive to the long-term existence of sandy material, it would likely be there naturally. If it is not there, it is because the energy is either too great to allow it to remain in place, or not great enough to wash away the finer materials. In either case, sand fills on the littoral shelf of lakes often disappear in a relatively short time, either by washing away or simply sinking out of sight in a few years into the softer underlying sediments.

Sand dumped on a property in an attempt to restore a former beach will likely have the effect of eventually replenishing the beach of the neighbor on the down-drift side and burying valuable aquatic habitat.

Although a natural sand beach functions well at erosion control and is desirable to walk on, it is the least productive type of sediment from a biological aspect. The introduction of sand fill can bury otherwise productive aquatic habitats, such as gravel, rocks, weed beds, and organic deposits.

In a few cases on inland lakes, sand fill may be justified. These include restoring beach materials which were excavated in the past, sites where natural sediment sources have been cut off, and sites where sand will have a large public benefit coupled with minor environmental impacts and acceptable longevity.

General Design Criteria

Sand used in beach fill projects should be well sorted. If fine sediment (silt or clay) is present, the fill may result in excessive turbidity and nutrient enrichment. Fill should originate from an inland, upland source and its excavation should not result in other unacceptable environmental impacts (local sources of suitable sand are not always available).

Generally, if beach fill is coarser than native material, it erodes more slowly; if finer, it erodes more quickly. Placement of a special geotextile under the sand fill will help prevent the sand from sinking into soft underlying bottom sediments. From an environmental standpoint, the best way to enhance or establish a sand beach is to fill only above the wave run-up zone, possibly coupled with a narrow sand fill only large enough to facilitate access to water deep enough for swimming.

INFILTRATION AND DRAINAGE CONTROLS
(Applicable to both lakes and streams)

General Description

Structures to control overland runoff, soil moisture, and ground water seepage can help improve bluff stability and prevent massive erosion. These include horizontal drains, vertical wells, drainage trenches, and runoff diversions.

A horizontal drain system generally consists of a small diameter perforated pipe, or series of pipes. Holes are drilled horizontally into the face of the bluff and the pipe is placed into the holes. The perforated drains collect seepage before it surfaces on the bluff face. The seepage is conveyed to a controlled outlet in a suitable location.

Drainage trenches (also called French drains), are similar to horizontal drains, except that they are installed near the surface by excavation rather than drilling. They are intended to intercept and divert shallow seepage moving toward the bluff face.

Both horizontal drains and drainage trenches operate similar to a septic system drainfield except in reverse (water is taken out of, rather than placed into, the soil).

A vertical well works much the same as a private residential well. If drilled into a soil layer in the bluff containing ground water which is causing a problem, it may be possible to pump away enough ground water to alleviate the problem.

Runoff diversion structures include ditches or dikes to intercept surface runoff before it travels either over the edge of the bluff or to an infiltration area which recharges problem ground water. The runoff is conveyed to a catchment basin and discharged ina controlled manner in a suitable location.

Design Considerations

Designing and constructing water control systems may be complex, difficult, and very expensive. Careful studies should be conducted to determine that the feasibility and benefits of water control will outweigh undesirable consequences before deciding on this as a course of action. A professional engineer with expertise in geologic applications is recommended for designing drainage systems.

SLOPE FLATTENING
(Applicable to lakes and streams.)

General Description

Reworking the face of a bluff can lessen the slope to a more stable angle and remove some of the overlying weight that contributes to instability. The use of heavy equipment is usually necessary. There are three basic slope flattening techniques: cutting, cut and fill, and terracing **(Figure 22)**.

Cutting is the excavation of unwanted or excess soil. The excavated soil is discharged in another location not on site. Cutting is the most common form of slope flattening.

Terracing involves the construction of a level bulkhead (or a series of bulkheads) across the face of an eroding slope. This results in a flatter, more stable slope adjacent to the bulkhead. This technique may reduce the amount of excavated material which needs to be disposed, but incurs extra expense and long-term maintenance in the form of bulkheads.

Cut and fill techniques have been used to reduce bluff angle. However, this is not recommended along shorelines because discharge of fill into surface waters reduces bottomland area and may result in negative water quality impacts. It should only be considered under special circumstances.

General Design Criteria

A slope of 1:1.5 (vertical:horizontal) should be the maximum steepness of the final grade, even less if conditions allow. Excavated soils should be disposed of properly in an upland location. The freshly excavated slope should be replanted quickly to prevent erosion from surface runoff.

It may be necessary to couple slope flattening with toe protection to completely protect against erosion. If subsurface water is contributing to a bluff stability problem, drainage controls can be installed at the time of slope flattening.

