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SHORELINE EROSION IN SOUTHEASTERN WISCONSIN

by
David W. Hadley
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WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

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This report is a product of the Geological and Natural History Survey Environmental Geology Program which combines geologic, hydrologic, and soil facts, theory, and analysis to investigate, explain, and solve environmental problems. Such problems typically involve mineral resources, water supply, pollution, construction siting, utility routing, the natural processes of erosion, weathering, and sediment transportation and deposition, and others. The Environmental Geology Program is one of eight Survey program areas which include the systematic collection, analysis, and cataloging of basic data, the impartial research and investigation of Wisconsin's rock, mineral, soil, water resources, and climatology, and public service and information.

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CONTENTS

INTRODUCTION

Near record high water levels in the Great Lakes during the early 1970s contributed to accelerated erosion along the highly developed shoreline of Lake Michigan in southeastern Wisconsin. Extensive slumping took place along the high bluffs that border the lake in much of this region, resulting in property damage, reduction in property values, and concern about the personal safety of residents living close to the edge of the bluffs.

The large number of requests for information and advice that were received by the Wisconsin Geological and Natural History Survey indicated the need for a summary of the current state of knowledge concerning the problem, and led to the preparation of this report.

In the report, the natural processes at work along the shoreline are described and put into geological and historical perspective, possible remedial measures are described and discussed, and alternatives for dealing with the problem are suggested.

GLACIAL HISTORY AND GEOLOGIC SETTING

The Origin of Lake Michigan

The formation of the basin in which Lake Michigan now lies began with the erosion of the preglacial land surface by streams. When the ice of the great continental glacier entered the Great Lakes region from Canada, its flow was directed down a pre-existing stream valley system that had been cut along the present north-south trend of the lake. In the course of time, the glacier made a series of advances and retreats, and with each advance, the ice modified the basin.

During the last major advance of the glacier down the Lake Michigan basin some 14,000 years ago, the ice laid down extensive deposits, called moraines, which parallel the lake shore but occur inland. Prominent among these moraines is a series of concentric ridges that formed roughly parallel to the lakeshore. These are called the Lake Border Moraines and are significant because they control the surface drainage (Figure 1). Streams that originate to the east of the moraines in Wisconsin flow into Lake Michigan, while most streams to the west ultimately drain into the Mississippi River. Because of this, only a limited number of relatively small streams flow into the lake in southeastern Wisconsin. Many of the areas along the shore with high, steep bluffs were formed where the Lake Border Moraines were cut through by shoreline erosion.

As the ice that deposited the Lake Border Moraines began to retreat northward up the Lake Michigan basin, the water released as the ice melted was trapped between the ice front to the north and the high ground surrounding the basin to the south. The surface of the lake thus formed was about 60 feet above the modern lake level. Shoreline processes along this ancestral lake built beaches, cut bluffs and terraces, and formed sand dunes. The remnants of these features are still to be seen in places high above the present shoreline, and attest to the fact that shoreline erosion in the area is far from a recent phenomenon.

The very complex details of the evolution of the Great Lakes are beyond the scope of this report. Let it suffice to say that Lake Michigan drained either southward or eastward through a succession of outlets, that a new lake level was established with each successive outlet, and that along the shore line of each of these levels features were developed that are similar to those being formed today (Figure 2).

The process culminated about 2,000 years ago when the present drainage outlet through the Straits of Mackinac was established. Since that time, only relatively minor fluctuations in the level and extent of Lake Michigan have occurred.

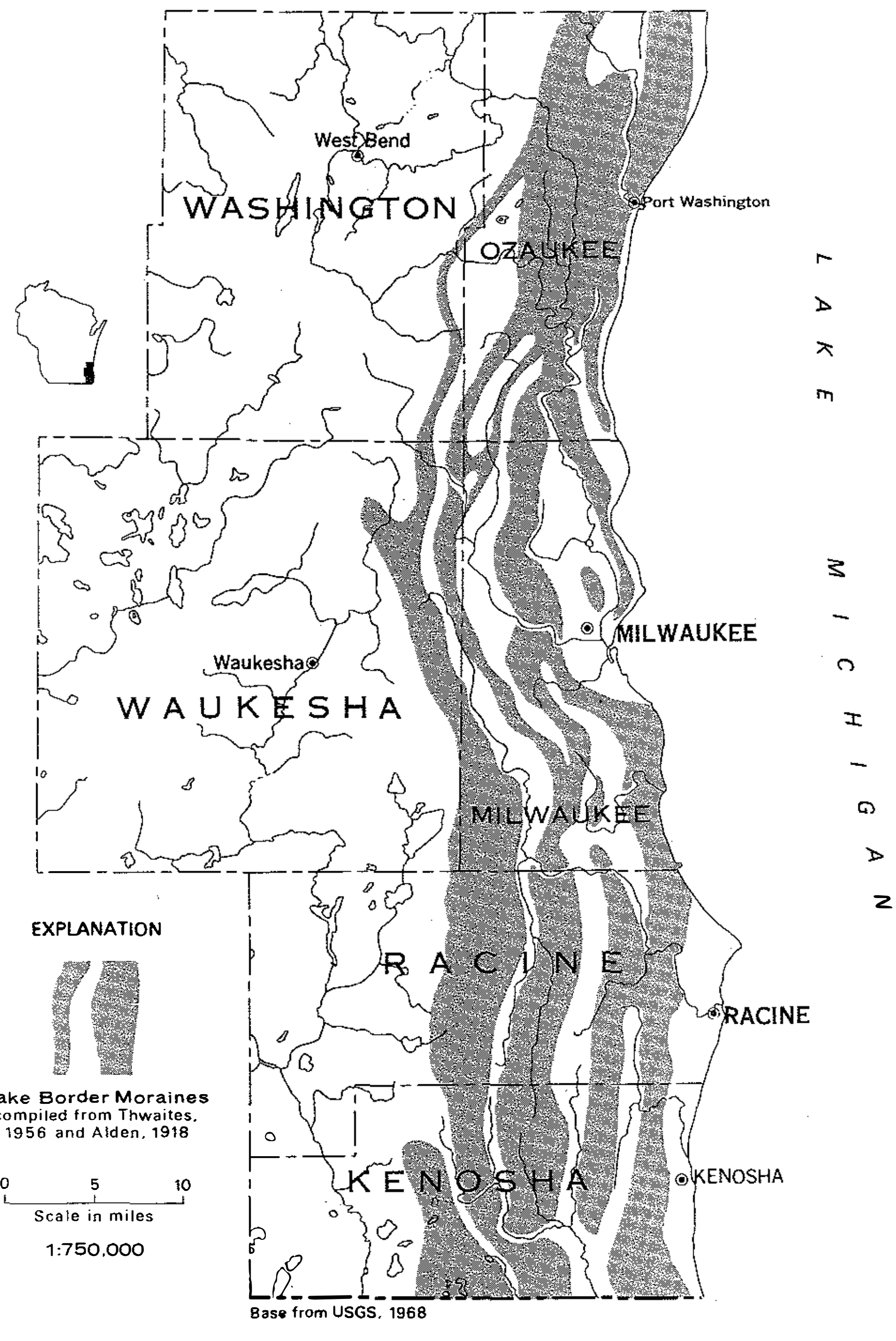

Figure 1. The Lake Border Moraines limit the size and number of streams supplying sediments to the lake.

