Living on the Coast

Protecting Investments in Shore Property on the Great Lakes

Sea Grant
University of Wisconsin

US Army Corps of Engineers
Detroit District

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Note: CENG is a Chartered Engineer, the UK equivalent to a Professional Engineer (P.E. or P.Eng.). P.G. means Professional Geologist.

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INTRODUCTION

This booklet is about living and working on the attractive edges of the dynamic Great Lakes. There are risks from natural coastal hazards to be understood and managed when buying, building and operating private homes, residential and commercial developments, industrial buildings, and recreational facilities. This booklet provides information on the coastal environment and how to protect coastal investments.

A principal message

Do everything possible to avoid placing buildings and other structures where flooding, storm waves and erosion are likely to damage them or shorten their useful lives. If it is not possible to avoid these hazards, use shore protection methods that work with nature or have minimal negative effects on the nearshore environment and on neighboring properties.

This message is different from the message implicit in the *Help Yourself* booklet (1978) that this booklet replaces. The 1978 booklet promoted the use of traditional shore protection structures. This difference in message is due to an understanding that many traditional types of shore protection structures are undermined and their useful periods shortened by lakebed erosion and freeze/thaw cracking of armor stone. The difference is also due to a greater awareness of the adverse effects of many shore protection structures.

For whom is this booklet intended?

If you are interested in buying coastal property, this booklet will help you make an informed decision. The booklet will be a helpful resource if you are a realtor, banker, insurer, appraiser, regulator, developer, engineer, marine contractor or other professional person who influences coastal development. The scope of the booklet covers Canadian as well as United States shores of the Great Lakes.

If you own coastal property on the Great Lakes, this booklet is also for you. For tens of thousands of present coastal property owners, the land remaining between building and lake is uncomfortably small and has been partly used up as erosion has carried away some of the land. The booklet contains information for people who are not able to relocate existing buildings to safe sites, people for whom improving stability of the land and shore protection seem to be the only option.

What's in the booklet?

Advice is offered on how to stabilize bluffs and banks, control surface water and groundwater, and build environmentally friendly shore protection structures. This work, in many situations, is no longer a "help yourself" proposition. Property owners should work together with neighbors to hire trained engineers and contractors to perform desired work.

The booklet begins with a brief description of the natural processes that affect the coast and those who live, work or play on the shore. The next section describes how to protect coastal investments and the environmental impacts of shore protection structures. The third major section is on risk management and the economics of protecting coastal investments.

This booklet complements the U.S. Army Corps of Engineers/Great Lakes Commission booklet *Living with the Lakes*, the University of Wisconsin Sea Grant Advisory Services publication *Coastal Processes Manual* and the Ontario Ministry of Natural Resources booklet *Understanding Natural Hazards*. More extensive information on the subjects covered in this booklet can be found in the U.S. Army Corps of Engineering *Coastal Engineering Manual* and in the Ontario Ministry of Natural Resources CD titled *Great Lakes — St. Lawrence River System and Large Inland Lakes Technical Guides for Flooding, Erosion and Dynamic Beaches*.

NATURAL PROCESSES THAT AFFECT THE COAST

The Legacy of the Glaciers

All of the Great Lakes except Lake Superior were river valleys about two million years ago when glaciers first entered the region. The Lake Superior basin was formed by faulting long before the glaciers. As many as 15 times, the glaciers formed and advanced from the north. Each time they came, they carved the lake basins deeper until they reached their present size beneath the last glaciation, which occurred between 25,000 and 10,000 years ago. Water levels in these basins fluctuated many dozens of feet (tens of meters) because of outlet changes, formation and removal of dams produced by glacial deposits (and by the glacier itself), climate variations, and tilting of the basins due to crustal rebound. Crustal rebound is the upward movement of the land that is still taking place because the land was pushed down by the weight of glacial ice more than a mile thick in places. Because ice was thicker in the north, the land was depressed more there; therefore the land is still rising more quickly in the north than in the south.

Glaciers erode rock and soil and carry it along with moving ice to the glacier edge where it is released from the melting ice and deposited as till, a mixture of sand, silt and clay. When the glaciers receded, there were many minor readvances of the ice edge. Each ice advance deposited till with a different composition. Between these till layers are layers or lenses of sand and gravel that were deposited in water in front of the retreating glacier. Between glacial advances there were also layers of silt and clay deposited on the lake bottom. These varied layers and lenses are now exposed in eroding bluffs and banks in many places along the shores. Water drains through the porous sandy/gravelly layers to the shore, creating slope instability.

All of the exposed soil materials in coastal slopes are subject to wave erosion, but different soil types have different properties. The varieties of soil types are particularly noticeable in high coastal bluffs. Some soils, like clay, can stand as very steep slopes when dry but may fail as large landslides when wet or severely undercut. Sand holds a more gentle slope and rarely fails catastrophically. In some places the shoreline consists of rock, with little or no sediment cover. This is especially true in the northern Great Lakes area where the glacier was mostly erosive, and the rock was resistant enough to withstand glacial erosion. There are also bedrock areas along many other Great Lakes shores.

The present shoreline position is not the shoreline position of the past. In bluff areas the shoreline may have retreated several miles since the last glacier melted away. Even bedrock shorelines have been eroded by waves, though to a lesser extent. Old shorelines are hidden in many places by modern shorelines. Low wave-cut terraces were portions of lakebed covered by sand during ancient higher water levels and lie in front of older shoreline bluffs. Former beaches and beach ridges are preserved inland above the present shore. Early footpaths and modern roads follow the old beach ridge crests. Along parts of the coast, sand supplies brought by coastal currents have pushed the present shoreline lakeward. Offshore, lakebed forms containing rooted stumps of bushes and trees are the remains of old shorelines and streambeds that existed when lake levels were much lower than at present.

Coastal property owners who plan to own the property for a long time are advised to anticipate future lake levels beyond the ranges indicated in the historical records.

Lake Level Responses to Weather and Climate

The midcontinental Great Lakes basin is subject to harsh, rapid changes in weather and climate. Each year, Great Lakes waters change from cold and ice covered to warm enough for swimming in as little as four months. The Great Lakes also can experience rapid changes in their water balance brought about by changes in the atmosphere. These changes may occur from season to season, over a few years, over ten years, or more. Lake levels are determined primarily by precipitation, evaporation, river and groundwater flows. (See the companion booklet, *Living with the Lakes*, for a description of the hydrologic cycle.)

Sometimes there are rapid lake level changes. On at least five occasions, Lakes Michigan and Huron rose or fell more than three feet (one meter) in about a year and a half. In about the same interval, Lake Erie rose nearly three feet in 1991-1993 and dropped about three feet in 1930-1931 and 1986-1988. In 1930-1931, Lake St. Clair dropped 3.8 feet (1.2 meters) in eight months.

Lake levels respond to the cumulative effects of weather systems passing over the Great Lakes basin. There are significant decade-to-decade shifts in the common tracks of storms that pass over or miss the lakes. Storm tracks are influenced by the high-altitude jet streams, and the jet streams are influenced by global atmospheric circulation patterns.

Periods of great shoreline damage and property loss are related more to times of high wave power than to times of peak water levels. The intensity and frequency of storm activity strongly influences lake levels and shoreline damage. Wave power is determined primarily by wind speed, wind duration, and the open water distance over which the wind is in contact with the water surface (fetch). Shoreline damage also depends on the erodibility of the shore and on water depths great enough for storm waves to reach these shores.

Plausible Future Climate Effects on Lake Levels

The Great Lakes have had their present connections for the past 3,000-4,000 years. Water level fluctuations over this time were due to natural climate variability, except for some effects from diversions and dredging of connecting channels since the 1850s. There has been a lot of experience in dealing with high levels over the last half of the 20th century but relatively little experience with low lakes levels. For information on past, present and expected future lake level ranges, see "Where to Go for More Information" at the back of this booklet.

Computer modelers ask, "What would happen to lake levels if climate conditions that developed elsewhere occurred in the Great Lakes basin?" The "borrowed" climate conditions may be extreme and short term (like the Mississippi River flood of 1993) or long term (such as Ohio River valley or gulf coast climates within the 20th century). These methods do not produce predictions or forecasts. They provide a range of plausible futures for exploring the implications of a changed climate system or future climatic variability that is not found in the climate records and lake level records of the Great Lakes basin. Technical judgment is needed to decide which scenarios of climate change seem most likely to occur.

Results from climate modeling are used with other models to estimate how lake levels will change in response to climate changes. The most important finding so far is that present high and low record levels could be significantly exceeded under some of the modeled scenarios.

If the extremely wet climatic conditions of the upper Mississippi River basin in the spring of 1993 had occurred in the Great Lakes basin instead, the Great Lakes would have experienced unusually rapid rises of one to two feet in three to four months, depending on the lake.

A major issue of importance is how the paths, intensities and frequencies of storms will change as the climate changes. Storm tracks shift in and out of the Great Lakes

future climate and lake levels

Three methods are presently used to develop a range of plausible future climates and lake levels for the Great Lakes. They are based on the following:

- climatic predictions from regional and global atmospheric circulation models (GCMs) for future climate changes, including global warming.
- transfer to the Great Lakes basin of real climatic conditions that occurred in other regions.
- statistical use of data from historical water supplies for computing possible extreme water levels and their probabilities of occurrence.

The very short recorded history of Great Lakes water levels is inadequate to forecast lake levels that will occur in the next 20, 50 or 100 years. Future climatic conditions may be quite different.

Honey Harbour, Georgian Bay, 1964

basin under the influence of the atmospheric jet streams. The jet streams are influenced by global atmospheric circulation patterns, which are controlled by sea surface temperatures in the oceans. Will global climate change bring regional climate changes that alter Great Lakes storms?

Human Influence on Lake Levels

Humans influence, but nature controls the water levels of the Great Lakes.

The *Living with the Lakes* booklet describes the system of diversions and control structures used to adjust outflows from Lake Superior and from Lake Ontario. Flow adjustments are made at two control points. On the St. Marys River at Sault Ste. Marie, river flow is mainly used by passing the water through power-generating turbines. Additional flow modifications are made by adjusting gates called the Compensating Works in a dam spanning the river. The flows are adjusted to balance desired lake levels upstream and downstream. On the St. Lawrence River at Cornwall, Ontario/Massena, New York, most of the river passes through power-generating turbines. Spillway gates in the Iroquois and Long Sault dams are used for ice control.

Flows at the two locations in both rivers are adjusted in a decision-making process that attempts to balance the various needs of Great Lakes users and shoreline property owners and to distribute the adverse effects of too-high or too-low water levels. This flow regulation process works well when natural climatic variations are slow and modest, and the seasonal cycles of lake levels are typical cycles with summer high levels and winter low levels. This flow regulation process does not work well when natural climatic variations are rapid, substantial and persistent. At such times, the lake level responses to flow adjustments are too slow and produce water level changes of a few inches when changes of a foot or more are desired.

Compared to no diversions, the combined effects of existing diversions of water into and out of the Great Lakes has resulted in raising Lake Superior one to four inches (three to nine centimeters). The effects on the other lakes were temporary and small: less than four inches (10 centimeters). Water flow control at Sault Ste. Marie since 1921 has had similar small effects on lake levels.

Dredging the connecting channels between the lakes has also had small but significant effects on water levels. Dredging in the St. Clair River since 1900 lowered the level of lakes Michigan and Huron by 11-16 inches (27-40 centimeters). This change affected both the mean water levels and the water level ranges of the natural seasonal cycle. Dredging of the river channels temporarily increased the level of Lake St. Clair a few inches (about six centimeters).

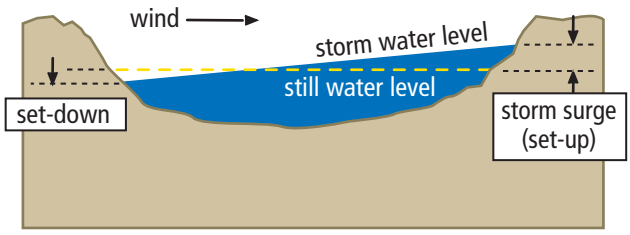
Storms and Storm Surges

As the wind blows across the surface of a Great Lake, energy is transferred from the wind to the water surface. Most of this energy generates currents. The rest of the wind energy builds waves. The lakes respond to strong winds more quickly with waves and storm surges than with currents. Storm winds may last less than an hour, or they may blow for three days or more. Storm wind conditions are least common in the summer.

A storm surge lasts about as long as the storm wind blows on shore; it rises rapidly with rising wind speed and drops as the wind speed falls or the wind changes direction.

Storm winds cause rapid changes in water levels. As the wind blows across many miles of open water, it drags some water towards the downwind side of the lakes. This causes a temporary rise in water level along the downwind shore and a lowering of water on the upwind shore. The temporary rise in water level is called a storm surge, storm set-up, or storm-induced rise. The drop in water level is a set-down. Storm surges and set-downs occur along all of the Great Lakes shorelines.

A storm surge may last all day. Storm surges in bays are typically larger than storm surges on the open coast. Storm surges on island and peninsular coasts are typically smaller than storm surges on the open coast. Storm surges typically rise one to two feet (0.3 – 0.6 meters) on the open coast, two to five feet (0.6 – 1.5 meters) in bays, and up to eight feet (2.4 meters) at the eastern end of



Lake Profile Showing Wind Set-Up

Lake Erie near Buffalo (with a similar set-down at the western end of the lake). For more on storm surges, see "Where to Go for More Information" on page 40.

Periodic oscillations of lake levels are called seiches. Seiches are caused by rapid changes in air pressure or rapid shifts in wind direction as weather systems pass over the lakes. Seiches last seconds to minutes and reoccur at intervals (or periods) of tens of minutes to more than eight hours. One or more seiches following a storm may cause repeated flooding of low-lying land.

An edge wave is a rare, sudden water level change caused by a fast-moving line squall crossing a Great Lake. These line squalls are called derechos. They typically move at 40 to 50 miles per hour (18–22 meters per second), with wind speeds within the storm fronts of 60 to 100 miles per hour (27–45 meters per second). Edge waves appear to originate near the location where the squall reaches the shore after crossing the lake. An edge wave races around the perimeter of the lake many miles from, and hours later than, the squall line passage. Edge waves are hazardous to people on breakwaters and may flood and damage lakeside buildings and marinas.

Lake Michigan shoreline at Lake Forest, Illinois, Fall 1986.

Temporary rises in lake level associated with storms need to be considered in order to minimize property damage from flooding and from larger waves reaching shore.

Trained design professionals take into account the various types of rapid water level changes that can occur at a particular site, when designing shoreline structures.

Waves and Wave Climate

The fetch distance (which is the length of water surface exposed to the wind), the wind speed, and the duration of the wind blowing from roughly the same direction over water are important factors in deep-water wave development. Deep-water waves have a range of heights and other characteristics at every location.

Storm wind speeds and storm wave heights can increase rapidly. A typical fall storm wind speed can increase from about 2 to 40 miles per hour (0.9-18 m/s) in less than eight hours. With such a wind speed increase, the lake surface may go from flat calm to rough with waves two feet (0.6 meters) high within an hour. Within eight hours, wave heights may approach 17 feet (5.2 meters), and higher. These deep-water waves move toward shore and form large breakers in the surf zone and in harbor entrances.

A wave climate record is the history of the distribution of wave conditions over a period of years at a particular location. The average wave conditions for a particular section of shoreline, can be misleading. An average annual wave height of two feet may be the result of many days of near calm separated by relatively few days of severe storms waves. More informative are statistics that show how often waves of particular heights and periods occur at locations of interest.

Wave climate statistics suggest the extent of extreme wave conditions, such as those associated with a 20-year storm. Such a storm is expected, on average, to occur only once in 20 years. There is a 40 percent chance of a 20-year storm occurring during a 10-year period and a 71 percent chance of such a storm occurring during a 25-year period of coastal property ownership. Wave climates (and wave climate statistics) shift as the climate changes.

Local Wave Conditions

Shallow-water wave conditions depend upon deep-water wave conditions, nearshore obstacles in wave paths, depth of water and lakebed slope near shore. Wave direction and height can change as waves "feel bottom" and their paths bend (refract) due to friction from lakebed shoals or bars. Waves also bend (diffract) around points of land and ends of breakwaters, allowing waves to move behind such obstacles.

Fortunately for coastal property owners, shallow nearshore water depths are typical of most coastal sites; they cause much wave power to dissipate before it reaches land.

As large storm waves approach shallow water, they lose their power—first by partial spilling of the wave

crests, followed by wave breaking and finally in wave runup on the shore. The wave power can be released gradually in spilling breaking waves running over gradually shoaling lakebeds or released suddenly in plunging breakers running over steeply shoaling lakebeds. Water depth limits the height of waves passing through shoal waters to approximately one-half to one times the water depth, depending on the lakebed slope and the wave characteristics.

Rising lake levels and/or lakebed erosion create deeper water close to the water's edge and allow more wave power to attack the shore. Falling lake levels have the opposite effect.

Coastal property may be protected from damaging breaking waves by unseen offshore shoals and/or a gently sloping lakebed that causes most of the storm wave power to dissipate before it reaches shore. Where deep water is closer to shore and the unseen underwater portion of the beach has a steep slope, large waves may reach and damage the shore.

Spilling breaking wave

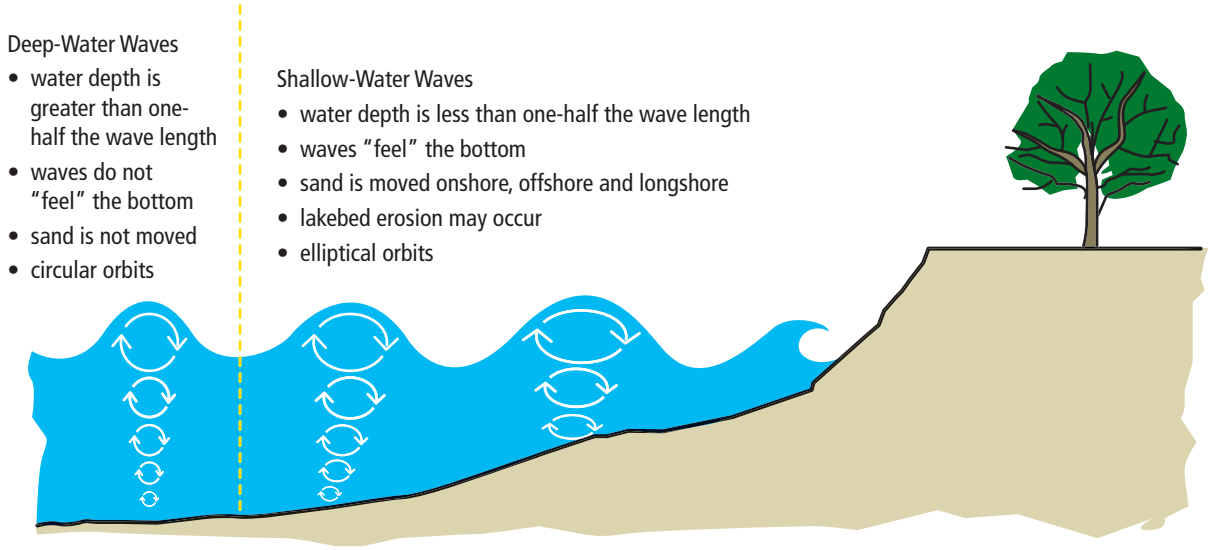
Plunging breaker

A trained professional is needed to estimate wave conditions.