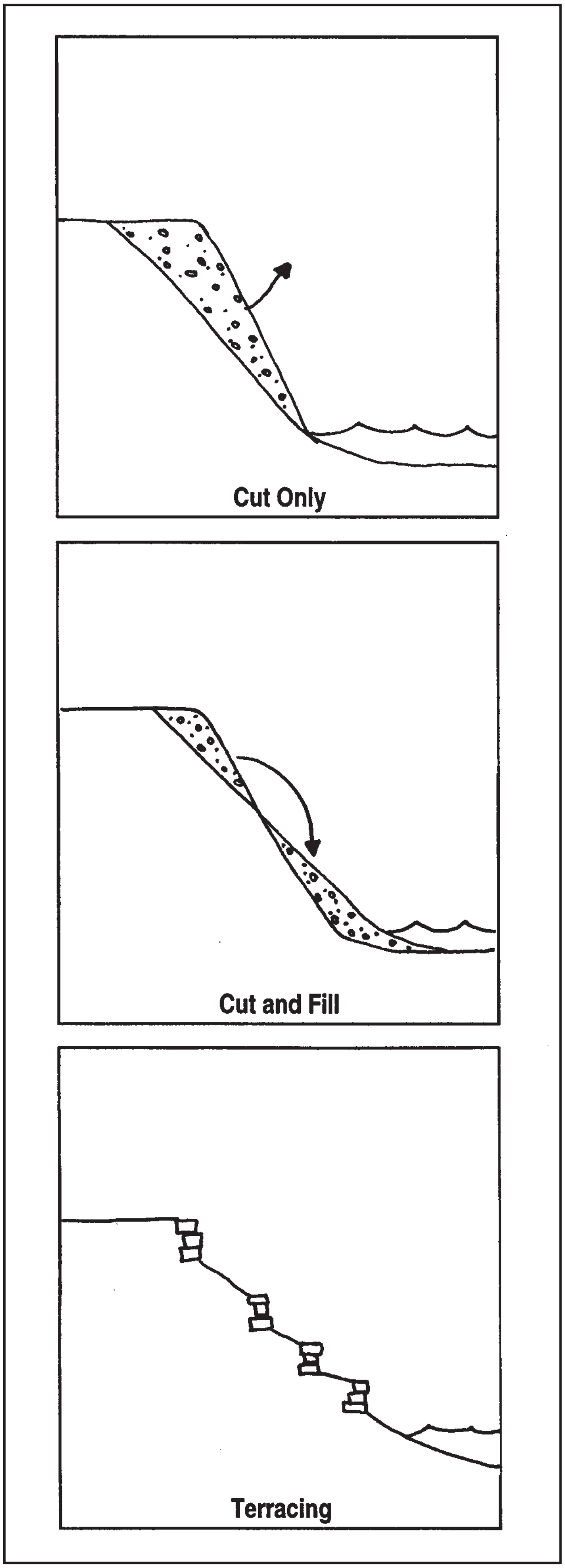


Figure 22: *Bluff flattening techniques.*

Slope flattening is usually only feasible when adequate room exists at the top and it does not interfere with existing desirable land uses (such as homes). It is probably most applicable to bluffs less than 20 feet high. However, slope flattening should not be used on stable ice shove ridges along lakeshores.

If the bluff is forested on top, the consequences of forest destruction may outweigh the benefits of recontouring. Bluff flattening reduces the amount of level land along the shoreline. Revegetation techniques discussed in the section on BEC should be used whenever bluff flattening is performed.

BREAKWATERS
(Applicable to lakes only)

General Description

Almost everyone has seen massive concrete or rubble breakwaters protecting harbors and marinas on the Great Lakes or the oceans. They are structures placed out in the water, rather than directly on shore, to intercept the energy of approaching waves and form a shadow zone of low-energy on their landward side. Although their purpose is usually to create a safe mooring area, they also reduce the ability of waves to erode and transport sediment.

While large breakwaters such as this are not appropriate for private property situations on inland lakes due to environmental impacts and safety concerns associated with navigation, in some situations small structures submerged just offshore may be useful for breaking waves and diminishing their energy before reaching the shore.

In addition to diminishing wave energy, small offshore structures can trap or hold sand. The preceeding section on groins discusses the pros and cons of sand trapping. A submerged barrier which breaks the waves may result in a wider zone of emergent plant growth.

Natural materials such as boulders and waterlogged tree trunks act as breakwaters. Shorelines naturally reached a dynamic equilibrium in their presence. In many locations, these objects have been removed as shoreline property became developed, upsetting the dynamic equilibrium and causing accelerated erosion. After careful assessment of the situation, placing (or replacing) similar objects could help protect shorelines. They also may have an added benefit of aquatic habitat enhancement.

A temporary offshore breakwater berm can provide valuable time for establishment of vegetation as part of a BEC project. This could be as simple as a mound of gravel, rock, or bundles of branches which will break apart after a season or two. Even though these materials are natural and may be biodegradable, this technique should be used only after careful consideration because of the filling it involves. Figure 23 shows several types of small temporary near-shore breakwaters.

A more permanent low impact technique is to stagger and partially bury large fieldstones (2' to 3' in diameter) near shore. The large boulders break incoming waves yet are not obtrusive or an impediment to navigation. The staggered configuration allows easy passage for bathers. Because most of the mass of the boulders are buried, they resist the forces of waves and ice and are quite stable.

NO ACTION
(Applicable to both lakes and streams)

Although this method may seem like a contradiction in terms, in some cases it is preferable to any other action when all aspects of the problem are considered. The option of taking no action is at least worth considering when trying to evaluate long-term erosion trends and their consequences.