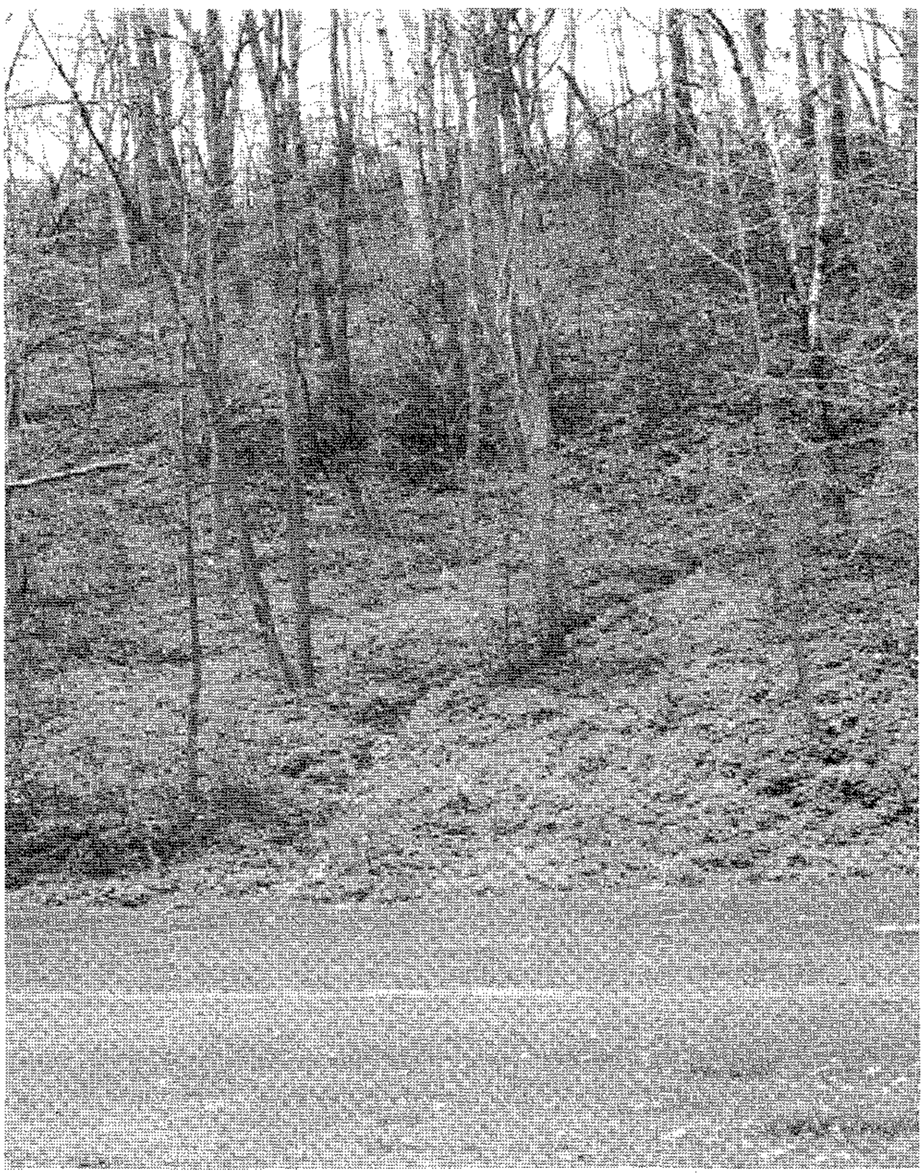

Figure 2. This terrace and low bluff were cut during glacial times when the lake was at a significantly higher level than it is today.

Glacial Deposits

As the glacier advanced southward from its source area in Canada, it picked up rock and soil that was transported southward and subsequently deposited. The general term for such deposits is glacial drift. Drift may be subdivided into a number of types, each having characteristics related primarily to the manner in which it was deposited. Only the more significant deposits are described here.

The most characteristic material deposited by glaciers is till. This is made up largely of material that was "plastered" on the ground surface at the base of the ice sheet. Because there was no sorting mechanism involved in the deposition of till, it may contain particles ranging in size from single pieces of rock as large as a house to particles of clay so small that they can be studied only under a powerful electron microscope.

The second major type of glacial deposit is made up of the material that was washed out and away from the glacier by the water released as the ice melted. Logically enough, this type of deposit is called outwash. Since the finer particles tended to be carried away with the running water, outwash normally consists largely of sand and gravel.

When the meltwater streams flowing from the glacier discharged into a body of standing water, such as a lake, the coarser particles were deposited near the stream mouths in deltas, while the finer particles were carried out into the lake and slowly settled to the bottom. The resulting deposits of glacially derived fine-grained lake-bottom sediments are referred to as glaciolacustrine deposits.

Geology of the Lakeshore

In extreme northern Ozaukee County, and from the vicinity of Kenosha south to the Illinois state line, the lands adjacent to the lake are low sand plains made up of ancient beach sands and dunes. The remainder of the Lake Michigan shoreline in southeastern Wisconsin is an area of moderate to high bluffs, broken only by emerging stream valleys and be scattered low terraces formed during the higher glacial lake levels described earlier and cut by recent erosion along the shores.

The geology of the bluffs is extremely complex. In the southern portion of the area, south of Milwaukee, the bluffs are often made up of till and associated outwash deposits overlaid by finer grained lake sediments. From Milwaukee northward, this sequence is in turn overlaid by another sheet of till and often outwash sediments. In areas where earlier lake sediments were overridden by younger glacial ice, they may be extensively reworked and distorted, which adds greatly to their complexity.

PROCESSES AT WORK ALONG THE SHORELINE

Waves

Most of the features that develop along the margin of the lake are the result of the action of waves against the shore. Waves are generated primarily through the action of the wind blowing across the open waters of the lake.

The water takes up energy from the wind and generates wave forms that travel through the water in the direction of the wind. The size of the waves that form is dependent upon four principal factors:

1. Wind velocity.
2. Length of time that the wind continues to act against the water.
3. Distance that the waves are free to move in the direction of the wind. (This distance is termed the fetch of the waves.)
4. Depth of the water.

The largest waves to affect the southeastern Wisconsin area are usually generated by storm winds blowing from the northeast; these waves have a fetch of hundreds of miles down the length of Lake Michigan. Wave heights of up to 16 feet have been reported at the Milwaukee harbor.

If you watch the motion of a piece of floating wood, you will see that as a wave passes, the wood moves both back and forth and up and down in a circular path, returning to its starting point after each wave has passed. The motion of the wood indicates the form of the wave that travels through the water. The water itself remains essentially in place.

The picture changes rapidly, however, when waves near the shore and enter progressively shallower water. As this occurs, waves begin to interact with the bottom, their speed decreases, and they become more closely spaced. As waves move into progressively shallower water, they begin to increase in height and to tilt forward toward the shore. Eventually, they become unstable and fall forward, or break (Figure 3).

When a wave breaks, the energy that was picked up from the wind is released (Figure 4). A large part of this energy is released as turbulence that churns up the bottom at the point at which the wave breaks. Most of the remaining energy is used in the formation of currents and in throwing the water from the breaking wave against the shore.

Because of the interaction of the waves with the bottom in the nearshore area, waves that approach the shore at an angle tend to be bent, or refracted. As a result, the trend of the waves as they break against the shore is much more nearly parallel to the shoreline than it was while the waves moved across the open waters of the lake. Where headlands project out into the lake, refraction causes the waves to wrap around the projection and attack it from both the front and the side. This greatly increases the amount of energy directed against the headland and causes increased erosion.

Longshore Currents and Littoral Drift

As waves break along the beaches, they generate a current that runs parallel to the shore in the general direction of the waves. This is called the longshore current. As a result of the turbulence set up by the breaking waves, the lake bottom is stirred up and a large amount of sand is put into suspension. Much of this sand is picked up by the longshore current and carried, bounced, or rolled along parallel to the shore.

Figure 3. As waves interact with the bottom, they become more closely spaced, increase in height, and eventually fall forward and break against the beach. Notice the pebbles being moved along the beach by the uprushing water.