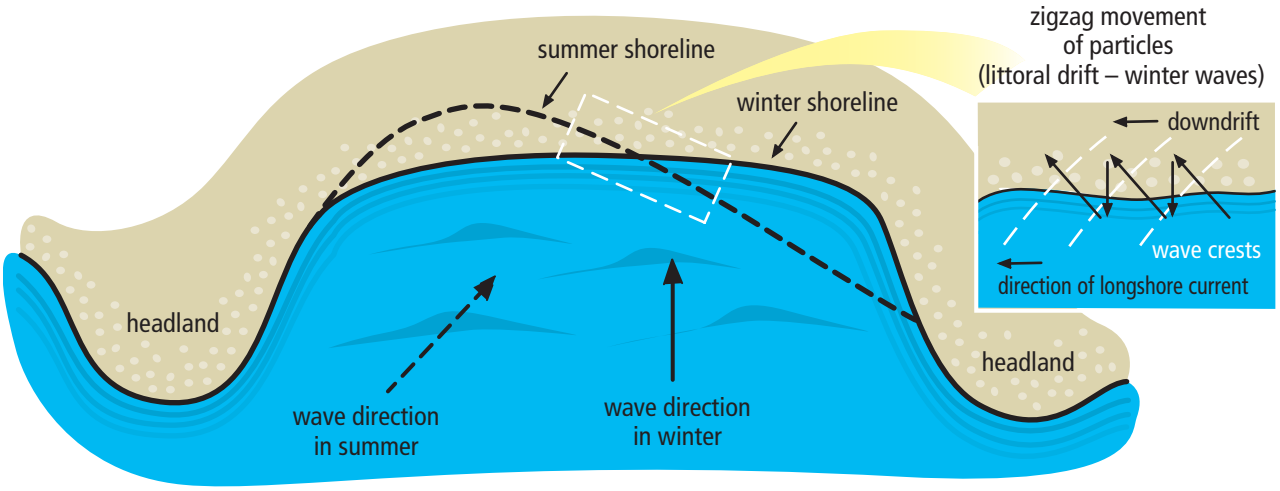
Local Water Currents

Strong winds and large waves drag some water towards the coast. Between the breaking waves and the dry beach, the water can be higher than the lake level. This elevated water will return to the lower lake level beyond the breakers either as return flow beneath the waves (sometimes called an undertow), or as currents that flow parallel to the beach as "longshore currents" before turning lakeward as "rip currents" to move offshore. The longshore currents and the rip currents are typically narrow streams moving at speeds of one to five miles per hour (0.4 – 2.5 meters per second).

The direction of the longshore current will usually be similar to the direction that waves are traveling as they approach at an angle other than perpendicular to the



Waves Feeling the Lake Bottom



Littoral Drift and a Shoreline Response to Waves

shore. When facing the lake, if the waves are approaching the breakers from the right, the longshore current is likely to be moving to the left.

Dangerous rip currents may occur where structures and natural features jutting into the lake alter the path of the longshore current.

Possible rip current locations include harbor breakwaters and jetties, long solid piers or groins, large shoreline rock outcrops or points of land, nearshore shoals and areas offshore of beaches with sand bars and troughs. Strong, dangerous currents can also be found at times in the armored coves or cells constructed to provide small, sheltered pocket beaches. Rip currents may be hard to spot. Look for a stretch of relatively unbroken water in a line of breakers, or telltale signs like patches (or lines) of foam or debris, or discolored water moving in a direction from inshore of the breakers to offshore. Once rip currents have formed, they cut troughs in sand bars and remain fairly stable until wind conditions change.

Longshore and Cross-Shore Transport of Sediment

Littoral transport is nearshore sediment transport driven by waves and currents. This transport occurs both parallel to the shoreline (longshore) and perpendicular to the shoreline (cross shore or on-off shore).

Storm waves carve beaches, ridges and banks, transporting large volumes of sand to nearshore bars. Where the rate of offshore sand transport exceeds the rate of supply from updrift sources, the beach erodes. During calmer periods, waves transport sand from offshore bars and deposit it on the beach face. Through these cycles, there is a movement of sand and gravel along shore in response to the shifting directions and sizes of waves. In many places there is a net movement in one direction. The transport direction depends on such factors as wave climate, bathymetry, shoreline orientation, and the presence of natural or artificial features that deflect waves and currents. Cross-shore transport is affected by changes in lake levels.

Sediment transport is the method by which dynamic coastline features, such as beaches, spits, dunes and offshore bars, are built and maintained.

The "littoral zone," where littoral transport occurs, extends roughly across the surf zone from where the waves begin to break near shore to the shoreline. Wave conditions and current speed determine the size of material that can be transported. The rate of transport within the littoral zone is relatively small along erosion-resistant rocky shorelines and along cohesive soil shorelines but may reach several hundred thousand cubic yards (a hundred thousand cubic meters) per year along some sandy coastlines.

Beach-building materials are mostly sand, gravel, and stone that enter the littoral transport system from dune, bluff and lakebed erosion along the coastline with additional material contributed by streams. Material may be blocked from entering the littoral system in many ways. Material from streams may be blocked by dams or removed from river channels and harbors by dredging. Littoral contributions may be blocked by shore protection structures. Sand and gravel mining and dredged material

Nearshore ice complex

disposal in deep water are additional ways in which beach-building material can be kept from the littoral system.

An understanding of littoral transport is important for predicting erosion trends and evaluating the possible effects of engineered coastal structures. Because coastline erosion supplies most of the material for littoral transport, deficits or surpluses of littoral material available to an area (indicated in a "sediment budget") are likely to result in changes in the erosion rate as well.

Beach-building materials are in many places prevented from entering the littoral transport system, resulting in diminished beaches and nearshore bars.

Ice on the Shore

The type and amount of ice that forms along the shores varies from location to location and from day to day. A frozen beach is the first ice feature to form. Waves drive slush ice to shore to form an icefoot. On beaches exposed to waves, a nearshore ice complex forms, extending lakeward from the icefoot and containing relatively smooth sheets of ice. Ice ridges form where waves break, such as over nearshore sandbars, and provide a lakeward boundary for this ice mass. There may be several parallel rows of ice ridges; usually there are more ice ridges than sand bars. Lakeward of the ice ridges, a zone of slush ice may collect. This slush ice can be driven repeatedly by waves onto the outer ice ridge, raising its crest 15 feet (5 meters) high or higher above the lake. Ice ridges ground on the lakebed. The nearshore ice mass remains in place until warming air temperatures, wind and/or waves cause it to move or deteriorate. The ice mass may disappear abruptly during major storm events and can be destroyed and rebuilt several times during the winter.

Nearshore ice displaces wave energy lakeward, protecting the beach from wave-induced erosion, yet it may also contribute to erosion.

Waves breaking against grounded ice ridges scour the lakebed. The lakebed may be gouged by contact with the keels of ice ridges or "ice islands" moved by the wind (common on Lake Erie). Slush ice and anchor ice that releases from the bottom incorporate sediment. Drifting ice can transport significant quantities of sediment along and away from the shore.

An ice shove or ice push occurs when lake ice, moved by water currents or by wind (blowing over miles of ice), comes into contact with the shore. Ice is shoved up the shore away from the lake. Damage can result if the moving ice contacts structures, bluffs and banks. Ice shoves are unpredictable. The distance the ice moves onshore depends on whether the ice shove is a pile-up or ride-up event.

Pile-up occurs when the ice contacts an obstacle—an abrupt change of slope of the beach, or an existing ice ridge. The ice buckles and forms a large pile of broken ice

Ice shove

as the lake ice cover continues to fracture and contribute to the pile as it is driven ashore. Generally, an ice pile protects the area landward of the pile from burial by ice coming ashore. Ride-up tends to occur where a shore has a mild slope with no obstacles and is more likely to cause damage. The ice can be driven many feet (meters) inland. Ride-up often occurs in the early spring when an absence of nearshore ice masses and strong ice sheets creates favorable conditions.

Horizontal ice forces and ice damage depend on such factors as the surface roughness and slope of the ground or structure over which the ice is moving, properties of the ice, thickness of the ice, and the magnitude and duration of the driving force. Horizontal forces become highly slope-dependent for slopes of more than 40 degrees from horizontal. Most revetments have slopes with angles from horizontal of 20 to 34 degrees.

Moving ice, called ice runs, in the connecting channels between lakes damages unprotected structures. Ice jams (large accumulations of stationary ice that restrict flow) may also form, flooding low-lying land along the channels and rivers. Ice booms are placed in the St. Mary's River, in the outlet of Lake Erie at the head of the Niagara River, and on the St. Lawrence River. Ice booms are necklaces of large floating timbers, chained together and anchored on the riverbed. Ice booms help form a stable ice cover that reduces the frequency, severity and duration of ice runs in the rivers.

Ice also causes problems in protected areas along the shore. Piles supporting docks that are left in the water can be damaged by thermal expansion of the ice and by pile jacking. Over the winter, the ceaseless rise and fall of water levels causes a rise and fall of ice sheets. As the ice sheet alternately freezes to and releases from piles, the process pulls (or jacks) piles out of the lakebed, distorting and breaking pile-supported piers.

Shoreline Erosion

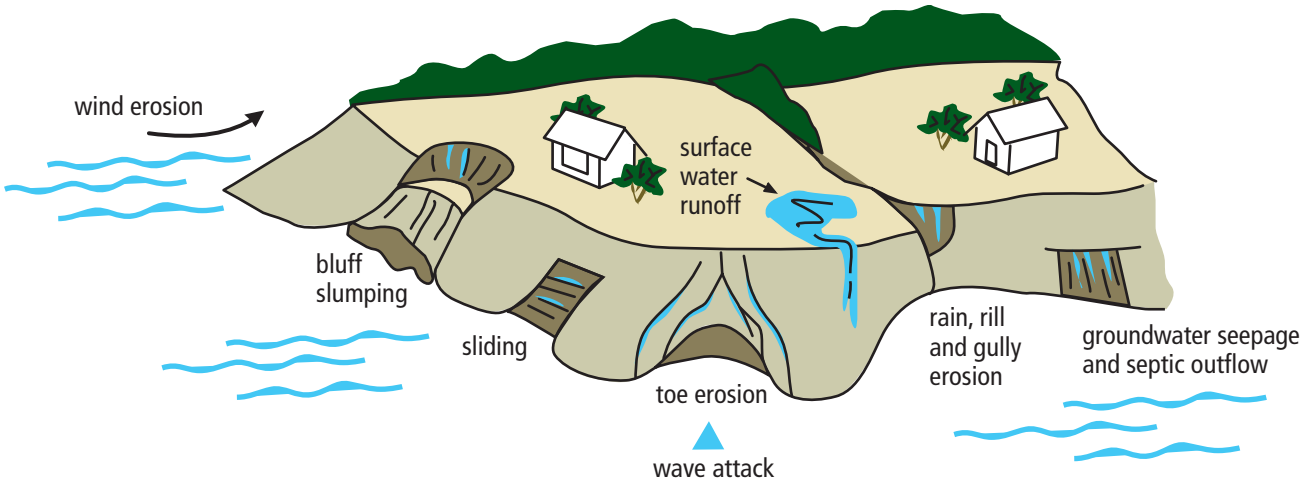
In the spring of 1985, owners of some low terrace properties on the Wisconsin coast of Lake Michigan were surprised when 30 to 50 feet (10 to 15 meters) of their front yards disappeared in one or two weekend storms. There are few exceptions to this retreat, although most are considerably less dramatic. Shores that have cohesive materials (clay, till and bedrock) have strong binding forces. Shores that have noncohesive materials (sand and gravel) have weak or no binding forces. Rock is the least erodible; sand and gravel the most erodible of these materials. One type of material may occur in a low bank, but several types typically occur in layers or mixtures within higher banks and bluffs.

The erosion of a coastal slope occurs in response to storm waves attacking the slope toe, rising groundwater and instability in slope soils, surface-water runoff over the faces of slopes, and other factors. Contributing factors include soil composition; weathering of the slope face by freezing and thawing; vertical cracks in upper slope soil; steep slope; lake level; nearshore shoals and lakebed slope; storm wave energy and duration; amount of precipitation; shoreline ice cover; shoreline orientation; beach composition, width and slope; presence or absence of shore protection, and type of shore protection. Given enough time and a stable slope toe, erosion to a gentler slope and revegetation of the eroded slope face can produce a stable slope. However, in many places, wave erosion of the slope base (or toe) prevents development of a stable slope.

In general, Great Lakes shorelines are retreating. They retreat at various rates—sometimes slowly and unnoticed, sometimes rapidly and alarmingly.

Erosion on rock shores typically involves rock falls where the toe of the slope has been gradually undercut by wave action. The rock above the undercut section remains relatively stable until erosion at the toe intersects a plane of weakness (or fault) in the rock, causing the failure of the rock slope. Rubble from rock falls forms temporary protection for the shore.

Sandy beach ridges, banks and beaches are sometimes the exception to the rule of retreat. Sandy shorelines



Causes and Effects of Coastal Erosion

advance and retreat as water levels rise and fall, storms come and go and sand supplies shrink or expand. Sandy shores tend to retreat in the face of high lake levels and storms as shore materials move offshore. Such shores may advance lakeward during times of low lake levels as mild winds and waves build beaches, ridges and dunes from nearshore deposits. Rebuilt ridges and dunes become significant reservoirs of sand. When storm waves erode the beach, these reservoirs of sand nourish the beach.

Erosion of the lakebed is a common feature along cohesive shorelines of the Great Lakes.

Lakebed Erosion

Sand or gravel in a narrow beach or present as a thin layer over an erodible lakebed acts as an abrasive, wearing away the lakebed under nearly constant wave motion. Measurements have shown rates of vertical erosion in the range of one-half to six inches (1 to 15 centimeters) per year in glacial till. More typical erosion rates are one to two inches (three to five centimeters) per year. Lakebed erosion rates tend to be highest close to shore where the waves break and cause turbulence. Erosion rates tend to decrease further from shore to less than 1/10th inch (just a few millimeters) per year in water depths of seven to nine feet (greater than a few meters).

A key feature of these shorelines is that when erosion of the nearshore lakebed takes place, it is irreversible—it cannot be restored as sandy shores can. The fine sediments are lost to circulate in the lake and settle out in deep water basins.

The strength of cohesive lakebed clays and tills is diminished by weathering. The thin weathered layer is easily removed by abrasive particles under small wave motion. Lakebed erosion proceeds modestly, a few millimeters at a time. The weathering process occurs throughout the year and extends into water depths greater than 33 feet (10 meters).

The underwater erosion of the lakebed often controls the rate at which the recession of adjacent cohesive shoreline slopes takes place, allowing larger waves to reach the toe of the bluff and increasing rates of recession. Lakebed erosion and bluff recession proceed in unison. The rate of vertical erosion on the nearshore profile is in proportion to the profile slope: the steeper the slope, the greater the erosion rate. An indication of lakebed erosion is the concave shape of most cohesive profiles with steep slopes close to shore where erosion rates are highest, and the slope decreasing offshore into deeper water where erosion rates decrease.

Lakebed erosion (or lakebed downcutting) also occurs on nearshore lakebeds of relatively weak bedrock such as shale and some sandstone.

Where lakebed erosion is occurring, any structure built to protect the toe of the bluff is subject to increasing wave energy and undermining of the foundation as the water depth in front of the structure increases.

In areas where strong bedrock occurs in shallow water, or an accumulation of cobbles and boulders forms a protective lag deposit over the cohesive lakebed, a nearly horizontal platform will develop, ultimately reducing the rate of recession of the bluff toe. A lag deposit is a

A house lost to erosion

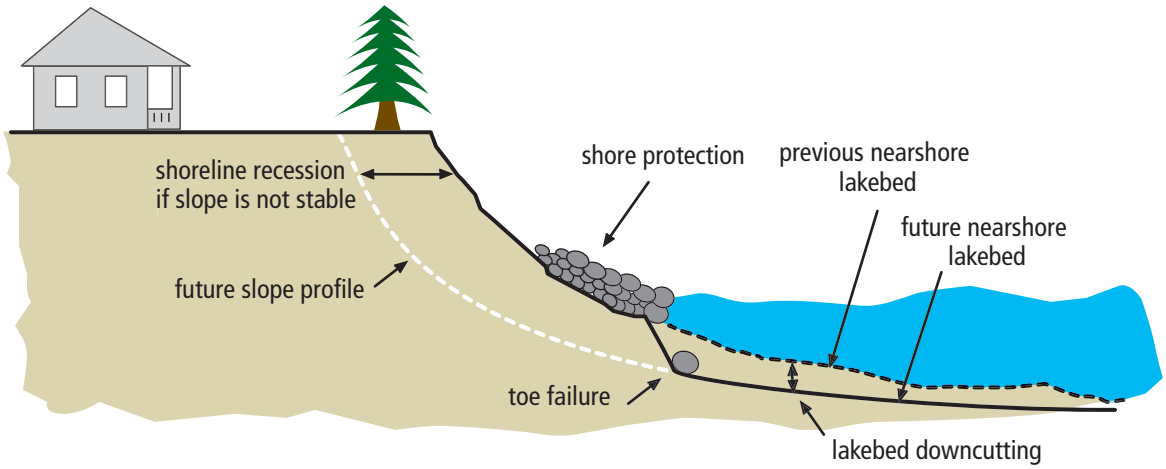
layer of stones left in glacial sediments after fine material is eroded.

During periods of low lake levels, the nearshore lakebed is subject to higher water velocities from wave motion, and the zone of wave breaking (where erosion is highest) occurs further offshore. When high water levels return, the water depth close to shore is greater than it was during the previous high water period, increasing wave impacts and erosion on the shore.

If recession of a coastal bluff occurs from wave action without lakebed erosion, then a shallow platform is left as the bluff recedes. Waves dissipate their energy on this platform, reducing the ability of the waves to erode the bluff toe.

How Stable Is a Shoreline Slope?

Erosion can be spectacular and threatening with sudden slumping and sliding of massive blocks of soil, or it can be subtle, significant, and undetected. Typically, cracks on the ground surface landward of the bluff edge or a slight drop in a section of a bluff or bank top is a warning that slope slumping is about to happen, or has started. The erosion of bluffs along the coast can be quite unpredictable. A bluff edge may not have moved



Lakebed Erosion with Slope Recession and Failure of Shore Protection Structure

Bluff failure at Klode Park, Lake Michigan

significantly in 40 years yet may lose 5 to 50 feet (1.5 to 15 meters), or more, next week. Bluff slumping can be triggered by wave or current erosion in the lower parts of the slope and the lakebed.

Landslide-triggering mechanisms on bluff slopes include intense rainfall or rapid snowmelt that quickly seeps into the bluff, causes a rapid rise in groundwater levels, adds to soil loads, and weakens soil strength. Sand layers and lenses sandwiched between soils that don't easily permit water to pass allow easy groundwater passage and discharge at the bluff face, which destabilizes the soil above the eroding sand layer.

There are opposing forces acting on a mass that may slide along a potential failure surface. Some bluffs are closer than others to sudden failure. The perceived state of stability against future sliding or slumping is commonly expressed as a safety factor (or factor of safety). A safety factor is the ratio of the forces resisting failure divided by the forces pulling down the potential sliding mass along the failure surface. Each soil has a maximum capacity to resist sliding or shearing, known as shear strength. A safety factor greater than one is good because it means that the forces resisting failure are stronger than the forces working toward a failure. Once the balance of forces (safety factor) is reduced to less than one, slope failure is likely to occur.

As the climate changes, changes in the frequency and intensity of storms and major precipitation events, and changes in the frequency and severity of freeze-thaw cycles, may bring soil conditions that will alter slope stability in ways that were not experienced by property owners during prior years of ownership.

Erosion can proceed undetected where slope soils are exposed. The strength of exposed till on slopes is weakened by freezing and thawing.

A geotechnical expert is needed to determine slope stability, evaluate erosion risk on properties with existing structures and select a safe setback distance for new construction. Coastal slope stability is highly variable from place to place around the Great Lakes, and soil characteristics and soil conditions may differ significantly on adjoining properties. Many properties depend upon shore protection structures to maintain the stability of the toe and face of the slope. The adequacy and durability of such structures can only be determined with professional assistance.

