COASTAL PROCESSES MANUAL

A Training Manual for Evaluating Coastal Property

J. Philip Keillor and Allen H. Miller

University of Wisconsin Sea Grant Institute WIS-SG-87-430

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Glossary of Terms

Bank	The lakeward edge of land, generally less than 10 feet high, containing a few simple soil layers and no groundwater.
Bar	A submerged embankment in shallow water built by waves and lake currents.
Beach Ridges	A series of elongated sand ridges parallel to the shoreline formed during past periods of high lake levels.
Bluff	The lakeward edge of land, generally higher than 10 feet high, that is high enough to contain complex, multiple layers of soil and groundwater.
Recession	The landward movement of a shoreline caused primarily by erosion of the shore.
Revetment	A sloped structure of stone or concrete designed to protect a bluff or bank from recession.
Riprap	A layer of stones or concrete rubble on an embankment slope to prevent erosion; a type of revetment.
Seawall	A vertical structure — usually made of concrete, steel or wood beams — installed to protect a bluff or bank from recession.
Seiche	A small rise or drop in water level caused by oscillations (a sloshing) of the water back and forth in the lake bed as a result of strong winds, storms and atmospheric pressure changes.
Setback	The distance a building should be back from the edge of a bluff or bank to be reasonably safe from shore recession and to be relocated if necessary.
Shoal	An offshore sandbar that creates an area of shallow water.
Slump Block	A large block of earth that has broken off or slid down a bluff face.
Stable Slope	The natural angle to which a coastal bluff or bank will erode even when unaffected by other forces, such as shoreline recession or heavy loads like buildings.

Still Water Level	The normal level of a lake when it is unaffected by winds, storms or seiches.
Storm Surge	A temporary rise in water levels along downwind coasts caused by the drag of storm winds on the lake's surface.
Toe	The lake-level base of a bluff, bank or shore protection structure.
Wave Runup	The vertical distance storm or wind-driven waves will rise upon encountering a beach or sloped shore protection structure.

Preface

The University of Wisconsin Sea Grant Institute is part of the the National Sea Grant College Program, a network of 30 university-based marine research and public service programs supported by federal, state and private grants. Headquartered on the UW-Madison campus, the UW Sea Grant Institute is a statewide program with Advisory Services field offices located in Milwaukee, Green Bay, Sister Bay and Superior/Ashland. At present, more than 150 faculty, staff and students are involved in Sea Grant projects on campuses throughout the state -- at UW-Green Bay, UW-Extension, UW-Madison, UW-Milwaukee, UW-Parkside, UW-Stevens Point, UW-Superior and Lawrence University in Appleton. Its major research areas include Great Lakes fisheries, environmental contaminants, cool-climate aquaculture, diving physiology, Great Lakes management policy and a comprehensive Green Bay research program.

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The Wisconsin Coastal Management Program was established in 1978 to direct comprehensive attention to the state's 820 miles of Lake Michigan and Lake Superior coastline. The WCMP analyzes and develops state policy on a wide range of Great Lakes issues, coordinates the many governmental programs that affect the coast, and provides grants to stimulate better state and local coastal management. Its overall goal is to preserve, protect and develop the resources of Wisconsin's coastal areas for this and succeeding generations.

For more information about the program, contact the Wisconsin Department of Administration, Division of State Energy and Coastal Management, P.O. Box 7868, Madison, WI 53707.

Introduction

Storms and record high Great Lakes water levels in recent years have caused shoreline erosion, flooding and property damage on a scale unprecedented in the recorded history of the region. New geological evidence indicates that the lakes' actual range of water levels may be broader than the range of lake levels experienced during the last 140 years of coastal development. This means that most of the cities, homes, harbors, industrial plants and municipal facilities along the Great Lakes have been built too low and too close to the dynamic boundary where these inland seas meet erodible or low-lying shorelines.

Residential development of the Great Lakes coastline is principally a 20th century phenomenon. It accelerated after World War II, when increasing numbers of people had enough income to build second homes or principal residences on the lakeshore. Much of this development occurred during the 1960s, when the Great Lakes were at their lowest levels in 100 years. Several years of above-normal precipitation then caused the lakes to rise from record low levels in 1964 to set new 20th century record high levels during 1973-74, causing severe erosion problems and coastal property losses in the millions of dollars. During the last 10 years, the Great Lakes Basin has once more had above-normal precipitation, and the lakes have again risen to record levels. During 1985-86, all of the Great Lakes except Lake Ontario set new 20th century highs.

Many people who consider purchasing property along the shores of the Great Lakes tend to have the mindset of inland people -- people accustomed to stable hillsides, streams that remain in their beds and small lakes that retain their present shorelines. However, much of the 9,400 miles of Great Lakes shoreline is not stable, but retreating.

Since storms, shore erosion and bluff recession are natural processes, their threat to coastal property is largely the product of inadequate consideration of their effects and inappropriate siting of coastal buildings and structures. Understanding the dynamic forces and processes affecting the Great Lakes coastline can help safeguard investments in coastal property by minimizing potential losses of both land and buildings.

This manual describes the natural processes at work along the Great Lakes shoreline that may adversely affect investments in coastal property. It provides information and advice on how to evaluate the likely effects of changing lake levels, storm surges, wave runup and shoreline recession on Great Lakes coastal property. It also suggests ways to evaluate existing or proposed shore protection structures.

The information in this manual can help lenders and prospective buyers make informed decisions about investing in Great Lakes coastal property. It can help realtors make better disclosures to prospective buyers of the possible hazards to lakeside property posed by flooding and shore erosion. And it can help local administrators and citizen members of planning and zoning commissions and boards of appeal make informed decisions on the zoning and development of coastal properties.

The coastal processes described in this manual affect the entire shoreline of the Great Lakes. While the tables of data in this manual apply only to Wisconsin's Great Lakes shores, the procedures described can be applied to other areas of the Great Lakes by replacing these data with equivalent information for those locations. Each reach of Great Lakes shoreline has a unique set of geological features, however, and a site-specific coastal engineering study is the only way to minimize the uncertainties involved in estimating the effects of erosion, flooding and shore protection on the long-term value of a parcel of coastal property.

In many cases, however, the cost of a detailed engineering study is out of proportion to the investment or impractical for other reasons. This manual is designed to fill the gap between mere guessing and a detailed engineering study. Be aware that choosing to use the generalized procedures in this manual in lieu of a site-specific engineering study involves certain trade-offs. Generalization increases the uncertainties involved in estimating storm water levels, adequate home elevations and setback distances. Even in the case of on-site studies, coastal engineering is the practice of applying incomplete information to an environment that has storms, water level changes and recession rates that do not observe design limits. For a more detailed discussion of the assumptions and sources for the technical information presented in this manual, see Appendix 3.

Evaluating the Risks of Investments in Coastal Property

Despite the complexities involved in estimating future lake levels, storm surges, wave runup and shoreline recession, it does not take an expert to evaluate the risks of investments in Great Lakes coastal property. A reasonable evaluation of most coastal property can be performed by using readily available and easily understood information. It is not possible, however, to anticipate all possible site conditions. Uncertainties about future water levels, the date of the next big storm, future rainfall amounts, erosion rates, bluff stability, and the effectiveness and durability of shore protection structures are a fact of life of coastal living. The step-by-step evaluation process described in this manual is intended only to help reduce the uncertainties of investments in coastal property.

The evaluation process described in this manual can be used with a minimum of effort for sites without special complicating factors requiring professional evaluations by an engineer or geologist. Typical complicating factors include:

- Locations with recession rates that differ significantly from the rates suggested in Appendix 1;
- Exposed locations on points of land subject to wave action from several directions;
- Sites on rocky shorelines;
- Locations inshore of large shoals;
- Evidence that recession occurs in infrequent episodes of massive bluff slumping;
- Storm water depths greater than 3 feet at the base of a shore protection structure (see Appendices 2 and 3), and
- Nearshore lakebed slopes steeper than 10:1 horizontal feet per vertical foot (see Appendix 3: Wave Runup on Vertical Seawalls).

The process described here can help you distinguish between high- and low-risk investments in coastal property. When in doubt, however, consult an engineer or geologist about the need for an on-site inspection.

Options for Protecting Coastal Property Value

For many coastal properties, the best economic choice is to allow natural processes to proceed. A Michigan study during the high-water period of the 1970s concluded that relocation of endangered coastal houses was the most economical option in cases where relocation was feasible.[1] The same favorable economics will prevail for the construction of new buildings that are set back far enough from the shore to allow natural erosion to continue without the need and expense of installing and maintaining shore protection.

The bluff recession and the erosion of low sandy terraces experienced recently by many Lake Michigan property owners demonstrate that individual severe storms or solitary bluff slumping events can cause sudden recessions of 20 feet or more. A lakeshore bluff or bank can recede so much in a few months that much of a building's value is suddenly lost. Where rapid recession is a possibility, relocation is a prudent -- and possibly the most economical -- option in the long run. The feasibility of relocation depends on the structural integrity and complexity of the building, the depth of the lot, suitability of the soil for relocating the septic system, and sufficient land between the building and the edge of the bluff or bank edge for house moving equipment to be used safely.

For undeveloped coastal properties where the option of letting natural processes continue uninterrupted cannot be followed, new construction in highly erodible coastal areas needs proper siting and well-maintained shore protection structures. It is important to estimate the ability of a shore protection system to safeguard an investment in coastal property when evaluating the merits of that investment. The potential for flooding also needs to be evaluated.

Low-lying shore land that is occasionally wetland is a natural buffer for upland coastal areas, so development of such land is both inappropriate and probably uneconomical as well. Lakeshore sand ridges and beach dunes are also natural defenses that should not be breached nor used for building sites or access roads. These ridges and dunes come and go with falls and rises in lake levels -- and houses or roads built on them suffer the same fate. Some houses south of the Black River near Sheboygan that were built several hundred yards back from the lakeshore are currently being protected from erosion by the lakeside ridge. Their owners have seen this lakeside ridge disappear and reappear with each major rise and fall of lake levels since the 1940s.

How to Evaluate the Risks of Flooding

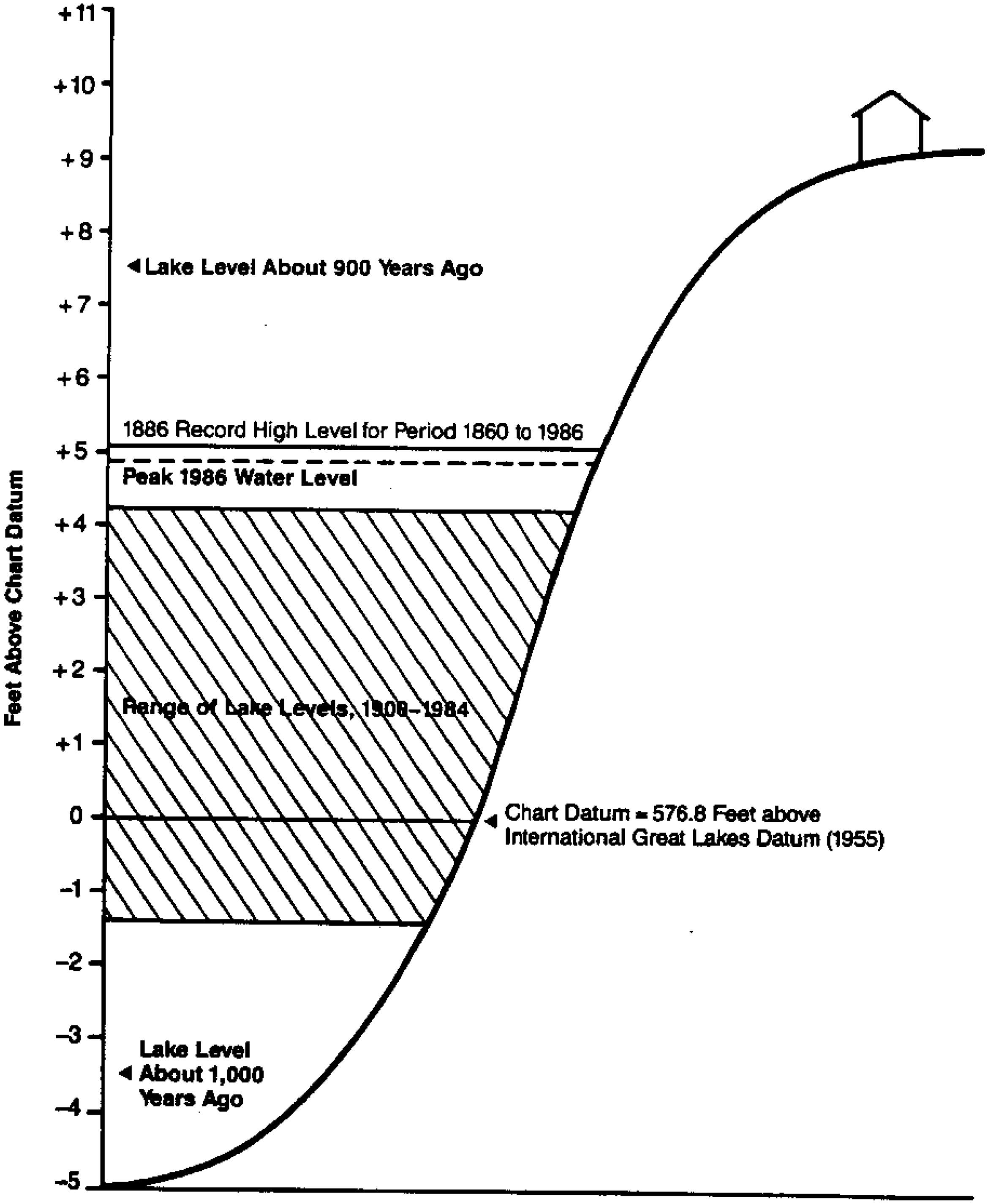
Evaluating the risks of flooding for a Great Lakes coastal property requires three steps: (1) estimating the highest likely still water levels, which rise and fall from season to season and from year to year; (2) estimating the height of storm surges, temporary rises in the water level caused by storm winds blowing towards shore; and (3) estimating storm wave runup on the property. The sum of these is the height that water can be expected to reach on the property.