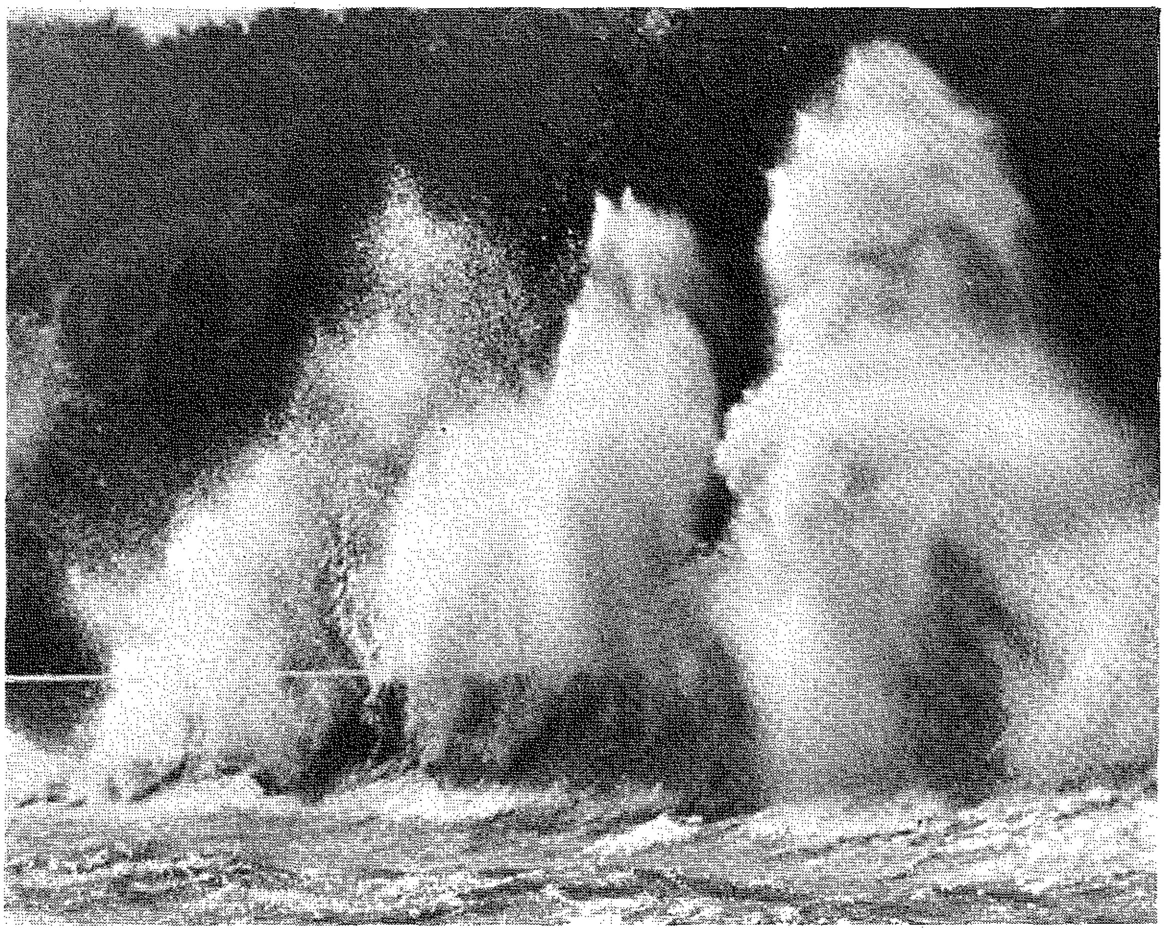

Figure 4. The energy picked up from the winds blowing across the open waters of Lake Michigan is released when the resulting waves break against the shoreline. (Milwaukee Journal Photo)

An appreciable amount of sediment is also moved laterally along the beach itself through the action of the surf. As the breakers wash up the slope of the beach, they carry with them sand grains and pebbles (figure 3). Since most waves approach the shore from an angle, the sand and gravel are usually washed obliquely up the beach. As the backwash from the breaker moves back down the beach in response to gravity, it carries sand and pebbles with it. As a consequence, particles are repeatedly washed obliquely up the beach and then returned perpendicularly to the shoreline. Because of the oblique upward path and nearly perpendicular return path, the particles are not returned to the water's edge at the lame locations they were picked up but instead are moved a short distance down the coast each time they are thrown up against the beach. In this manner, the materials that make up a beach are moved along the shore.

The overall movement of sediment along the shoreline is called littoral drift. Although the direction of transport depends on the direction from which the waves approach the shore, one direction usually predominates. Along most of the southwestern shore of Lake Michigan, net sediment transport is to the south.

In the course of a year, hundreds of thousands of cubic yards of sediment may be moved past a given spot on the shore. If this flow of material is blocked, sand is not available to replenish and thus protect downdrift beaches and rapid erosion of these areas may occur.

Beach Erosion

The amount of material moved by the uprush from breaking waves and that returned to the lake by the backwash need not be the same.

It has been found that in the case of large storm waves, the backwash is a more effective agent than the uprush. As a result, large amounts of sand may be removed from the beach during a storm and deposited offshore. On the other hand, gentle waves tend to move sand back onto the beach. The size and shape of a beach is, consequently, constantly changing in response to energy conditions related to waves and currents. Thus, dramatic erosion of the beach by storm waves is followed by a gradual rebuilding during periods of more moderate wave action. If, however, the littoral drift along a segment of the shore does not provide an adequate amount of sand for the rebuilding process, erosion of the beach will predominate.

The materials that make up the beaches are derived from the erosion of the lands surrounding the lake. The major sources are the sediments delivered to the lake by streams and the material eroded from the lakeshore.

In southeastern Wisconsin very little material enters the lake from streams. The Lake Border Moraines limit the size and therefore the erosion capability of streams, and most of the sediment of the larger streams is trapped by harbor structures before it can enter the lake. Protective structures along the coast have reduced the erosion of the bluffs and further limited the supply of sand. In addition, the bluffs are largely composed of fine-grained lake sediments and silty and clayey glacial till. A relatively large percentage of the material eroded from lakeshore bluffs is in particles too small to be retained in the beaches and is carried out into the lake in suspension. The amount of material supplied to the littoral drift is therefore quite limited, and beach erosion predominates throughout most of the region.

Water Levels in Lake Michigan

The water levels in the Great Lakes have fluctuated over a total range of about 6 feet during the past 100 years of record (Figure 5). Fluctuations result primarily from changes in the amount of rain and snow that fall on the lakes and on land areas that drain into the lakes, and on the amount of evaporation from the lakes.

During the period between 1962 and 1964, precipitation was below normal, and in 1964-65 the level of Lake Michigan reached an all-time recorded low. Since that time, above average precipitation has led to a slow rise in the lake levels. The water returned to its normal level in 1969 and has continued to rise since that time.

In addition to these major fluctuations, the water level also shows a regular seasonal variation, with winter levels averaging about a foot lower than those in the summer. The lake is also subject to short-term rises in water level. Strong winds and storm waves can pile up water along the windward shore of the lake in a process known as wind setup. Water levels in southern Lake Michigan can rise as much as 3 feet under such conditions.

Reliable records of the water levels in the Great Lakes have been kept since 1860. Attempts to predict future maximum levels for purposes of design or for long-term planning should be tempered by the recognition that these predictions are based on a fairly shor time-span and that any significant climatic change would drastically alter the recorded pattern.

A factor that is not widely appreciated is the near impossibility of effectively regulating the levels of the Great Lakes. The area and volume of the lakes are extremely large. By contrast, the outlets have a very limited capacity. Even with maxiumu flow through the outlets, the effect on water levels is very small.

There is a tendency to consider the high water level of 1973 unusual. It was not. The high water levels were just as "normal" as the low levels of 1964-65. What _is_ normal is a fluctuating water level. The water level in the lakes is going to continue to fluctuate, and may fluctuate well outside the limits that have been recorded in the past.

The Effect of High Water Levels on the Rate of Erosion

With low water levels, the brunt of the force of storm waves is taken by the beaches. When the water levels are high, however, the beaches are partially or wholly submerged and storm waves break close to and in some cases directly against the bluffs (Figure 6). This brings about the rapid erosion of the poorly consolidated materials exposed along the foot of the bluffs. As a result the base of the bluffs is undercut, the bluffs become oversteepened and unstable, and massive slope failures along the bluffs may follow.

The Role of Ice

During a normal winter season, substantial ice develops along the shore of Lake Michigan. For the most part this is beneficial, since the ice serves as a protective barrier against winter storm waves (Figure 7).

