University of Wisconsin-Extension

GEOLOGICAL AND NATURAL HISTORY SURVEY
3817 Mineral Point Road
Madison, Wisconsin 53705

M.E. Ostrom, State Geologist and Director

SHORELINE EROSION IN SOUTHEASTERN WISCONSIN

by

David W. Hadley

Open-File Report 74-7
40 p.

This report represents work performed by the Geological and Natural History Survey, and is released to the open files in the interest of making the information more readily available. This report has not been edited or reviewed for conformity with Geological and Natural History Survey standards and nomenclature.

1974

74-7

SHORELINE EROSION IN SOUTHEASTERN WISCONSIN

by

David W. Hadley

DRAFT COPY
NOT FOR DISTRIBUTION

1974

COVER PHOTO

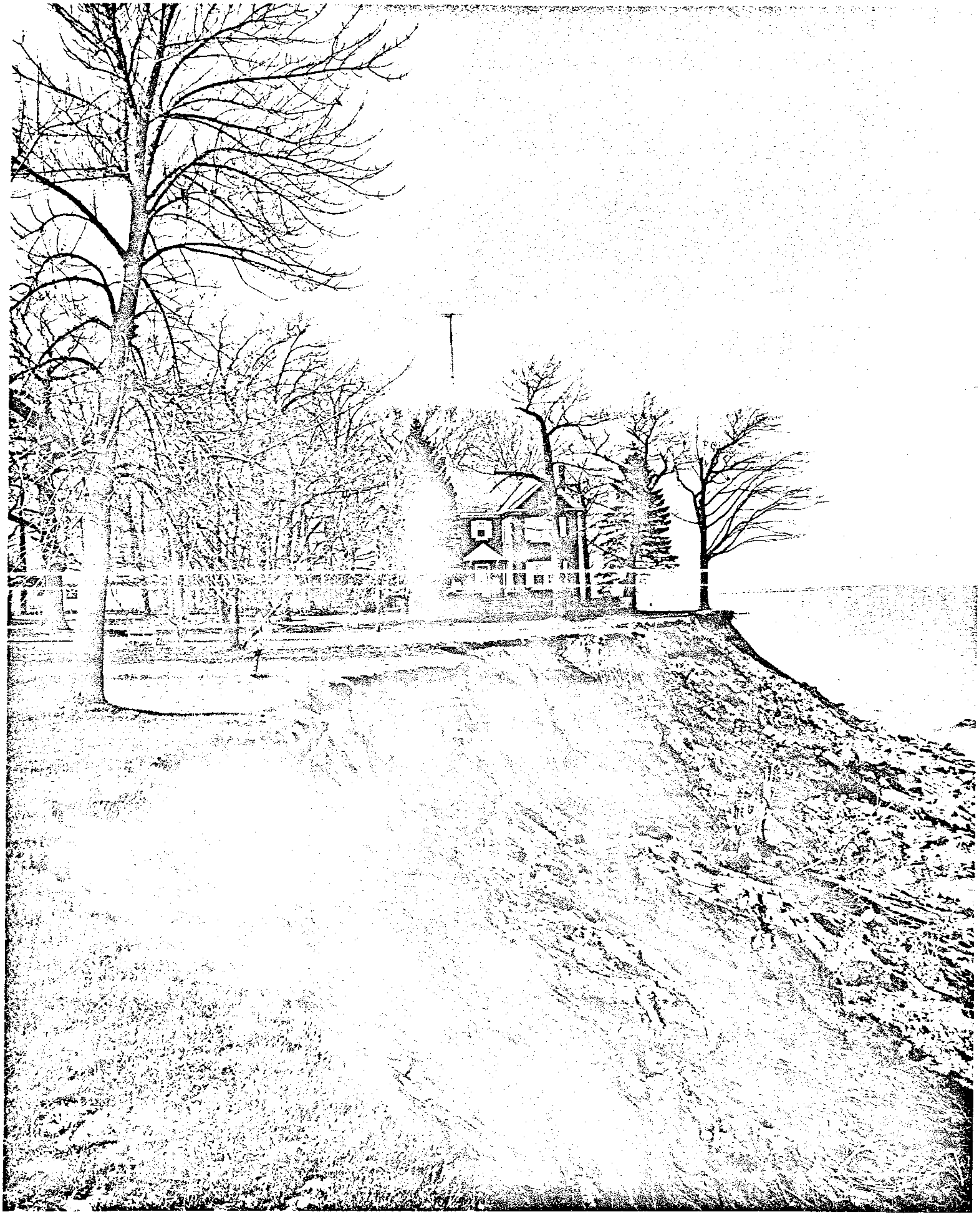


TABLE OF CONTENTS

INTRODUCTION

Near record high water levels in the Great Lakes during the early 1970's 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 which had been cut along the present N-S 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, consisting of sand, gravel, silt, and clay along what is now the margin of the lake. Prominent among these moraines is a series of concentric ridges which formed roughly parallel to the lake shore. These are called the Lake Border Moraines and are significant because they control the surface drainage. Streams that originate to the east of the moraines 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.

As the ice that deposited the Lake Border Moraines began to retreat into the Lake Michigan basin, the water that was released as the ice melted was trapped between the ice front to the north and the high ground surrounding the basin on the south. The surface of the lake thus formed was about sixty 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 being a recent phenomenon (Figure 1).

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 corresponding to each new outlet a new lake level was established, and that along the shoreline of each of these levels features were developed that are similar to those being formed today.

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.

Glacial Deposits

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

The most characteristic material deposited by glacier 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 glacio-lacustrine deposits.

Geology of the Lake Shore

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 by scattered low benches 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 overlain by finer grained lake sediments. From Milwaukee northward, this sequence is in turn overlain 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, greatly adding 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 which travel through the water in the direction of the wind. The size of the waves that form is dependent upon four principal factors, namely:

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, which have a fetch of hundreds of miles down the length of Lake Michigan. Wave heights of 15 to 16 feet have been reported at 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 a wave nears the shore and enters progressively shallowing water. The wave will begin to interact with the bottom, the speed of the wave will decrease, and the waves will become more closely spaced. As the wave moves into progressively shallower water, it will begin to increase in height and to tilt forward toward the shore. Eventually it becomes unstable and falls forward, or breaks (Figure 2).