Seasonal and Long-Term Changes in Great Lakes Water Levels

The Great Lakes region lies in the boundary between arctic and temperate air masses and is a focal point for low-pressure storm systems moving across the continental United States.[2] One consequence of this is that the region is subject to periods of wet or dry weather that can be decades or more in length. When the climate is cool and moist, lake water evaporation is decreased and precipitation is heavy, so the lake levels rise. When the climate is warm and dry, evaporation is increased and precipitation is light, so the lake levels decline. There are other possible combinations and complicating factors, but this relationship between climate and lake levels is direct.

Figure 1

Range of Water Levels on Lake Michigan



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Research on past climatic conditions indicates that the Great Lakes region has had long periods of considerably wetter and cooler weather than that of the last 100 years.[2] Recent research indicates that Lake Michigan has a range of water levels twice that experienced during the past century.[3] Wood and peat deposits in prehistoric sand ridges and swales along Lake Michigan's southwest coast indicate that during the last 1,000 years the lake has on several occasions risen several feet higher and fallen several feet lower than the highest and lowest water levels recorded during the last 140 years. This means development of the Lake Michigan shoreline during the last 140 years was based on an assumption of a "normal" range in water levels that now appears to have been substantially lower and narrower than the actual long-term natural range. This situation may also be true for the other Great Lakes.

The water levels of the Great Lakes also respond to seasonal changes in climate. Lake levels rise in the spring due to precipitation entering the lake directly from the atmosphere and indirectly as runoff from winter snowmelt and spring rains. Lake levels decline in the fall, when conditions generally favor evaporation as cold, dry arctic air blows across the surface of the relatively warmer water of the Great Lakes. Fall and early winter winds can produce rapid and significant drops in lake levels.

Estimating Still Water Levels

The first question to ask in evaluating a coastal property is, "How high can the lake level be expected to rise during the expected lifetime of the structure or of a mortgage on that structure?"

Long-range predictions of future water levels are based on computer simulations of the lakes' responses to changes in water supply. In early 1987, for example, experts predicted that if temperature and precipitation in the Great Lakes region return to average conditions, Lake Michigan and adjoining Lake Huron will return to "normal" water levels in 6 to 10 years. If the region has dry conditions like those during 1961-64, however, the water level of these two lakes will return to average levels in only 3 or 4 years.[4] But if the region continues to have wet weather like that in 1985, the water level of both lakes could rise 1.5 feet higher than the record levels of 1986. And if the basin has a number of years of even greater precipitation (50 percent or more above average), the water level of Lakes Michigan-Huron could rise as much as 3 feet higher than the record levels of 1986 in 5 to 7 years.

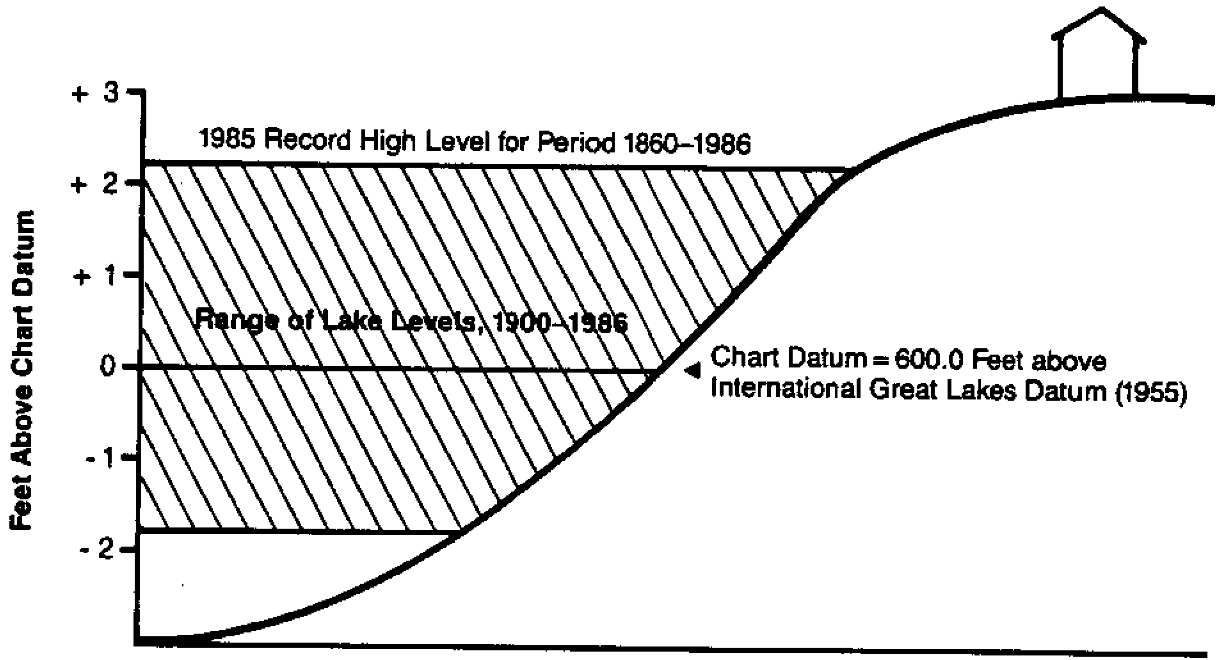
The possibility that even higher lake levels could actually occur is supported by recently published evidence of prehistoric lake levels in old beach ridges that indicate Lake Michigan's water levels during the last 1,000 years have at times been 2 to 3 feet higher than 1986's record levels (Figure 1). The authors are unaware of any published research on the prehistoric water levels of the other Great Lakes similar to that work by Curtis Larsen of the U.S. Geological Survey.[3] The recorded range of water levels for Lake Superior is presented in Figure 2.

The lake level information available for evaluating the risks to coastal property is based on data from little more than a century of record-keeping. As a result, calculations based on this information will produce levels that may be underestimated, considering the possibilities discussed above, so it would be wise to increase estimates of lake level elevations accordingly to hedge against the possibility of higher levels in the future.

In this manual, determination of the still water level is based on the highest monthly mean level for the lake (NOTE: The highest monthly mean is an average level for the lake over the entire month and therefore is lower than the highest daily lake level). This informa-

Figure 2

Range of Water Levels on Lake Superior



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tion is readily available -- simply select the highest 20th century mean level from either the U.S. or Canadian monthly Great Lakes water level bulletin.[5,6] For example, the U.S. Army Corps of Engineers' January 1987 lake levels bulletin (Figure 3) indicates the highest monthly water level for Lake Superior is 2.2 feet above chart datum, recorded during October and November in 1985.

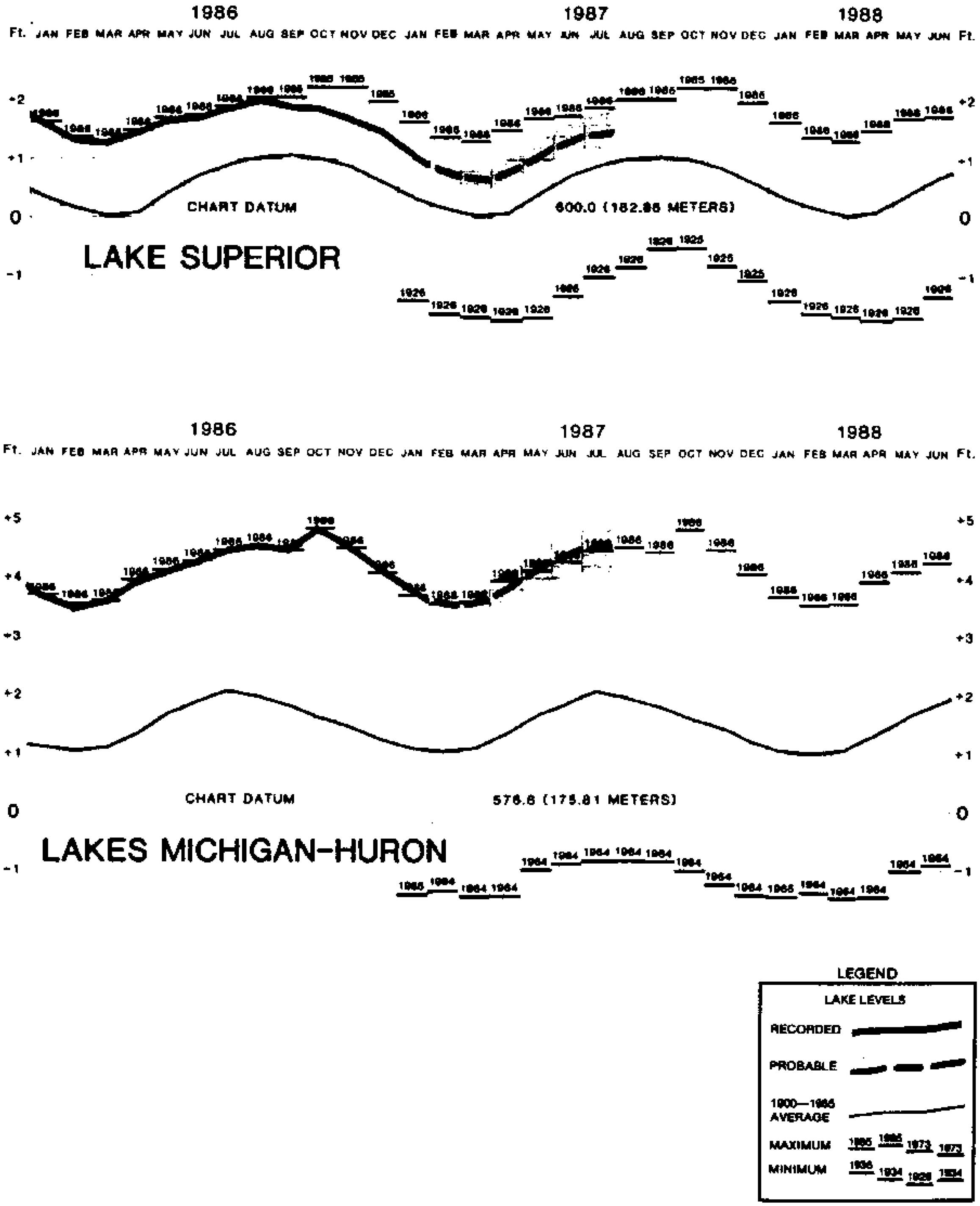
Estimating Storm Surge Heights

As storm winds blow across the many miles of open water on the Great Lakes, they drag water towards the downwind side of the lakes, causing a build-up in water level along the downwind shore (Figure 4). This temporary rise in water level is called a "storm surge" or "storm set-up." The corresponding drop in water level on the upwind side of the lakes is called a set-down.

Storm surges affect all of the Great Lakes shoreline and are most severe around shallow parts of the lakes. During unusually severe storms with strong westerly winds, for example, Lake Erie -- the shallowest Great Lake -- has had storm surges approaching 8 feet high at the eastern end near Buffalo, N.Y., with a similarly large drop in water level at the western end of the lake. Open-coast sites like Milwaukee typically have storm surges only 1 to 2 feet high.

Figure 3

January 1987 Lake Level Bulletin



U.S. Army Corps of Engineers

Storm surges last about as long as the storm winds do, rising rather quickly with wind velocity and dropping when the wind speed falls. Even after the wind has died down or switched direction, one or more smaller rises in water level may occur up to 8 hours after the storm surge due to lake level oscillations called "seiches." Seiches are basically a back-and-forth sloshing of the water in the lake bed caused by a disturbance from a storm, wind shift or air pressure change. The seiches following a storm may cause repeated flooding of low-lying property, but they usually have less of an effect on coastal erosion because they are not accompanied by waves as high as those accompanying a storm surge. Small seiches (less than a foot in height) are an everyday result of weather systems passing over the lakes.