If the erosion seems to be the result of natural shoreline processes without exacerbation by human activities, if water resources impacts are not severe, if the recession rate is not great, if no property structures are threatened, or if the erosion is caused by temporary factors, then no action may be the best course of action.

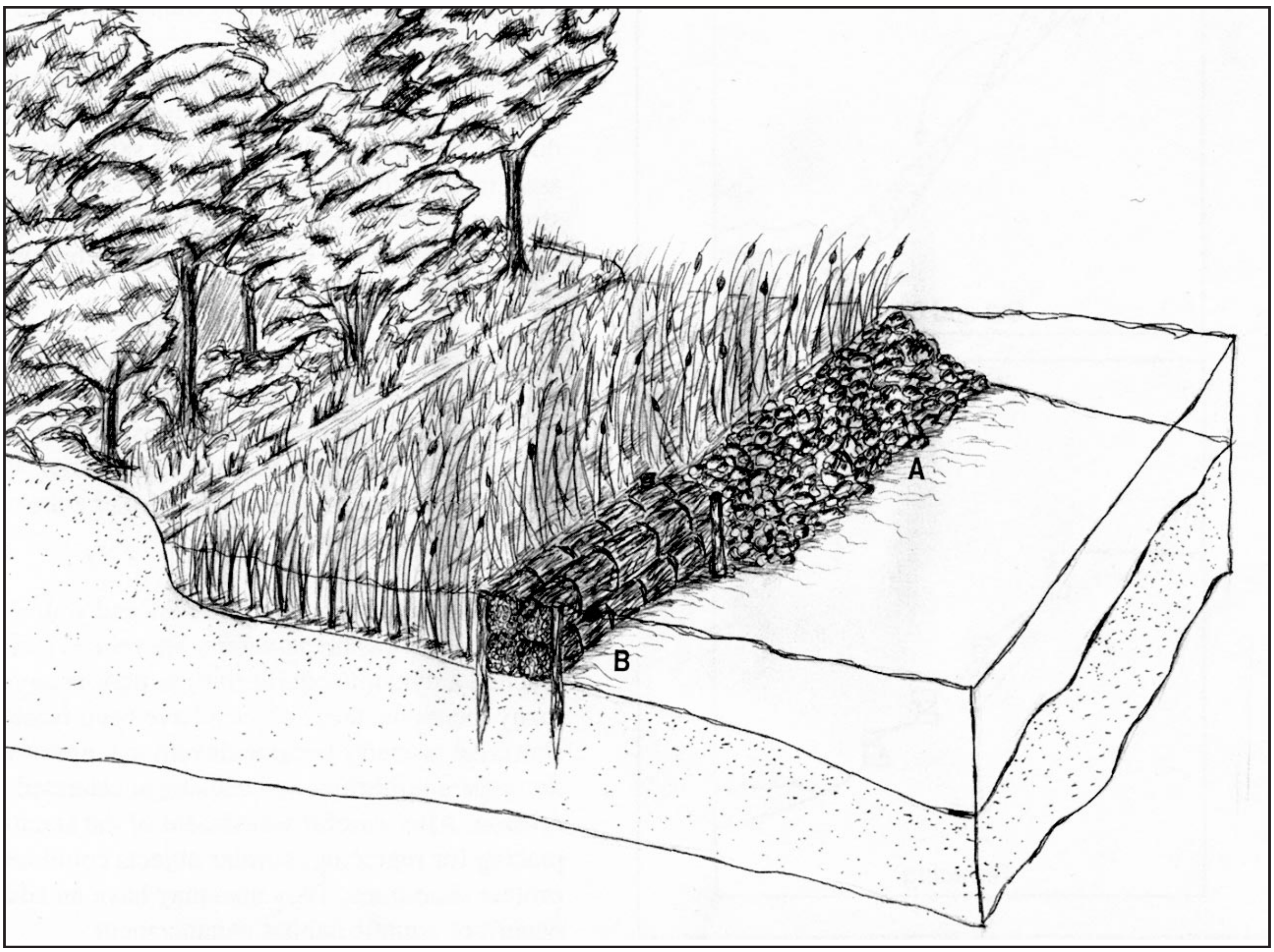


Figure 23: *Examples of temporary near-shore breakwaters. A–stone berm, B–branch bundles..*

If saving threatened property is the only goal of erosion control, it may in some cases, be more cost effective to relocate threatened structures than to stabilize the shoreline. However, with the no action alternative human use of the shoreline is not enhanced and erosion, even if naturally occurring, may continue to the detriment of the environment.

The no action alternative may best help to preserve or reestablish the dynamic equilibrium in many cases. Many shoreline erosion problems will heal themselves eventually when dynamic equilibrium becomes reestablished.

Section Seven

Eight Basic Steps to Planning and Implementing an Erosion Control Project

Photo I
(chapter head picture from Section 6 of first edition)

High water during spring runoff is eroding a clay bank just upstream, as evidenced by the plume of muddy water along the left bank.

The best erosion control method is a proactive one. Primary actions should be to prevent situations where erosion must be controlled...