When a wave breaks, the energy that was picked up from the wind is released (Figure 3). 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 will tend to be bent, or <u>refracted</u>. 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 will cause the waves to wrap around the projection and attack it from both the front and 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 long-shore current. This current is generally located just to the lakeward side of the zone in which the waves are breaking. As the 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 long-shore current and carried, bounced, or rolled along parallel to the shore.

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 2). Since most waves approach the shore from an angle, the sand and gravel will usually be washed obliquely up the beach. As the backwash from the breaker moves back down the beach in response to gravity and generally perpendicular to the shoreline, it will carry 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 will not be returned to the water's edge at the same locations they were picked up but instead will be moved a short distance down the coast each time they are thrown up against the beach. In this manner, all the materials which 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 down drift beaches, and rapid erosion of these areas may occur.

Beach Erosion

As was previously described, beach materials are carried up the beach by the uprush from breaking waves and returned to the lake by the backwash. The amount of material moved by each of these processes need not, however, 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 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, 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 clayer glaycial till. A relatively large percentage of the material eroded from lakeshore bluffs is too small in size 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. Reduction of the amount of material supplied to the littoral drift would, therefore, tend to accelerate beach erosion.

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 4). Fluctuations result primarily from changes in the amount of rain and snow that fall on the lake and on land areas that drain into the lakes and to a lesser degree on the amount of evaporation from the lake.

During the period between 1962 and 1964, precipitation was below normal and in 1964-1965 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 set up. Water levels in southern Lake Michigan can rise as much as three 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 short 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 maximum 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 were 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 of 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 up by the beaches. When the water levels are high, however, the beaches are partially or wholly submerged and storm waves will break close to, or in some cases, directly against the bluffs. 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 5).