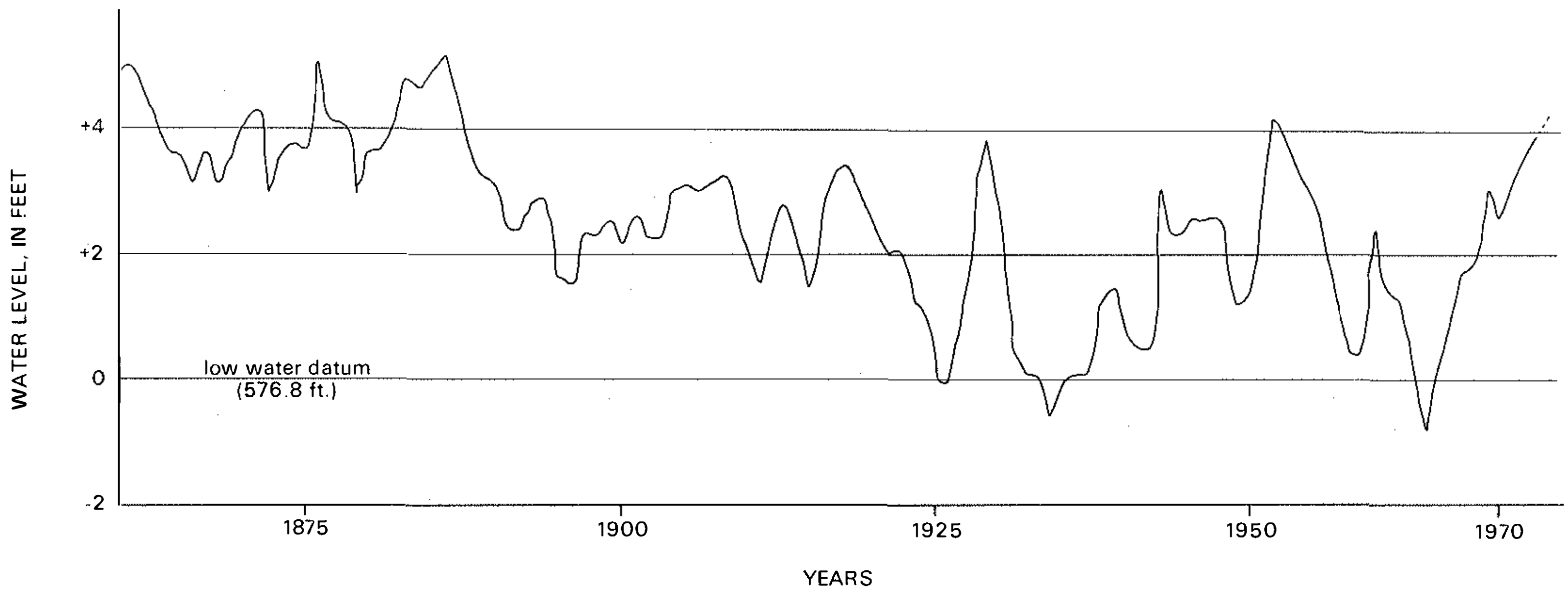

Figure 5. Annual maximum levels in Lake Michigan 1860-1973 (based on monthly mean water levels). Data from Lake Survey Center-NOAA, U.S. Department of Commerce.

Figure 6. During periods of high lake levels the beaches may be submerged, leading to rapid erosion at the base of the bluffs.

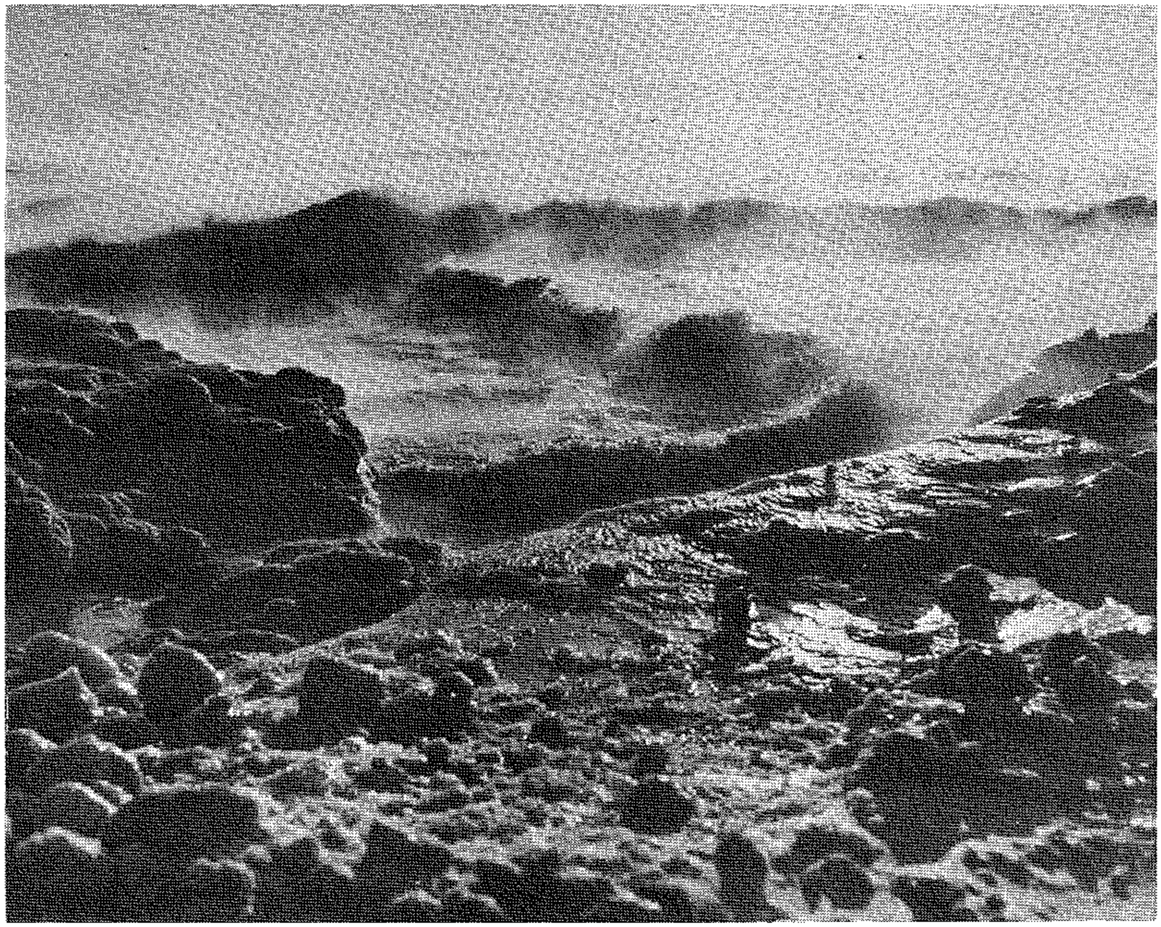

Figure 7. Ice protects the shoreline from erosion by winter storm waves. Wind-driven free-floating ice can, however, do extensive damage. (Milwaukee Journal Photo)

Once the ice begins to break up, however, the picture can change rapidly. Masses of free ice, driven by strong winds and storm waves, can cause extensive scour of the lake bottom and damage to structures along the lakeshore.

EROSION OF THE BLUFFS

The aspect of shoreline erosion that is of immediate concern to most residents along the coast is the rapid retreat of the bluffs along the lake. Comparison of early maps of the area with more recent aerial photographs shows that the bluffs have been worn back at an average rate of more than 2 feet a year. In some areas, the rate has been much higher (Table I). Although the rate of erosion has in places been slowed through the construction of protective structures, the bluffs are still actively retreating along most of the shoreline.

Slope Stability

The stability of a slope is dependent upon its height and steepness and on the strength and arrangement of the materials in which the slope has formed. Experience gained from highway construction in the area shows that slopes that rise more than 1 foot vertically for every 2.5 feet of horizontal distance often fail. If seams of sand or of soft clay are present, a condition prevalent in the bluffs, even more gentle slopes must be used to insure stability. In terms of these criteria, most sections of the high, steep bluffs that have been cut in the relatively weak materials exposed along the lake are highly unstable. This is demonstrated by the numerous slides that have occurred.

The primary process by which nature moderates the steep slopes formed by wave erosion is called slumping. This type of failure is caused by gravity acting on the material exposed in the slope. In addition to the downward force, there is a strong force directed outward toward the face of the slope. The situation can be visualized as similar to that of a heavy pendulum that has been pulled back from its equilibrium position. If this pendulum were released, it would move down and out along a circular path. A massof soil that slumps has a tendency to follow a similar path.

The forces acting on the soil to cause slumping are opposed by the strength of the soil along the potential failure surfaces. Any factor that either increases the forces acting on the soil or lowers the strength of the soil mass will increase the chances of the slope failing. One of the most common causes of failure is the removal of material from the base, or "toe", of the slope. This reduces lateral support for the slope and in that way reduces the force necessary to cause failure. The removal of material from the foot of the bluffs by wave action is the underlying cause of most slope failures along the bluffs.

Most slope failures occur after periods of heavy rain or the melting of a snow cover. The rapid addition of a large amount of water raises the ground water table and increases the pressure within the pores of the soil. These factors reduce the amount of force necessary to slide the soil particles past one another and, in that way, lower the strength of the soil. With some materials, repeated freezing and thawing, or wetting and drying, will break down the structure of the soil and lower its strength. Increasing the load

Table 1. Shoreline Erosion During the High Water Levels of 1951-52
(Data from Department of the Army Corps of Engineers)

LOCATION	EROSION
North Ozaukee County line to Port Washington Harbor	10 feet (average)
Port Washington Harbor to Milwaukee Harbor	5 to 20 feet
Milwaukee Harbor to Racine Harbor	15 feet (average)
Racine Harbor to Illinois state line	up to 75 feet

on the slope through the application of fills, increasing the water content of the soil through faulty drainage structures, and even vibrations due to construction or heavy traffic also contribute to the instability of a slope.