Adequate planning is important to almost any serious endeavor, and shoreline erosion control is no exception. There are eight basic steps to planning and implementing a shoreline erosion control project.

1. Determine the nature of the erosion problem,
2. Decide if the problem is serious enough to warrant corrective action,
3. Identify project goals and select a control method,
4. Inventory available human, financial, technical, and material resources,
5. Develop a project work plan,
6. Obtain necessary permits,
7. Construct the project, and
8. Monitor and maintain the project.

Although some of these actions might seem troublesome or unnecessary, experience has shown that they are all important. Proper planning and implementation may mean the difference between success and failure. Each of the steps to a successful erosion control project is described in more detail below.

1. Determine the nature of the erosion problem.

The first step in considering corrective actions for an accelerated erosion problem is to try to understand the cause of the problem and characteristics of the shoreline. Otherwise, any effort at corrective actions may be a waste of time and money.

Using **Section 4** as a guide, try to determine why the problem is occurring. Assess whether the conditions contributing to the problem are site-specific or systemic, and whether they are related to human activities or natural processes. If unsure about the cause of the erosion, seek technical assistance. **Appendix 7** lists potential sources of technical assistance throughout Michigan.

2. Decide if the problem is serious enough to warrant corrective action.

There are two basic reasons for controlling erosion—to protect property and to protect the environment. If a shoreline erosion problem becomes serious enough, corrective measures may be needed to prevent both environmental degradation and excessive property loss.

Ascertain the likely environmental impacts of the erosion. If the erosion is largely the result of natural processes but which do not threaten the environment, determine the nature of the threats to property. What is the erosion rate? How soon will structures be threatened? How much investment in erosion control is it worth to protect property?

3. Identify project goals and select a control method.

If it is determined that the erosion can be controlled and that the problem is serious enough to warrant action, review the information in **Section 6** and identify methods which are appropriate for the type of problem. If you have an idea for a solution not described in this guidebook, you should seek technical advice first to avoid unforeseen problems.

Evaluate all project alternatives under consideration for both beneficial and detrimental environmental impacts. Think through the likely response of the lake or stream to the management practice, both at the site-specific and watershed-wide levels. Conduct a cost-benefit analysis of the various options. Choose a method which is achievable, will successfully protect property, and will not have unacceptable environmental consequences.

Both tangible and intangible considerations (such as legal and political consequences) should be weighed. Success depends on working in conjunction with, rather than in opposition to, the natural forces of the site and the ability to be adaptable and flexible.

The best erosion control method is a proactive one. Primary actions should be to prevent situations where erosion must be controlled, such as avoiding building structures in close proximity to the shore. Do not disturb near-shore vegetation or bottom substrates, and let natural forces prevail.

If existing erosion is slight to moderate and is causing an environmental or socioeconomic problem, the next level of action is micro-management to "tweak" nature slightly to minimize erosive forces. Due to the process of dynamic equilibrium, there is a tendency for erosion problems to correct themselves. This should be recognized and accounted for in erosion control schemes. Avoid spending a lot of time and money on sites that are naturally healing or unchanging. Look at adjacent stable areas, determine why they are that way, and try to duplicate those conditions on your shoreline.

Finally, if the rate and consequences of erosion are clearly intolerable, consider more drastic action. However, always keep disturbance to a minimum and actions as harmonious with the environment as possible. Previously disturbed sites generally require the most human intervention and elaborate methods to overcome problems.

Keep in mind that erosion control is simply one management technique which should be used in combination with more holistic water resource management. Any change which occurs on the shoreline will affect the equilibrium of the entire lake or stream system. Erosion control techniques should be planned carefully so that an erosion problem is not transferred to some other area.

4. Inventory available human, financial, tech-nical, and material resources.

Although it may be possible to install an erosion control structure by yourself, it is best to consult with a resource professional familiar with erosion control engineering and environmental protection when planning the installation of an erosion control structure.

Use caution when consulting with an individual or business that stands to profit from erosion control projects on your property—there is always the risk that they may advise an expensive solution that is unnecessary or environmentally damaging.

Occasionally, programs are available which offer financial assistance. The sources of technical assistance listed in **Appendix 7** should be able to inform you of the current status of any financial assistance programs.

A realistic level of the assistance you can expect to receive is possibly some free technical advice with the responsibility for arranging and paying for labor, equipment, permits, and materials being left up to the individual landowner. Because erosion problems seldom end at property lines, cooperative efforts between several landowners which pool resources may benefit everyone.

5. Develop a project work plan.

Prepare detailed drawings showing top, front, and cross-sectional views of existing shoreline conditions and proposed actions. This is often done by a paid consultant or the work contractor. It is best to have plans, especially those which are designed by a lay person, reviewed by an impartial expert (see **Appendix 7**).

Determine if the project can be built using only hand or portable power tools, or if heavy equipment is also necessary. Work can usually be done by hand only in cases where structural components are minimal. If accessibility to the site is limited, then the use of heavy equipment may not be possible.

Plan the construction sequence (beginning to completion) to coincide with material availability and best weather and environmental conditions (i.e., lower water). Locate sources of materials and determine their availability. If hiring a contractor, choose one based on experience and reputation as well as on cost estimates.