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 lake shore.

EROSION OF THE BLUFFS

The aspect of shoreline erosion that is of immediate concern to most resident along the coast is the rapid retreat of the bluffs along the lake. Comparison of early maps of the area with more recent areal 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, its steepness, and 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 one foot vertically for every $2\frac{1}{2}$ 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 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 being similar to 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 mass of 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 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 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 6). 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 will again slow. 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 7). Such sections may appear to be relatively stable, but the writer has observed instances in which the entire sequence of slumps has slipped rapidly into the lake.

The Role of Ground Water in Erosion of the Bluffs

When rain falls over an area such as southeastern Wisconsin, most 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 is 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 is unusually high, and 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, ground water moves slowly through the rock and soil toward areas of lower elevation. Where the water table is intersected by surface streams, the water will drain into the streams and be carried away. In fact, almost all of the water carried by streams during dry periods is groundwater which 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 ground water 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 heavy rains or a sudden thaw with a heavy snow cover that the true 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 a low permeability. The water will pile up over this layer, giving rise to what is called a perched water table. This 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 or 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 8)

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 for the overlying material, and collapse of the overlying soil mass eventually follows. This process if known as spring sapping.

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

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 Preventative 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 lake shore, 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 any one or several measures on a single property or along a particular section of coastline to remedy the problem.

For example, if a section of the bluffs has been rendered so 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 must 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 9). 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 the individual property owners will likely be substantially reduced.

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 will be necessary. However, this method will 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, the construction of a series of benches, or regrading completely 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, 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.

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. The structures are of two broad classes. In the first class are structures designed to protect the shore by directly blocking the waves. The second class of structures are designed to form and hold a beach. The force of the waves will then be directed against the beach rather than 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

These are both essentially 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.

Revetments

These 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.

Seawalls and 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, breakwaters, and perched beaches.

Groins

These 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 which 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 properties down drift, raising the possibility of legal problems (Figures 10 and 11).

Breakwaters

These 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. They 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.

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

Perched Beaches

Perched beaches consist of a containing structure (basically two groins connected by a submerged breakwater at their lakeward end) filled with sand.

As is the case with groins, perched beaches can cause greatly accelerated erosion of adjoining stretches of the coast. In addition, it is usually necessary to periodically replenish the sand from an outside source.

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.

The Effectiveness of Protective Structures

As a part of the investigation upon which this report was based, the writer 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, it was 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 victins 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 12 and 13).

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 probable life and effectiveness of the structure and the true value of the property that they are 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.

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 would 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, 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 it has restricted development in flood plain 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 14).

A major problem concerning zoning of the lake shore is that there is not at the present time a sufficiently good 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 the geologic hazards are high. At the same time, zoning should not be so stringent as to preclude development of areas which will be safe for periods far exceeding the expected life of the proposed development.

Another major problem, and one which 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 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 squandered.

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 badly needed.

SUMMARY

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

Near record high water levels, the result of unusually high precipitation in recent years, have greatly accelerated the rate of 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 large numbers 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 bluff 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 involved slope stabilization through regrading and the 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 shore line. This study should delineate areas in which the risk of extensive property damage and possible loss of life are 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.

Table I

SHORELINE EROSION DURING THE HIGH WATER LEVELS OF 1951-1952

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

Data from Dept. of the Army Corps of Engineers.

Figure 1

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

Figure 2

As waves interract with the bottom, they become more closely spaced, increased in height, and eventually fall forward andbreak against the beach. Notice the pebbles being moved along the beach by the uprushing water.

Figure 3

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.