In some cases, the entire mass of soil will slide rapidly down the failure surface and into the lake below. For the most part, however, slumps move relatively slowly in their early stages (Figure 8). Movement, rather than being continuous, occurs in a series of short spurts. As the soil structure is progressively broken down along the failure plane, movements become larger and more rapid. As the soil mass approaches an equilibrium position, the rate of motion again slows. Many slumped soil masses temporarily stabilize after moving only part way down the slope. Their movement, however, removes support from the soil behind, and this factor, coupled with continued erosion at the base of the bluffs, may cause additional slumping to occur to shoreward. This often leads to a succession of slumps. Along some sections of the shoreline, the bluffs are seen to be composed of a series of short, discontinuous benches. Each of these benches represents the upper surface of an old slumped soil mass (Figure 9). Such sections may appear to be relatively stable, but I have observed instances in which the entire sequence of slumps has slipped rapidly into the lake.

The Role of Groundwater in Erosion of the Bluffs

When rain falls over an area such as southeastern Wisconsin, much of the water is carried off by surface streams. A smaller but still significant amount soaks into the soil and slowly percolates downward until it reaches a zone in which all of the available open spaces in the soil or rock are filled with water. The surface of this saturated zone is popularly called the water table.

Rather than being a flat surface, the water table is usually irregular, reflecting approximately the topography of the ground surface. It is generally highest under the hills and lowest in the valleys, where it roughly coincides with stream levels. In addition to this topographic control, the water will mound up under areas in which the supply of water from the surface is unusually high and will be drawn down in areas from which the water is being removed.

Just as surface streams flow downhill toward the sea under the force of gravity, groundwater moses slowly through the rock and soil toward areas of lower elevation. Where the water table is intersected by surface streams, the water drains into the streams and is carried away. In fact, almost all of the water carried by streams during dry periods is groundwater that has been discharged into the stream channels. As a result of this discharge, the water table is drawn down in the regions adjacent to the streams.

In the same way, the discharge of groundwater into Lake Michigan causes the water table adjacent to the lake to approach the water level of the lake. This effectively drains the bluffs, and it is only after a heavy rain or a sudden thaw with a heavy snow cover that the water table rises and saturates significant portions of the bluffs.

In many areas, water moving downward toward the water table is blocked by a layer with low permeability (permeability can be defined as the ease with which water passes through the layer). The water mounds up over this relatively impermeable layer, giving rise to what is called a perched water table. This

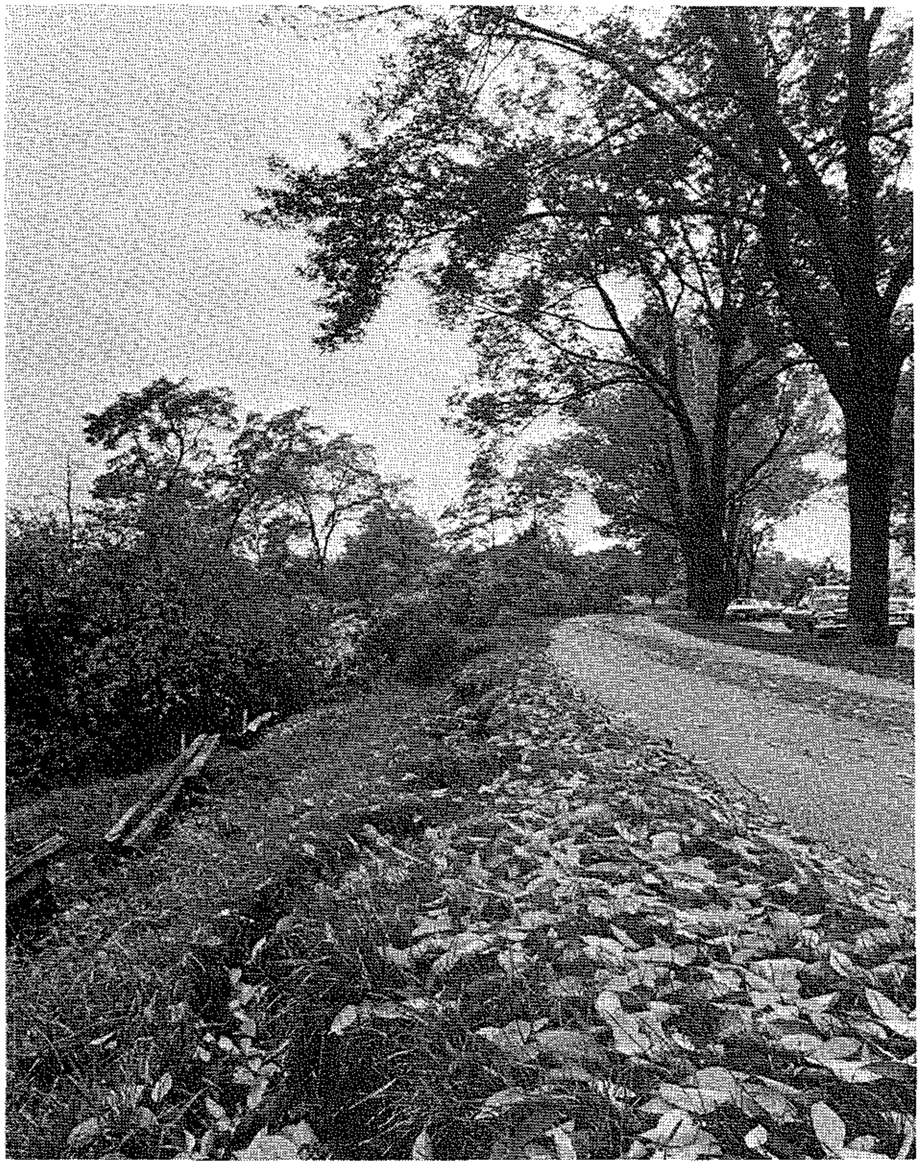

Figure 8. The slumping of a soil mass is often slow in its early stages. The crack shown here is an example of the initial phase in many earth movements of this type. (Milwaukee Journal Photo)

Figure 9. Continuing erosion at the toe of the bluff has caused a series of slumps to occur along this section of the shoreline. (Milwaukee Journal Photo)

phenomenon is of considerable significance along the Lake Michigan bluffs in southeastern Wisconsin. In many areas relatively impermeable clayey tills or lake sediments are overlain by permeable sands or sandy silts. Following periods of abundant rainfall, perched water tables may form in these more permeable beds. Lines of springs will develop where these beds are exposed along the bluffs.

Although damp sand and sandy silt are able to maintain a steep slope, these materials have very little strength when they are saturated. The saturated sands and silts associated with the springs along the bluffs are often unable to hold the steep slope of the bluffs, and consequently numerous small failures occur (Figure 10).

In some cases, the water flows from the springs with enough force to push grains of sand or silt out from the exposed face of the permeable beds. This greatly accelerates the rate of erosion. The retreat of the permeable beds removes support from the overlying material, and collapse of the overlying soil mass eventually follows. This process is known as spring sapping.

In areas in which the vegetation has been removed from the bluffs by slumping, the exposed materials dry out rapidly. Dry sand has very little strength, and on steep slopes, the surfaces of exposed sand beds will slowly trickle away as the sand dries. This also leads to theundermining, or sapping, of the overlying beds and can lead to further slope failures (Figure 11).

POSSIBLE COURSES OF ACTION FOR THE LAKESHORE RESIDENT

Many property owners along the shore of Lake Michigan in southeastern Wisconsin and elsewhere are faced with the necessity of making a decision as to what can best be done to cope with the problem of the rapid and continuing erosion of their property by the lake. This decision will be influenced by the physical conditions at the site and, often to a larger degree, by the financial resources available to the property owner. There are three basic alternatives. These are:

1. Let Nature Take Its Course

In many cases, erosion has progressed to the point where the expense of correcting the damage already done and attempting to prevent further erosion is actually greater than the value of the property involved. Under these conditions, eventual abandonment would be the wisest course of action.

2. Relocation

If a suitable location is available, moving a threatened residence to a new site with a reasonable setback from the shoreline may turn out to be the cheapest and most reasonable alternative.

3. Corrective and Preventive Measures

In many cases, an owner may decide to attempt to preserve and protect his property. If this approach is taken, it must be remembered that there are a number of processes at work along the lakeshore and that all of these must be taken into account if efforts to preserve a lake-front property are to be successful. Thus, it may be necessary to employ several measures on a single property or along a particular section of coastline to remedy the problem.