Water on the Land

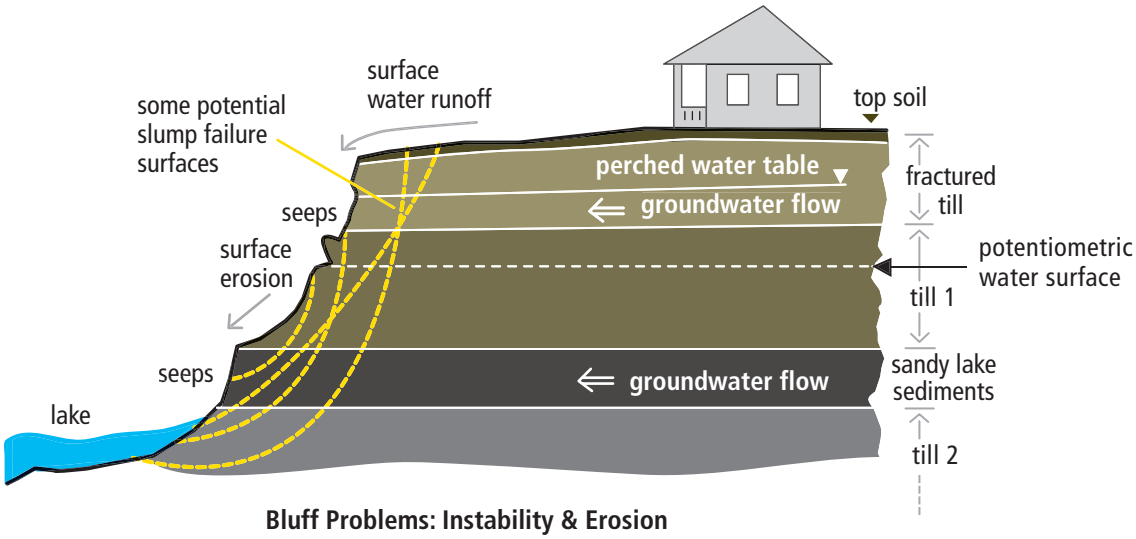
Water arrives on the land as either surface-water runoff or as groundwater. Some of this water originates on the coastal property. Other surface water and groundwater is flowing through on its journey to the lake from inland sources.

Surface-water runoff may come from rain water, snow melt, groundwater seeps or springs, and lawn or garden sprinkling systems. It may come from roofs through gutter pipes or from driveways, parking lots and roads. Surface runoff over the face of a coastal slope gradually loosens and visibly removes exposed soil on the slope, resulting in up to half of the loss of slope soils in some places. The volume of rain water, snow melt or artificially discharged water and the rate at which it arrives on the ground surface has a large influence on erosion.

signs of surface-water problems

There are a number of indicators of surface-water problems on and near coastal slopes. They include:

- Large exposed soil surfaces on the slopes
- Miniature troughs or larger gullies
- Exposed lengths of drain pipe
- Exposed foundations of stairways or other structures
- Areas of decayed vegetation in low areas
- Exposed soil surfaces on the land



Bluff Problems: Instability & Erosion
Surface Water Runoff Groundwater Seepage

Surface runoff from grass lawns is greater than runoff from grass lands and can be almost as great as runoff from paved areas. Water runs off steeply sloped land faster than gently sloped land. Low spots on land behind coastal slopes collect surface water. Land surfaces that are highly permeable allow water to penetrate the soil easily and cause less surface runoff but more groundwater infiltration than less permeable surfaces. Gullies or small troughs in the face of a slope channel surface water down the slope.

Groundwater infiltrates into the soils of coastal properties and moves to the slope face from surface water sources, off-site groundwater sources, septic systems or dry wells. The hidden activity of groundwater can be more dangerous than the visible effects of surface water runoff because groundwater can trigger large, deep landslides that sometimes have catastrophic consequences. The presence of water in soil pores and soil fractures beneath a slope weakens the soil by adding weight and by reducing the frictional resistance among soil particles that are in contact with one another. Groundwater flowing in a soil layer confined between two less-permeable layers (like till 1 and till 2 in the figure above) will rise in vertical wells to the potentiometric water surface (shown as a dotted line the figure above).

All coastal properties have groundwater flow beneath them; the ground adjacent to and lower than the lake surface elevation will generally be saturated. The surface of this zone of saturation (called the water table) is at lake level at the shoreline and rises gradually in the inland direction. For any banks consisting entirely of sand and/or gravel, this will be the only groundwater flow system present. Infiltrating water moves directly into the lake-level groundwater flow system and causes little weakening of the soil.

Many coastal bluffs contain soil layers (clays and tills) that retard water flow into the water table near lake level. Coastal landslide problems develop primarily where there are zones of water saturation above the lower, main water table; these are called perched groundwater tables. At such sites, groundwater collects in the sand and gravel layers because underlying soil layers that are resistant to flow slow downward movement of the water. The water flow in these sand and gravel layers is usually toward the slope face, where the water emerges in the form of seeps or springs.

Groundwater's influence on slope stability is controlled by several factors, including the quantity and distribution of groundwater beneath coastal property. The amount and rate of water infiltration is also important. The greatest infiltration comes from prolonged, slow application of water at infiltration locations. The soil moisture content and the soil structure's ability to pass water through the soil are also important.

Groundwater problems are most severe in times of greatest infiltration. Expect a bluff to be least stable during times of heavy precipitation or rapid thawing of significant snow cover. Some places, water tables can rise temporarily from several feet to tens of feet in a few days to a few weeks following a single intense rainfall or

snowmelt. Significant water storage within a bluff can develop during cold periods when freezing of the surface soil on the slope temporarily blocks groundwater discharge at seeps or springs.

Bluff movements tend to follow seasonal cycles. Rates of movement tend to increase with the arrival of late fall storm events and the beginning of bluff surface freezing. A frozen bluff face causes a back-up of the groundwater into vulnerable perched aquifers. More rapid bluff movements continue through the winter while perched water tables remain high. Movement continues into the spring through spring rains, rapid snow melt, and bluff-face thawing that releases the excess perched groundwater through soil weakened by winter's freeze-thaw activity. The bluff-destabilizing effects of storm waves diminish during periods of low lake levels, but groundwater activity and bluff movements may persist.

signs of groundwater problems

There are some indicators that property might contain perched groundwater and be vulnerable to water-induced landslides. They include the following:

- Clay and till layers between the bluff top and the beach level.
- Wetlands near, or on, the property.
- Seeps or flowing springs emerging from the bluff or bank face.
- Indications of perched groundwater in driller's logs from water well drilling.
- Types of vegetation on the slope that require abundant soil moisture.
- A piece of the land near the top of the slope that is at a slightly lower elevation than the adjoining land surface. This could be evidence of the first movement in a bluff slump sequence that may lead to the eventual sliding of the slumped section into the lake.
- Trees and large shrubs on the slope leaning toward the lake.
- Linear shoreline-parallel "wrinkles" in grassy slopes that may be indications of a gradual creeping of slope masses towards the water's edge.

PROTECTING YOUR COASTAL INVESTMENT

The cost of living along the shore is higher than the cost of owning and using similar inland properties.

Along Great Lakes shores, there is a high demand for coastal properties, which drives up the price. There is a trend towards building much larger coastal homes than in the past. Premium coastal land is being used for high-density housing like condominiums, and for other large projects. These large investments require the best available professional help in deciding what steps to take to protect an existing or planned investment from the hazards of natural coastal processes. "Best professional help" usually means a geotechnical engineer or geologist trained in slope stabilization, an engineer trained in shore protection design, and a qualified marine contractor. It is often more economical and effective to plan a shore protection strategy with neighbors.

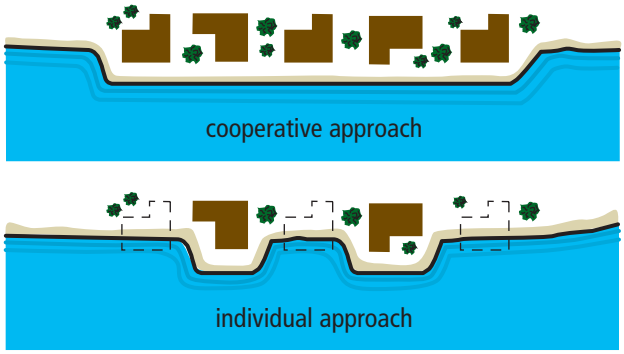
Coastal property is unlike inland property in one critical way: natural processes and forces work to remove the lakeside portion of the land.

There are some vital reference points needed to protect a present or planned coastal investment. They include elevations, setback distances and the depth of the lot.

This section describes four options for protecting coastal investments: adaptation to natural coastal processes, restoration of natural defenses, moderation of the effects of coastal processes and armoring the shore. The environmental impacts of shore protection structures are described.

If you are considering the purchase of coastal property

The land resists erosion with natural defenses, including retreat. Some properties appear to have a stable lakeside edge with trees and other vegetation. However, vegetation only indicates stability during the lifetime of the plants and is not adequate for predicting the land's response to long-term changes. A large yard between the lake and buildings provides a buffer to protect the buildings from being undermined and destroyed as the land retreats. Using constructed shore protection to gain a close-up view of the lake is problematic and costly.



Protecting Your Coastal Investments

If you own a coastal property with one or more buildings on it

Your options are limited and your strategy for protecting your coastal investment will probably differ from the strategy used by a buyer of an empty coastal lot. If the lakeside edge of your coastal property has active erosion, the retreat of the land is shortening the useful life of your building(s). Adequate protection of your investment requires periodic monitoring of the condition of your bank/bluff/beach and shore protection and prompt corrective action when needed.

Knowing Where You Are on Coastal Property

Knowing where you are with respect to the lake will help determine the vulnerability of property to damage from extreme lake levels, storm waves and erosion, and the practicality of options for reducing that vulnerability.

The first set of key reference points are the elevations above lake level of: property, crest (top) of a shore protection structure, basement, and first floor of buildings. Lake levels are measured in feet or meters above or below a reference elevation called chart datum, or Low Water Datum (LWD), for each lake. Both terms are used for navigation charts and lake level forecasts. Chart datum is a handy reference to compare predicted lake level changes and storm wave runup with the elevations of land and structures. The land and structure elevations need to be converted to feet or meters above chart datum.

The second key reference points are the distances of structures from the lakeward edges of coastal slopes. These distances are called setback distances. They show how far structures are from a receding, or potentially receding, bluff or bank edge. The setback distance is one indication of the seriousness of an erosion threat to

structures. Professional engineering assistance is needed to estimate setback distances that are adequate for future recession and for slope stabilization.

A third key reference point is the depth of a coastal lot—the distance from the landward edge of a property to the lakeward edge of a property. This distance indicates how much space is available to safely locate, or relocate, a building or other structure in order to gain an adequate setback distance and reduce the risk of damage and loss from shore erosion during the desired life of the structure.

Adaptation to Natural Processes

Adaptation is people adjusting to natural coastal processes by staying out of nature's way. It is a strategy of siting new buildings far enough from the edge of coastal slopes and high enough above the water that erosion won't claim them and flooding won't reach them during their useful lives. Adaptation is relocating existing buildings inland of erosion hazard areas and designing new buildings that can easily be relocated in case erosion is more rapid, or water levels higher, than anticipated. Adaptation does not mean moving building sites lakeward as lake levels drop and shorelines advance lakeward. In some situations, adaptation means passing up an opportunity to buy property where a building is threatened from erosion, or not constructing a permanent structure on threatened land.

Adaptation may be difficult if climate change brings lake levels beyond the design range used in building and operating lakeside power plants, water intakes, pumping stations, sewage treatment plants, industrial plants, and other infrastructure serving millions of people.

For lakeside residents, adaptation may work best at times of low lake levels where beaches, dunes and ridges rebuild as natural defenses against storms. When high water levels occur with more intense and more frequent precipitation events and periods of damaging storm waves, adaptation will be more challenging.

In such stormy, high water times, adaptation will be difficult for owners of large homes built close to slope edges and owners of older, smaller homes on small lots with few years left before erosion threatens.

Staying out of nature's way

A setback distance should allow for continuing erosion, formation of a stable slope once the slope toe has been stabilized, and some space for equipment to relocate a building if future slope failure jeopardizes the building. An expected recession setback distance is the expected future average annual recession rate multiplied by a chosen number of years.

Pick the time period during which you desire the building to be safe from failure due to erosion. Regulatory agencies that require a time-based setback generally use a period of 30 to 100 years. A well-constructed house may have a useful life of 70 to 100 years, or more. Act conservatively by using a setback that is greater than required. Historic recession rate information may not represent future recession rates, particularly with a changing climate. A building's location with respect to the edge of the bluff or bank at the time of sale will affect its value.

Staying out of nature's way includes identifying a safe setback distance from the top edge of a bank or bluff that provides protection from erosion for the expected life of the building.

The view from the dwelling may be an important consideration. Consider building a gazebo or a readily moveable detached deck in a location lakeward of the house to provide the view.

Setback distances for buildings on properties with existing or planned shore protection structures should be estimated as if the shore protection structures were not present. Shore protection can fail—sometimes quickly and catastrophically. When this happens, the previously protected shoreline tends to recede rapidly toward the

safe setback distance

At least four factors should be considered when estimating a safe setback distance:

- The expected recession distance of the slope edge over the life of the building
- The height of the bank or bluff
- Stability of the slope
- The amount of room necessary to relocate the building if necessary

Relocating a house

position of neighboring unprotected shorelines, erasing the benefits gained from the former shore protection structure.

Relocating threatened buildings

Once a building is threatened with erosion damage, there are four options: do nothing and use the building until it needs to be demolished; sell the property and transfer the risk to the new owner; install bank/bluff and shore protection; relocate the building landward on site or to a new property. In many situations, relocation is the most cost-effective and certain way of increasing a home's longevity. This is especially true in bluff areas where shoreline stability is complex and erosion control is difficult. The cost and effort involved in relocation is extremely variable and depends on the characteristics of both the structure and the site.

Plan for possible future relocation when selecting a new building design and a location for the building on the property.

Plan for building relocation in case estimates of future recession rates turn out to be underestimates. The important structural elements that affect ease of relocation are foundation type, above-foundation framing, type of exterior siding, size and configuration of the building footprint, and presence of fireplaces and chimneys. Fireplaces and chimneys may require additional bracing, depending upon the design. Work with an architect, builder, and structural mover early in the design phase to ensure that all aspects are considered (see sidebar).

Relocating an existing building offers the peace of mind that comes when your building is a safe distance away from an eroding shoreline.

By reducing the hazard facing the home you can increase its value and decrease the need for costly slope stabilization and shore protection which may or may not work satisfactorily.

Contact a building mover to assess the project. Taking action before a building is undermined is important to ensure the feasibility of relocation. Movers may be reluctant to relocate a building perched on the edge of a bluff or bank. The moving cost depends on the characteristics of the building. It's less costly if the destination is on the same property. The cost will also depend on site characteristics. Is the terrain level enough and open enough to get moving equipment in and the house moved to a new site? For relocation on the property, it is important to have adequate depth on the lot roughly perpendicular to the lakeshore. The width of a building may present problems in a relocation due to obstacles located along the route.

Prior to relocation, certain agencies must be contacted for permits. Local professional movers know the

making relocation easier

Things to consider in making a proposed coastal building easier to relocate:

- It is easier to move a building with crawl spaces, basements, or pilings beneath the main floor than it is to move a building built on a slab.
- Buildings with stud frame walls supported by a floor joist system are generally easier to move than walls built of logs, concrete blocks, poured concrete, or solid stone.
- Buildings with exterior siding of wood, aluminum, steel, vinyl, brick, or stucco are generally easily moved .
- A building with the main floor on one level is easier to move than one constructed on multiple ground levels.
- Compact homes with rectangular footprints (ground area covered) are easier to move than are homes with large or irregular footprints.

procedures required. When looking at the project to determine costs, determine what it will take to bring the building to "turn-key condition"—ready to move back in.

Restoration of a Natural Shoreline

Restoration of a natural shoreline is bringing back natural coastal defenses against the processes that cause erosion. Restoration is nourishing and retaining beaches, revegetating beaches and slopes, reconstructing dunes and beach ridges, creating or restoring wetlands, and removing failed and failing shore protection structures. Where there are diminished supplies of sand and gravel for beach-building, restoration materials may come from upland sources such as sand and gravel pits. When low lake levels occur, most restoration activities should be easier to accomplish. Coastal wetland restoration may be an exception. Restoration efforts will be impeded by damaging storm waves riding ashore on high lake levels and by more frequent and/or more intense precipitation events.

Nourishing a beach

When the Great Lakes are in a period of low water levels there is an opportunity for natural shoreline protection features to rebuild and become vegetated.

Retaining and nourishing beaches

One major difference between cohesive and sandy shorelines is the ability of sandy shorelines to recover from erosion events. Beach retention is an important defense of coastal property against erosion by waves. Beach retention can be done by mimicking nature, creating miniature armored headlands, or by replacing lost sand and gravel with coarser, larger beach materials. Beach retention can be done on individual properties and in community-wide projects. Some methods of beach retention are mentioned in “Armoring the Shore” in this booklet. Permits are commonly required for both beach retention and beach nourishment projects.

Beach nourishment is one way to introduce needed beach-building materials into the longshore sediment transport system. Sand dunes and beach ridges (or foredunes) are important features along the shores of the Great Lakes. They trap windblown sand, store excess beach sand, and serve as natural erosion buffers.

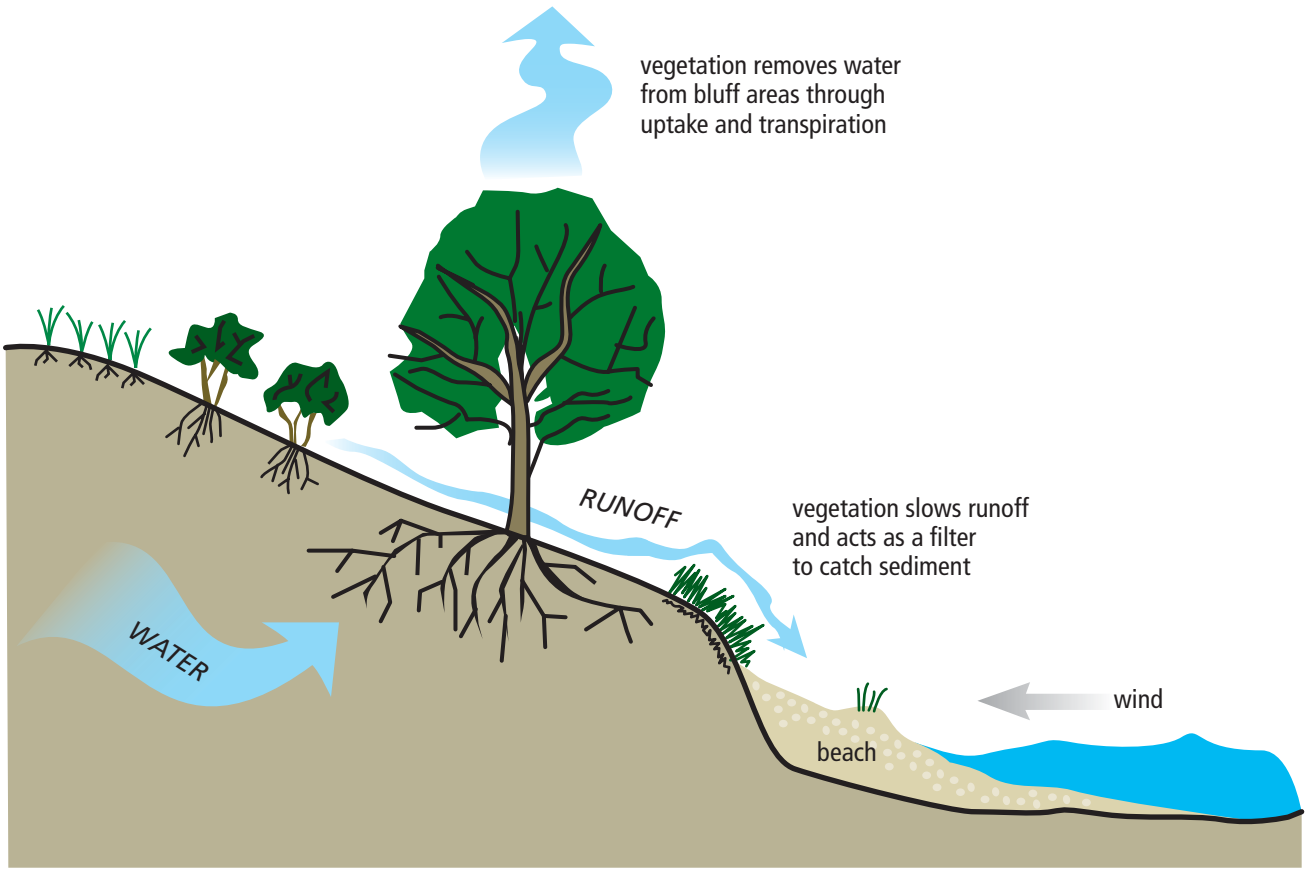
On the Great Lakes, beach nourishment is considered a means of sediment conservation. There are two main types of nourishment methods. One involves placement of “new” material trucked in from inland sources; the other involves reintroducing material that has been removed from the littoral transport system. The second type includes placement of clean, suitably sized dredged material on beaches or in nearshore waters. At some locations, littoral transport is a significant source of beach material, amounting to several hundred thousand cubic yards (a hundred thousand cubic meters) per year.