Figure 4

Storm Surge

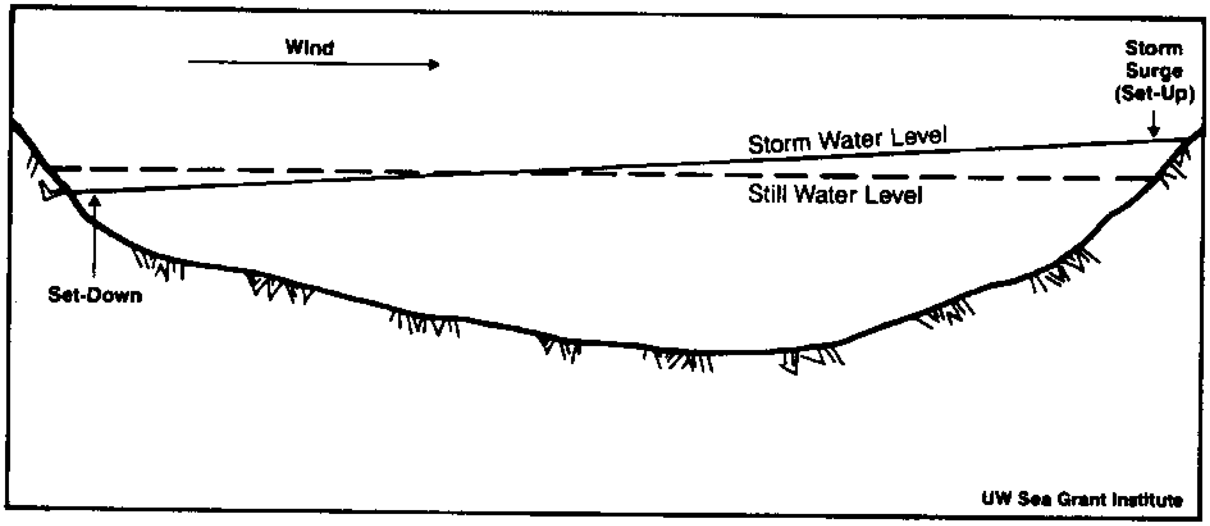


Figure 5 shows storm surge values for most of the U.S. and Canadian Great Lakes coastline. The surge height is presented in feet above the still water level. These storm surge values are not maximum values: Storm surge records for Duluth, Milwaukee and Green Bay indicate that storm surges in some locations can be twice the values indicated in Figure 5. For example, extreme storm surges of 3 to 5 feet have been recorded at the city of Green Bay, 2.5 feet at Milwaukee and 1.8 feet at Duluth-Superior.[7] The greatest storm surges occur in shallow bays where the wind can blow long distances across the water.

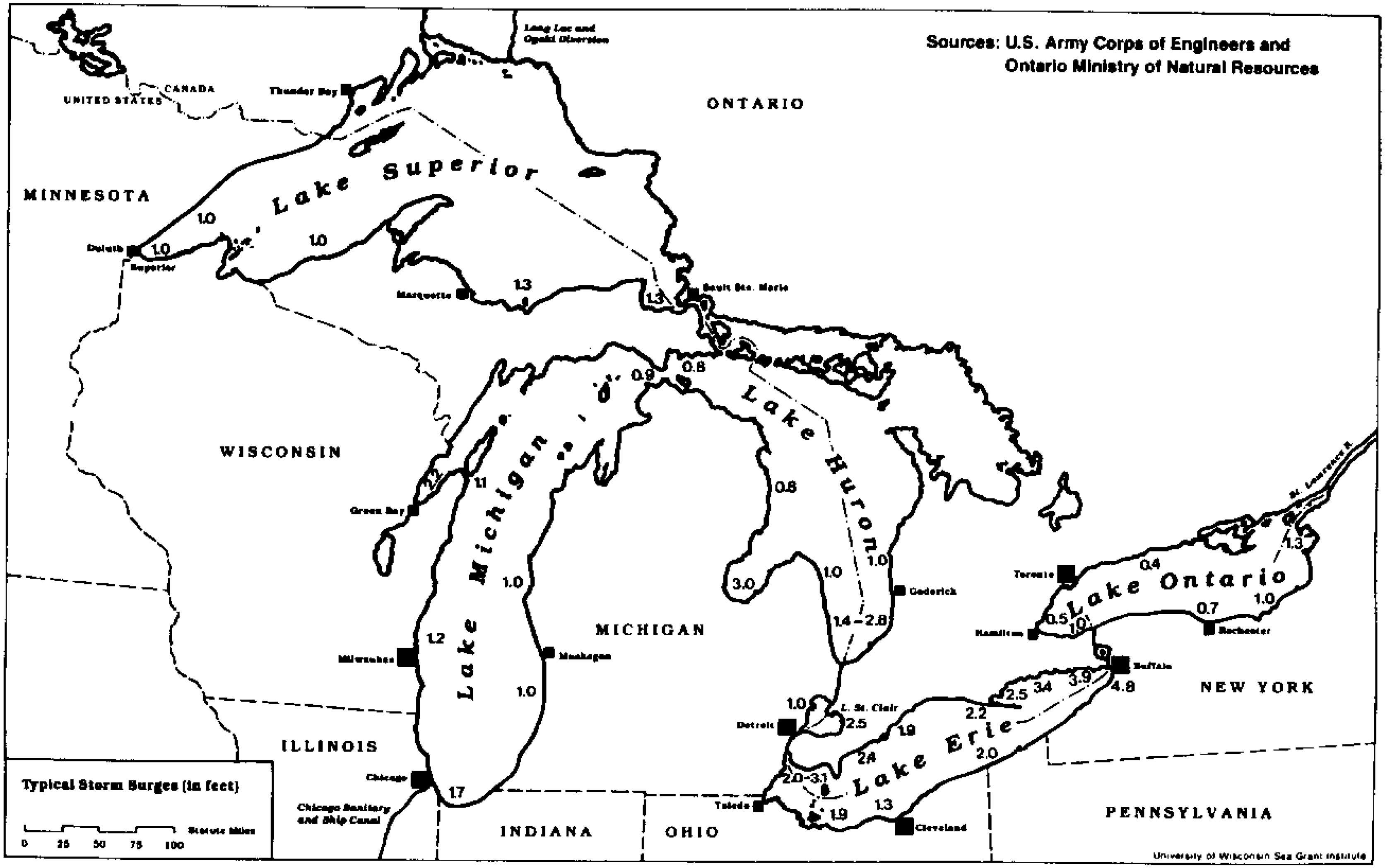
Complex calculations are required to determine extreme storm surges and storm surges where coastal waters are confined by bays, islands or large shoals. Extreme storm surges are not used in the following examples because the information can only be obtained from long-term water level records or by engineering calculations.

Estimating Storm Wave Runup

Flooding from high lake levels or storm surges can cause a great deal of damage. However, the waves produced by storms run even further up the shore and can cause

Figure 5

Generalized Storm Surges in the Great Lakes


Sources: U.S. Army Corps of Engineers and Ontario Ministry of Natural Resources

flooding as well as erosion. The three kinds of coastal flooding are shown in Figure 6. Thus, to estimate the full impact of a storm, it is also necessary to estimate the extent of wave runup on a coastal property.

During storms, waves in deep water 5 miles or more from shore may have a wide range of heights. Deepwater storm waves as high as 25 feet have been reported on the Great Lakes.[8] Shallow nearshore water depths help protect the shoreline, however. As waves approach the shore, they are modified by the friction of contact with the lake bed. As the waves reach shallow water and reach a limiting depth that is proportional to their height, the waves will break. While the relationship is complex, as a rule nearshore wave heights are limited to 55 to 65 percent of the water depth on lakebed slopes typical of most shores.[9] By the time waves reach the shoreline, the largest waves have broken. This is a very important form of protection, since the amount of wave energy that breaks against the shoreline is proportional to the wave height squared. This is why rising lake levels and storm surges -- because they create deeper water nearshore and cause larger waves to break against the shore -- have such a large effect on rates of shoreline recession and damage to coastal structures.

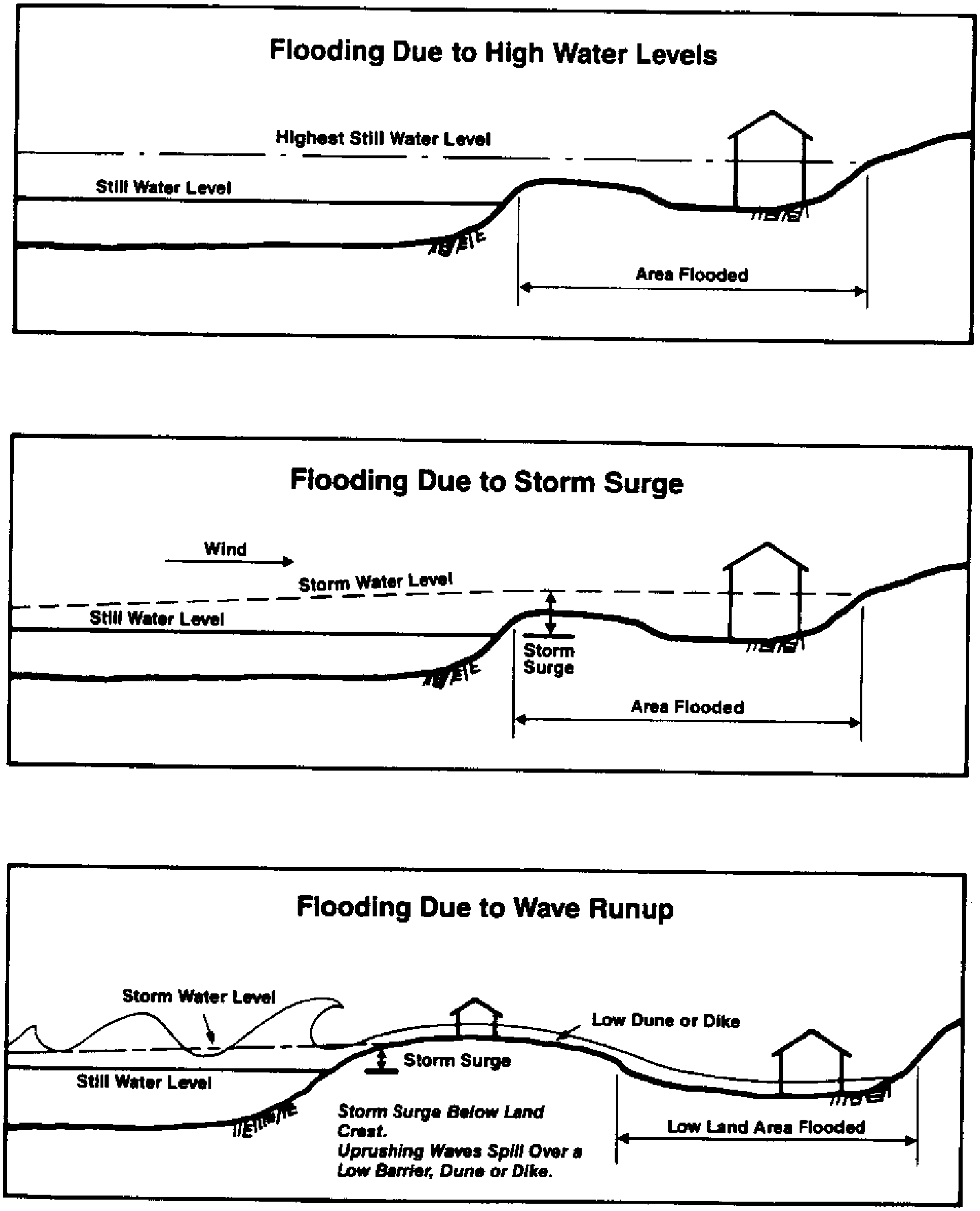
Wave runup is the vertical distance a wave will rise when washing up on a beach or on a shore protection structure (Figure 7). This distance depends on wave characteristics as well as the make-up and slope of the beach or shore protection structure. The important wave characteristics are wave height (the vertical distance from trough to crest) and wave period (the time it takes for two successive wave crests to pass). Generally, because a cobble beach or rubble revetment is more porous, it will absorb more of a wave and have less runup than a sandy beach or a sloping concrete slab revetment. Also, a wave will run higher (vertically) up a steeply sloping structure than up a gently sloping structure.

It is difficult to estimate runup on a sand, gravel or cobble beach because beaches made of these mobile materials often have complex shapes and are constantly being reshaped by waves. Storm waves steepen such beaches, causing the runup distance to increase. In long periods between storms, small waves create a gentler beach profile, resulting in relatively less runup. This interaction of beach slope and wave conditions means that wave runup estimates for beaches containing large quantities of mobile sands, gravels and cobbles are best made in the spring or fall of the year, when the beach is most likely to be at its steepest slope.