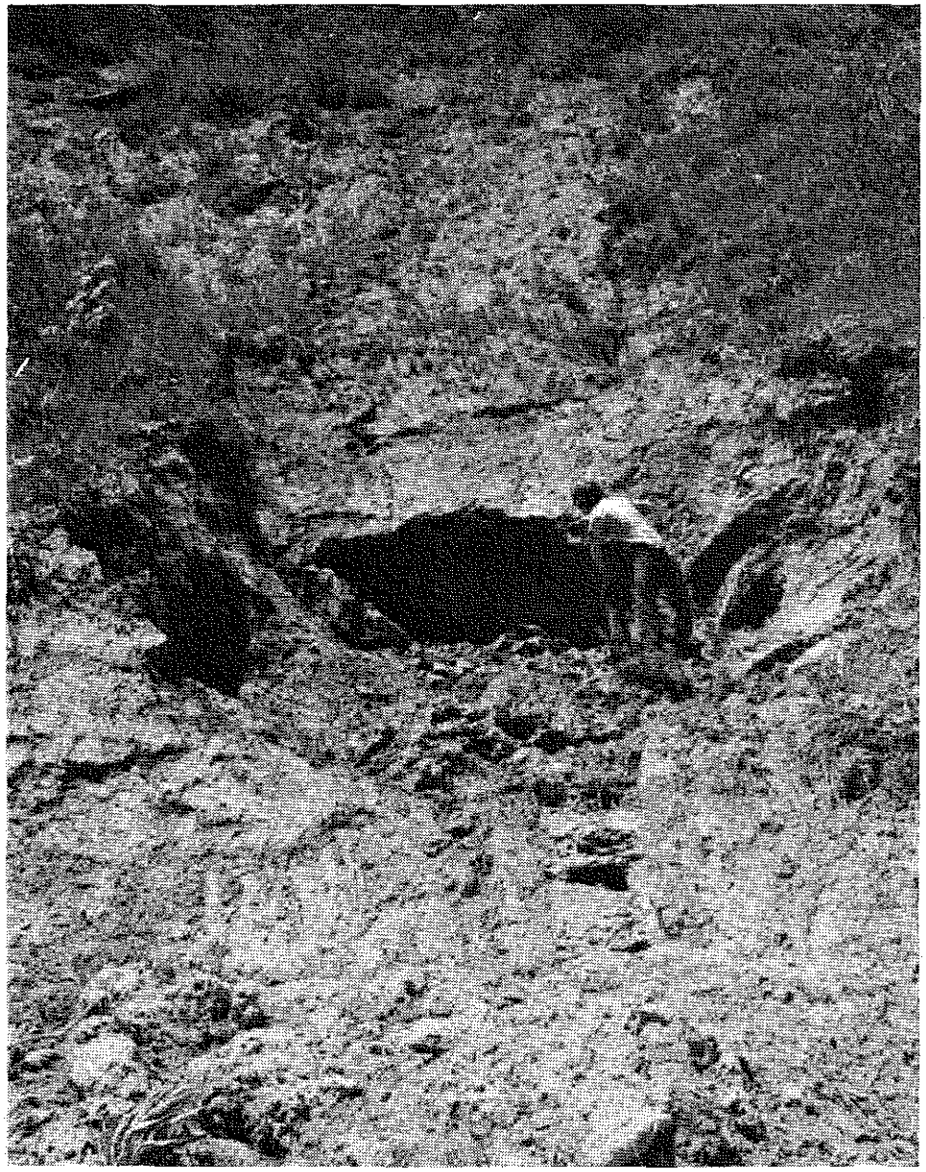

Figure 10. Springs such as this form where the groundwater moving downward through the bluffs encounters a zone of low permeability. Groundwater seepage plays an important role in the retreat of the bluffs along much of the Lake Michigan shoreline in southeastern Wisconsin.

Figure 11. All experienced sand-castle builders know that although moist sand will maintain a steep slope, failure will result when the sand dries (left) or becomes saturated (right).

For example, if a section of the bluffs has been rendered to unstable by wave erosion that massive slumping is probable, it would be unwise to construct expensive protective structures along the beach without first regrading the slope. If this were not done, the structure could be carried away by slides. If spring sapping is significant, adequate drainage structures must also be provided. Areas denuded of vegetation much be replanted, and surface runoff must be controlled so as to prevent gully erosion.

It has been found that very few attempts by individual property owners to protect isolated property are successful. This is primarily due to the fact that the erosion of surrounding unprotected sections of the coast soon exposes the sides of the protective structures, leading to rapid failure (Figure 12). Every effort should be made, therefore, to attack the problem of shoreline erosion on a community rather than an individual basis. If the property owners along a segment of the shore pool their resources, chances of building a successful structure will be greatly improved and the cost to individual property owners will likely be substantially reduced.

The primary measures that may be applied are slope stabilization, construction of permanent protective structures, and temporary protection.

a. Slope Stabilization. The methods commonly used to stabilize a slope are intended to either reduce or oppose the forces acting on the soil mass or to increase the strength of the soil.

One of the most commonly used methods is the construction of retaining structures at the base of the slope. These structures prevent slumping by providing additional lateral support and essentially take the place of material removed from the toe of the slope. For the most part, this method is not practical along the bluffs, since the bluffs are so high and steep that extremely massive and expensive structures would be necessary.

Another common method is to construct a system of drains to lower the water table and prevent the buildup of high pressures within the soil pores. In sections of the bluff where water-bearing sands and silts occur, some provision for draining the slope is necessary. However, this method does not, in itself, prevent failures where active wave erosion at the base of the bluffs is also occurring. In these cases, a combination of methods must be used.

The most positive method, and the one most widely applicable along the Lake Michigan bluffs, is to regrade the slope to a stable profile. This may involve removing material from the top of the bluffs to reduce the load, constructing a series of benches, or regrading to a smooth and adequately gentle slope.

Solution to the problem of groundwater sapping involves the design and construction of a system that will effectively remove water from the saturated beds. This may be done by intercepting the water before it reaches the bluffs, by constructing a system of drains to remove water at the bluffs, or possibly by the drilling and pumping of wells.

The problem of slope stability is extremely complex, and no work should be undertaken without first obtaining competent engineering advice.

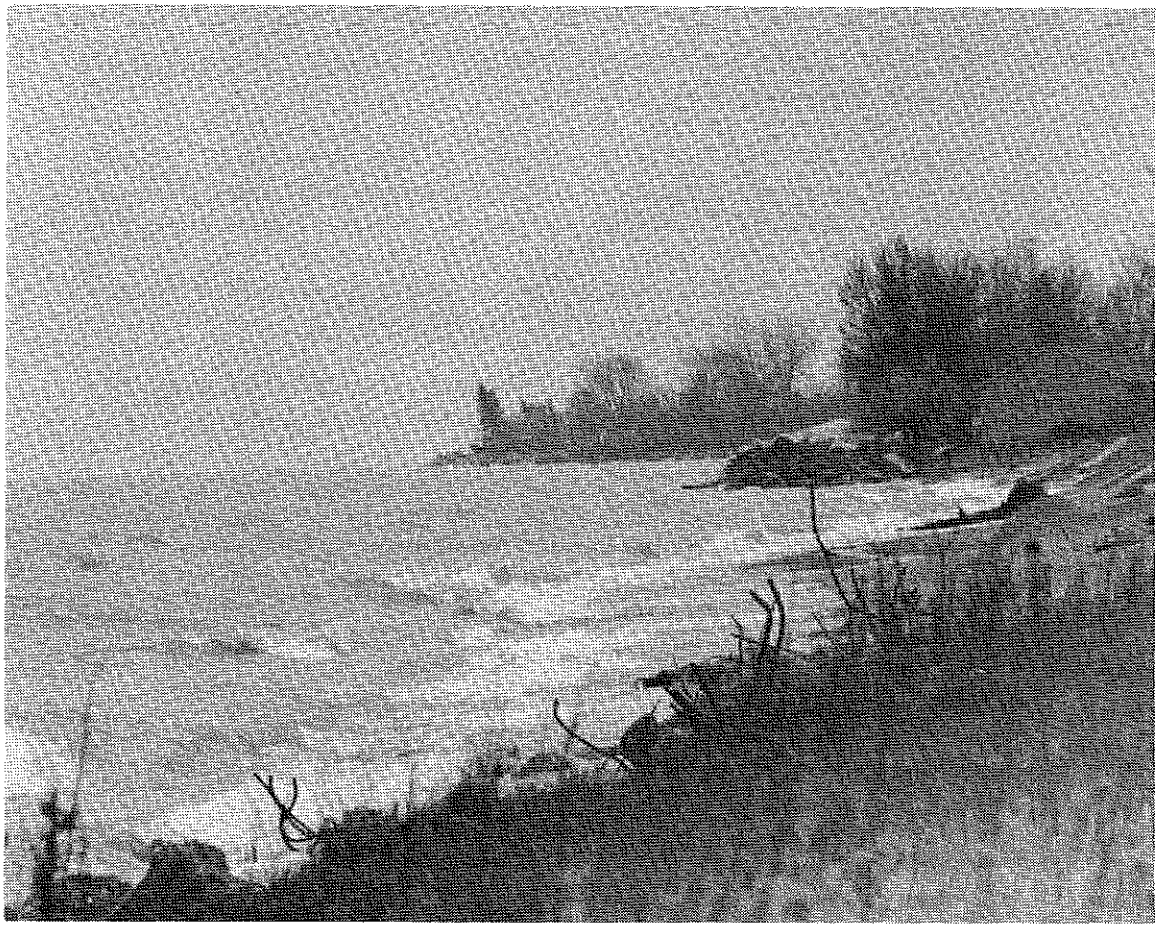

Figure 12. Although these homes are protected by stone revetments, the unprotected adjacent shoreline has been rapidly eroded. The exposed flanks of the properties now must also be protected.