Revegetating the shore

Vegetation on coastal slopes stops surface erosion and may prevent shallow slides. Rising water levels and storm waves strip vegetation from shoreline beaches, beach ridges and eroding dunes. The natural establishment and growth of new vegetation is a key step in the rebuilding process of beach ridges and dunes. Cutting of vegetation to improve a view can have detrimental effects on slope stability.

Exposed soils on coastal slopes may need some help to become quickly revegetated and to stop surface erosion. Plant shrubs, grasses, and other ground cover.

Planting vegetation in Hamilton Harbour, Ontario

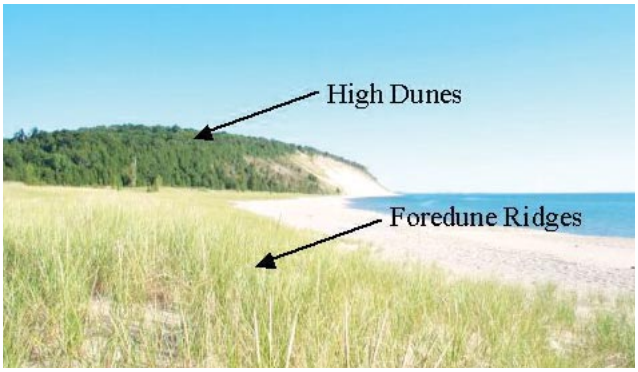


Revegetated Coastal Slope

Surface and shallow groundwater is removed from the soil by transpiration through plants, strengthening the soil. Deep-rooted vegetation that will help to stabilize the slope is preferred. Small trees that will not grow to be large trees are preferred because large trees cause large, concentrated loads on slopes, partially offsetting the added strength their roots provide to slope soils.

Constructing dunes and beach ridges

Low-lying foredune beach ridges are at the back of the active beach and closer to the water's edge than the dunes. The relatively higher dunes are landward of the beach ridges. The beach ridges are the youngest of the coastal sandy landforms. The high coastal dunes are typically older than the ridges and exhibit a more stabilized forest growth.



Typical coastal dunes

Property owners can use the natural forces that create these ridges and dunes to build (or rebuild) this environmentally friendly form of shore protection.

Beach ridge construction starts when an obstruction on the beach interferes with the wind, causing sand to accumulate. Two common methods for creating this wind interference are installation of sand fencing and planting of dune grass.

Fencing is a common means of trapping sand. A relatively cheap and easy fence to install is a slot-type snow fence, but other types of materials can also be used. Here are some basic guidelines to consider when installing sand fencing:

- Fencing should be about 50% porous.
- The fence line should coincide with the natural vegetation line.
- The fence should be roughly parallel with the shoreline.

Sand fencing

There are two common ways to build a dune or beach ridge with sand fencing. One is by installing one line of fencing and following it with another single fence as each line fills. The other way is to install double fence rows with the distance between rows roughly four times the fence height.

Dunes built using fences should be stabilized with vegetation, or they will easily erode away from wind and wave action. Using both methods together is an efficient way to build dune shore protection. Planting vegetation alone can also be a good way to create a dune. Before planting dune grass or installing sand fences, consult an expert on this subject.

There are a few species of plants that are recommended for use in the Great Lakes Region. To initiate the stabilization process, plant one or more of the following species:

- marram (dune) grass,
- wheat grass,
- wild rye,
- dune willows.

Once these plants are established and flourishing, plant the following species:

- sand cherry
- choke cherry.

Dune grass planting

After these plants are growing well, plant cottonwood and/or basswood to advance mature development.

The mentioned species are capable of surviving harsh beach environments and can weather drought, flooding, high surface temperatures and sunlight exposure. In addition, these species grow quickly through sand that has accumulated over them, and their vast root network helps stabilize the sand that they grow upon.

Installing pile-supported timber walkways over vulnerable sand ridges and dunes can also be helpful in protecting vegetation. Avoid walking through vegetated areas of sand dunes and ridges because the paths that develop lead to blow-outs and more sand losses from wind erosion. Wind erosion can be slowed by prohibiting the use of all-terrain vehicles (ATVs) and other vehicles on beaches, sand ridges and dunes; these vehicles destroy sand-anchoring vegetation.

Creating or restoring wetlands

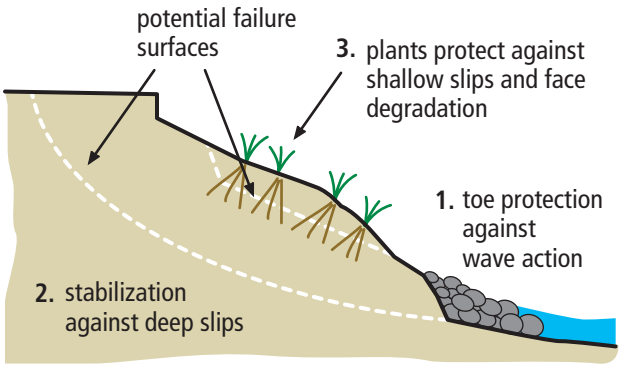
Great Lakes coastal wetlands are areas where water levels and land merge to form unique ecosystems that sustain a multitude of life. Coastal wetlands occur where there is some natural protection from high wave power. They absorb some of this power.

Coastal wetlands are a valuable buffer between the lake and upland areas. Restoring and preserving coastal wetlands requires understanding the processes that maintain a wetland, identifying the causes of degradation, and possessing the technical experience to formulate a plan. Wetland specialists should be consulted to ensure success in preserving and restoring these unique ecosystems.

Approaches to restoration can be either hydrological or biological. Hydrological remediation includes restoring hydrologic connections between lakes and wetland water bodies and restoring wetland water tables. Biological methods include control of nonindigenous plants and animals, increasing populations of native wetland plants and animals, and enhancing habitat through management of plant species that provide habitat or introduce constructed habitats.

Removing failed or failing structures

A walk along the beach is often hindered by abandoned or destroyed shore protection from a previous era—an overturned seawall, scattered remnants of a bulkhead or groin, pieces of concrete. Some of these failed structures and materials offer limited shore protection, but many are unsightly, a safety hazard and an obstruction to beach use.



Three Basic Bluff Stabilization Strategies

If a structure required a federal, provincial or state permit, it is likely that the permit included conditions for repairing, reconstruction, retrieval or removal. Permit conditions may also have included measures for mitigation of any adverse impacts caused by the project, such as interruption of sand transport or acceleration of erosion at adjacent properties. In some instances, failed structures were constructed prior to implementation of regulatory measures that included permits and permit conditions. In such cases, jurisdiction over these failed structures can be confusing and complicated.

It is important to understand your legal responsibilities for your existing shore protection structure, including a failing or failed structure, whether or not you have a federal, provincial or state permit for the structure.

Moderation of Erosion

This strategy involves slowing erosion and improving existing shore protection by managing water on the land and making coastal slopes more stable, tripping storm waves, paving the lakebed, and other measures. Erosion moderation probably works best in times of low lake levels. When storm tracks shift and bring more frequent and or more intense snowfall or rainfall, management of surface water and groundwater will become more important and more difficult. High lake levels, more frequent and stronger storms and storm waves will challenge a moderation strategy.

Making a bluff or bank more stable

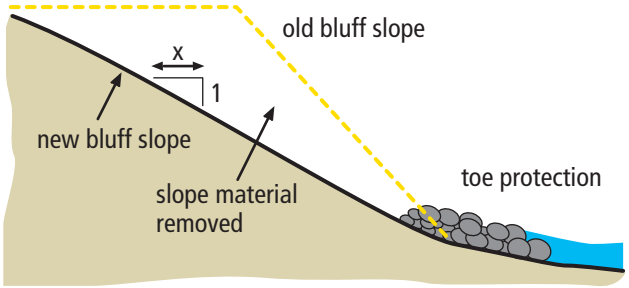
Toe protection is a form of armoring the shore and is described elsewhere in this booklet.

Stabilization against deep slips may involve different approaches depending on the conditions. Typical approaches involve some modification of the slope, making the slope less steep or buttressing it against sliding. Some examples are shown on this and the next page.

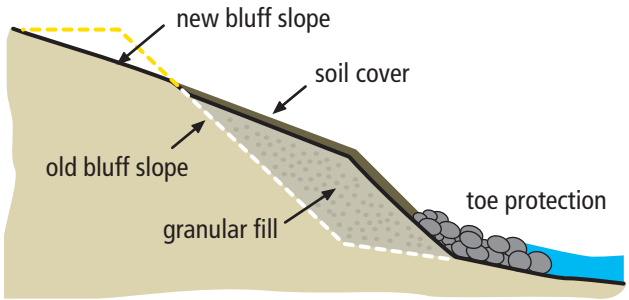
improving stability of slopes

There are four measures that can be taken to improve the stability of slopes on coastal banks and bluffs. They are the following:

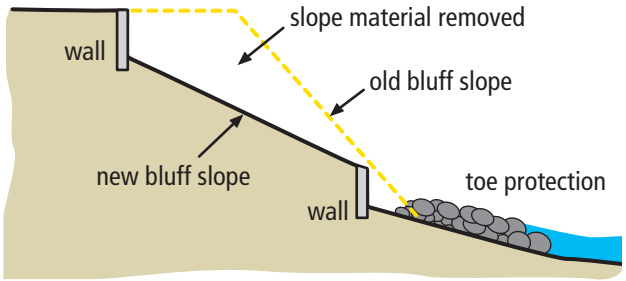
- Toe protection against wave action
- Stabilization against slope failure as deep slips
- Protection of the slope face against shallow slides and surface erosion
- Control of surface water and groundwater



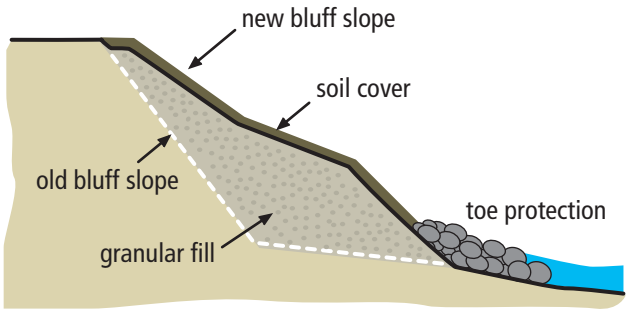
Cutback Slope Stabilization Method
x:1 = Recommended stable slope ratio



Cut and Fill Slope Stabilization Method



Terraced Bluff Stabilization Method



Fill Slope Stabilization Method

Protection of a slope face typically involves providing vegetation, called soil bioengineering, and controlling surface-water runoff. Roots of plants enhance the stability of the surface of a bluff that is already stable against deep slips.

Managing water on the land

Surface-water management and groundwater management are in the first line of defense for protecting slope stability.

surface-water management

Surface-water management on a coastal property includes the following steps:

1. Collect surface-water runoff in a storm sewer or private drainage system.
2. Prevent surface water from running over the edge and down the face of a slope.
3. Avoid creating tilled gardens and flower beds of significant size near coastal slopes. These gardens and beds may become significant recharge areas for surface water to move into the groundwater flowing towards the slope.
4. Minimize ponding of water on land near coastal slopes.
5. Divert water from seeps or springs on the slope, collect and drain it from the slope.
6. Decrease the velocity of water flowing across coastal land in gullies to reduce the erosive scour potential of this water.

groundwater management

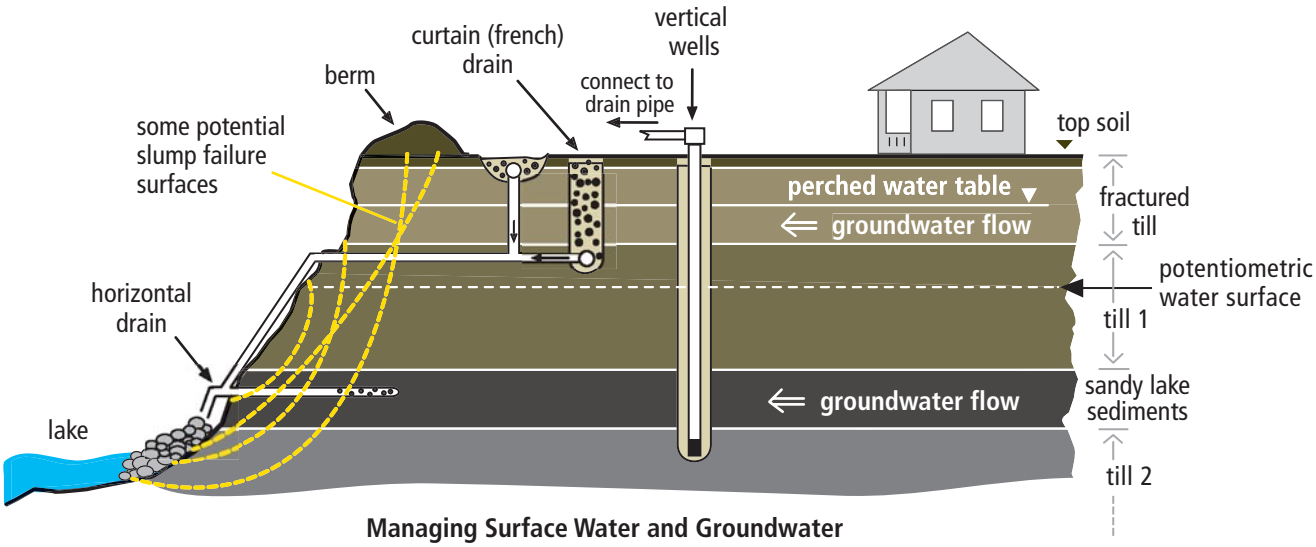
Some ways to manage groundwater flowing beneath a coastal property and towards a coastal slope:

1. In areas of new construction, or construction of new septic systems, leach fields should be located as far from the coastal slope as possible with discharge directed away from the coast.
2. Intercept groundwater flowing beneath the property and toward the coastal slope.
3. Remove groundwater from perched zones of saturation.

Professional advice and judgment is needed to anticipate how severe future precipitation events and conditions are likely to be and how best to manage surface water and groundwater on a coastal property.

It's critical to remove water from perched zones of water saturation beneath the property near the coastal slope and slope face in the places where future landslides could be initiated. Not all groundwater need be removed, only the excess water that could cause soil instability following future extreme precipitation events and extreme groundwater conditions.

There are several ways to drain the critical zone of groundwater. One way is to drill one or more rows of shallow, vertical wells roughly parallel to the edge of the slope. These wells can drain aquifer soil layers within the critical zone beneath the slope by pumping into drainage pipes. These wells can act as sumps: the pumps turn on only when perched water tables rise above levels established by careful analysis of the bluff failure system. Another way is to drill short, horizontal drains into the slope. Water in the perched aquifer layers within the critical zone beneath the slope will drain by gravity, discharging through pipes or tubes. Horizontal drains are favored by most geotechnical engineers because of their mechanical simplicity. If a bluff is experiencing significant slump displacement, horizontal drains can become distorted, damaged and ineffective if the movement persists. Trenches, drains and wells must be landward of all possible slope failure surfaces.



Managing Surface Water and Groundwater

Surface-water and groundwater problems on a coastal property may be local indications of much larger problems that affect multiple land owners.

Monitor changes in land development occurring landward and adjacent to the property. Roads, ditches, and residential/commercial/industrial developments can alter groundwater and surface-water flow to the detriment of coastal slope stability. Contact the developer responsible for the project and the government agency that regulates the development. The mitigation of water problems might require major construction.

Slowing wind erosion

Wind erosion can be slowed with vegetation, including "wind breaks"—trees and bushes that absorb wind energy. Avoid removal of portions of beach ridges and sand dunes to improve the view of the lake or to allow more convenient access to the water's edge. Such actions remove one of the natural protections of coastal property from wind and from storm waves. Removal of beach ridges and dunes may also be illegal, particularly where the ridges or dunes are lakeward of the public lakebed boundary.

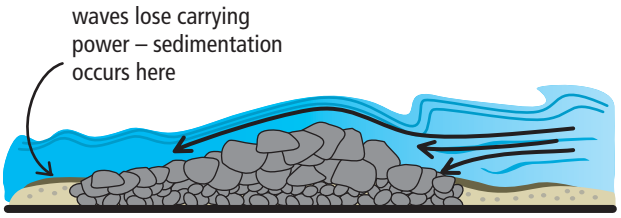
Improving existing protective structures

If a shore protection structure provides inadequate protection, or is damaged, there may be ways to improve the structure and lessen its adverse environmental impacts. Some structures with wave overtopping problems can be improved by constructing a stable, armored slope behind the structure that is designed to drain overtopping water without causing erosion. Another example of improvement is construction of an armor stone berm in front of the structure. Installations that have been in place for a few years should be investigated to see how well they have performed. Ineffective groins that are suspected of starving beaches along the coast should be dismantled. The materials may be useable in constructing other effective forms of shore protection.

Tripping waves

Wave energy approaching the shore can be reduced by "tripping" large waves before they reach shore, releasing much of their destructive power.