Calculating wave runup is a complicated process and best left to a professional engineer. A simplified interim method, described in Appendix 2, will provide reasonable estimates of runup for beaches, riprap revetments and vertical seawalls. In any case, an estimate of wave runup is essential to calculating the highest elevation water is likely to reach on a coastal property. Table 1 provides minimum values of runup that can be expected on open coasts for beaches, revetments and vertical seawalls. Waves can be expected to run up to at least these values anywhere along the coast: In most cases, actual runup will exceed these values. For a more accurate evaluation of wave runup, use the process described in Appendix 2 or consult an engineer.

Figure 6

Types of Coastal Flooding



Flooding Due to High Water Levels

Flooding Due to Storm Surge

Flooding Due to Wave Runup

Storm Surge Below Land Crest.
Uprushing Waves Spill Over a Low Barrier, Dune or Dike.

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TABLE 1

MINIMUM WAVE RUNUP VALUES FOR OPEN COASTS OF THE GREAT LAKES

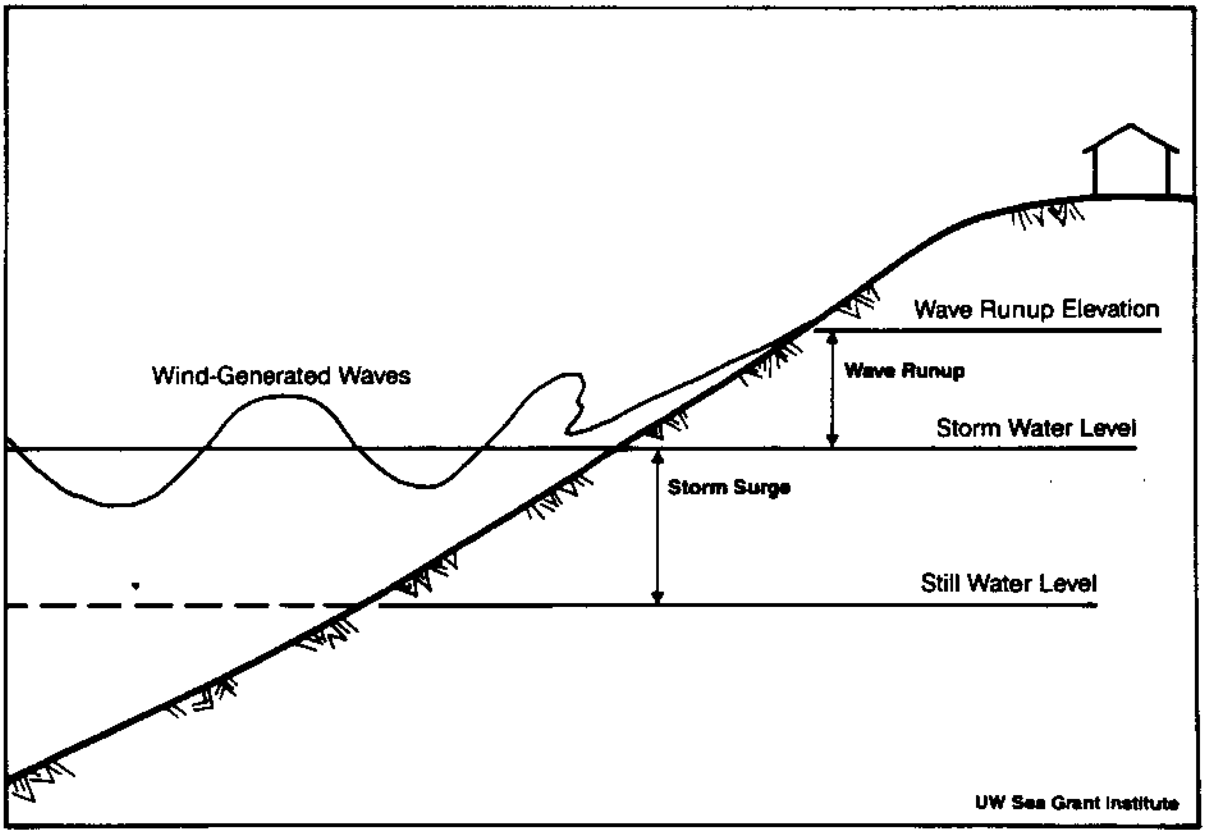
Beaches	2.0 feet
Riprap Revetments	1.0 foot
Vertical Seawalls*	2.0 feet (45 gpm/ft) 3.0 feet (4.5 gpm/ft)

* Wave runup on seawalls is treated differently than runup on beaches or revetments. These are the heights of the seawall crest above storm water levels (freeboard) that are estimated to be adequate for acceptable storm wave overtopping rates of 45 and 4.5 gallons per minute per foot of shoreline.

SOURCE: The bases for this table are described in Appendices 2 and 3.

Figure 7

Storm Surge and Wave Runup



Estimating Storm Wave Runup Elevations

The storm wave runup elevation for a coastal property is the sum of the estimates for still water level, storm surge and wave runup. The result will not be a precise elevation. The combined uncertainties for all three factors will total more than a foot. An evaluation of the property's susceptibility to erosion and/or flooding requires a comparison of the estimated storm wave runup elevation and the elevation of the land or the crest elevation of a shore protection structure. In sheltered waters where waves are not a significant factor, this requires only a comparison of the storm water level elevation and the land elevation.

For these comparisons, the storm wave runup or storm water level elevation needs to be converted to the same measurement system used for land elevations. Suitable land elevations can usually be obtained from topographic maps for the area and by estimating on-site variations in elevation. In cases where it is difficult to estimate land elevations, a site survey may be necessary.

The U.S. Army Corps of Engineers' Monthly Bulletin of Lake Levels for the Great Lakes and the Canadian Monthly Water Level Bulletin give lake level information in terms of feet and meters, respectively, above or below a reference level, or chart datum, for each lake.[5,6] The chart datum is "zero feet" or "zero meters" on the vertical scale of these bulletins. These chart datums provide elevations above the International Great Lakes Datum (IGLD 1955). For example, the chart datum for Lake Superior is equal to 600 feet or 182.9 meters above the IGLD.

Land elevations, on the other hand, are referenced to a completely different type of datum. The currently recommended U.S. datum is the National Geodetic Vertical Datum (NGVD 1929). However, topographic maps may show elevation in feet above Mean Sea Level (MSL 1929, or simply MSL). NGVD and MSL are different terms for the same datum. Canadian land elevations are referenced to Geodetic Datum as determined by the Geodetic Survey of Canada.

The differences between the water-based IGLD and the land-based NGVD and Canadian Geodetic Datum are not constant, but vary slightly with latitude and elevation because Earth is not a perfect sphere. However, for the purposes of this manual, it is sufficiently accurate to use a simple conversion value for each of the lakes.[10,11]

Table 2 shows each lake chart datum in terms of the IGLD (1955), NGVD (1929) and Canadian Geodetic Datum. Table 2 can be used to make a simple conversion of estimated storm wave runup elevations to the land-based datum system so that the water and land elevations can be compared.

Coastal property within city limits will have elevations referenced to city datum. For example, the City of Milwaukee Datum (CMD) is 579.30 feet above IGLD. For other cities, contact the city engineering department to get the proper conversion of water level elevations to local city datum.

Example 1 applies the information provided so far to a hypothetical shore property. While the conversion from chart datum to mean sea level is the last step in the process, it can also be made after the still water level has been determined.

TABLE 2
LAND ELEVATION EQUIVALENTS FOR INTERNATIONAL GREAT LAKES CHART DATUMS

Lake	Chart Datum (IGLD 1955) Feet	Chart Datum (IGLD 1955) Meters	Equivalent Land Elevation (NGVD 1929) Feet	Equivalent Land Elevation (Geodetic Datum-Canada) Meters
Superior	600.0	182.9	601.0	183.0
Michigan	576.8	175.8	578.1	N/A
Huron	576.8	175.8	578.1	176.0
St. Clair	571.7	174.2	573.1	174.4
Erie	568.6	173.3	570.1	173.5
Ontario	242.8	74.0	244.0	74.1

NOTE: The above equivalent elevations are from U.S. and Canadian master lake level gauging stations on each lake. They apply also to the chart datums used on the monthly lake level bulletins. The NGVD elevations are the same as Mean Sea Level (1929) elevations. The equivalent elevations shown above are unsuitable for survey purposes and do not represent the elevations of any other coastal sites (see Appendix 3).

SOURCES: The U.S. National Ocean Service, National Oceanic and Atmospheric Administration, and the Canadian Hydrographic Service.

EXAMPLE 1: Estimating the Storm Wave Runup Elevation for a Property

A 30-year-old house is located on a coastal lot in Sheboygan County on Lake Michigan. The elevation of the basement floor is about 6 feet below ground level. A topographic map of the area indicates that the ground around the house is about 588.5 feet above sea level. The shoreline is a sandy beach. What is the likelihood that the building will be flooded during the next 20 years?

Step 1: Determine the highest predicted still water level.

First, find the highest monthly mean water level for Lake Michigan from the U.S. Army Corps of Engineers' monthly bulletin of Great Lakes water levels (Figure 3). This is 4.8 feet above chart datum (October 1986). Next, check to see if higher levels are projected. The Corps of Engineers' monthly lake levels bulletin for January 1987 (Figure 3) projected that Lake Michigan's water level in July 1987 would be 4.1 to 5.0 feet above chart datum. To be safe, use the higher maximum value: 5.0 feet above chart datum.

Step 2: Determine the local storm surge.

The open coast at Sheboygan has a typical storm surge of 1.2 feet (Figure 5).

Step 3: Select an appropriate wave runup value.

The minimum wave runup on a sandy beach is 2.0 feet (Table 1).

Step 4: Estimate the storm wave runup elevation.

The wave runup elevation is the sum of the highest projected water level, typical storm surge, minimum runup value and the equivalent Mean Sea Level (MSL), or NGVD, elevation for International Great Lakes Chart Datum for Lake Michigan (Table 2).

Highest still water level (step 1)	5.0 feet above chart datum
Typical storm surge (step 2)	1.2 feet
Minimum wave runup (step 3)	2.0 feet
Lake Michigan elevation (Table 2)	+578.1 feet above MSL
Estimated storm wave runup elevation	586.3 feet above MSL

Step 5: Compare the storm wave runup elevation to the building site elevation.

Building site elevation	588.5 feet above MSL
Storm wave runup elevation (step 4)	-586.3 feet above MSL
Difference	2.2 feet

Answer: The land around the building is about two feet above the estimated storm wave runup elevation, so it appears unlikely that the house will be flooded. However, the basement could flood if substantial water seepage through the ground from the lake occurred, or if storm wave runup flooded the yard, which is likely because wave runup is likely to be higher than the minimum value used. In this case, a better estimate of wave runup is needed (see Appendix 2), and the property owner may need to consider installing a storm water drainage system, a raised berm behind the beach or a riprap revetment.

How to Evaluate the Risks of Coastal Erosion

Besides determining the likelihood of flooding due to high water levels, storm surges and storm wave runup, it is equally important to determine if an existing or proposed lakeshore house is set back far enough from the lake to prevent damage to or loss of the building due to erosion during the life of the mortgage or the projected life of the structure. In coastal engineering terms, this is called "construction setback."

Erosion and recession of bluffs and banks is the rule for most coastal properties. From a geological perspective, the Great Lakes are relatively young, and erosion of their shores continues to be an active natural phenomenon. Bluffs recede as waves chew away at their base, or toe. Over the years, this action will result in the shoreline continually moving inland -- a process known as shore recession. When lake levels are low and the bluff is no longer subjected to wave attack, erosion of the bluff face will continue until the bluff achieves a naturally stable slope. Thus both factors -- recession and slope stablility -- must be considered in estimating the proper distance that a building should be set back from the shore.