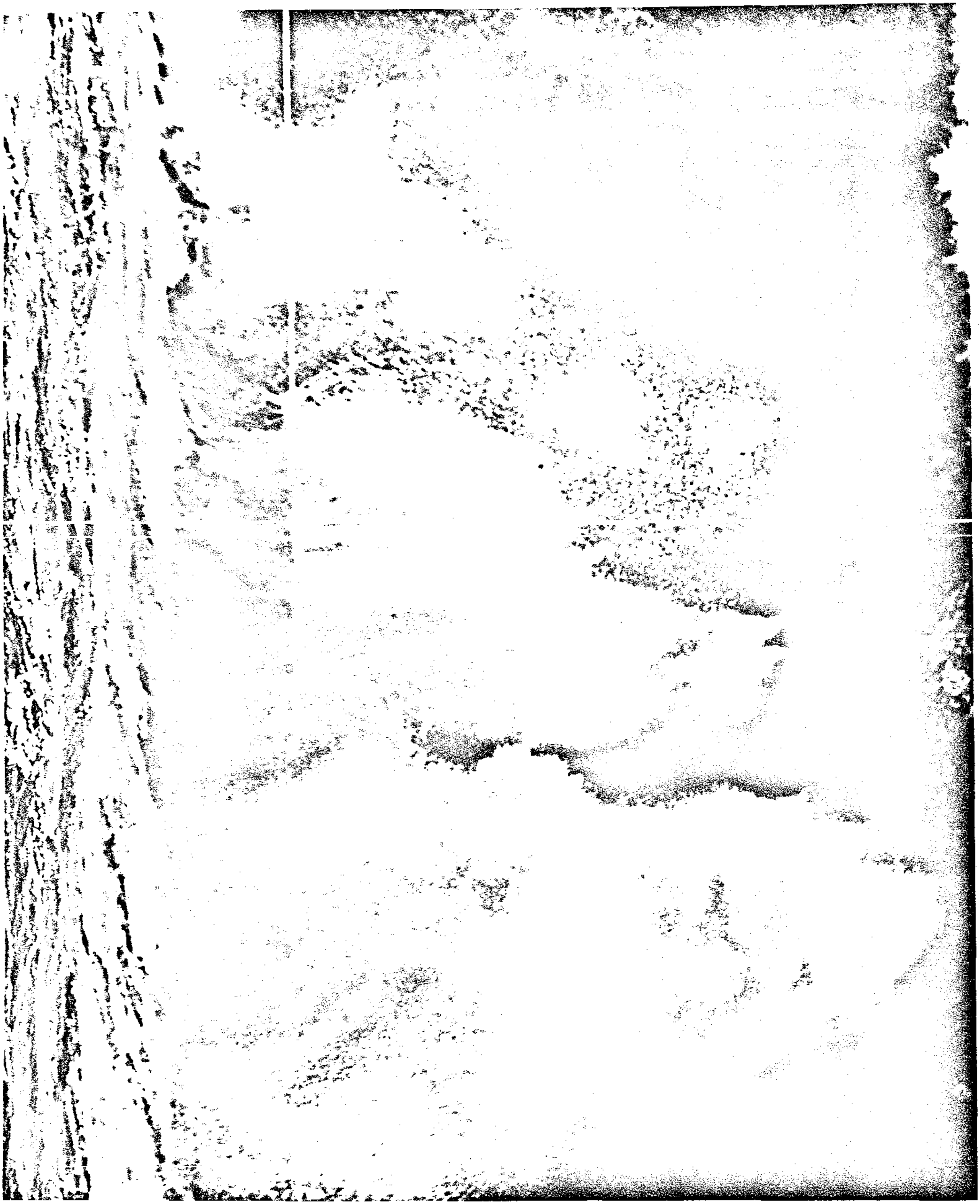