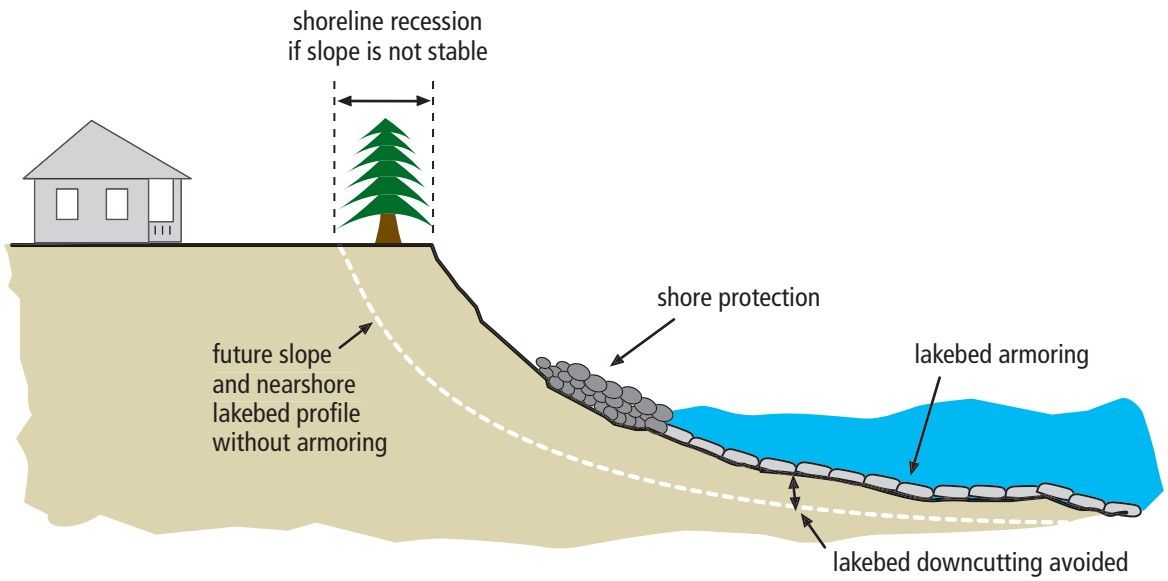
Waves can be tripped by building submerged breakwaters that are sometimes called artificial reefs, or by building nearshore shoals and bars. Such structures can be used to increase the fill life of renourished beaches. No general rules exist at this time for wave-tripping devices. Some of the features that need to be determined are the structure's design height, length, depth, possible hazards to navigation, and possible adverse impacts on neighboring properties.



Tripping Waves (Submerged Breakwater)

Armoring the lakebed

Lakebed armoring is the use of cobble-size stones to protect an eroding nearshore lakebed from wave energy. The stone is typically 6 to 18 inches (15 to 46 centimeters) in diameter and densely packed. If the paving protects the lakebed from downcutting, a shelf will form. As waves come in, some of their energy will dissipate over



Lakebed Paving and Shore Armoring to Protect Land from Shore and Lakebed Erosion

this armored shelf, improving the protection of the beach and the land behind it.

Lakebed armoring mimics some natural lakebeds where the glacial till contains boulders and cobbles that remain as "lag deposits" after the soft clays and sands have eroded. These lag deposits may armor the lakebed from further erosion by waves.

Lakebed armoring has been done on an experimental basis in the Great Lakes. The stability and life of this type of erosion moderation are still unknown. There is the possibility that nearshore lakebed habitats could be affected in positive or negative ways.

Armoring the Shore

Armoring the shore is an option of last resort. Armoring is a strategy for land with vulnerable buildings that would be extremely expensive or impossible to relocate once they are threatened by erosion or storm wave overtopping—large coastal homes, power plants, industrial plants, etc.

Armoring may be needed when climate variations bring periods of high lake levels and storms of greater frequency and/or intensity. During periods of low water levels, construction of shore protection is easier and allows better placement against erodible bases of coastal slopes, deeper foundations, and better placement of toe protection. Storms of greater frequency and/or intensity than structures are designed to withstand are likely to cause unexpected and premature failures of structures. If climate change brings more freezing and thawing cycles during the winter, there will be more rapid disintegration of poor quality armor stone in shore protection structures. Cracking of some armor stone by freezing and thawing is a serious problem in the Great Lakes Basin.

The purpose of shore protection structures is to make the land more resistant to erosion and to protect upland facilities from damaging wave action. Most structures protect only the land directly behind them and have no beneficial effects on adjacent shorelines or on beaches lakeward of them.

Flexibility is a feature of armor stone, or rubble, structures. It is the ability of a structure to shift in response to wave forces or changing foundation conditions and retain structural stability.

Revetments

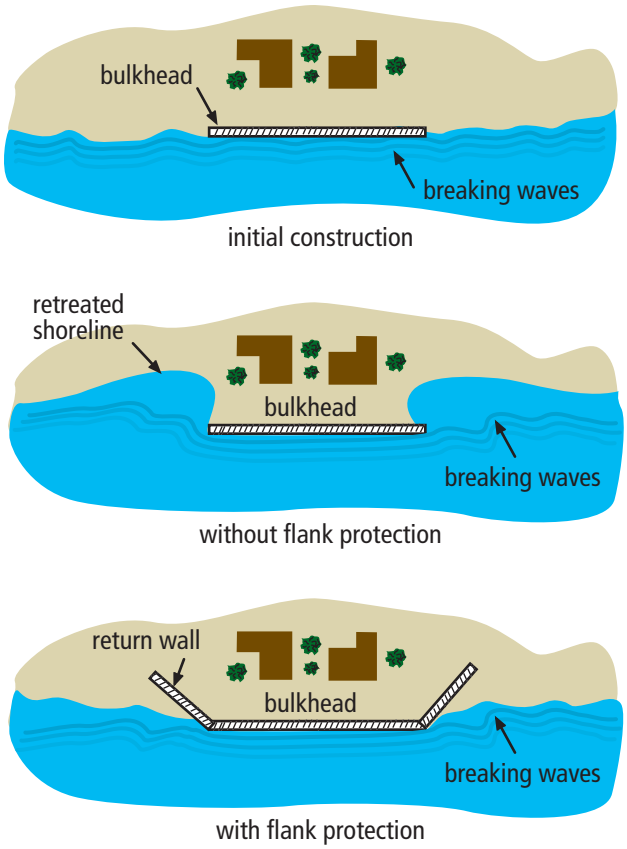
Revetments are probably the most-used shoreline-hardening structures in the Great Lakes and are the easiest type of shore protection structure to construct. A revetment is a shore-parallel structure with a sloping face, designed to protect the bank or bluff of a shore against the erosive attack of waves and/or currents.

Revetments generally consist of one or more protective outer (armor) layers of dumped or placed materials

shore armor

Common features of shore armor include:

- **Length.** The length of the structure is determined by the length of shoreline to be protected and the length of the return (or tie-in) of the ends of the structure back into the upland area to protect them against flanking.
- **Height.** The height of a structure above a lake level or a fixed elevation is determined by the expected wave height, wave runup and degree of protection against water overtopping desired.
- **Depth**. The depth to which the base or bottom of a structure penetrates the beach.
- **Shape**. The shape of a structure is the profile of its face. Shapes include vertical, sloping, convex, concave, and stepped.
- **Surface Texture**. The texture of a structure's face plays an important role in affecting wave runup and scour. The more irregular the texture, the greater the reduction in wave runup, overtopping and scour.
- **Permeability.** The ease with which water can flow through a structure. Permeability allows structures to absorb wave energy and reduces wave runup, overtopping and scour.
- **Toe Protection**. A lakeward projection of a structure that protects its foundation from undermining and scour by wave action.



Example of Flanking and Return Walls

(rock, manufactured concrete units, etc.) and a transition layer between the original soil and the protective armor that is intended to minimize loss of the soil beneath and behind the structure. A rock armor design may allow for some rock movement and "self-healing" following movement or loss of some armor stone on the slope.

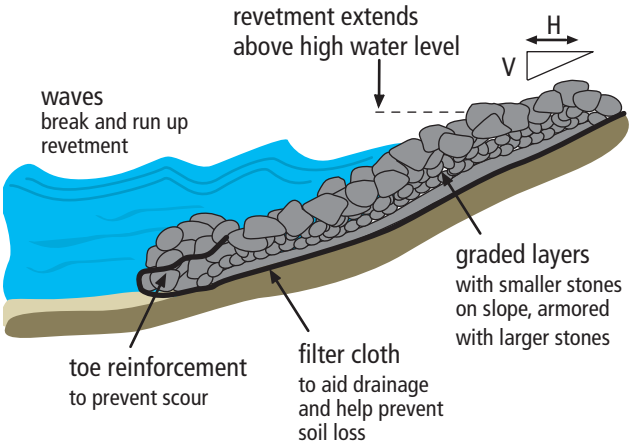
The lower the slope angle from horizontal (the more gentle the slope), the less scour is likely to occur in front of a revetment. The ability of sloping surfaces to reduce wave overtopping depends on slope angle, surface texture and structure permeability, plus height. Surface roughness and permeability on a revetment can have a significant positive effect in reducing wave runup, overtopping and scour.

The design of the outer protective armor layer is critical to the success of the revetment. It should be designed on the basis of extreme wave conditions, not average wave conditions. If the armor layer is rock, generally two or more layers of high-quality rock are needed. Rock is good at dissipating wave energy and reducing wave runup.

The transition layer may consist of one or more "filter layers" (stone smaller than the protective layer) and placement of a filter cloth directly against the native material. The filter cloth will prevent the native soil from being transported through the revetment and lost.

The toe and flank protection are critical elements that protect the structure from wave and end scour that could cause the revetment to collapse. The ends of the structure need to be protected from erosion moving around and causing structural collapse at either end.

Revetments should be constructed on relatively gentle slopes, about 1:2 to 1:4 (vertical rise to horizontal run). A 1:1.5 slope may be feasible if an engineering



V:H describes the slope

Typical Revetment Profile

analysis proves that the revetment will be stable during extreme storm and water level conditions.

For stone revetments, the quality and durability of the stone making up the protective layer is a key consideration, particularly in the sub-freezing winter environment of the Great Lakes. Fracturing of armor stones by freeze-thaw action over the winter months can greatly reduce the useful life of a revetment. Stone selection should be undertaken by a qualified geologist or engineer. For concrete structures, high-density/high-quality concrete with internal steel reinforcement provides additional resistance against abrasion by sand and gravel moved by waves, as well as protection from breaking during minor unit movement by waves.

revetment design

Revetment designs should provide adequate information, including details about:

- Armor layer
- Transition (filter) layer
- Structure toe
- Flank protection
- Revetment slopes
- Quality and durability of armor materials
- Plan for inspection and maintenance

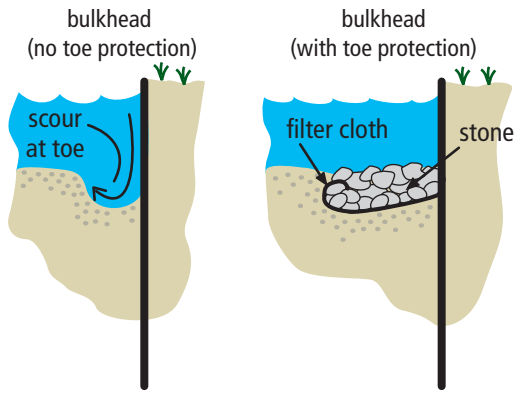
Inspection and maintenance of the revetment is required in order to ensure continued successful performance. Cracked armor stone needs to be removed and replaced with good stone (preferably stone that has aged three or four years). Inspections should be carried out annually and following large storm events.

Seawalls

Seawalls are shore-parallel structures consisting at least partly of a vertical surface facing the water. The primary purpose of a seawall is to protect the land and property behind the wall from damage by storm wave action. Its secondary purpose is to prevent the land from sliding onto the beach or into the water. Seawalls require drainage or weep holes through the structure to relieve excess water pressure from the landward side. Seawalls tend to be more vulnerable to wave scour at the toe than are revetments because they tend to reflect more wave energy.

Seawalls may be cast-in-place or pre-cast gravity structures that rely on their own weight (and/or anchoring systems) to maintain their upright position. The land or fill behind them may contribute limited structural support. Seawalls may be smooth- or rough-faced and have various face shapes or combinations of shapes. They can be built as solid structures to reflect wave energy or as porous structures to absorb some wave energy within the structure. Seawalls may be constructed of a wide variety of materials and combinations of materials. Concrete, steel sheet pile, timber, and rock-filled timber cribs seem to be the most popular materials.

Massive, cast-in-place concrete seawalls can provide reliable and long-lasting protection from storm wave attack. They are usually used where a high degree of protection is required for high-value facilities and improvements. These seawalls may be of any size, large or small, and can be designed with any face shape, but they will



Example of Wave Scouring at Bulkhead

Seawall on Lake Superior

usually have faces that are relatively smooth in texture. Sometimes they have stepped faces.

Some seawalls are constructed of pre-cast concrete parts in easily-handled sections. These parts are often cast as concrete cribs, with solid sides and bottoms and a solid front in the desired profile shape. The back may be solid or omitted, depending on the engineering and design requirements. Pre-cast concrete seawalls are especially suited to applications where protection from low to medium wave action is required. The advantages of pre-cast units are rapid and relatively easy installation. Disadvantages include the possible scouring, undermining and settling of the individual units.

Seawalls may also be built like bulkheads to provide limited protection from waves. These walls are made of upright sheet materials with the lower portion of the sheets driven into the lakebed and a system to anchor the portion above the lakebed. Typical sheet materials for bulkheads are wood (generally pre-1960s) and steel. Usually the anchors are tie rods extending from the sheeting landward to piles or horizontal logs buried in the land behind the bulkhead.

Groins

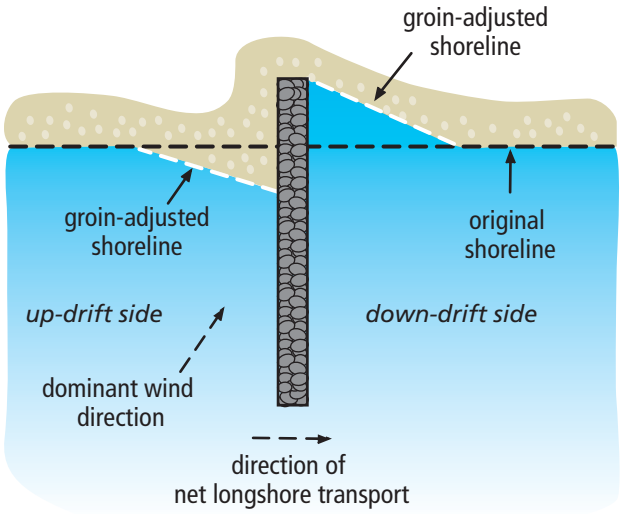
Groins are shore-perpendicular structures designed to stabilize a beach by holding beach material in place. Groins also trap sediment carried alongshore in the littoral transport system.

Groins can be used singularly or as part of a system (groin field), and they can be constructed of various materials, such as steel, rock, timber or concrete. On Great Lakes shores, groins are generally between 25 and 100 feet (8-30 meters) in length.

The main design features that affect groin performance include height, length, permeability, and spacing between groins. Impermeable high groins do not allow sediment to pass through; permeable groins have structural gaps that allow sediment to move through the structure. It is difficult to design groins that allow sediment to flow through portions of the structures.

Determining the best length of a groin is also difficult. Because the majority of sediment moving along a shore is found between the shoreline and the first sandbar, a groin that reaches the first bar will usually build a substantial beach up-drift but will also have a significant, negative down-drift impact. Determining groin length based on sandbar location is complicated due to the seasonal migration of sandbars.

Groin spacing of two to three times the length of the groin is generally recommended. Groins that are spaced too closely cause sediment to bypass the compartments between groins. Spacing groins too far apart allows erosion of beach material between the groins.



Beach Response to a Groin

The effectiveness of groins in protecting shorelines has been debated for a century and continues. Groins can work effectively where there is abundant sand and gravel moving along the shore and where the spaces between groins are kept filled so that most of the littoral material in the longshore transport passes by the groin or groin field to nourish other coastal properties down the shore. Some agencies require property owners to maintain adequate beach fill in the compartments between groins.

Waves, high water levels, and a lack of sediment supply limit the effectiveness of groins. Groins cannot prevent sediment movement offshore by storm waves. Sediment moves offshore during periods of high water and storms, emptying groin compartments and rendering the groins ineffective when they are most needed. As wave direction changes, the direction of sediment transport changes and may cause the groin(s) to lose material that had earlier been retained. Sediment supply is a critical factor in the functioning of a groin. Climate variations can bring a reversal of the dominant direction of longshore sediment transport and lead to a loss of beach material trapped by a single groin.

The role of groins in the Great Lakes may diminish to occasional attempts to hold a nourished beach in place. Lack of sand and gravel in transport along Great Lakes shorelines hinders groin function. The negative environmental impacts of groins makes their use controversial.

Breakwaters

Breakwaters are built to create areas of sheltered water, reduce the amount of wave energy eroding shorelines and help stabilize beaches. These structures can be located offshore or connected to the shoreline. A set of breakwaters may be connected to shore with steel sheet-pile groins to retain artificially created beaches for recreation and shore protection.

Breakwaters are used to protect large properties with long shorelines, or to protect many properties in a community. A typical breakwater is a large structure that influences the shape of the shoreline for several hundred feet (a hundred meters) on either side of the structure and landward of the structure.

A common type of breakwater is the rubble mound structure. The structure has three layers: rock fill core stone, an under layer to prevent the core stone from moving and to provide seating for the armor layer, and armor (outer) layers to absorb and dissipate the oncoming wave energy.

Breakwaters for captive beaches at Lake Forest, Illinois

Experienced designers shape a breakwater to fit the purpose and environment of the site. The predicted maximum water level range, water depths, lakebed soil properties and conditions, extreme wave conditions, and currents affect the design. Key to the integrity and long life of the structure are the geometry, quality of construction, and durability of the material. Geometry includes the height and length of the structure, slope, sizes of stone, and toe protection details. The quality of construction depends upon the quality and placement of the stone material, especially the armor stone. Freeze-thaw cracking of armor stone threatens the stability and effectiveness of many breakwaters. The amount of contact between adjacent stones and a high degree of interlocking of the armor are crucial for good long-term performance.

Regular monitoring and prompt maintenance of breakwaters is very important. For breakwaters that have been well designed, well constructed and properly maintained, a 25-year design life can be achieved, and in some cases the structure can function as long as 50 years.

Unsuitable shore protection

There is a never-ending search for low-cost or more effective shore protection. It's common to try to make shore protection structures from readily available materials. Many kinds of shore protection devices have been tried that are generally unsuitable for shore and wave energy conditions on the Great Lakes (see sidebar). In the hands of skilled, experienced professionals, some "unsuitable materials" may be suitable for shore protection in conjunction with other measures.

Junk shore protection

Junk shore protection is material that is commonly found in recycling centers, junkyards, or landfills. This material is always unacceptable for shore protection (see sidebar). Some of this material may be toxic to aquatic organisms or become hazardous to swimmers on site and down the coast as the materials move off site.

Proprietary shore protection systems

Proprietary shore protection devices are structures and structure designs that are owned by particular individuals or firms. They are usually patented. They can be effective in a proper environment. However, in the wrong situation, proprietary devices (like other shore protection systems) may not provide adequate protection, or they may increase erosion problems. It is reasonable to expect marketers of such systems to provide substantial evidence for their performance claims. Get a second or third opinion from experts who are not involved in marketing these products.

Most proprietary shore protection systems are based on the same concepts or ideas as historically common shore protection methods. Proprietary shore protection systems may offer new technology, new materials, new installation methods, or new forms that mimic these concepts. An independent professional coastal engineer should be consulted when seriously considering a proprietary system. This expert can give an unbiased opinion on whether or not a proprietary system can work for a particular situation.

junk shore protection

Junk shore protection includes:

- Old cars and parts of cars
- Steel or plastic drums
- Concrete rubble with reinforcing rods or wire
- Wooden pallets
- Steel bedspring frames
- Concrete pours from cement making
- Plastic fencing
- Scrap steel parts, including wire
- Stone-filled grocery carts
- Cast-iron steam radiators
- Stacks of fiberglass sinks
- Rubber tires, loose or bound together
- Appliances
- Barges scuttled in nearshore waters

unsuitable shore protection

Shore protection devices that are generally unsuitable for the high-energy open coast environments of the Great Lakes include:

- Revetments formed of stone or concrete pieces light enough for a strong adult to lift
- Seawalls formed of softball- to basketball-sized stone in wire baskets
- Seawalls made of concrete blocks
- Seawalls made of vinyl sheetpiling in areas with heavy shore ice
- Plastic strands or plastic nets intended to build and retain beaches
- Plate-like concrete rubble from construction demolition
- All-timber bulkheads made of materials purchased at typical building supply stores
- Seawalls made of discarded sewer pipe.
- Sheet pile walls that don't sufficiently penetrate the lake bed
- Sand-filled bags

Environmental Impacts of Shore Protection Structures

Shore protection structures are intended to have an effect on the coast—to stop erosion of uplands or to stop erosion of beaches or both. Shore protection structures can have beneficial impacts by stabilizing beaches and by preventing shore land retreat behind the structures. Shore protection structures are controversial and can impact the shore in undesirable ways. A limited ability to predict the long-term impacts of such structures on other shoreline properties is a concern for designers and for the owners of the structures.