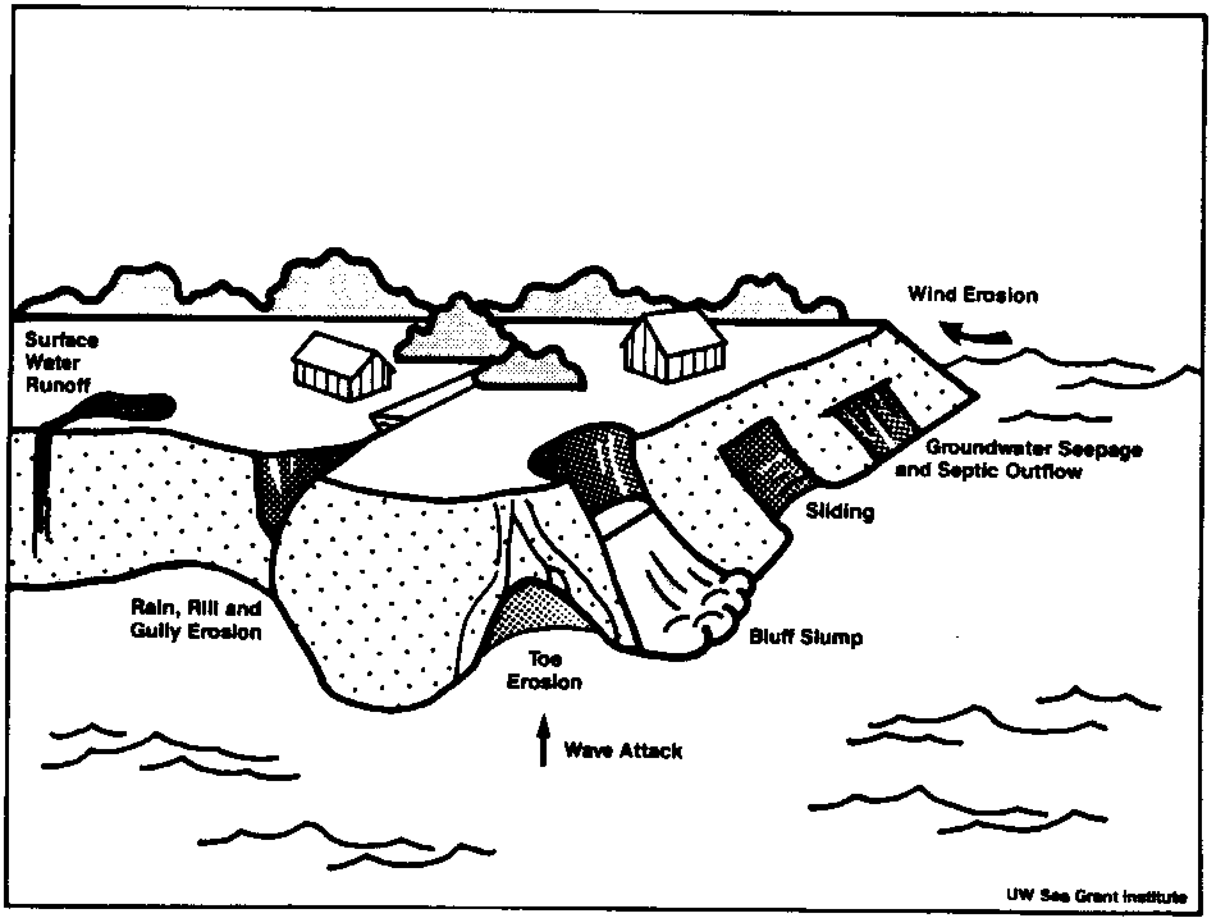
It is important to recognize the signs of severe, rapid coastal erosion and to evaluate the stability of the ground near the edge of a bluff or bank. Once the stability of the ground near the edge becomes marginal, it is unsuitable for supporting a building. If portions of the bluff or bank face are raw earth, it is a sign of active erosion. The presence of slump blocks or the absence of mature vegetation (trees and shrubs) are other indications that a slope is or has recently been actively eroding. The various ways in which coastal bluffs erode are shown in Figure 8.

Generally speaking, stable slopes have fairly uniform faces and are likely to remain stable as long as the toe is protected from wave attack and the face of the slope is protected from erosion by vegetation. Bluffs and banks remain stable as long as the soil's resistance to failure remains greater than the forces that can cause failure.

The forces that cause the collapse of a bluff include the weight of the soil and groundwater in the bluff, and the weight of any buildings or heavy machinery on top of the bluff. Bluffs often fail in a sequence of events that includes heavy rains, elevated

Figure 8

Coastal Erosion Problems



groundwater levels, increased bluff load (or decreased soil strength), failure in upper portions of the bluff, and erosion of the toe during storms. The presence of groundwater in the bluff can weaken the frictional forces that hold soil particles together and give the soil its strength. Groundwater seeping from the raw face of a bluff is also a sign of bluff instability.

Bank erosion is less complex but no less dramatic than bluff erosion. During the 1985-86 period of high lake levels on Lake Michigan, severe storms caused episodes of rapid erosion on Wisconsin's coast where the combination of high lake levels and storm surges allowed storm waves to break against unprotected, highly erodible sand banks. Sandy banks 2 to 6 feet high retreated 10 to 30 feet in a single storm.

Significant but less obvious coastal erosion may occur as bluffs and banks experience shallow slides, surface water runoff and mudflows, or they may wash away in small clumps and individual grains (rain, rill and gully erosion). A University of Wisconsin Sea Grant study of the state's Great Lakes coastal bluffs indicated that as much as half of the long-term erosion of some bluffs is caused by these almost imperceptible forms of erosion.[12]

Recession is not limited to clay bluffs and low sandy banks. Rock terraces and bluffs also recede. Over decades, wave action and the ceaseless wash of gravel and cobbles against rocky ramparts of the coast undercuts the rock. Storm waves also drive water into crevices with great force, enlarging the fissures. In cold weather, water draining into rock crevices from overlying topsoil freezes and expands, applying large separation forces to the rock along the sides of the cracks. Eventually, blocks of rock fall from the face of the bluff.

Recession, in theory, occurs in direct proportion to rises in water level as soil is added to nearshore sediments where the shore is no longer in equilibrium with the lake.[13] As long as water levels continue to rise, a state of equilibrium between the land and the lake -- and therefore a slowing or halting of recession -- cannot be expected to occur. As water levels decline, beaches are rebuilt with sediments brought ashore by waves. In reality, equilibrium occurs only when there is little or no net movement of nearshore sediment out of a coastal area. During the last period of rising lake levels (1967-76), a 31-mile stretch of sandy beach along Michigan's Lake Michigan coast was observed as it responded to rising lake levels.[14] As the water level rose, the nearshore sandbars moved up the beach slope and shore recession increased, though at a rate that depended on storm events. The sandbars continued to migrate shoreward even under relatively mild wave conditions. Shoreline retreat lagged behind rising lake levels, ultimately reaching a new position and reestablishing a series of stationary sandbars in equilibrium with the lake levels about 3 years after lake levels stabilized.

Wisconsin's Lake Michigan coast is different from Michigan's in that it lacks the extensive dunes and prevailing onshore winds common on the east side of the lake. Much of Wisconsin's Lake Superior and Lake Michigan shoreline consists of bluffs made up predominantly of fine glacial clays, which erode and move away from shore as suspended sediment. This sediment settles out in the deep basins of the lake, so bluff soils contribute little to the nearshore defenses of Wisconsin's coast. Where little or no sand beach and sandbars exist in front of a bluff yet mobile sand is present as an abrasive agent, the bluff's long-term recession rate will be related to the long-term average wave energy affecting the bluff.[15]

Natural defenses against coastal erosion include nearshore shoals of boulders, sand and gravel, which cause storm waves to break before reaching the land. Other natural defenses include wetlands and old dunes or beach ridges, which provide buffers that absorb wave energy. Beaches consisting of bedrock, boulders, gravel and sand also cause wave energy to spend itself before reaching the erodible land beyond.

High lake levels enable higher waves and much more wave energy to reach the bases of bluffs and banks. Consequently, recession will be more rapid during periods of high water levels.

Estimating Construction Setback

Three factors are involved in estimating construction setback: (1) the distance the bank or bluff edge is expected to recede during the life of the building or mortgage (recession setback), (2) the distance necessary for the bluff edge to recede to a stable slope (stable slope setback) and (3) the distance needed to allow house movers to safely relocate the building after recession has occurred (relocation setback).

Estimating Recession Setback. Recession setback is an evaluation of whether a proposed building is located far enough from the edge of the bank or bluff so that it is unlikely to be endangered by erosion during its useful life (or the life of the mortgage). This is simply a matter of determining the property's recession rate and multiplying it by the desired number of years of protection.

While the arithmetic is easy, picking a prudent recession rate requires considerable personal judgment. The information on recession rates is limited. Most records are available only for a relatively short period of time. Aerial photography (from which estimates of long-term recession are made) is generally not available prior to 1930, and in many photos the shorelines do not appear in a useable portion of the photos.

The rates of shoreline recession along Wisconsin's Great Lakes coasts over long periods of time (ranging from decades to a century or more) vary from less than a foot to 15 feet per year. A reasonable estimate of long-term recession rates can be made for shoreline section corners by using old land survey records. The recession setback for existing or proposed buildings can also be estimated with the available data on rates of shoreline recession for 10 Wisconsin coastal counties in Appendix 1.[16]

The best information on recession rates are the long-term rates determined where section corners are near the lake. Well-documented recession on similar and nearby property is another good source to use. Consult a local or regional planning agency regarding the availability of more information on long-term local recession rates.

Average recession rates determined for long periods of time (50 years or more) usually cover several high water periods as well as several low water periods, and the significance of possible error in the measurements is diminished as compared to short-term recession rates measured over periods of 10 years or less.[17]

There is always uncertainty in picking the best recession rate. The shore property may be located in an area where recession rates are unknown or vary greatly. Perhaps the shoreline is now armored and recession is no longer as great as it was in the past. The recession measurements may have been made from poor-quality aerial photographs and contain considerable errors. Recession of the shoreline in the present period of record-high lake levels may be faster than the recession rate measured in the past.

Long-term recession rates are used in this manual because many of these uncertainties and associated errors are minimized over the decades between measurements.

Even if the toe of a receding shoreline is protected by a broad beach or shore protection structure so that no further wave-induced erosion will destabilize the bluff, erosion of the bluff face will continue until the bluff face reaches its ultimate angle of stability.[18] It is necessary, therefore, to also determine the property's stable slope setback.

Estimating Stable Slope Setback. A stable slope is one that is no longer likely to fail by slumping, though surface erosion will continue unless the slope is well vegetated. Slope stability depends on the properties of the bluff soil, on loads placed on the slope and on the presence or absence of water in the soil.

A stable slope angle is the natural angle to which a slope would erode if the toe of the slope stabilized and no longer continued to recede. Such stabilization of the toe could occur naturally if water levels drop and form natural protection (e.g., a beach). Stabilization of the toe of the bluff or bank can also be achieved by building and maintaining effective shore protection at the toe.

The most obvious way to recognize a stable bluff is to examine whether the slope above the beach has mature vegetation or not. If the vegetation is mature shrubs or trees and if there are no signs of slump blocks, the slope has probably been stable for as long as the vegetation has been there. However, sometimes slump blocks are so large and thick that, as they sink below the bluff top, they carry along the mature vegetation intact.

TABLE 3
SUGGESTED STABLE SLOPE RATIOS
FOR WISCONSIN GREAT LAKES COASTAL BLUFFS

Location on Wisconsin Great Lakes Coastlines	Maximum Height of Groundwater in Bluff (H = bluff height)	Ultimate Stable Slope Ratio in Feet per Foot (horizontal:vertical)
Lake Michigan	0	1.7:1
	1/4 H	1.8:1
	1/2 H	3.0:1
	3/4 H	3.5:1
	Unknown	2.5:1
Lake Superior		
Douglas County	1/2 H	3.4:1
W. Bayfield County	1/2 H	3.6:1
E. Bayfield County	0	2.2:1
Madeline Island	0	2.6:1
Ashland/Iron counties	1/2 H	3.7:1
	Unknown	3.0:1

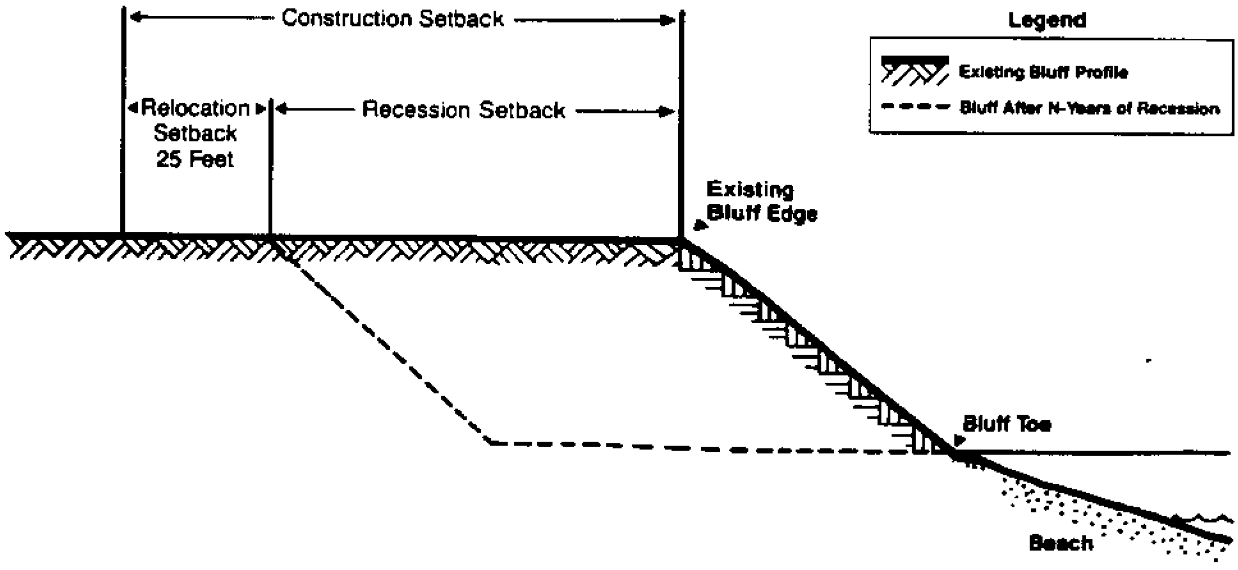
SOURCES: References 20 and 21.