6. Obtain necessary permits.

Permits from the Michigan Department of Environmental Quality (MDEQ) and a local soil erosion control permit will be needed at a minimum for shoreline erosion control projects. The MDEQ's "Joint Permit Application" is available online, or from MDEQ district offices. The local erosion control permit is administered differently in each county, typically by the county building inspection department or the county soil and water conservation district. In addition, permits may be needed from the U.S. Army Corps of Engineers (for Great Lakes shoreline projects, and other waters deemed federally navigable) or from the local unit of government depending on zoning or building code requirements.

The permit process may take several months, so it is wise to begin the permit application process early in the project planning stage.

7. Construct the project.

It is good to install the project as quickly as possible, to minimize the length of time the shoreline is disturbed. If a contractor is performing the work, inspect the work to be sure that the design is being followed and environmental precautions taken.

8. Inspect and maintain the project.

Early detection of any problem is a key component of a successful project. Determine if the project is adequately resisting the erosive forces which caused the problem. Observe whether any new forces are acting on the shoreline which may create additional problems or undermine the effectiveness of the recently installed project.

As in the site assessment, observing the area during times of high waves or high water levels as well as during normal conditions is recommended. Spot treatments or even extensive remedial actions may be necessary if the project is not functioning as intended or if unforeseen problems arise.

Since erosion typically progresses slowly, the effectiveness or shortcomings of a project may not become apparent for some time, possibly even a period of years. Photographs, drawings, and detailed notes can all be used to document conditions for future reference. Table Four shows an example of a formal monitoring log for a shoreline erosion control project.

Projects relying primarily on vegetation will need a period of intensive maintenance immediately after installation to ensure that the plants survive. If significant mortality occurs, replacement plantings may be needed.

Although other types of projects may need less intensive maintenance, some maintenance will likely be necessary to achieve maximum effectiveness. For instance, subtle readjustment of a few key rocks in a revetment may result in better stability.

Overland erosion control practices associated with the shoreline erosion control will need to be maintained until all disturbed land surfaces are again stabilized. This includes properly installing, inspecting, and maintaining silt fencing, sediment basins, and diversion structures. When these structures are of a temporary nature, they should remain in place until vegetation is established and be removed when the soil surface is fully stabilized.

Section Eight

Case Study

A Project on Crooked Lake, Emmet County, Michigan

Scan photo from book? or updated photo on file??

Accelerated erosion plagues many lakeshore homes where lawns have replaced native shoreline vegetation.

"This property had been in our family for more than 70 years. One day, we realized that our shore used to extend much further out, and that we had better do something to prevent further loss. Although we were unfamiliar with biotechnical erosion control methods, we agreed to participate in a demonstration project using this technique. We are very pleased with the results and appearance of our shoreline, and believe that it has solved our problem."

—Lewis Hopkins
Crooked Lake Property Owner

Background

One component of the grant the Tip of the Mitt Watershed Council received from the Great Lakes Commission (which also funded for the creation of this guidebook) was the construction of a shoreline erosion control demonstration project. The project was constructed in summer, 1995, on two adjoining private property parcels along nearly 180 feet of shoreline on Crooked Lake in Emmet County, Michigan. The demonstration project was constructed using biotechnical erosion control (BEC) techniques.

Figure 24: Condition of the shoreline prior to the erosion control project.

Significant shoreline erosion had occurred on these properties over past decades. Although serious erosion was not obvious to the casual observer, property owners had documented many feet of recession since the 1920's, when their cottages were built. They sensed that erosion rates had increased in recent years, possibly averaging as much as six inches per year. The erosion was characterized by slumping undercut sod banks along the shoreline. Use of a probe revealed that the undercut extended up to four feet back under the land surface. **Figure 24** shows the condition of the shoreline prior to the project, and **Figure 25** shows a cross-sectional view of shoreline characteristics.

Assessing the Problem

After observing conditions in the vicinity of the site, the erosion was thought to be due to the following combination of factors:

1. The removal of the native vegetation (both woody terrestrial vegetation and emergent aquatic vegetation) which was present before shoreline development and establishment of a monoculture of turfgrass. Although a few scattered, mature trees remained along the shoreline, and their roots strengthened the shoreline soils somewhat, they were too few and far between to achieve maximum or even adequate strengthening.

2. The presence of highly erodible shoreline soils. This site was originally a wetland which was filled long ago for cottage development. Soils at this site consist of sandy fill over the original muck soils.

3. Destabilization of the lake bottom by dredging to create a navigational channel. This site is on

Figure 25: Cross-sectional drawing of pre-project shoreline characteristics. A—undercut bank, B—slumping sod, C—mowed lawn, D—sandy soils, E—sand beach (fall), F—lake bottom, S—summer water level, W—winter water level.

Figure 26: Cross-sectional view of the biotechnical erosion control project. A—coir fabric roll, B—synthetic or jute fabric to hold soil in place (gap between coir roll and fabric layer exaggerated for illustration), C—submerged, partially buried boulder to break waves and deflect ice, D—rock toe protection (D50=6", 2:1 slope), E—rushes, F—herbaceous plant mixture, G—shrubs, H—tree, S—summer water level, W—winter water level.