As soon as the work on the slope has been completed, immediate steps must be taken to prevent continued erosion along the base of the bluffs.

b. Protective Structures. A number of methods have been developed to reduce shoreline erosion through the construction of protective structures. These structures are of two broad classes. In the first class are structures designed to protect the shore by directly blocking the waves. Structures of the second class are designed to form and hold a beach. The force of the waves will then be directed against the beach rather than against the bluffs lying behind it.

The principal structures of the type designed to actively block the waves are seawalls, bulkheads, and revetments.

Seawalls and bulkheads are walls built along the shoreline. They differ only in terms of their primary function. Seawalls are designed to take up the force of the waves, while bulkheads are primarily designed as retaining structures, meant to hold up the face of the soil materials lying behind them. Wave action against the vertical faces of these structures often causes erosion at the base of the structures, leading to failure.

Revetments are structures designed to protect the foot of a stable slope, and consist of thick layers of wave-resistant materials placed directly against the base of the slope.

Revetments are the structures most suitable for use along the Lake Michigan shoreline over much of southeastern Wisconsin. They provide positive protection against wave action, are relatively simple to design and construct properly, and have the least effect on erosion of the down-drift shoreline.

Structures of the type designed to protect the shore by forming a beach include groins and breakwaters.

Groins are structures built out from the beach in order to block the flow of the littoral drift and cause the buildup of sand behind them.

Groins are not recommended for use in most of southeastern Wisconsin. There are three major factors that argue against their use. First, a great deal of information about the waves, wind, bottom conditions, and currents in the lake is necessary for the design of a successful groin. In addition since relatively little sand is supplied to the shoreline through erosion, even a well-designed groin might not form and hold a beach without the periodic addition of large amounts of sand from an outside source. Finally, blocking the littoral drift would almost certainly result in greatly increased erosion of the shoreline located down drift, raising the possibility of legal problems (Figures 13 and 14).

Breakwaters are structures built some distance out in the lake, roughly parallel to the shoreline. Their major function is to dissipate the energy of the waves before they reach shore. Breakwaters also serve to lower the strength of the longshore current and consequently reduce the ability of the current to transport sand. The result is the deposition of sand along the shoreline behind the breakwater.

Figure 13. Groins interrupt the flow of sand being carried along the shoreline by the littoral drift. The resulting beach protects the shoreline.

Figure 14. The section of shoreline in the background has been protected by the groins shown in Figure 13. By interrupting the flow of sand along the shore, however, these groins have also contributed to the accelerated erosion of the shoreline shown in the foreground.

Although they are often successful structures, breakwaters can be expensive to build and, since they interrupt the littoral drift, can also cause increased down-drift erosion.

c. Temporary Protection. Unfortunately, the periods of high water levels during which protective structures are most needed are by far the worst times to attempt construction. Due to the submergence of the beaches, access is limited, construction is difficult, and costs are correspondingly high. In many cases, it may be necessary to erect temporary defences and defer the construction of more permanent structures to a period of low water levels. The high cost of permanent structures may also force many residents to rely on temporary measures for protection of their property.

In the construction of temporary structures, sandbags, timbers, rock, broken concrete, gravel, or other locally available materials are placed at the foot of the slope in a position to take up as much of the force of storm waves as possible. Although these measures do have a beneficial effect, appreciable erosion may still occur. It should also be remembered that extensive maintenance will probably be necessary after each storm. The annual maintenance costs may well be more than the initial cost of construction.

d. The Effectiveness of Protective Structures. As a part of the investigation upon which this report is based, I inspected much of the shoreline of Lake Michigan from the Illinois-Wisconsin state line to the northern border of Ozaukee County. In the course of this inspection, I found that the lake shore was strewn with the remains of supposedly permanent protective structures. Some of these structures likely failed as the result of poor design and some because of poor construction. Some were, no doubt, the victims of scour by wind-driven ice. Regardless of the cause of failure, however, most efforts to control shoreline erosion in the area have been ineffective and short-lived (Figures 15 and 16).

For the most part, the successful structures observed were built either by units of government or, to a lesser extent, by industry. These structures are massive, well engineered and constructed, and probably much too expensive to be justified for the protection of even the most valuable private residential properties.

On the basis of the observed failure of so much of the earlier construction, it is apparent that only truly well designed and constructed structures can be expected to provide any measure of lasting protection. These structures are expensive. It is strongly recommended that any individual or group of individuals contemplating construction carefully balance the costs against the probably life and effectiveness of the structure and the true value of the property that it is intended to protect.

ZONING - THE NEED FOR A DATA BASE

To a resident of the Lake Michigan shoreline, the continued encroachment of the lake presents a serious problem. In the eyes of an outside observer, however, the problem can be seen in a somewhat different light.

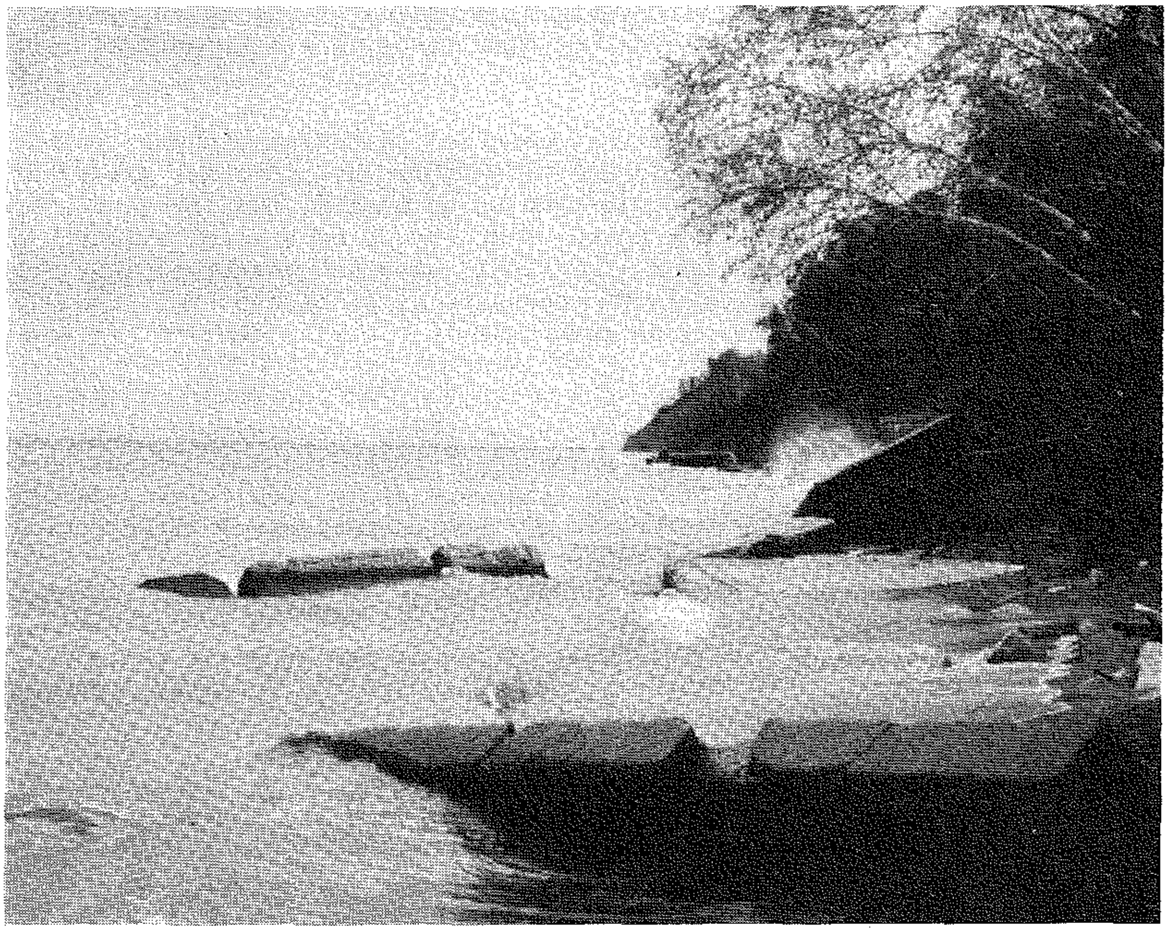

Figure 15. The shoreline of Lake Michigan in southeastern Wisconsin is strewn with the remains of unsuccessful protective structures.