In the mid-1970s, University of Wisconsin Sea Grant geotechnical engineers surveyed 180 slopes along Wisconsin's Lake Michigan and Lake Superior shores.[19] Nearly half (i.e., 81) of these slopes were stable. This survey indicated that a slope is stable if it has a fairly uniform grade not steeper than those described in Table 3. These "stable slope angles" are conservative, but they depend on the assumptions made about the maximum elevation of groundwater in the bluff. Some bluffs may have stable slopes steeper than those indicated in Table 3, but making this determination requires a detailed investigation by a technical expert.

As a rule of thumb, a stable slope angle for Wisconsin's Lake Michigan coastal bluffs is 2.5 feet horizontal for each vertical foot (2.5:1). For the Wisconsin coast of Lake Superior, use 3 feet horizontal for each foot vertical (3:1).

Figure 9

Construction Setback Distance for Property Without Shore Protection (Example 2)



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EXAMPLE 2: Construction Setback Distance for Property Without Shore Protection

The property in this example is located in the northern part of Racine County (T5N R23E, Section 6) on a bluff 40 feet high (Figure 9). The property owner has applied for a 30-year mortgage to construct a new building on the property, which has no shore protection. How far back from the bluff edge should the building be sited?

Step 1: Select an appropriate recession rate.

Using the tables in Appendix 1, look up Racine County and find the section in which the property is located. The long-term recession rate given in Appendix 1 is 3.0 to 4.0 feet per year. Select the higher long-term rate: 4 feet per year.

Step 2: Select the number of years of desired protection.

Pick a time period that ensures the safety of the building from the risks of shore recession. While mortgages have periods of 10 to 30 years, buildings have useful lives of 50 to 100 years or more. Racine County uses a 50-year time span for its shoreland ordinance for bluff recession for construction in undeveloped portions of the county.[22] In other counties, check with the county planning and zoning administrator and check also for any minimum setback distances. For this example, select a 50-year safety period, as required by the Racine County ordinance.

Step 3: Multiply the recession rate by the number of years of protection desired.

Recession rate (step 1)	4 feet/year
Desired time span (step 2)	x 50 years
Recession setback	200 feet

Step 4: Calculate the construction setback.

The construction setback is the sum of the recession setback and a relocation setback. In many locations, a relocation setback distance of 25 feet is adequate to bring in house moving equipment should the house need to be relocated at the end of 50 years of recession.

Relocation setback	25 feet
Recession setback (step 3)	+ 200 feet
Construction setback	225 feet

Answer: From a lender's viewpoint, the recession setback distance for the building is adequate for the life of the mortgage even if the recession rate is as high as 6.7 feet per year (200 feet divided by 30 years). Appendix 1 lists no long-term recession rates in Racine County higher than 5 feet per year, so the minimum setback of 225 feet seems adequate at least for the mortgage period and probably will allow the owner several options at the end of that period as well.

Evaluating Shore Protection

The key to estimating the appropriate construction setback for properties with shore protection is to correctly estimate the effectiveness of the shore protection structure. Each element of a shore protection system has strategic importance. Forget one element and the whole system is in danger of failure. Figure 10 shows a typical shore protection system and the most important elements. An important element not depicted in this profile is how the system is protected from flanking erosion on both ends.

An indication of the adequacy of a planned or existing shore protection structure can be obtained by comparing the design or structure to actual structures that have successfully survived severe storms or to similar designs in the U.S. Army Corps of Engineers "Help Yourself" brochure or the Ontario Ministry of Natural Resources' booklet, "How to Protect Your Shore Property."[23,24] If a proposed or existing shore protection system has a slope steeper than those shown, if its components are smaller or of lighter weight, if its crest elevation cannot meet expected future high water levels, or if it is missing some of the elements shown in Figure 10, the structure may be inadequate. A thorough evaluation of existing or proposed shore protection structures requires a professional coastal engineering analysis.

Some structure designs that cannot be evaluated with these methods also require an engineering evaluation. For example, a much thicker armor layer of a smaller stone size may be adequate for a revetment. A gentler, porous slope having a lower crest elevation may have minimal wave overtopping. A bulkhead or seawall fastened to underlying bedrock will not need toe stone for scour protection.

Even if an existing shore protection structure appears adequate in design, it may not be in good condition and may fail in the next severe storm. Shore protection structures need periodic maintenance. If they are not maintained, they fail to perform their task and eventually need to be replaced. Some ways in which shore protection structures can fail are shown in Figure 11.

Figure 10

Example of a Well-Designed Shore Protection System

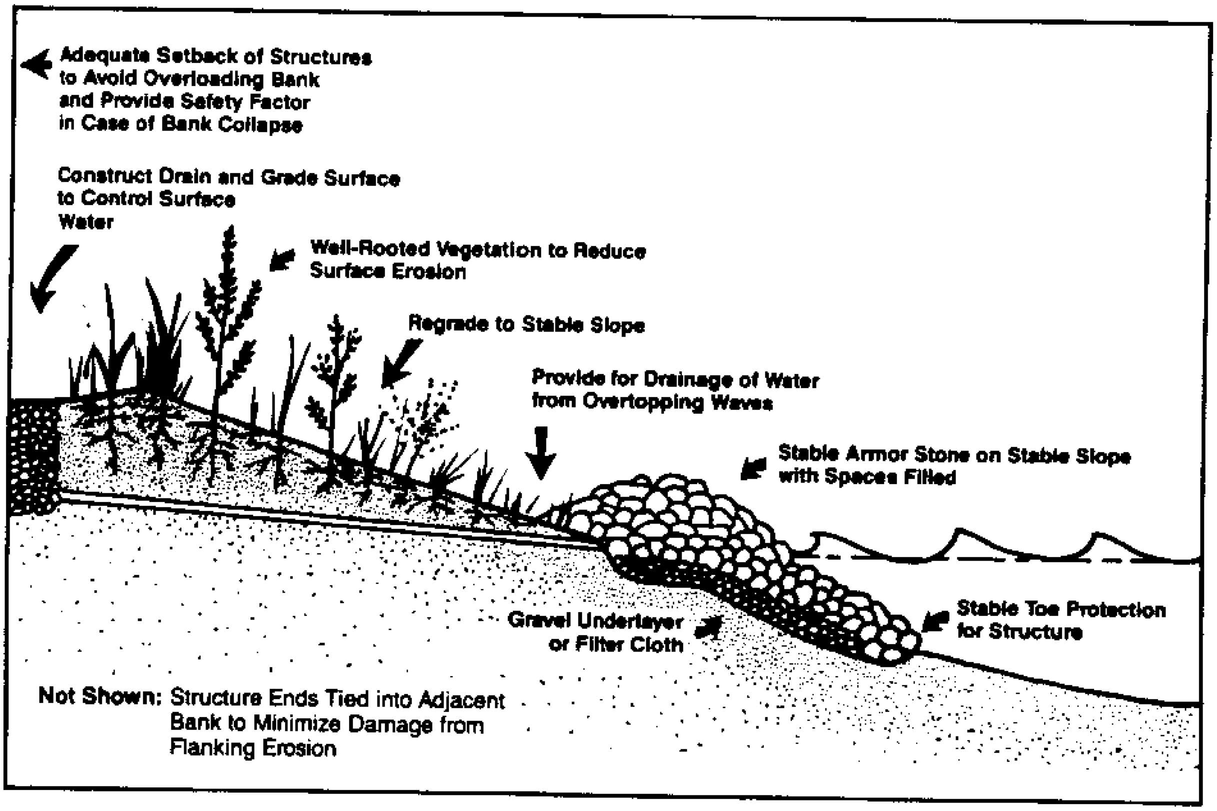

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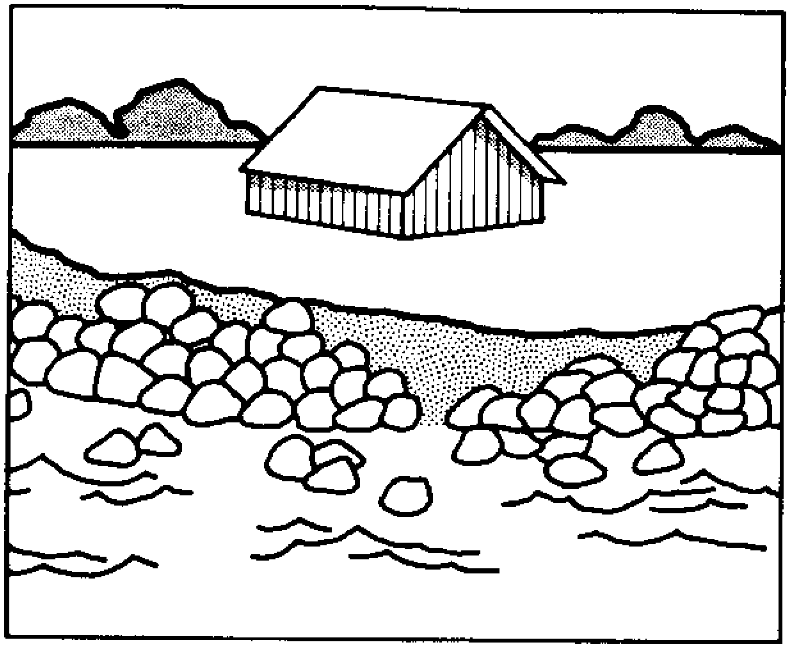
Figure 11

Shore Protection Failures: Causes and Corrections



Shore Protection Failure

■ Gaps In the Structure

Failure: Gaps in the Structure

Causes: Wave Forces Too Great for the Structure to Withstand, or Large Spaces Between Stone

Correction:

- Add Structural Material Adequate in Size and Density to Withstand Wave Forces
- Fill Spaces Between Stones

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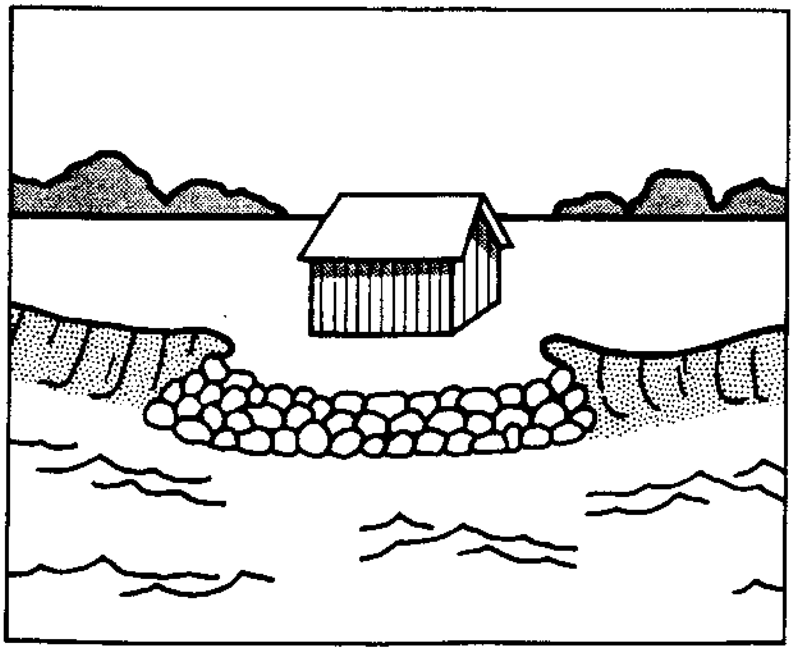

Shore Protection Failure

■ Flanking

Failure: Flanking Erosion Around the Ends of the Structure

Causes: Wave Action and/or Bluff Slumping Adjacent to Stabilizing Bank

Correction:

- Add Structural Elements at Structure Ends
- Tie Structure Ends Back into the Bank
- Stabilize Adjacent Banks