Northern Michigan's Inland Waterway, a 45-mile long, navigable chain of lakes and rivers. The dredging was done by the U.S. Army Corps of Engineers in the late 1950's, and created a channel running parallel to the shore, about 150 feet offshore.

4. Boating patterns have changed in recent years, and increasing numbers of large, high-speed powerboats generate large wakes in this area.

5. Natural shoreline processes–waves generated over a three mile fetch, longshore currents, and periodic ice action.

Choosing an Erosion Control Method

Property owners felt that the rate of erosion was unacceptable. Several large trees were being threatened, and on one of the properties the shoreline had advanced to within about 30 feet of the dwelling. The following alternatives were considered to address the erosion problem:

- no action,
- rock revetment only,
- bulkhead, and
- biotechnical erosion control.

The no action, rock revetment, and bulkhead alternatives were rejected in favor of a biotechnical erosion control project. Since the factors causing the erosion still existed, the yearly recession rate would likely have continued without some type of action. This would result in further water quality degradation (primarily due to sedimentation by organic soils), loss of land surface, and increased threats to structures and other property amenities.

The use of a bulkhead would have the highest cost of any of the methods considered. In addition, it would cause further loss of shoreline habitat, be the least aesthetically attractive, least conducive to recreational use (including safety concerns), and have the greatest chance for impacting neighboring properties and massive structural failure. Additionally, there was no need for deep water conditions near shore, which is one of the major advantages of a bulkhead.

Although a standard rock revetment design would likely effectively control the erosion and would probably be the cheapest action, it was judged to be less aesthetically pleasing than a BEC method and would result in more fill on the lake bottom. A BEC method using both living vegetation and a coir bundle coupled with light rock armoring of the shore was chosen. Reasons for choosing this method included enhancement of shoreline wildlife habitat, aesthetic appeal, relatively low cost, proven effectiveness in similar situations, and least prone to massive failure.

Project Design, Permitting, and Construction

The project was designed to stabilize the shoreline using the following practices:

1. placing several types (for comparison purposes) of filter fabric over the substrate,
2. installing 12-inch-diameter, 20-foot-long bundles of coir fabric end-to-end along the bank,
3. backfilling the coir with sand and topsoil,
4. reestablishing a 10 to 15-foot-wide strip of trees and shrubs (except in designated access areas),
5. placing appropriately sized fieldstone along the toe of the coir rolls, and
6. positioning large boulders just offshore in small selected areas to protect from wave and ice scour in locations where recreational access limits other options.

Figures 26 and 27 show cross-sectional and plan (overhead) views of the features and characteristics of the designed BEC project.

Two state/local permits and one federal permit were needed for a shoreline erosion control project in this area. Section 404 of the Clean Water Act requires a permit for the placement of fill below the ordinary high water mark of "navigable waters of the United States." Section 404 permits are administered by the U.S. Army Corps of Engineers. Similarly, Part 301 of Act 451 of 1994 (formerly known as Michigan's Inland Lake and Stream Act) requires a permit for the placement of fill below the ordinary high water mark of a lake or stream. This permit process is administered by the Land and Water Management Division of the Michigan Department of Environmental Quality. Additionally, Part 91 of Act 451 of 1994 (formerly known as Michigan's Soil Erosion and Sedimentation Control Act) requires a permit for earth change activities within 500 feet of a lake