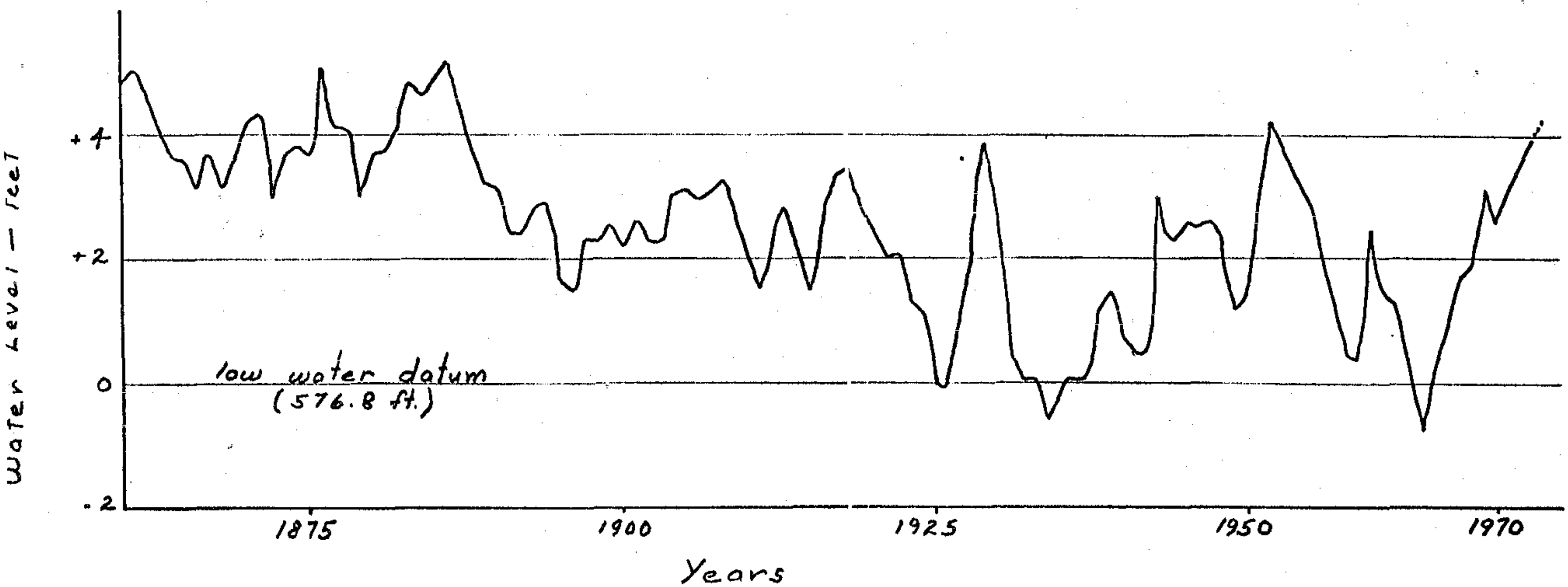