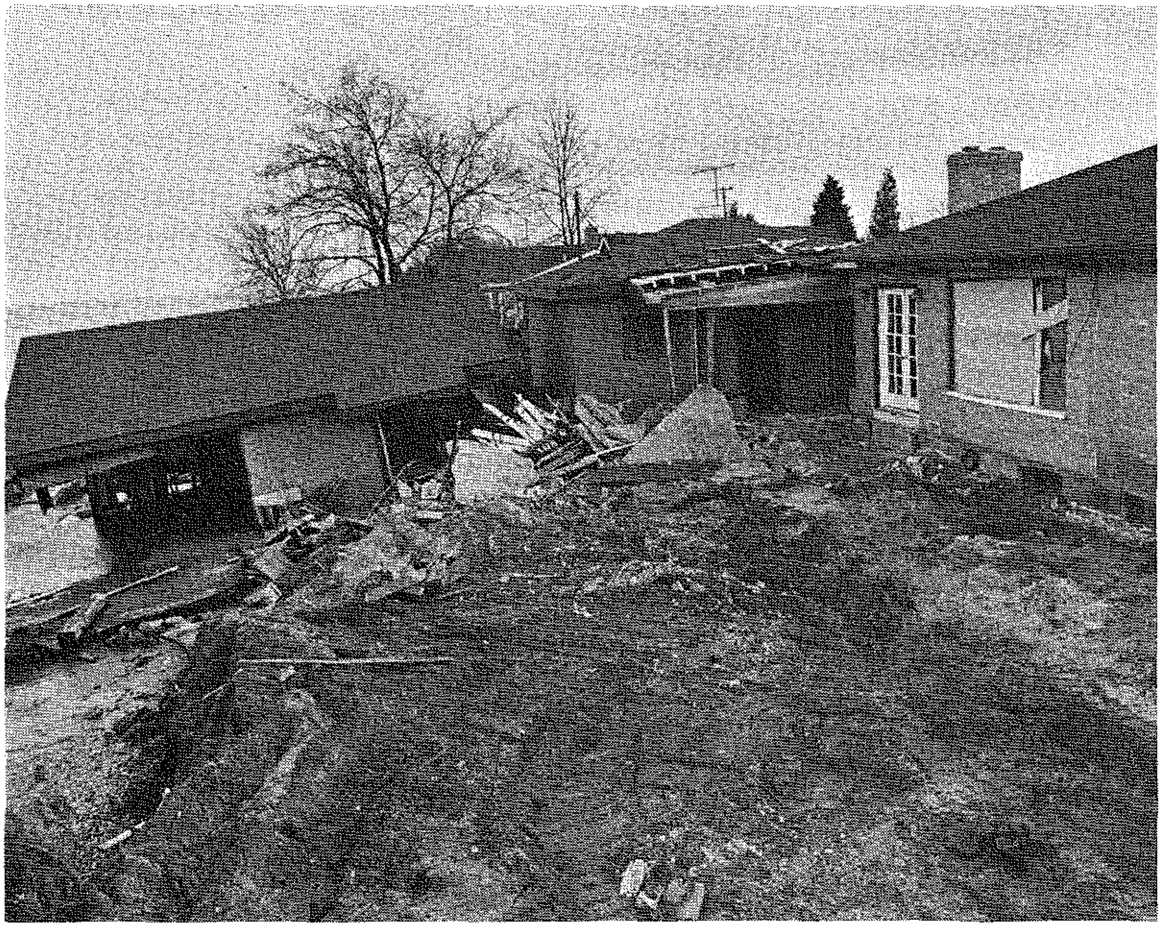

Figure 16. Attempts to protect this residence have obviously been unsuccessful. (Milwaukee Journal Photo)

Erosion of the Lake Michigan shoreline has been occurring for the past 14,000 years. The first man to see the shore would have seen much the same steep, rapidly eroding bluffs that characterize the region today, but he could not have considered the erosion of the bluffs to be a problem. It became a problem only when man decided to occupy the bluffs on a permanent basis and to attempt to oppose or alter the natural processes at work along the shore. The energy available to these processes is enormous, and it is not surprising that man's attempts to oppose nature have, for the most part, been unsuccessful. In the long run, most if not all of the present coast will be taken by the lake. The question is not if this will happen, but rather, how soon.

The coast of Lake Michigan is, and has always been characterized by extremely rapid erosion, and it probably never should have been the site of extensive residential development. It has become obvious that it is a prime responsibility of government to prevent, if possible, further development of the shoreline in regions vulnerable to rapid erosion, in the same way that development has been restricted in floodplain areas. The zoning and setback requirements that all counties and many local units of government have recently adopted reflect a growing awareness of this fact (Figure 17).

A major problem concerning zoning of the lakeshore is that there is not at the present time a sufficient body of factual information on the geologic, hydrologic, and geotechnical or engineering conditions along the lake to allow rational decisions as to the stringency of zoning necessary along the various segments of the coast. On one hand, zoning must assure that development does not take place in areas in which geologic hazards such as extremely rapid erosion or very unstable bluffs are present. At the same time, zoning should not be so stringent as to preclude development of areas that will be safe for periods far exceeding the expected life of the proposed development.

Another major problem, and one that is in many ways more important, is that of protecting those already in residence along the lake. Areas in which the hazards are high should be delineated as rapidly as possible, and every effort should be made to encourage residents of these areas to vacate the properties. In the same way, areas in which attempts to stabilize the bluffs and halt erosion would not be economically or physically feasible should also be identified and the residents told of the situation before large sums of money are unwisely spent.

It is apparent that a comprehensive geologic and engineering study of the shoreline would be of great value. Such a study could pinpoint the areas of high risk, prevent ineffective and wasteful construction along the shore, help retain on the tax roles property that might otherwise be lost through overly restrictive zoning, and above all, provide the basis for rational planning concerning the zoning and management of the shoreline. Such a study is now being planned in conjunction with the Coastal Zone Management Program.

Figure 17. The scars of recent landslides show that this home is being built near the edge of a high, unstable, and actively eroding bluff. Zoning ordinances are needed to protect the unwary citizen. (Milwaukee Journal Photo)

SUMMARY

Much of the shore of Lake Michigan in Ozaukee, Milwaukee, Racine, and Kenosha Counties, Wisconsin, is an area of high, steep bluffs developed in loose, unconsolidated silt, sand, gravel, and clay of glacial origin.

Lake water levels of near record height, the result of unusually high precipitation in recent years, have greatly accelerated the rate of shoreline erosion. Storm waves are breaking against or in close proximity to the bluffs, and erosion at the foot of the bluffs has rendered them highly unstable. This has resulted in a large number of landslides. The highly unstable nature of the bluffs, coupled with the presence of occupied dwellings close to their edges has produced highly dangerous conditions in many areas. The situation is further aggravated by groundwater seepage from the bluffs over large portions of the region.

Although relocation of dwellings is sometimes possible, many residents are faced with the decision of whether or not to spend the large sums of money necessary to adequately protect and rehabilitate their properties. The costs for this are high, especially in the areas of high bluffs where protection involves not only the construction of protective structures along the lake but often also slope stabilization, including regrading and construction of drainage structures. Costs in many cases would be more than the value of the property.

A definite need exists for a comprehensive scientific and engineering analysis of the shoreline. This study should delineate areas in which the risk of extensive property damage and possible loss of life is high, should point out those segments of the shore where shoreline protection and rehabilitation would and would not be feasible, and should provide a rational basis for shoreline management and zoning. A study of this type is now in the planning stages.

SUGGESTED READING

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