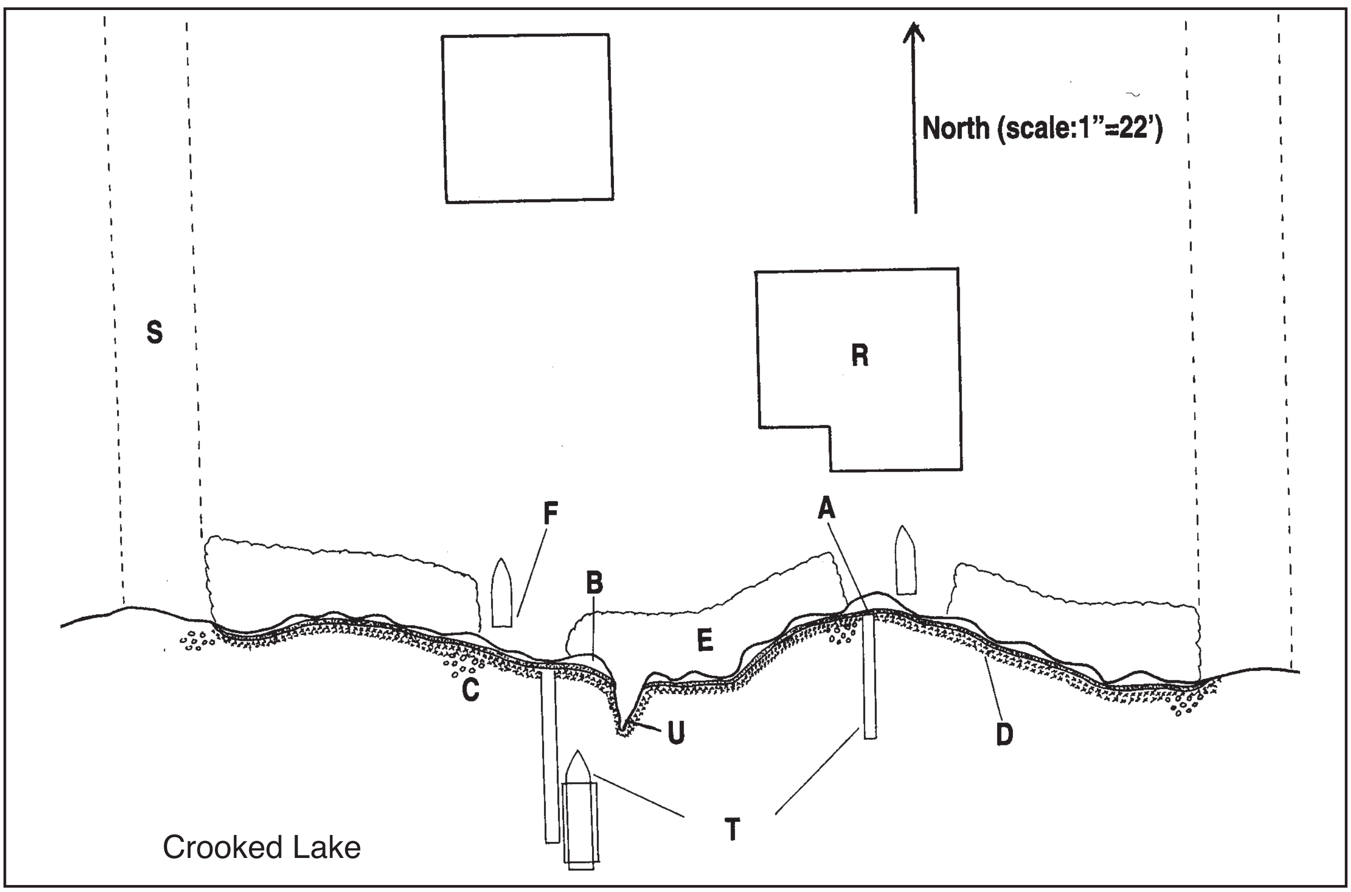


Figure 27: Plan view of the biotechnical erosion control project. A—12" diameter coir roll, B—sand fill, C—submerged, partially buried 2'-3' diameter boulders, D—rock toe protection (D50=6", 2:1 slope), E—vegetative buffer strip, F—small craft landing area, R—residence, S—road easement, T—seasonal docks (pre-existing), U—existing rock groin.

or stream. This permit is administered locally by the Emmet County Building Department in Emmet County. Permit applications for all three were submitted in mid-May, 1995, and the last one was approved in early July, 1995.

The project began by placing nine coir bundles end-to-end along the original shoreline and securing them with hardwood stakes driven both along the inside and outside edges at approximately 18-inch intervals. Coir (fibers from the outer husk of the coconut) is flexible, strong, and rot-resistant. It provided immediate protection against erosive energy and eventually provided a good growing medium for both woody and herbaceous vegetation. Although the coir itself functions as a filter fabric, several types of conventional filter fabric (both synthetic and natural fibers) were placed under portions of the coir to further help keep the underlying soil in place.

After the coir was positioned, areas of undercut, slumping sod were excavated using hand tools to allow the undercut cavities to be filled. Sod and topsoil which were excavated were stockpiled for later reuse. Sand fill (10 cubic yards) and topsoil (1 cubic yard) were used in back of the coir to fill cavities and reestablish a level grade. **Figure 28** shows the coir in place, with sod excavation and stockpiling and sand backfilling in progress.

In most areas, stockpiled sod was replaced to immediately create a stable ground cover. However, in one area where the shoreline was deeply indented, there was not enough sod available. There, imported topsoil was seeded with a “rapid start” grass mixture and covered with a biodegradable woven mulch blanket to protect against raindrop impact and overland erosion.

Woody root systems increase the strength and erosion resistance of all soils. Probably the key component of this project was the establishment of a 10- to 15-foot-wide buffer area containing a diversity of woody vegetation to provide long-term, self-renewing soil strengthening. Although buffer areas like this can be reestablished simply by ceasing mowing, we planted a multitude of trees and shrubs to speed the process. Some of the plants did not survive the first winter, however most survived and became well established. The buffer was delineated with marked wooden stakes to help minimize disturbance by foot traffic or accidental mowing.

Native species were primarily used because they are best adapted to environmental conditions and do not pose the threat of introducing an invasive species. However, several nonnative species were used here

Trees
1. 35 northern white cedar (Thuja occidentalis)
2. 3 colorado blue spruce (Picea pungens)
3. 3 norway maples (Acer platanoides)
4. 3 white birch (Betula papyrifera)

Shrubs
1. 50 silky dogwood (Cornus obliqua)
2. 2 swamp rose (Rosa palustris)
3. 20 pussy willow (Salix discolor)
4. 20 streamco willow (Salix purpurea)
5. 25 highbush cranberry (Viburnum trilobum)
6. 25 nannyberry (Viburnum lentago)
7. 25 red osier dogwood cuttings (Cornus stolonifera)
8. 25 willow cuttings (species unknown, Salix sp.)