Construction activity in building such structures has temporary, negative impacts. Equipment damages or destroys vegetative cover, beach and nearshore habitat.

The activity may cause short-term and local increases in water turbidity.

Many shore protection structures replace natural, area-based shore defenses with linear defenses. One problem with this substitution is that the area-based erosive attack of storm waves may require an area-based defense.

Natural shoreline defenses break storm waves and absorb their power over the broad areas of shoals, barred lakebeds and beach slopes before the destructive waves reach the highly erodible faces of coastal upland slopes. During storms and periods of high lake levels, some of the mobile material is borrowed from the beach as the defenses are rearranged. When waves subside and water levels drop, the borrowed material may be returned to the beach. Losses of mobile materials are made up by new supplies, unless people, or nature, interfere. Other area-based defenses include bedrock outcrops near shore and on shore.

A negative impact common to all shore protection structures is that the intentional halting of erosion landward of the structures robs the littoral transport system of beach-building materials—sand, gravel and rocks.

Constructed, linear defenses are intentional barriers to the offshore movement of upland beach materials, blocking one of the natural responses to wave attack. Near these barriers, mobile materials are "borrowed" from adjoining unprotected shore slopes, beaches, and the nearshore lakebed to respond to wave attack in front of the linear structures. This borrowing makes neighbors' unprotected coastal properties more vulnerable to damaging wave attack.

Where shore protection structures mimic nature, the defense is like an area-based defense. Examples include confined and maintained beach nourishment, lakebed armoring, armored mini-"headlands" and captive beaches, and submerged nearshore breakwaters.

The negative effects of shore protection structures tend to be greater for structures that are perpendicular to shore than for shore-parallel structures. The negative effects tend to be less for structures landward of the active beach than for structures in the water or at the water's edge. The negative effects also tend to be less for permeable structures than for impermeable structures. The magnitude of a structure's interference with natural sediment movement increases with the length of the structure. An experienced professional is needed to design a structure appropriate to site conditions that maximizes performance and minimizes adverse impacts to client's and neighbors' properties.

Impacts of groins

Modern engineering practice is to combine groin construction with beach nourishment. The intended purpose of a groin or groin field is the retention of beach material, in order to widen or maintain the width of the beach without depriving down-drift properties of beach-building littoral material. The practice is also to keep groins and compartments between groins filled.

There is a short supply of experience in designing groins and groin fields without negative impacts. Negative local and distant impacts include a narrowing of down-drift beaches, an increase in down-drift erosion, and increased lakebed erosion. Groins that are not maintained in a filled condition have beach material accreting on the up-drift side of the barrier with a net loss of beach and nearshore material affecting multiple properties on the down-drift side. The higher and longer a groin is, the more material is captured and the greater the impact on adjacent beaches. The impacted shoreline may continue to lengthen long after construction has been completed. The placement of one groin often leads to the need for another. Before long, a series of groins forms a groin field that will take longer to fill, cause a greater disruption to longshore sediment transport and increase the cumulative effects on properties down the coast.

Negative impacts of groins can be reduced by using short, low-profile groins no higher than the designed or natural beach elevation to allow for overtopping and bypassing of material to the adjacent shoreline. Impacts can be reduced by locating the water end of a groin landward of the shoreward boundary of the breaker zone at high water levels. Frequent changes in direction of longshore transport, changes in water levels, and the erosive nature of storm waves on the Great Lakes combine to empty groin compartments, requiring refilling or increasing negative impacts.

Impacts of seawalls and revetments

The best chances for seawalls and revetments to work with minimal adverse environmental impact is where the structures are placed at the intersection of an upland slope and a broad sandy beach, and where there is a gen-

tle nearshore lakebed slope with abundant longshore transport of sediment. Structures placed landward of the beach will serve as a defense of last resort when rising lake levels and/or severe storms temporarily wipe out natural beach defenses against erosion. During times of falling and low lake levels, wind-blown sand covers some low structures built against the upland slope. Only the sandy beach is visible. Minimal adverse impacts may also be expected where there is minimal longshore sediment transport and an erosion-resistant lakebed. Minimal impacts can be expected where the structure augments natural protection, such as a seawall built on a too-low, sloping bedrock shore.

The closer that a seawall or revetment is to the water, the greater the negative impacts on the protected property and on neighboring properties. Shore protection structures in the water or at the water's edge reflect wave energy, alter longshore currents, and may alter sediment transport. Storm waves can cause localized lakebed scour in front of, and at the ends of, the structures. Deepening of the water in front of a lake-edge seawall or revetment by localized scour or lakebed erosion may undermine the structure and cause it to collapse.

Construction of any shore protection structure that impedes the longshore transport of sediment should be avoided, or approached with extreme caution.

During periods of low water levels, shoreland should not be "reclaimed" by building revetments and seawalls near the receded water's edge to protect beaches, sand ridges, and swales that have emerged while lake levels were declining. Structures built in these locations interfere with the beneficial restoration of natural shore protective buffers and may be destroyed when high lake levels return and storms occur.

Impacts of breakwaters

A nearshore breakwater breaks waves and creates a zone of quiet water on the inshore, sheltered lee side of the structure where a change in habitat and animal communities is likely to occur. Longshore movements of fish may be impeded. This local change in nearshore conditions can contribute to a local degradation in water quality and cause longshore transport to deposit sediments in the sheltered waters. Breakwaters can deflect longshore sediment transport offshore into deep water where the material will not return to the nearshore and to beaches.

Designers shape breakwaters to maximize desired effects and reduce negative impacts. A breakwater may be located lakeward of the normal breaker zone, or the structure length may be made less than the distance between the structure and shore to avoid the creation of a shoreline spit that eventually reaches the breakwater and forms a "tombolo" that blocks longshore sediment transport between the structure and the shore.

Water safety, shoreline aesthetics, altered habitat, and cumulative impacts

Rip currents that are dangerous to swimmers can be formed adjacent to long groins or piers, where structures have altered nearshore bar formation, and within the water cells framed by breakwaters and pocket beaches.

As more shorelines become developed, armored, and exposed at low water levels, the massive appearance of many shore protection structures becomes a growing issue with neighbors and with regulators as the shore loses its natural look.

Shoreline and nearshore habitats on the Great Lakes are important. Shore protection structures may alter habitat for birds and other animals living in nearshore waters and on the beach. Shoreline waters are used by many fish and by organisms on which fish feed. The influence of shore protection structures on these nearshore habitats is poorly understood but could have significant effects on the Great Lakes fishery over long periods of time as such structures multiply.

As shoreline structures multiply along a section or reach of shoreline, cumulative impacts are of growing concern. Cumulative impacts are poorly understood and have had little investigation. The issue can appear in at least three ways: 1) impacts on the shoreline and nearshore from the addition of multiple shore protection structures, 2) a total impact greater than the sum of effects from individual structures, and 3) impacts from one or more structures multiplying over time and distance along a shore.

Private actions, public consequences

Private actions on private property can have public consequences. This is often the case for slope stabilization and shore protection on coastal property. Private actions may adversely affect the properties of neighbors and more distant residents along the coast. The adverse effects are progressive over time and distance. Some of these adverse effects may be undetected, occurring in the midst of shore-land changes caused by winds, water on the land, storm waves, and lake level changes. The public

consequences of private shore protection actions become more significant as coastal investments increase, and beaches diminish.

Distant public and private actions far from any shore protection structure may also be responsible for the losses of beaches and protective nearshore bars. Beach sand and gravel from inland sources are lost or diminished by soil erosion control, construction of dams and breakwaters, harbor deepening (creating sediment traps) and the placement of dredged material containing clean sand and gravel in upland locations or offshore sites beyond the reach of the littoral system.

Working with Engineers and Contractors

Shore protection as a do-it-yourself project is often done as a series of short-term experiments in a vain and costly search for a long-term solution. Qualified and experienced professionals are necessary for finding long-term solutions. They can support the permitting process and help deal with public concerns and neighbors' concerns about a planned project. An investment in these services is the best way to achieve the desired performance, attain the desired life of a project, and reduce costs during the period of ownership.

steps of a shore protection project

- Selection of technical advisor or consultant
- Analysis and design by consultant (detailed below)
- Preparation and submittal of permit applications to regulatory agencies
- Design modifications (if needed) and permit approvals
- Solicitation for bids and selection of a contractor
- Construction
- Monitoring the shore protection at least annually and after major storms
- Repairing and replacing the shore protection as needed

working with a contractor

A typical shore protection contractor will do the following:

- Provide references of clients for whom similar work was done
- Submit a bid to construct the works and execute a construction contract
- Mobilize material and equipment on site
- Provide people to manage and carry out the construction
- Meet on a regular basis with the owner and engineer to review progress and resolve problems as they arise
- Demonstrate that the work is being performed in accordance with the specifications

If an anticipated project is to include slope stability and erosion control, and/or shore protection structures, select only qualified consultants who are experienced in slope stability, erosion control, and/or shore protection design. Such consultants are typically geotechnical or coastal engineers. They should also be registered and licensed to practice in the state or province where the work is to be done. Licensing requires proof of significant experience and indicates an expected high level of professional conduct.

A slope stabilization/shore protection project that goes beyondrevegetation and surface-water control generally follows the steps shown in the sidebar.

Nearly all of the property owner's decisions that affect the final cost will be made with the engineer before the structure is built. The decisions include: what slope stabilization option to accept, which structure option to choose, and whether or not to accept a set of plans. Bids need to be solicited from contractors and accepted or rejected. The decisions will affect initial cost, maintenance costs and the expected life of the protection system. During construction, the engineer can represent the owner in administration of the contract and monitoring work in progress. The engineer can do periodic post-construction monitoring of the slope and structure condition.

The contractors (and subcontractors) should be experienced in the work they are expected to do, whether

working with a designer

The following list indicates what a coastal property owner can reasonably expect from a competent experienced designer of shore protection structures:

- References of clients for whom similar work was done
- A stated specific life expectancy (design life) based on the owner's needs
- A statement of specific extreme combinations of storm water levels and storm wave conditions used in design, with a stated level of damage acceptable to the owner
- A statement of the percentage chance that excessive damage will occur over the expected period of ownership
- A design that addresses potential wave scour and lakebed erosion issues
- A plan to avoid or accommodate overtopping by storm waves in a way that minimizes damage
- Evidence of flank protection for both ends of the structure
- A design of a sound structure foundation to prevent structural settling and loss of soil landward of the structure
- Plans that include dimensions of the structure referenced to a water level measurement stated in feet or meters above or below a particular stated Great Lakes datum
- A written statement explaining how the design takes into account the possibility of creating adverse environmental effects on neighboring shore properties and identifies measures to be taken to minimize this potential
- A written statement of steps to be taken by the design professional and the contractor to ensure adequate quality of construction
- A written statement of the need for inspection and repair/replacement of damaged structure portions following major storm events
- A written statement of the regulatory issues that need to be addressed

Some of the items in the list apply to plans for nonstructural measures

selecting and planting vegetation, constructing for groundwater control and slope stabilization, or constructing waterfront works, such as armor-stone structures and seawalls. The contractor is responsible for taking the design prepared by the engineer and carrying out the project in conformance with the plans and specifications. A contractor can be expected to provide the services listed in the box on page 32.

The importance of obtaining a competent contractor to build to the engineer's plan cannot be overstated. Request names and contact previous customers of contractors being considered for a project: customers for whom similar work was done.

Do not assume that the contractor with the lowest bid should be awarded the construction contract. A low bid may reflect inexperience in construction of coastal works. If the construction quality is poor, the constructed or reconstructed project will require a high degree of maintenance (or replacement), resulting in long-term costs that may be higher than the overall costs of an adequate protection system. Coastal construction on the land/water boundary of the Great Lakes is a specialty.

THE ECONOMICS OF PROTECTING YOUR COASTAL INVESTMENT

The economics of protecting coastal property are important to people seeking long-term coastal property investments for a future retirement home, for profitable resale, or to pass along to children and grandchildren. Choices that prospective buyers of coastal property make affect the future fate and value of their investment. When buyers compete for more desirable properties (including less risky investments), property prices will be bid up. Buyers desire coastal buildings that are secure from the hazards of flooding and erosion.

shores, low-lying shores with flood hazards, and sandy shores with fine recreational beaches. Important attributes that have significant effects on coastal property value are included in the box below.

The best coastal properties for investment on Great Lakes erodible shores have deep lots with large setback distances between existing buildings and the edges of coastal slopes or ample spaces for new buildings with large setback distances.

There are at least two ways to recover property value lost to erosion. One way is to relocate a threatened house further from the lake. The other way is to construct shore protection.

Shoreline Property Features and Value

The physical characteristics of coastal property safe from flooding and erosion are well known. The effects of these characteristics on market value are less known. There is some information from studies of Great Lakes coastal real estate markets in Michigan, Ohio and Wisconsin. The information applies to informed buyers of property with erodible bluff and bank shores but not to uninformed buyers, nor to the less-common rocky

property value influences

Coastal property features that influence property value include:

- Lakefront location
- Severity of a coastal erosion hazard
- The presence of shore protection
- Risk of flooding
- Spaciousness of the house and property
- Age of house
- Type of construction
- Neighborhood attributes
- Accessibility attributes: distance to shopping, workplace, entertainment, etc.
- Amenities: fireplaces, number of bathrooms, etc.

Lakefront location adds about 50 percent value to Great Lakes shore property compared with a similar house and lot at a nearby inland location. Property value decreases as shoreline erosion brings the edge of a coastal slope closer and closer to a building. This decrease in value is more noticeable and occurs earlier in the Great Lakes region than in Pacific, Atlantic and Gulf Coast regions of the United States. Property value losses accelerate as erosion proceeds and the time until a coastal building becomes uninhabitable dwindles. A house is given an extended lease on life (and greater value) when it is relocated landward to a new site. Such an increase in value may be greater than the costs of relocation.

A building that can be easily relocated is the best type of building to build or buy where erosion has taken away much of the remaining setback space and time before a building site is threatened with loss.

The presence of recognizable, high-quality shore protection adds value to coastal property. This fact is known from studies involving constructed shore protection and seems likely to be true for natural shore protection as well. Shore protection structures that have been designed to be effective and arrest erosion for 25 years will restore more property value than shore protection that is not designed and is likely to arrest erosion for only 10 years. As coastal property becomes much more valuable, larger investments are economically justified in pursuing the best options for protecting coastal investments.

From a community perspective, the added value of shore protection to the property owner may be offset by

declining property values of inland and adjoining neighbors if the armor degrades an accessible recreational beach or creates adverse effects (increased erosion, disappearance of beach) on neighboring property. There are negative economic effects of armoring just as there are negative environmental effects.

In circumstances where coastal property owners want to work cooperatively to improve shore protection and are individually willing to contribute at least the cost that their participation imposes on the group, each owner is likely to realize higher net economic benefits than if he/she had acted alone.

Ordinances restricting how close buildings can be placed to the lakeward edge of a bluff or bank cannot be assumed sufficient to protect long-term coastal investments.

Discounting of property value for erosion hazard increases markedly as a house becomes visibly and obviously endangered. Similarly, the recovery of property value with relocation of a house or construction of a shore protection structure is greater when the action is taken at the time of danger rather than long before the danger becomes obvious. One problem with waiting to take action is that in many places erosion doesn't occur incrementally in small predictable losses but massively in large, unpredicted slump blocks. Another problem with waiting to act is that building movers may refuse to bring heavy equipment on site when erosion has proceeded to a stage where the danger is obvious to the property owner. Waiting too long to act is one of several reasons for houses falling over faces of Great Lakes bluffs.

Will Government Regulations Protect a Coastal Investment?

It is common for governments to adopt shoreland ordinances that limit how close buildings can be built to the edges of coastal bluffs and banks along the Great Lakes. In some places this coastal buffer of unbuildable land is called an environmental corridor, or an erosion hazard zone, or erosion hazard area. Such buffers have environmental benefits and contribute to the value of adjacent property.

The widths of coastal environmental corridors are picked for environmental reasons. The corridors also provide protection for buildings on the landward side of the corridors. However, such corridors may not be adequate for protection of coastal buildings. The selection of coastal erosion hazard areas is based on compromises with competing desires: a) a desire for consistency with earlier planning horizons, b) a desire to avoid creating "unbuildable" lots already platted, c) a desire to avoid litigating a "taking" of private property, and d) a desire to provide long-term safety for coastal buildings. Governments' incentives to avoid litigation tend to be stronger than incentives to provide safe distances between buildings and the dynamic boundary of the Great Lakes. It is common for governments to grant variances for coastal construction setback requirements.

A common situation where variances are considered and granted is an application for construction on land between lots where buildings exist that don't meet present minimum setback requirements. Shore erosion in front of neighboring older buildings has used up some of the distance and time until those buildings are threatened. A common variance method is averaging of the existing setback distances on either side of the applicant's property and using that average distance as the setback required on the applicant's lot.

Such setback variances fail to bring reduced risk of damage from erosion to new construction in developed areas where risk reduction may be most needed. Limiting setback variances to coastal properties with easily relocatable buildings is one way to lessen future risk of damage and loss from erosion.

limits of setback averaging

Setback averaging on eroding shores:

- Shortens the time until erosion poses a threat to the new building
- Perpetuates past, unwise building site decisions
- Allows the construction of new buildings at distances that are not adequate for the useful lives of the new structures

Costs of Shore Protection

It is tempting to choose shore protection structure bids based on initial costs without knowing the expected life of the structure and expected maintenance costs during that lifetime. The lifetime costs of a well-designed structure with a higher initial cost may be less than the lifetime costs of a poorly designed structure with a lower initial cost. Where coastal property values have been rising faster than construction costs, the cost of shore protection is becoming a smaller percentage of coastal investments. Some of the shore protection strategies mentioned in this booklet may be more effective, and less costly, if done cooperatively. A common group effort to construct shore protection structures can sometimes save between 20 to 40 percent compared with the costs of acting alone. An experienced professional can develop cost comparisons for property owners.

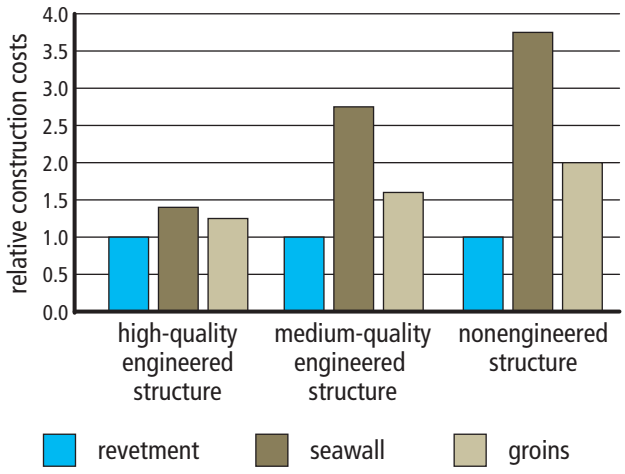
Initial costs

The graph shows the relative costs of three typical types of shore protection structures—revetment, seawall, and groin—for three different levels of design. The initial construction costs considered in this graph are labor and material costs. Preparation costs, such as site clearing, excavation, grading, splash aprons and drainage systems are not included here. Neither is the cost of periodically filling and refilling groins included.