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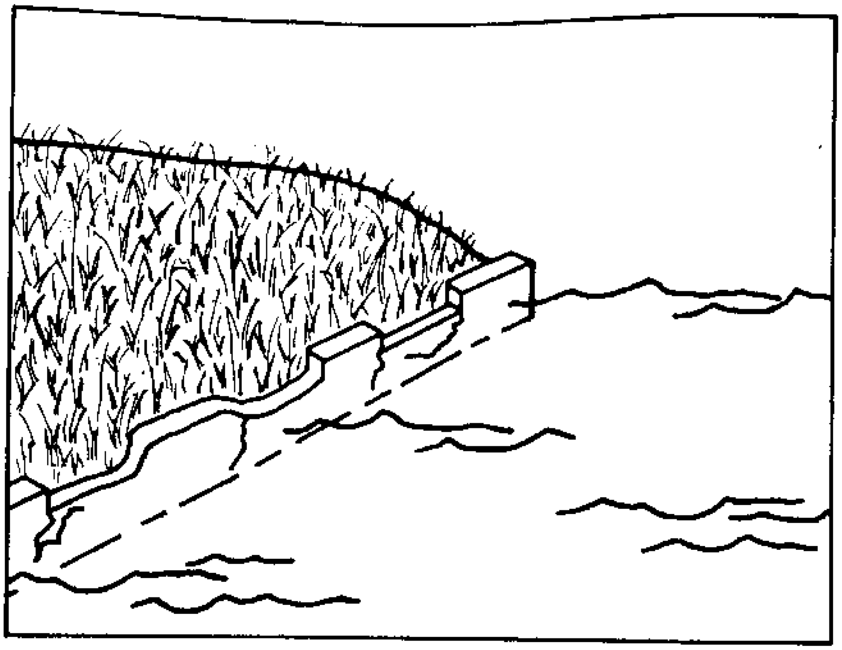
Figure 11 (continued)



Shore Protection Failure

- **Settling or Slumping**

Failure: Settling or Slumping of the Structure

Causes: Soft or Unstable Foundation Soil, and/or Excessive Groundwater Pressure

Correction:

- Remove Unsuitable Foundation Material and Replace with Stable Material
- Stabilize the Bank Behind the Structure
- Dewater the Bank Behind the Structure
- Rebuild the Structure

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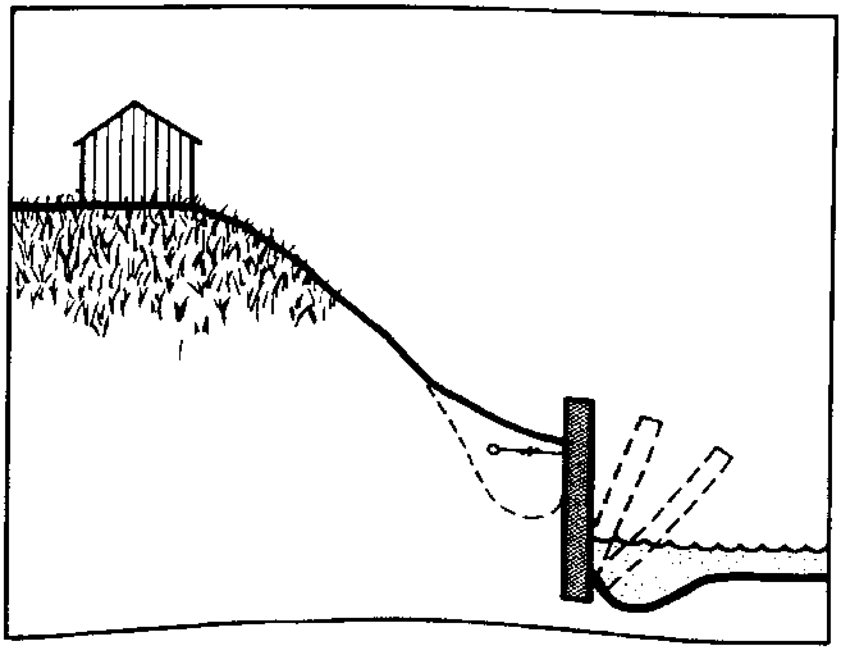

Shore Protection Failure

- **Overtopping, Scouring and Undermining**

Failure: Undermining and Scour at the Base of the Structure and Erosion Behind the Structure

Causes: Waves Eroding Lake Sediments in Front of the Structure and Washing Out Soils Behind the Structure

Correction:

- Build the Structure High Enough to Avoid Wave Overtopping, and Pile Stone at the Base to Prevent Scour of Sediments

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EXAMPLE 3: Construction Setback Distance for Property With Maintained Shore Protection

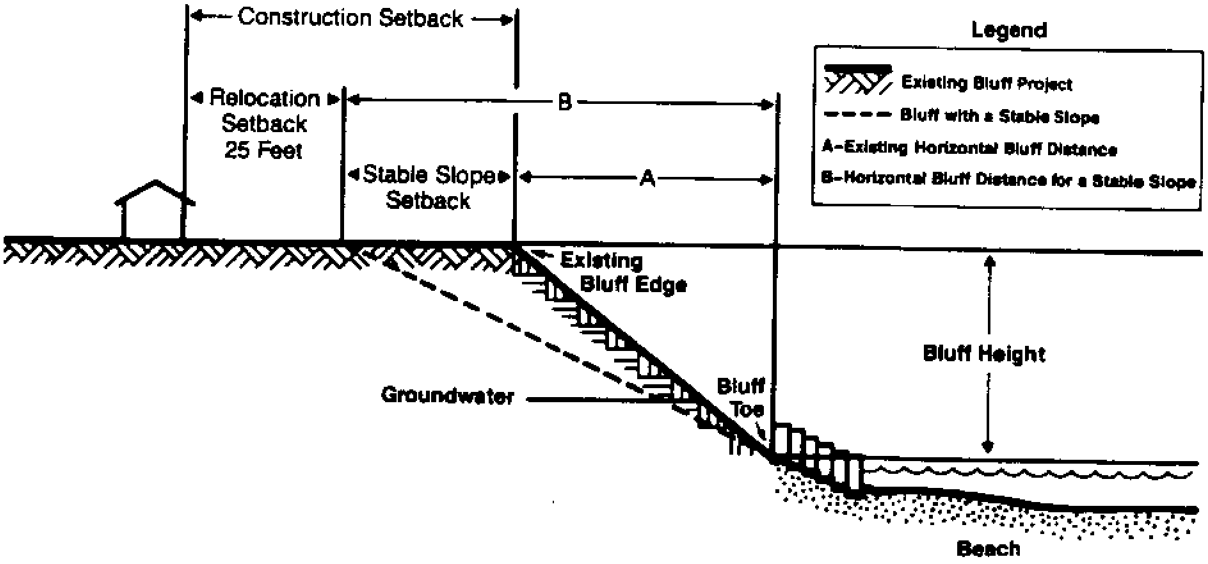
The property is located in Manitowoc County, T17N R23E, Section 34. It has a building located about 70 feet from the edge of a 40-foot-high bluff (Figure 12). Seepage from the raw face of the bluff indicates that, during wet periods, the groundwater level is about 10 feet above the water level of Lake Michigan. The house has a new 30-year mortgage secured by other property. The existing shore protection revetment appears to have been well maintained, and the previous owner claims that the revetment crest elevation is adequate to prevent overtopping by high water and wave runup. Is the house set back far enough from the bluff edge to be safe through the life of the mortgage?

Step 1: Evaluate the effectiveness of the shore protection.

If a shore protection structure seems inadequate, the property should be evaluated as if it had no shore protection at all. However, as compared to Figure 10, this revetment appears to have all of the elements noted. The previous owner says the revetment survived the storms and high water levels of 1985 and 1986 without damage except for some minor erosion at the ends (flanks), which a contractor says can be repaired for $2,500. None of the other damage shown in Figure 11 is visible, nor is there evidence that wave runup

Figure 12

Construction Setback Distance for Property with Maintained Shore Protection (Example 3)



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during high water has overtopped the revetment and caused washout behind the structure -- substantiating the previous owner's claim that the revetment crest elevation is adequate. This claim could also be checked by comparing the estimated storm wave runup elevation to the revetment crest elevation using the procedure described in Example 1.

Step 2: Determine the horizontal distance between the top edge of the bluff and its toe.

The present bluff edge appears to be about as far from the bluff toe in horizontal distance (A) as the bluff is high, so the horizontal bluff distance is estimated to be about 40 feet.

Step 3: Determine the stable slope ratio.

Table 3 shows, with the height of the groundwater at 1/4 the bluff height (10 feet / 40 feet = 1/4), that the stable slope ratio is a horizontal distance of 1.8 feet horizontal for each foot vertical (1.8:1).

Step 4: Calculate the stable slope setback.

The bluff is 40 feet high. First, multiply that measurement by the stable slope ratio from step 2.

Bluff height (step 1)	40.0 feet
Stable slope ratio (step 2)	x 1.8 feet/vertical foot
Stable slope distance (B)	72.0 feet horizontally from the toe

Then, to estimate the stable slope setback from the top edge of the bluff, subtract the horizontal bluff distance (A) measured in step 1.

Stable slope distance (B)	72 feet from bluff toe
Horizontal bluff distance (A)	- 40 feet from toe to bluff edge
Stable slope setback	32 feet inland from bluff edge

Step 5: Estimate the construction setback.

Since the shore protection structure shows none of the signs of failure shown in Figure 11 and the structure elevation and design seem adequate, the total construction setback distance is equal to the stable slope distance plus a relocation distance of 25 feet.

Stable slope setback (step 3)	32 feet from bluff edge
Relocation setback	+ 25 feet
Construction setback	57 feet from bluff edge

Answer: The house is presently 70 feet from the bluff edge and, if the protective structure is properly maintained, the house should be safe for the duration of the mortgage.

Other Considerations in Estimating Setback

Examples 2 and 3 described how to generally estimate adequate construction setbacks for situations with and without shore protection. Several other possibilities should also be considered.

For example, if the actual recession rate for the property in Example 2 turns out to be twice the assumed rate, how many years will the owner have before shore protection must be installed, allowing also for a stable slope to develop, or the house relocated? If the shore protection assumed to be adequate in Example 3 were to suddenly fail next year during an unexpectedly severe storm, how many years could the shore be allowed to recede, according to the annual recession rate listed in Appendix 1, before new shore protection must be installed or the house relocated?

A proper evaluation of the risks of investing in coastal property should consider several such alternatives and "worst case" contingencies in the event one or more assumptions turn out to be wrong.

Conclusion

The process of estimating storm water levels, wave runup elevations and adequate construction setback distances on a coastal property as described in this manual is a major step toward reducing the uncertainties in assessing the risks of investments in coastal property. It also shows the importance of considering all elements (future lake levels, storm surges, wave runup, land elevation, the adequacy of shore protection structures, recession rates and stable slope angles) that can affect coastal properties and the importance of the remaining uncertainties as well. Every coastal property should be evaluated according to how vulnerable or safe it appears to be in the face of remaining uncertainties about future lake levels, storms and erosion.

Each property should be considered in terms of the available contingencies. Some of these contingencies require consultation with a professional engineer or contractor. Do natural defenses seem adequate to protect the property from unforeseeable combinations of high water and storms? Is the lot size adequate for relocating the house if the property's recession rate is greater than estimated? Can an existing shore protection structure be reinforced or have its elevation raised if lake levels are higher or storm waves run up higher than expected?

The steps outlined in this manual offer a more scientific way of thinking about coastal property. With practice, these procedures should help improve decisions involving coastal property with a reasonable expenditure of time, money and effort.

APPENDIX 1

Estimated Long-Term Recession Rates for Some Wisconsin Great Lakes Counties

(All measurements are in feet per year. N/A = not available.)