Figure 4. **Changing water levels in Lake Michigan are largely due to differences in the amount of rain and snow that fall on and near the lake.**



ANNUAL MAXIMUM WATER LEVELS IN LAKE MICHIGAN 1860 - 1973

(based on monthly mean water levels)

Data from Lake Survey Center - NOAA
U.S. Department of Commerce

Figure 5

Ice protects the shoreline from erosion by winter storm waves. Wind driven free floating ice can, however, do extensive damage.

Figure 6

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.

Figure 7

Continuing erosion at the toe of the bluff has caused a series of slumps to occur along this section of the shoreline.

Figure 8

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

Figure 9

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

Figure 10

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

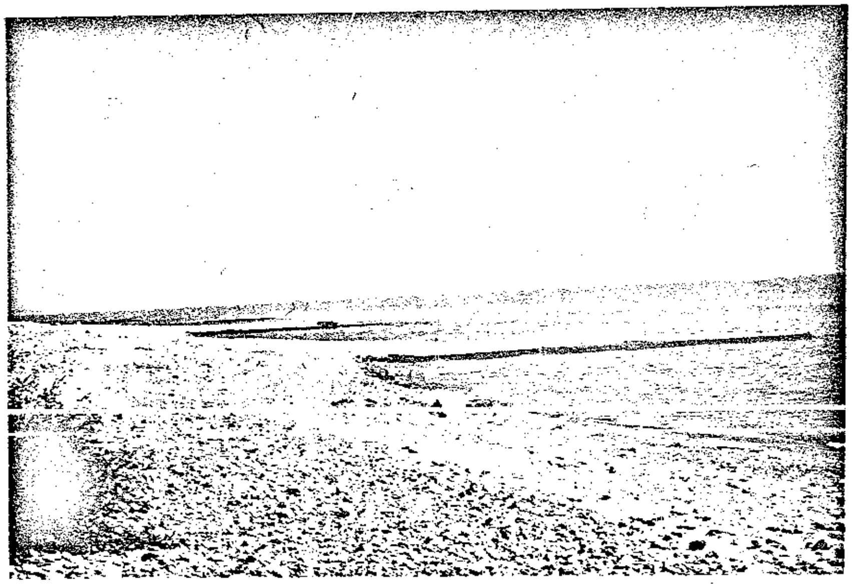


Figure 11

The section of shoreline in the background has been protected by the groins shown in Figure 10. 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.

Figure 12

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

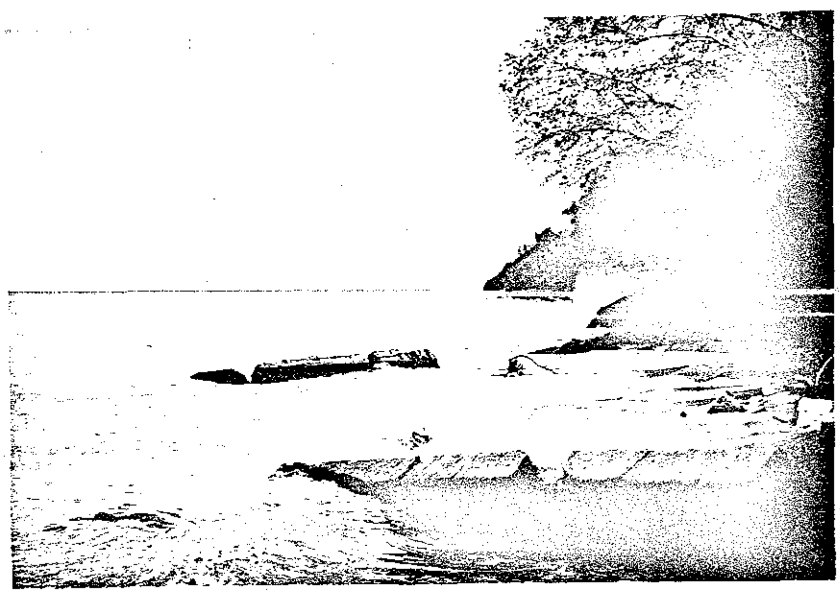


Figure 13

Attempts to protect this residence have obviously been unsuccessful.