Maintenance costs

Maintenance costs depend on past decisions and actions by a property owner—the design and construction quality, and the frequency of inspection and minor maintenance. Maintenance costs also depend on physical environmental factors (such as the frequency and severity of storms, range of lake levels) beyond the control of a property owner. Regular maintenance will maintain the performance and durability of the structure and lengthen its useful life.

Experienced contractors and consulting engineers have some idea of the relative magnitude of monitoring and maintenance costs to expect for particular types of structures in particular environments. For example, one suggested rule of thumb is that the average annual inspection, maintenance and repair cost for armor stone shore protection along the margins of the Great Lakes ranges from 2 to 5 percent of the initial construction cost for well-engineered structures. For an engineered, well-built structure, replacement may come in 20 years—a common design life. For a nonengineered structure, the useful life is difficult to estimate.



Relative Construction Costs of Shore Protection Structures

The cost to remove and dispose of old riprap may be 75 to 100 percent of the cost of placing new riprap. The cost to remove and dispose of old sheet pile may be 50 to 100 percent of the cost of installing new sheet pile. Extra costs may be incurred because of weather interruptions and delays, limited access to the site, costs of equipment mobilization and demobilization, extent of work required, and labor costs.

Risk Management

Risk exists whenever and wherever there is a variability of outcomes associated with an event or situation. Risk management can be applied to any situation in which there is risk. Many people with a long-term ownership or investment interest in coastal property face a risk of property damage or loss. The risk exists because

the risk managment process

- Specify problems and opportunities
- Identify and assess exposures
- Formulate alternative plans
- Evaluate potential effects
- Compare alternative plans
- Select and implement plan(s)
- Monitor

A Great Lakes beach during low water levels

the investment is in close proximity to powerful natural forces that are not adequately understood and are not controllable.

The following section briefly describes each of the steps of the risk management process applied to coastal erosion. Professional advice is needed in following this process.

Risk management is the patient practice of following a cycle of steps that will control one's exposure to losses.

Step 1: Specify Problems and Opportunities: The property owners need to identify objectives. Was the property purchased for the superior location and view? Was the property purchased as a long-term investment or as a short-term investment in order to turn a profit at resale? Be actively involved in stating problems and identifying opportunities. One common problem is a home (or other building) threatened by coastal erosion. One opportunity is to add amenities and value to the property when implementing some measure to reduce the erosion risk.

Step 2: Identify and Assess Exposures: The consultant will determine what property characteristics could prevent the property owners from meeting their property goals. The consultant will determine how susceptible the property is to erosion loss and how soon a building is likely to be threatened by structural instability from erosion. It seems reasonable and desirable to compare the erosion risk to buildings on coastal property with other long-accepted risks to buildings on all kinds of properties. The probabilities of such risks occurring can be compared, with the assistance of professionals.

Steps 3-5: Formulate Alternative Plans, Evaluate Potential Effects and Compare Alternative Plans: From a property owner's perspective, these steps can be lumped into one category. The consultant develops and analyzes the options available for minimizing the chances of erosion loss. The consultant determines which options will provide the most erosion protection with the fewest negative effects. The property owners should indicate how much money they are willing to spend to minimize this loss.

Step 6: Select and Implement Plan: The property owners choose a plan based on (a) costs, (b) levels of erosion reduction, and (c) effects on the owners' objectives. After the erosion control plan is selected, the consultant arranges for it to be put into practice.

Step 7: Monitor: Regular monitoring is an essential element in managing risk in coastal investments. This step begins as soon as the selected plan has been put into effect. The property owners take the greatest responsibility for the erosion risk management by inspecting (or contracting with the consultant to inspect) the property at regular intervals to look for any changes that might increase the likelihood of erosion loss. The consultant should develop a checklist of erosion warning signals. If the condition of the property has changed, prompt corrective action may be required.

Remember that coastal erosion risk management is an ongoing process. With the help of coastal professionals

and proper usage of the risk management process, coastal property owners can meet their underlying objectives of secure property investment.

Accounting for Climate Change

The success of strategies for protecting coastal investments depends in part on the nature of climate changes during the period of property ownership. Will the effects of climate changes come soon? Will there be more, or fewer extreme precipitation events? Will lake levels be higher or lower than historic levels? Will storm events be more or less severe, more or less frequent?

Adaptation strategies for shore protection should be easier if climate change brings slow change, lower lake levels, fewer extreme precipitation events, and fewer extreme storm wave events. These strategies become more challenging if damaging storm waves riding in on high lake levels hammer the shore as they did in the early 1970s and mid-1980s, if more extreme precipitation events occur, or if effects of climate change come quickly.

The same Great Lakes beach shown on page 37 during high lake levels

levels. Armor-stone structures will experience more rapid disintegration if climate change brings to winters a greater frequency of freezing and thawing cycles.

There has been a lot of experience in dealing with high lake levels over the last half of the last century, but relatively little experience with low lake levels.

Most shore-side facilities on the Great Lakes were designed and sited for the climate conditions that existed at the time. It is a challenging task to adapt lakeside power plants, water intakes, pumping stations, sewage treatment plants, industrial plants, harbors and marinas to lake levels and storm conditions beyond the ranges for which they were designed. Adaptation is also a challenging task for owners of old homes on small lots and owners of large, new homes close to the lakes on the edges of eroding coastal slopes if climate change brings high water levels and greater or more frequent storm events.

Restoration of protective beaches, dunes and ridges will become easier if climate change brings low lake levels, but only where there are ample sand and gravel deposits near shore. There has been a loss of beach-building materials due to coastal armoring, soil loss control on basin lands and upland placement of clean dredged material. Restoration of coastal wetlands may become difficult if water levels drop below historic low levels.

Armoring will become more challenging if climate change brings more frequent or more intense storm wave events, or if lake levels return to, or exceed historic high

One approach to climate change is to base shore property development and protection decisions on the historical record of erosion (if known) with an allowance for future extreme lake levels and storms, beyond those of the historical record. A statistical study (like the one mentioned in "Future Climate Effects on Lake Levels") can be useful.

A second approach is an incremental adaptive approach that recognizes the short-term risk: water levels can change more than three feet (more than one meter) over several years. It is important to learn about the latest results from modeling of climate change and plausible water-level change scenarios, particularly with respect to the timing, magnitude and direction (higher or lower water levels) of the change. Climate change could bring occasional periods of high water levels, even if low water levels become common. It's also important to watch for predictions about changes in the intensity and frequency of storm and precipitation events. A risk assessment can then be made based upon the expected economic life of the coastal investment and the timing of expected climate changes.

SUMMARY

Owners of property along the edges of the Great Lakes have land with soil characteristics left by ancient glaciers and larger old lakes with much higher and lower water levels. There is a lot of variation in soil properties from lot to lot and from lake to lake. Shore property owners also have land with a wide range of natural shore and slope protection—in some places insufficient—making human intervention necessary.

Water on and in the land, waves, wind, and below-freezing air temperatures work in concert to alter coastal slopes, undermine and destroy built shore protection, flood beaches and low-lying land, or expose beaches and nearshore lakebed.

Lakefront location appears to add about 50 percent to the value of Great Lakes residential shore property compared with the value of similar property at a nearby inland location. A safe distance between a coastal home and the edge of its coastal slope property is of greater economic value than proximity to the shore or size of the home. A coastal house imperiled by erosion gains economic value and a new lease on life when relocated, or when slope and shore protection is constructed.

Many people who own coastal property face a risk of property damage or loss because their investment is in close proximity to erratic powerful natural forces. Risk management should be applied to coastal property ownership to minimize the adverse consequences of risk. The seven common steps of risk management are relevant to all sizes of coastal property from unbuilt lots to major developments. The most neglected element in coastal risk management is regular monitoring to detect changes that may increase the likelihood of loss.

Water and wind combine to rearrange the margins of the coastal lands around the Great Lakes.

The best responses to natural processes that threaten coastal buildings and other land structures are a mix of adaptation to the processes, restoration of natural shoreline defenses, and slowing erosion. These responses are challenging when climate change brings rapid change, high water levels and storm events of greater frequency or intensity and where the depth of coastal lots is marginal for relocation of existing buildings and selection of large setback distances for new buildings. These responses are easier when climate change brings slow change, low water levels and less frequent or less intense storms and where coastal lots are spacious.

Armoring the shore should always be a measure of last resort. Armoring is not a one-time action but requires constant monitoring and occasional repair or replacement. Armoring has impacts on neighboring properties—many of them negative impacts. Shore protection along the open coasts of the Great Lakes is no longer a "help yourself" situation in many places. Armoring and slope stabilization are complex activities that need the services of experienced engineers and contractors.

Climate change should be anticipated in making and safeguarding coastal property investments. There are several possible approaches. One is a conservative approach that allows for greater extremes in lake level, ice conditions, precipitation and storm intensity and frequency than those of historical record. Another approach is an incremental adaptive approach that responds to climate changes as they happen.

The practice of building close to the edges of erosive coastal slopes should be discouraged because it minimizes a natural buffer distance that is needed to keep risk management options open and to accommodate climate changes that are more extreme than the climate conditions encountered during the historical period of coastal settlement.

WHERE TO GO FOR MORE INFORMATION

Most of these sources have Web sites.

Climate change, or its effects on Great Lakes lake levels

Adaptation and Impacts Research Group, Atmospheric Environment Service, Environment Canada

Canadian Climate Impacts and Adaptation Research Network

Climate Prediction Center, NOAA National Weather Service,

Great Lakes Environmental Research Laboratory, NOAA

Intergovernmental Panel on Climate Change (IPCC), United Nations Environmental Program

National Academy Press Publications Catalog, National Academy of Sciences

Pew Center on Global Climate Change

U.S. Environmental Protection Agency

U.S. Global Change Research Program

World Meteorological Organization (WMO)

Great Lakes information

Great Lakes Hydraulics and Hydrology Office, Detroit District, U.S. Army Corps of Engineers

Great Lakes Information Management Resource (GLIMR), Canada Centre for Inland Waters

Great Lakes Information Network (GLIN), Great Lakes Commission

Great Lakes water levels

Canadian Hydrographic Service, Department of Fisheries and Oceans, Canada (present and forecasted levels)

Center for Operational Oceanographic Products and Services, National Ocean Service, NOAA

Great Lakes Environmental Research Laboratory, NOAA

Great Lakes Hydraulics and Hydrology Office, Detroit District, U.S. Army Corps of Engineers (present and forecasted levels)

Marine Environmental Data Service, Department of Fisheries and Oceans, Canada

Great Lakes storm surges

Conservation Authorities and Water Management Branch, Ontario Ministry of Natural Resources

Great Lakes Environmental Research Laboratory, NOAA (storm surge planning program software)

Great Lakes Hydraulics and Hydrology Office, Detroit District, U.S. Army Corps of Engineers (storm surge statistics)

Great Lakes wave conditions

National Data Buoy Center, National Weather Service, NOAA (present and recent wave and wind conditions)

Wave Information Studies of US Coastlines (WIS reports) Publications. Coastal and Hydraulics Laboratory, Research and Development Center, U.S. Army Corps of Engineers (wave statistics)

Ice on the shore

Ashton G. D. *River and Lake Ice Engineering*. Water Resources Publications

Assel R. *Great Lakes Ice Atlas*, Great Lakes Environmental Research Laboratory, NOAA

Cold Regions Research and Engineering Laboratory, U.S. Army Corps of Engineers

Engineering Manual, Publications (1986) *Ice Engineering*. U.S. Army Corps of Engineers

Relocating buildings

International Association of Structural Movers

Midstates Housemovers Association

Minnesota Building Movers Association

Ontario Structural Movers Association

Strategies of adaptation, restoration, moderation and armoring in shore protection

Coastal Engineering Manual (May 2002) Part V, Chapter 3. Shore Protection Projects. Coastal and Hydraulics Laboratory, Engineer Research and Development Center, Waterways Experiment Station, U.S. Army Corps of Engineers. CD-ROM version from Veri-Tech, Inc., expected in fall 2003.

Ontario Ministry of Natural Resources (2001) *Great Lakes-St. Lawrence River System and large inland lakes, Technical guides for flooding, erosion and dynamic beaches in support of natural hazards policies 3.1 of the provincial policy statement*. CD-ROM. Watershed Science Centre Trent University, Peterborough, Ontario.

Ontario Ministry of Natural Resources (2001) *Understanding Natural Hazards*. 40-page booklet.

Pope J. (1997) *Responding to Coastal Erosion and Flooding Damages*. Journal of Coastal Research, vol. 13, No. 3, pages 704-710.

Nourishing beaches

North Carolina Shore and Beach Preservation Association

San Diego Association of Governments (SANDAG)

Shore and Beach. Journal of the American Shore and Beach Preservation Association

Vegetating the shore

Massachusetts Wetlands Restoration Program

Washington State Department of Ecology Shorelands and Coastal Zone Management Program, publication titled *Controlling Erosion Using Vegetation.*

Wisconsin Department of Natural Resources

Rehabilitation of wetlands

Association of State Wetland Managers, Inc.

Environmental Concern, Inc.

Society for Ecological Restoration

Society of Wetland Scientists

Wilcox, D.A., Whillans, T.H. (1999) *Techniques for Restoration of Disturbed Coastal Wetlands of the Great Lakes*, Great Lakes Science Center, U.S. Geological Survey, Ann Arbor, Michigan and Environmental and Resource Studies, Trent University, Peterborough, Ontario, Canada

Soils in coastal properties

Well drilling contractors' drilling records can typically be obtained from a county health department, county registrar of deeds, highway department, or from the contractors who drilled the wells.

Slope stabilization

Abrahamson, L. W., et al. (2002) *Slope stability and stabilization methods.* 2nd edition, John Wiley and Sons, NY, 712 pages.

Gray D. H. and Sotir R. B. (1996) *Biotechnical and Soil Bioengineering Slope Stabilization.* John Wiley and Sons, Inc., New York. 375 pages.

International Consortium on Landslides, Landslide Section, Japan

International Erosion Control Association

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Caulk A.D., Gannon J.E., Shaw J.R, and Hartig J.H. (2000) *Best Management Practices for Soft Engineering of Shorelines.* Greater Detroit American Heritage River Initiative and Partners, Detroit, Michigan.

Environmental Protection Agency and the Queensland Parks and Wildlife Service. Queensland Wildlife Parks Association

Northern Prairie Wildlife Research Center

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Washington State Department of Ecology Shorelands and Coastal Zone Management Program, Controlling Erosion Using Vegetation

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McConnell, K. (1998) *Revetment systems against wave attack: A design manual.* Thomas Telford Ltd., London, UK.

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Thorn, R.B. and Roberts, A. (1981) *Sea defence and coast protection works: A guide to design.* Thomas Telford Ltd., London, UK.

Watershed Science Centre and Ontario Ministry of Natural Resources (2001) *Great Lakes-St. Lawrence River System and large inland lakes, Technical guides for flooding, erosion and dynamic beaches, etc.* CD-ROM.

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Kraus N. C. and Pilkey O.H. (1988) *Journal of Coastal Research.* Special issue No. 4.

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Kraus N.C. and MacDougal W.G. (1996) *The effects of seawalls on the beach: Part I. An updated literature review.* Journal of Coastal Research, No. 12. p. 619-701.

Proceedings, Coastal engineering conferences. American Society of Civil Engineers

Finding qualified consultants

For the Qualification Based Selection (QBS) procedure for selecting a consultant, contact the

Wisconsin Association of Consulting Engineers, Madison, Wisconsin. A free QBS manual can be read or downloaded from the Internet. Do a Web search for "ACECWI"

Consulting engineers in Ontario. Contact the Consulting Engineers of Ontario (Phone: 416-620-1400) to learn of firms with capabilities in coastal engineering. Check with Professional Engineers Ontario to determine if particular consultants are members in good standing.

Consulting engineers and geologists in the United States. In the Yellow Pages of phone books, look for registered professional engineers under: marine engineers, consulting engineers, civil engineers, environmental engineers, or coastal engineers. To find registered professional geologists or geoscientists look in the Yellow Pages. Contact state and provincial associations of these professionals. One such association is the American Institute of Professional Geologists (AIPG). The association has a web page with links to various state sections of the association.

Risk management

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Heinz, H. J. III Center for Science, Economics and the Environment (2000) *The hidden costs of coastal hazards: Implications for risk assessment and mitigation*. Island Press, Washington D.C.

Institute for Business and Home Safety (IBHS). Boston, Massachusetts

Institute for Catastrophic Loss Reduction (ICLR). University of Western Ontario, London, Ontario, Canada

Jones C. P. and Rogers, S. M. Jr. (2001) *Establishing standards for building setbacks: incorporation of erosion rate variability*. Proceedings, Solutions to Coastal Disasters Conference. American Society of Civil Engineers.

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AGENCIES THAT REGULATE GREAT LAKES SHORELANDS

ILLINOIS

Illinois Department of Natural Resources
Office of Water Resources
James R. Thompson Center
100 W. Randolph Street, Suite 5-500A
Chicago, Illinois 60601

INDIANA

Information on shore protection
Lake Michigan Specialist
Indiana Department of Natural Resources
Division of Water
100 West Water Street
Michigan City, Indiana 46360
Phone: 219-874-8316

Indiana Department of Natural Resources
Public Education and Outreach Section (information)
Division of Water (regulation)
402 W. Washington Street, Room W264
Indianapolis, Indiana 46204
Phone: 317-232-4160 or 1-877-928-3755

Indiana Department of Environmental Management (regulation)
504 N. Broadway, Suite 418
Gary, Indiana 46402
Phone: 219-881-6712

Environmental Manager
Indiana Department of Environmental Management (regulation)
100 North Senate Avenue
P.O. Box 6015
Indianapolis, Indiana 46206
Phone: 317-232-8603 or 1-800-451-6027

Supervisor Residential Sewage Disposal (regulation)
Sanitary Engineering
Indiana State Department of Health
2 North Meridian Street, 5-E
Indianapolis, Indiana 46204
Phone: 317-233-7177

MICHIGAN

Michigan Department of Environmental Quality
Geological and Land Management Division
P.O. Box 30458
Lansing, Michigan 48909-7958
Phone: 517-373-1170

Permit applications should be obtained from the web site or from:
Michigan Department of Environmental Quality
Geological and Land Management Division
Permit Consolidation Unit
PO Box 30204
Lansing, Michigan 48909-7704

MINNESOTA

Minnesota Department of Natural Resources
Division of Water
DNR Building, 3rd Floor
500 Lafayette Road
St. Paul, Minnesota 55155
Phone: 651-296-4800

NEW YORK

New York State Department of Environmental Conservation
Bureau of Flood Protection
625 Broadway
Albany, New York 12233-3507
Phone: 518-402-8151

OHIO

coastal consistency, shore structure permits, coastal erosion area permits, submerged land leases, site visits
Ohio Department of Natural Resources
Office of Coastal Management
P.O. Box 373
Sandusky, Ohio 44871-0373
Phone: 419-626-7980
TOLL FREE: 888-644-6267

information on coastal erosion areas, Lake Erie geology and geologic processes, and site visits
Ohio Department of Natural Resources
Division of Geological Survey
Lake Erie Geology Group
1634 Sycamore Line
Sandusky, Ohio 44870-4132
Phone: 419-626-4296
TOLL FREE: 888-644-6267

water quality certification
Ohio Environmental Protection Agency
Division of Surface Water – 401/Wetlands Unit
P.O. Box 1049
Columbus, Ohio 43216-1049
Phone: 614-644-2001

PENNSYLVANIA

Pennsylvania Department of Environmental Protection
Bureau of Watershed Conservation
Watershed Support Division
Coastal Zone Management Program
Rachael Carson State Office Building
P.O. Box 2063, 400 Market Street
Harrisburg, Pennsylvania 17105-2063
Phone: 717-772-4785

Pennsylvania Department of Environmental Protection
Office for River Basin Cooperation
Coastal Zone Management Program
Rachael Carson State Office Building
P.O. Box 2063, 400 Market Street
Harrisburg, Pennsylvania 17105-2063
Phone: 717-772-4785

WISCONSIN

Wisconsin Department of Natural Resources
Bureau of Watershed Management
P.O. Box 7921
Madison, Wisconsin 53707
Phone: 608-267-7694

U.S. FEDERAL AGENCIES

Information on Great Lakes water levels and general information on their shoreline impacts:
U.S. Army Corps of Engineers, Buffalo District
1776 Niagara Street
Buffalo, New York 14207
Phone: 716-879-4104

U.S. Army Corps of Engineers, Chicago District
111 North Canal Street
Chicago, Illinois 60606-7206
Phone: 312-353-6400

U.S. Army Corps of Engineers, Detroit District
477 Michigan Avenue
Detroit, Michigan 48226
Phone: 313-226-6440

U.S. Army Corps of Engineers,
Great Lakes Regional Office
111 North Canal Street, Suite 1200
Chicago, Illinois 60606
Phone: 312-353-4333

ONTARIO

The starting place is the local Conservation Authority. They assist individual landowners with technical assistance and/or provide a list of qualified people who may help. The Conservation Authority does the pre-screening to determine whether or not they can handle the permitting issues themselves or whether to defer to the provincial and federal agencies. See the Conservation Ontario Web site for a list of the 36 Ontario Conservation Authorities, their addresses and Internet Web sites.