Herbaceous Plants
1. 5 garden phlox (Phlox paniculata)
2. 10 blue flag iris (Iris vesicolor)
3. 15 yellow iris (Iris pseudacorus)
4. 50 sweet flag (Acorus calanus)
5. 100 softstem bulrush (Scirpus validus)
6. 100 common three square (Scirpus americanus)
7. 15 royal fern (Osmunda regalis)
8. 10 day lily (Hemerocallis fulva)
9. 10 turks cap lily (Lilium michiganense)
10. 25 false dragon head (Physotegia virginiana)

Seed
1. 1 lb. reed canary grass (Phalaris arundinacea)
2. 2 lb. "wildflower restoration erosion mix" (contains 11 species)
3. 6 lb. of "fast start" grass seed mixture (mostly rye grass and red fescue)

Table 5: Species used for vegetative buffer strip establishment.

because they were the preference of the landowners. This buffer consists mostly of shrubs which either remain low or can be kept low through trimming in order to maintain views of the lake. In addition to controlling erosion, the buffer will reestablish near-shore wildlife habitat and the aesthetically pleasing appearance of a northern lakeshore. A list of the species planted for this project can be found in **Table 5**. Plants were obtained by mail order from commercial suppliers, from local nurseries, the local conservation district tree and shrub sale, and by cuttings (of willow and dogwood) obtained locally with permission.

To dissipate wave energy and provide additional shoreline protection, a low, gently sloping layer of small to medium sized rocks was placed along the coir's base. The longest fetch at this site is 3.0 miles, and the significant wave height during a 35 MPH wind would be 1.75 feet. According to design guidelines, recommended median rock size is 7.75 inches, with minimum and maximum sizes being about 3.9 and 11.6 inches. However, there is a wide, shallow, very gently sloping littoral shelf along this shoreline. Fifty feet from shore, the water depth is only 2 feet (taking into account the normal yearly maximum). Therefore, even though significant wave height based on fetch is 1.75 feet, actual design wave height is somewhat smaller (1.5 feet), with a recommended median, minimum, and maximum rock sizes of 6.5, 3.25, and 9.75 inches respectively.

Figure 28: Coir staked in place, with sod excavation and stockpiling and sand backfilling in progress.

Figure 29: Rock armoring in place with gravel top dressing partially completed.

Although in reality it is difficult to obtain rocks with exact median, minimum, and maximum specifications, from a local comemercial vendor the rocks we obtained appear to have a median diameter of about 6 inches and varied in size from 2 inches to 12 inches. Prior to their placement, a 6-inch-thick layer of 0.25 to 1-inch-diameter gravel (a mixture of what is commonly called pea-gravel and drainstone) was placed along the base of the coir. This served as a filter layer, especially in places where no filter fabric was used. Next, the larger rocks were dumped and then adjusted by hand to form a reasonably well-fitting layer several stones thick. Finally, another layer of 1" gravel was placed over the top to fill the voids between the rocks as completely as possible. Ten cubic yards of fieldstone and five cubic yards of drainstone were used. **Figure 29** shows the larger rocks in place with gravel top dressing partially completed.

A small point (labeled U) can be seen in the plan view drawing and some of the photos. This point is actually the result of a wide rock groin placed many years ago. Although piling rocks in this manner can cause increased erosion and is not recommended (see **Section 6**, Groins), this feature was not removed but was incorporated into the shoreline erosion control project because it was stable and well vegetated and it was felt that more disruption would result from removing it than letting it remain.

Openings in the buffer were created to allow adequate recreational access to the shoreline. On these properties, the openings are being utilized for beaching small craft and placing seasonal docks. Even though there is no woody vegetation in this area, it was felt that the coir and rock armoring would be adequate to protect the shoreline throughout these narrow openings in the buffer.

Figure 30: View of the site one year after project completion.

Staggered groupings of 2- to 3-foot-diameter boulders were placed in some areas to function as an offshore wave barrier. They cause the waves to break before they hit the beach, lessening the amount of erosive energy. They were placed in groups of 6 or 7 in 4 critical locations: at the terminal ends of the project and at the west ends of the recreational access openings in the buffer (due to prevailing westerly winds). Within a few weeks of placement, deposits of sand began accumulating in the "wave shadow" of the boulders, showing that the wave barriers were working as intended.

The materials (vegetation, topsoil, rock, gravel, various fabrics, permits, etc.) for this project along nearly 200 feet of shoreline cost about $3,500. About 130 person hours were required for design and construction. As of 2004, the total cost for this project would probably be about $65 per shoreline foot. Although each BEC project will be unique, this provides a rough idea of cost of a similar project.

Monitoring the Results

After one year, the project proved to be very successful with no measurable erosion along these properties. After some initial apprehension about how the reestablishment of a vegetative buffer strip would impact their use of the shore, the property owners were very pleased with the project and concluded that it did not diminish their use and enjoyment of the property. Vegetation growth and weathering of materials have given the shoreline a "natural" appearance. **Figure 30** shows a view of the shoreline one year after installation.