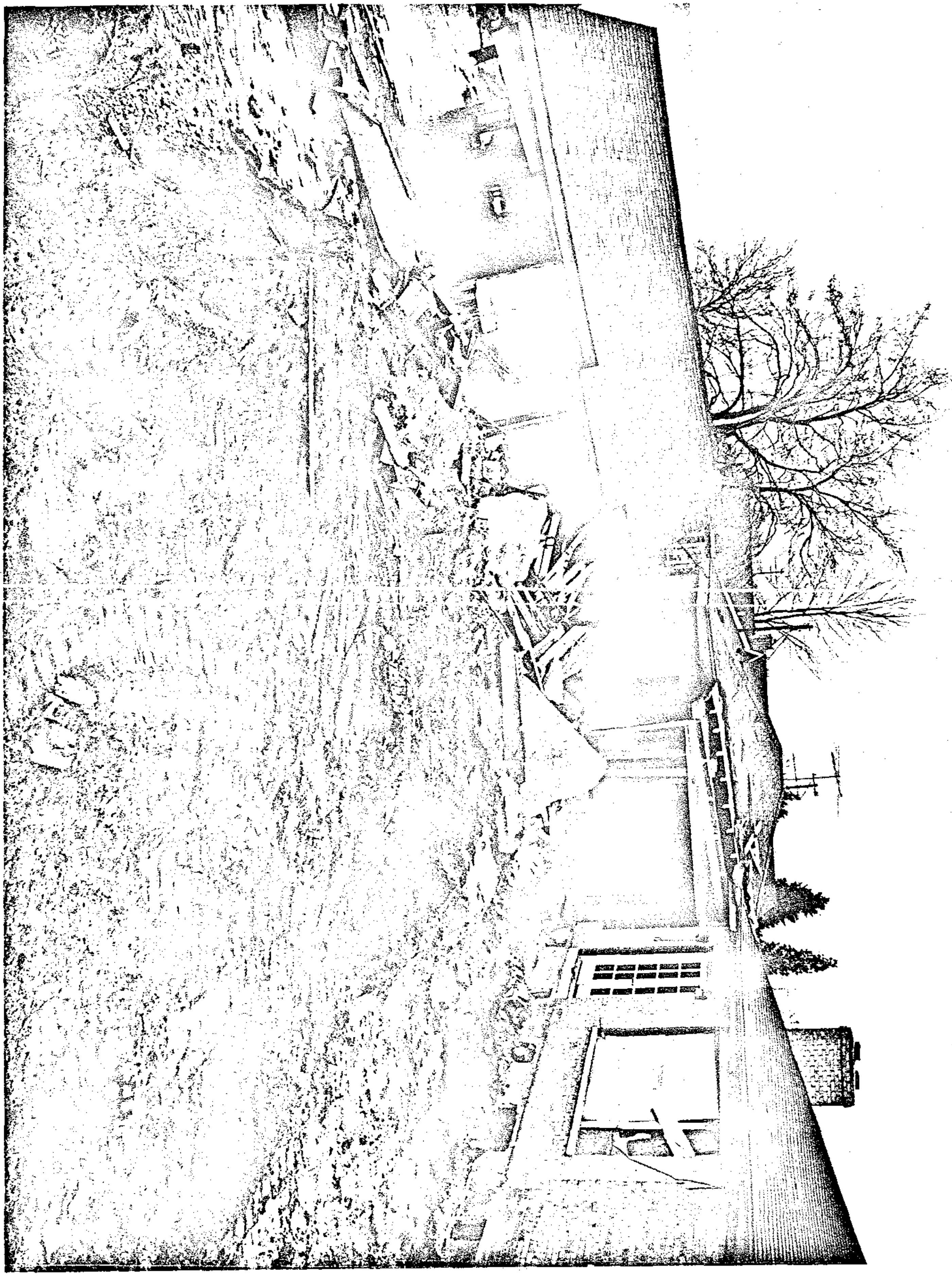


Figure 14

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.

SUGGESTED READING

Great Lakes Region Inventory Report, National Shoreline Study, Department of the Army, Corps of Engineers, North Central Division, August 1971.

Shore Protection Guidelines, National Shoreline Study, Department of the Army, Corps of Engineers, Washington, D.C. August 1971.

Shoreland and Flood Plain Zoning, A.R. Striegl, State of Wisconsin, Department of Natural Resources, Division of Resource Development.

Help Yourself, Department of the Army, Corps of Engineers, North Central Division 1973.

City of Kenosha, Wis. Beach Erosion Control Study, House Document No. 273, 84th Congress, 2nd Session, report of the Chief of Engineers, Dept. of the Army, May, 1955.

Beach Erosion Study, Lake Michigan Shoreline of Milwaukee County, Wisconsin - House Document No. 526, 79th Congress, 2nd Session, report of the Chief of Engineers, Dept. of the Army, 1945.

Racine County, Wisconsin, Beach Erosion Control Study, House Document No. 88, 83rd Congress, 1st Session, report of the Chief of Engineers, Dept. of the Army, 1952.

Shoreline Erosion, Lake Michigan Inter-League Group, League of Women Voters, 1974.