Ontario Ministry of the Environment
Water Policy Branch
40 St. Clair Avenue West, 12th and 14th Floors
Toronto, Ontario M4V 1M2
Phone: 416-314-3923

Ontario Ministry of Natural Resources
Peterborough Regional Office, 4th Floor
300 Water Street
P.O. Box 7000
Peterborough, Ontario K9J 8M5
Phone: 705-755-2500

Canadian Federal Agencies

Fisheries and Oceans Canada handles concerns about fisheries habitat impacts, The Canadian Coast Guard ensures that navigation is unimpaired, INAC is involved where First Nations lands may be impacted.

Canadian Coast Guard
201 North Front Street
Suite 703
Sarnia, Ontario N7T 8B1
Phone: 519-383-1865

Department of Fisheries and Oceans
Canadian Hydrographic Service
867 Lakeshore Road
P.O. Box 5050
Burlington, Ontario L7R 4A6
Phone: 905-336-4844 (water levels)
905-639-0188 (fisheries habitat)

Indian and Northern Affairs Canada (INAC) -
Ontario Region
5th Floor, 25 St. Clair Avenue East
Toronto, Ontario M4T 1M2
Phone: 416-973-6234

GLOSSARY OF COASTAL ENGINEERING TERMS

A more complete glossary can be found at the Publications web page of the Coastal Hydraulics Laboratory, U.S. Army Corps of Engineers under the Coastal Engineering Manual (CEM). Many of the following definitions come from or are modified from this source.

ACCRETION (of a beach) – Buildup of a beach by waterborne and/or airborne material, usually sand, gravel and larger stones.

ALONGSHORE (LONGSHORE) – Parallel to and near the shoreline.

AQUIFER – Soil layers through which water readily flows.

ARMOR STONE (ARMOR LAYER) – A number of relatively large quarrystone or concrete pieces that form primary wave protection on the outer surfaces of shore protection structures.

ARMORED SHORE – A shore with natural or constructed shore protection.

BEACH NOURISHMENT – The process of replenishing a beach with material (usually sand) obtained from another location.

BACKSHORE (BACKBEACH) – That zone of the shore or beach lying between the foreshore and the coastline comprising the BERM or BERMS and acted upon by waves only during severe storms, especially when combined with exceptionally high water.

BANK – A slope with relatively simple soil structure (and simple erosional processes) rising from the backshore of a beach with an elevation of 20 feet (6 meters) or less above the backshore elevation.

BAR – A submerged or emerged embankment of sand, gravel, or other unconsolidated material formed on the lakebed in shallow water by waves and currents.

BATHYMETRY – The measurement of depths of water in oceans, seas, and lakes; also information derived from such measurements.

BAY – An extension of a lake or ocean into a recess in the shore.

BEACH – The zone of unconsolidated material (usually sand, gravel, or larger stones called "shingle") that extends landward from the low water line to the place where there is marked change in material, or to the line of permanent vegetation (usually the effective limit of storm waves). A beach includes FORESHORE and BACKSHORE.

BEACH EROSION – The carrying away of beach materials by wave action, currents, or wind.

BEACH FACE (FORESHORE) – The section of the beach normally exposed to the action of the wave uprush.

BEACH FILL – Material placed on a beach to re-nourish eroding shores.

BEACH MATERIAL – Granular sediments (sand, stones) moved by the water and wind to the shore.

BEACH RIDGE – A nearly continuous mound of beach material that has been shaped by wind and waves. Ridges may occur singly or in multiple, approximately parallel forms.

BEACH WIDTH – The horizontal dimension of the beach measured perpendicular to the shoreline, from the still water level to the landward limit of the beach.

BEDROCK – The solid rock underlying soil and sediment, appearing at the surface where these materials are absent.

BERM – A nearly horizontal plateau on a beach face or backshore, formed by waves and wind.

BLUFF – A slope with relatively complex soil structure or complex erosional processes, rising from the backshore of a beach with a crest elevation of 20 feet (6 meters) or more above the backshore elevation. Bluffs are sometimes defined as high, steep banks or cliffs.

BLUFF RECESSION – The retreat of a bluff due to erosion.

BOULDER – A rounded rock more than 10 inches (25 centimeters) in diameter.

BREAKER – A wave breaking on a shore, over a reef, etc. Breakers may be classified into four types:

COLLAPSING – Breaking over the lower half of the wave.

PLUNGING – The crest curls over an air pocket and breaking usually occurs with a crash of the crest into the preceding wave trough.

SPILLING – Bubbles and turbulent water spill down front face of wave. The upper 25 percent of the front face may become vertical before breaking. Breaking generally occurs over quite a horizontal distance.

SURGING – The wave peaks up, and slides up the beach face with little or no bubble formation.

BREAKER ZONE – The area within which waves approaching the coast begin to break; typically landward of 16-33 feet (5-10 meters) water depths.

BREAKWATER – A structure protecting a shore area, or water area, from waves.

BULKHEAD – A structure or partition to retain or prevent sliding of the land. A secondary purpose is to protect the upland against damage from wave action.

CHART DATUM – A plane or level to which water depth soundings, land and structure elevations are referenced. Also known as LOW WATER DATUM in the Great Lakes.

COAST – A strip of land of indefinite width (may be several kilometers) that extends from the shoreline inland to the first major change in terrain features. The land regarded as near the shoreline.

COASTAL PROCESSES – Natural forces and processes that affect the shore and the nearshore lakebed.

COASTLINE – The boundary between coastal upland and the shore.

COBBLE (COBBLESTONE) – Loose stone, larger than gravel: approximately three to more than 10 inches (about six to more than 25 centimeters) in diameter.

COHESIVE SEDIMENT – Sediment with significant amounts of clay, having properties that cause the materials to bind together.

CREEP – Very slow, continuous down slope movement of soil or debris.

CREST – The highest point on a wave, beach face, berm, ridge, hill or shore structure.

CRITICAL ZONE – The soil mass within a slope where potential failure surfaces exist and where landslides may occur.

CURRENT – A flow of water. This flow may be persistent (as in a stream) or temporary (as a wind driven current).

CURRENT, COASTAL – One of the offshore currents flowing generally parallel to the shoreline in the deeper water lakeward of the surf zone; may be caused by seiche, winds, or re-distribution of water mass.

CURRENT, LONGSHORE – The littoral current in the breaker zone moving essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline.

DATUM (DATUM PLANE) – Any line or surface used as a reference for elevations.

DEEP-WATER – Water so deep that surface waves are little affected by the lakebed. Generally, water deeper than one-half the surface wavelength is considered deep water.

DOWNDRIFT – The direction of predominant movement of littoral materials.

DOWNCUTTING – Erosion of the lakebed.

DUNES – Ridges or mounds of loose, wind-blown material, usually sand.

DURATION – In wave forecasting, the length of time the wind blows in nearly the same direction over the FETCH.

EDGE WAVE – A solitary wave, or train of waves moving along the shore with crests roughly perpendicular to the shore. Its height is greatest at the shore and diminishes rapidly lakeward with negligible height one wave length from shore.

ELEVATION – The vertical distance of a surface from a DATUM.

ENVIRONMENTAL CORRIDOR – A strip of land with boundaries defined by government that is intended to protect natural resources, habitat, and space for recreational activities.

EROSION – The wearing away of land or a lakebed by the action of natural forces. On a beach, the carrying away of beach material by wave action, currents, or by wind.

EXPOSURE – Something of value that could be damaged or destroyed by a loss. It can be tangible (building, land, income) or intangible (access, enjoyment).

FACTOR OF SAFETY (SAFETY FACTOR) – The ratio of the strength of material (such as a soil mass) to the stress placed upon the material. A value of 1.0 represents a balance of strength and stress. Values greater than 1.0 indicate strength greater than stress.

FETCH – The area over which waves and wind setup (or surge) are generated by a wind having a fairly constant speed and direction.

FETCH DISTANCE (FETCH LENGTH) – The horizontal distance (in the direction of the wind) over which a wind generates waves, wind setup (or surge).

FOREDUNE – The front dune immediately behind the backshore.

FORESHORE – The part of the shore between the crest of the lakeward berm (or upper limit of wave uprush) and the low water line.

GABION – A wire mesh basket containing stone or crushed rock, designed to protect a slope from erosion by waves or currents. Sometimes used as a backing or foundation for shore protection structures.

GLACIAL TILL – Soils laid down by glaciers: consists of mixtures of silt, sand, clay and stones.

GRAVEL – small, loose stone; approximately 0.08 -3.0 inches (2-76 millimeters) in diameter.

GROIN – A shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore.

GROUND WATER – Subsurface water occupying the zone of saturation. In a strict sense, the term is applied only to water below the WATER TABLE.

GULLY – A miniature valley worn in the earth by running water through which water usually runs only after rain events.

HAZARD – Any condition that increases the likely frequency or severity of a loss.

HEADLAND – An erosion-resistant promontory (or projection of land) extending into the lake.

HIGH WATER PERIOD – Years when lake levels are much greater than average.

ICE JAMS – Large accumulations of stationary ice that restrict water flow, flooding low-lying land along channels and rivers

ICE RIDGES – Linear piles of ice, grounded on the lakebed at locations where waves break, such as offshore bars.

ICE RUNS – Flowing ice in a river.

ICE SHOVE (ICE PUSH) – Ice sheets moved by wind and currents that come into contact with the shoreline and are shoved up the shore away from the lake.

ICEFOOT – An ice mass formed at the shoreline by waves that drive slush ice to shore.

IMPERMEABLE GROIN – A groin through which sand cannot pass.

INSHORE (ZONE) – In beach terminology, the zone of variable width extending from the low water line through the breaker zone.

JET STREAM – A long, narrow, meandering current of air high in the atmosphere that blows at high speed (often more than 200 miles per hour) from west to east.

JETTY – A structure extending into the lake to protect a harbor entrance from shoaling with littoral material.

LAG DEPOSIT – Stones, boulders in a glacial till lakebed that are left behind after the fine till materials have softened and washed away.

LAKE BOTTOM (LAKEBED) – The ground or bed under the lake.

LAKEBED ARMORING – The use of cobble stones to protect a lake bed from erosion by waves.

LANDSLIDE – The rapid downward movement of a mass of rock, soil or other material on a slope that is caused by the force of gravity.

LITTORAL – Pertaining to the shore of a lake or sea.

LITTORAL MATERIAL – Sand and stones moved by waves and currents near the shore.

LITTORAL TRANSPORT (LITTORAL DRIFT) – The movement of littoral material by waves and currents. Includes movement parallel (longshore transport) and perpendicular (on-offshore transport) to the shore.

LITTORAL ZONE – In beach terminology, an indefinite zone extending seaward from the shoreline to just beyond the breaker zone.

LONGSHORE (ALONGSHORE) – Roughly parallel to and near the shoreline.

NEARSHORE – A zone extending seaward from the shoreline well beyond the breaker zone; typically to about 66 feet (20 meters) water depth.

NEARSHORE ICE COMPLEX – The varied ice cover features in a mass of ice anchored to shore.

OVERTOPPING – The passing of water over the top of a beach berm, dike, or other shore protection structure as a result of wave runup or surge action.

PENINSULA – An elongated body of land nearly surrounded by water and connected to a larger body of land.

PERCHED GROUNDWATER – Groundwater in a saturated soil zone above and separated from the main water table by unsaturated soil or rock.

PERCHED GROUNDWATER TABLE – The upper surface of a body of perched groundwater.

PERMEABILITY – The ability of water to flow through soil, crushed rock or other material.

PERMEABLE GROIN – A groin with openings large enough to permit passage of appreciable quantities of beach materials.

PIER – A structure extending out into the water from the shore, to serve as a landing place, recreational facility, etc., rather than to afford coastal protection. In the Great Lakes, a term sometimes applied to jetties.

PILE – A long, heavy section of timber, concrete or metal driven or jetted into the earth or lakebed to serve as a support or to provide protection.

POCKET BEACH – A beach (usually small) between two littoral barriers.

POINT – The outer end of any land area protruding into the water, less prominent than a peninsula.

POROSITY – The percentage of the total volume of a soil, or stones, occupied by air or water, but not by solid particles.

POTENTIOMETRIC WATER SURFACE (PIEZOMETRIC WATER SURFACE) – The level to which water will rise in avertical hole drilled into a water-bearing, water-transporting soil aquifer layer where water flow is confined to the aquifer layer because of higher flow resistance in soils above and below the aquifer layer; soils with lower permeability (lower hydraulic conductivity).

PROBABILITY – The chance that a certain event will occur, or be exceeded. Usually expressed as "p" with a value between 0 and 1.0.

QUARRY (QUARRYSTONE) – Any stone processed from a quarry.

REACH – A section of coastline that has characteristics in common.

RECESSION – The landward movement of the shoreline, beach, or lakeward edge of bank or bluff.

REEF – One or more stable lakebed forms of bedrock, loose rock or sand that rise above the surrounding lakebed.

REVETMENT – A structure of stone, concrete, etc., built to protect a shore against erosion by wave action or currents. Often used to refer to shore protection structures with sloping lakeward faces.

RIP CURRENT – A strong surface current flowing lakeward from the shore. It is the return movement of water piled up on the shore by incoming waves and wind.

RIPRAP – Protective layers of stone, randomly placed to prevent erosion, scour, or sloughing of a slope. Also used as a term to identify the stone used.

RISK – The possibility of negative outcomes or a loss.

RUBBLE-MOUND STRUCTURE – A mound of random-shaped and random-placed stones protected with a cover layer of selected stones or specially shaped concrete armor units.

SAND – Rock grains, most commonly quartz; that are 0.0025 – 0.19 inches (0.0625 – 4.76 mm) in diameter.

SCOUR – Removal of underwater material by waves and currents, especially at the base or toe of a shore structure.

SEAWALL – A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action.

SEDIMENT – Loose fragments of rocks, minerals, or organic material transported by air, wind, ice and water, and deposited. Also materials that precipitate from overlying water or chemically form in place. Includes all of the loose, unconsolidated material on a lakebed.

SEEP – A place where water in the ground oozes slowly to the ground surface.

SEICHE – An oscillation of the water mass in a lake that continues after the originating force has stopped. In the Great Lakes, such oscillations almost always have atmospheric causes. In other regions, seismic forces may be contributing causes.

SETBACK (SETBACK DISTANCE) – A selected (or required) space between a building (or other structure) and a boundary.

SHALLOW WATER – Water of such a depth that surface waves are noticeably affected by the lakebed. In terms of wave shoaling, it is water of depths less than one-half the wavelength.

SHEET EROSION – The removal of a thin layer of soil by wind or water.

SHEETPILE – Planks or sheets of construction material designed to be driven into the ground or lakebed so that the edges of each pile interlock with the edges of adjoining piles.

SHOAL (noun) – A detached elevation of the lakebed, comprised of any material except rock, which may endanger surface navigation.

SHOAL (verb) – (1) To become shallow gradually. (2) To cause to become shallow. (3) To proceed from a greater to a lesser depth of water.

SHORE – The narrow strip of land in immediate contact with the lake, including the zone between high and low water lines. A shore of unconsolidated material is usually called a BEACH.

SHORELINE – The intersection of a lake with the shore or beach.

SILT – Loose rock particles: smaller than sand particles and larger than clay particles.

SLOPE – The degree of surface inclination above a horizontal reference surface. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating 1 unit vertical rise in 25 units of horizontal distance; or in a decimal fraction (0.04); degrees (2° 18'); or percent (4 percent).

SLUMP – The movement of a soil mass downward along a curved failure surface; with the lower portion of the mass moving outward. A particular form of a slide, sloughing, or mass wasting from erosion.

SOIL - A layer of weathered, unattached particles containing organic matter and capable of supporting plant growth.

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

SQUALL LINE – A line of strong wind areas advancing ahead of a weather system along a boundary between air masses at much different temperatures.

STORM SURGE (WIND SETUP, STORM RISE) – A rise above normal water level on the open coast due to wind stress on the water surface over a long distance (fetch).

SWALE – The depressed area between two beach ridges.

SWASH ZONE – The area of wave action on a beach face from the lower limit of wave run-down to the upper limit of wave run-up.

TERRACE – A horizontal or nearly horizontal natural or artificial land surface feature interrupting a slope.

TOE – The lowest part of a structure forming the transition to the lakebed, or the lowest part of a slope forming a transition to a beach or terrace.

TOMBOLO – A bar or spit that connects or "ties" an island to the mainland or to another island.

TROUGH – A depression in the lakebed between bars – often created by breaking waves.

UNDERTOW – A periodic current beneath the water surface that flows lakeward when breaking waves are present, caused by the backwash of waves flowing down the beach face.

UPRUSH – The movement of water from a wave up a beach, or shore protection structure.

UPDRIFT – The direction opposite to the most common direction of littoral transport (or drift).

UPLAND – Land that is above the reach of waves and landward of the beach.

WATER DEPTH – The vertical distance between the lakebed and a water level, usually a still water level.

WATER LEVEL – The elevation of a still water surface relative to a datum.

WATER TABLE (GROUND WATER LEVEL) – The upper limit of the ground that is saturated with water.

WATER WAVE – A moving ridge, deformation, or undulation of the water surface.

WAVE BREAKING – The breakdown of a wave profile with a reduction in wave energy and wave height due to an unstable wave shape.

WAVE CLIMATE – The seasonal and annual distribution of wave heights, periods, and directions at a particular location.

WAVE CREST – (1) The highest part of a wave. (2) That part of the wave above still-water level.

WAVE DIRECTION – The direction from which a wave approaches.

WAVE HEIGHT – The vertical distance between a crest and adjoining trough.

WAVE LENGTH – The horizontal distance between two adjacent, successive wave crests.

WAVE REFLECTION – The process by which wave power and wave energy is returned lakeward.

WAVE PERIOD – The time for a wave crest to travel a distance of one WAVE LENGTH.

WAVE RUNUP (SWASH) – The rush of water up a structure or beach following the breaking of a wave; measured as the vertical height above still-water level to which the rush of water reaches.

WAVE TROUGH – The lowest water surface between two adjoining wave crests.

WETLAND – Land whose saturation with water is the dominant factor in determining the nature of soil development and the types of plant and animal communities that live in the soil and on the land.

WIND, DURATION – The length of time that the wind maintains roughly the same speed and direction.

REVIEW GROUP THAT HELPED DETERMINE THE SCOPE OF THE BOOKLET AND REVIEWED THE FINAL DRAFT

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