COUNTY Township	Range	Section	Long-Term Recession Rate
BAYFIELD COUNTY			
T49N	R9W	6	0.3
		5	1.4
		4	N/A
T50N	R6W	6	N/A
T50N	R7W	8	0.0
		7	0.0
		6	N/A
		5	1.6
		4	+1.1
		1	+0.3-0.9
T50N	R8W	30	2.1
		22	0.4
		21	0.0-12.7
		20	11.0-22.0
		19	N/A
		15	N/A
		14	N/A
		12	N/A
		11	0.0
T50N	R9W	36	0.1
		35	N/A
		34	1.5
		33	1.5
		25	0.0
T51N	R5W	--	N/A
T51N	R6W	34	3.3
		33	9.9-14.0
		32	2.0
		31	1.9-3.4
		29	3.8-3.9
		27	N/A
		24	0.6-1.4
		23	N/A
		22	N/A
BAYFIELD COUNTY (continued)			
T51N	R7W	36	+0.3-0.9
		35	+1.2-1.8
		34	0.4
		33	0.0
		27	1.7-1.8
		26	0.0-0.1
		25	N/A
		24	2.0-2.6
T52N	R5W	36	2.5
		35	0.0
		34	N/A
DOOR COUNTY			N/A
DOUGLAS COUNTY			
T49N	R10W	18	6.6
		17	N/A
		10	7.2
		9	N/A
		8	N/A
		3	6.0
		2	1.2
		1	1.3
T49N	R11W	30	N/A
		29	1.7-7.4
		28	0.4
		23	0.7
		22	1.3
		21	N/A
		14	2.7
		13	2.7

COUNTY Township	Range	Section	Long-Term Recession Rate
DOUGLAS COUNTY (continued)			
T49N	R12W	36	N/A
		35	1.6-1.9
		34	N/A
		33	N/A
		32	N/A
		31	5.9
		28	N/A
		27	3.2
		25	0.8
T49N	R13W	36	0.9
		35	0.5-1.2
		34	N/A
		28	0.7
		27	0.7
KENOSHA COUNTY			
T1N	R23E	32	9.0-12.0
		29	7.0-12.0
		20	3.0-7.0
		17	2.0-5.0
		8	4.0
		5	4.0-6.0
T2N	R23E	30	2.0-4.0
		19	2.0-3.0
		18	3.0
		5	2.0-3.0
KEWAUNEE COUNTY			
T22N	R24E	36	0.5-2.2
		25	N/A
		24	N/A
T22N	R25E	18	1.7
		7	0.4
		6	0.4-0.5
T23N	R25E	31	0.4-0.5
		30	0.6
		19	2.6

COUNTY Township	Range	Section	Long-Term Recession Rate
KEWAUNEE COUNTY (continued)			
(T23N)	(R25E)	17	1.1
		8	0.6-1.1
		5	0.6
T24N	R25E	32	N/A
		29	N/A
		28	0.3
		21	0.2-0.3
		16	0.2-0.7
		10	0.7
		9	0.7
		3	1.1
T25N	R25E	34	N/A
		26	0.5
		24	0.5
		23	0.5
		13	N/A
T26N	R26E	18	N/A
		7	N/A
		6	N/A
MANITOWOC COUNTY			
T17N	R23E	34	0.7
		27	0.3-0.7
		22	0.3-0.5
		14	0.5-2.0
		11	N/A
		1	0.3
T18N	R23E	36	0.3
		25	N/A
		24	N/A
T18N	R24E	18	0.2
		7	2.0
		5	1.0
T19N	R24E	32	1.0
		29	N/A
		20	N/A
		17	N/A
		16	N/A
		11	2.0

COUNTY Township	Range	Section	Long-Term Recession Rate
MANITOWOC COUNTY (continued)			
(T19N)	(R24E)	10	N/A
		1	N/A
T20N	R25E	--	N/A
T21N	R24E	31	N/A
		30	2.0
		25	3.0
		24	3.0
		13	3.0
		11	2.0
		2	2.0-4.0
MILWAUKEE COUNTY			
T5N	R22E	36	3.0
		25	2.0-3.0
		24	0.7-2.0
		13	0.7
		12	0.7-1.0
		1	1.0
T5N	R23E	31	3.0
T6N	R22E	36	0.3-1.0
		25	0.3-1.0
		24	1.0
		14	1.0
		10	1.0-2.0
		3	2.0
T7N	R22E	33	Harbor Breakwater
		28	Harbor Breakwater
		22	2.0
		15	2.0
		10	2.0
		3	2.0-3.0
T8N	R22E	34	3.0
		33	2.0-3.0
		28	2.0
		21	0.6-2.0
		16	0.6-1.0
		10	1.0
		4	0.2-1.0
		3	1.0

COUNTY Township	Range	Section	Long-Term Recession Rate
OZAUKEE COUNTY			
T9N	R22E	33	0.2
		28	2.0
		20	2.0
		17	2.0-3.0
		8	3.0
		5	3.0
T10N	R22E	33	3.0
		28	3.0
		21	N/A
		16	2.0
		10	2.0
		3	2.0
T11N	R22E	36	0.1
		33	N/A
		28	N/A
		25	0.1
		22	N/A
		15	N/A
		14	N/A
		11	1.0
		2	1.0
		1	1.0
T12N	R23E	30	N/A
		19	N/A
		18	0.1
		7	0.1
		6	0.2
RACINE COUNTY			
T3N	R23E	32	2.0-3.0
		28	2.0
		21	2.0
		16	2.0-4.0
		9	5.0
		8	4.0
		4	1.0-5.0
T4N	R23E	33	1.0-3.0
		27	1.0-3.0
		21	0.9-2.0

COUNTY Township	Range	Section	Long-Term Recession Rate
RACINE COUNTY (continued)			
T5N	R23E	17/16	1.0-2.0
		8/7	0.8-3.0
		6	3.0-4.0
SHEBOYGAN COUNTY			
T13N	R23E	31	0.4
		30	0.4
		20	N/A
		19	N/A
		17	0.4
		9	0.6
		8	N/A
		4	0.6
T14N	R23E	34	N/A
		33	N/A
		27	N/A
		23	0.6
SHEBOYGAN COUNTY (continued)			
(T14N)	(R23E)	22	N/A
		14	0.6
		11	1.0
		2	1.0
T15N	R23E	35	1.0
		26	1.0
		24	N/A
		14	N/A
		11	N/A
		3	2.0
		2	N/A
T16N	R23E	34	1.0
		27	1.0
		22	1.0-2.0
		15	1.0-2.0
		10	1.0
		3	N/A
T17N	R23E	34	N/A
		27	0.7-1.0

SOURCES: Data from Wisconsin Coastal Management Program's Shore Erosion Study Technical Report: Appendix 1, Kenosha County, February 1977; Appendix 2, Racine County, February 1977; Appendix 3, Milwaukee County, February 1977; Appendix 4, Ozaukee County, February, 1977; Appendix 5, Sheboygan County, April 1977; Appendix 6, Southern and Central Manitowoc County, April 1977; Appendix 7, Northern Manitowoc, Kewaunee and Door County Shorelines of Lake Michigan in Wisconsin, July 1980; and Appendix 9, Douglas and Western Bayfield Counties, Wisconsin Point to Bark Bay, July 1980.

APPENDIX 2

Interim Methods for Calculating Wave Runup

Wave runup can be more precisely estimated by obtaining additional information about a coastal property's shore, nearshore lakebed conditions and its shore protection structures, if any. The approach to calculating wave runup used here is based on recently published and soon-to-be published work available to the authors.

The tables of runup values and simple formulas for calculating runup must be considered "interim" values and formulas in need of comparison with actual Great Lakes shore conditions and also in need of a period of critical examination and further testing by the coastal engineering profession. For example, the U.S. Army Corps of Engineers' Coastal Engineering Research Center plans this year (1987) to run more laboratory tests of wave runup on vertical walls with computer-generated series of random waves.

Nonetheless, there are several reasons for using these new methods now. In the past, coastal engineers have had to use oversimplified approximations of real waves. Waves had to be treated as though they behaved in an orderly fashion, could be neatly grouped by size and traveled with uniform spacing. The recent work on random and irregular waves used here is closer to real sea and lake situations. The second reason for using these new methods is that they reference wave runup to nearshore rather than offshore wave heights. In earlier work on wave runup, wave heights were usually referenced to deepwater wave conditions, not to the actual waves that survive nearshore shoaling to spill or break on the shore. In most shoreline situations, waves that reach shore are severely limited in height by nearshore water depths. Large storm waves break offshore in the surf zone, which may be hundreds of feet to several miles wide.

The simplified approach used here considers the limits that shallow nearshore waters place on wave heights. However, other complicating effects of nearshore lakebed features that can spread or focus storm wave energy are ignored for the sake of simplicity.

Wave runup values for beaches and riprap revetments are the vertical height that waves are expected to reach as they rush up the slopes. Vertical seawalls are treated differently in many references and in this appendix. Wave runup values for seawalls are not determined; instead, the height of the seawall is given for a rate of overtopping water assumed to be acceptable. The heights of seawalls for zero wave overtopping can be estimated, giving the equivalent of "wave runup" distances, but these seawalls would be very high. In the interest of economy, a common practice is to calculate adequate seawall crest elevation by using a rate of overtopping at which water can be drained away without jeopardizing the integrity of the wall.[25]

In making comparisons between wave runup or storm wave runup elevations and land or shore structure elevations, the uncertainties of these estimates justify rounding off each elevation to the nearest foot, which is done in each of the example problems that follow.

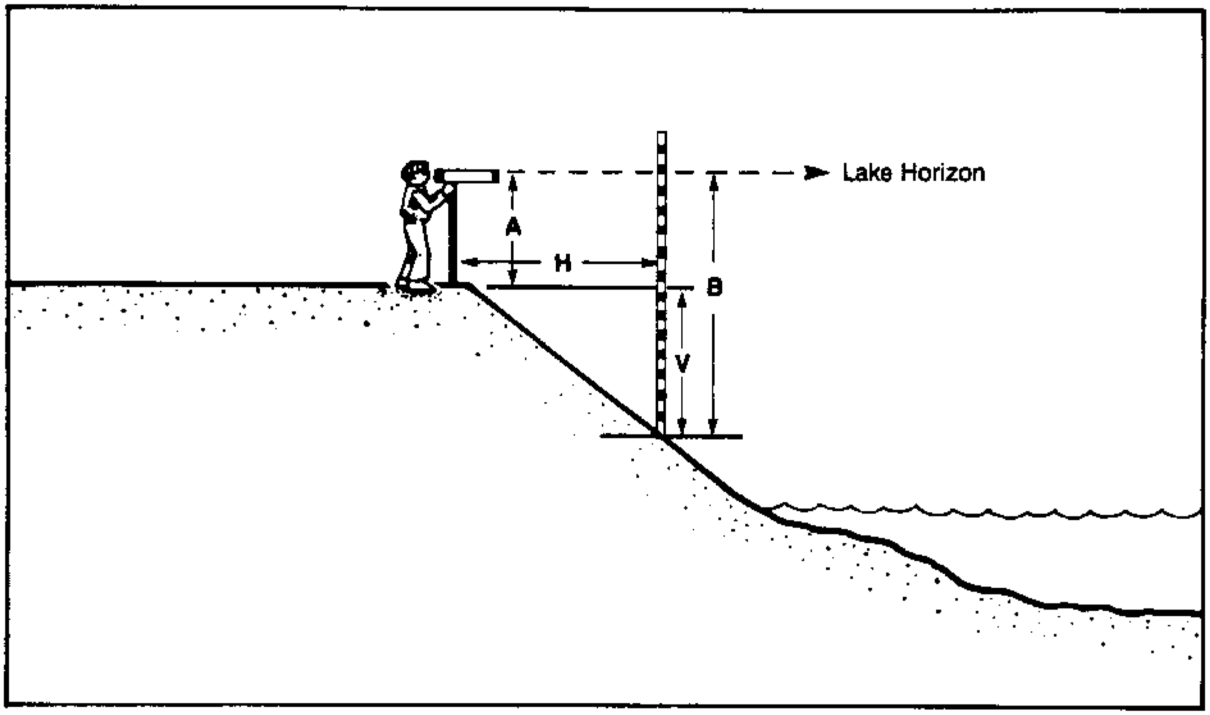
How to Make Shoreline Measurements

A few simple tools are needed to make the following measurements of the slopes of beaches, shore protection structures and nearshore lake beds, and the elevation of a shore protection structure and the depth of the water at its base. Because of uncertainties in estimating storm water levels and wave runup, these tools and methods need not be as complicated nor as accurate as those required by an engineering survey. These tools are:

- A 50-foot or 100-foot measuring tape.
- Two poles, one 8 to 10 feet long and another about 4 feet long, both marked at 3-inch intervals.
- A pair of chest-high waders, or a small boat or canoe and lifevest (PFD).
- A carpenter's level (optional).

Figure 13

A Simple Method for Measuring a Shoreline Slope



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Measuring the Slope of a Beach or Revetment

A simple method for estimating slope is shown in Figure 13. This method will work for revetments, earthen banks or bluffs where the upper portion of the slope is representative of the entire slope. It is best done by two people, but one person can do the job if the long pole is marked with large readable numbers and if one of the poles has a ring or hook for attaching the measuring tape so the horizontal distance between them can be measured.

Step 1: Plant the two poles vertically in the ground, the short pole near the top edge of the slope and the long pole just far enough down the slope that the top of the long pole is still higher than the top of the short pole. A carpenter's level will help ensure that the poles are vertical.

Step 2: Sight horizontally along the top of the short pole and note the spot on the long pole where it is intersected by the horizon. It will help to have stripes and large numbers on the long pole.

If the horizon is obscured by haze or fog, use a carpenter's level to get a horizontal sighting. Put it on top of the short pole so that it is approximately level. Aiming at the long pole, sight along the top of the level and note the corresponding height on the long pole.

Step 3: Measure the height of the short pole above the ground (A in Figure 13), its equivalent height on the long pole downhill (B) and the horizontal distance between the two poles (H) with the tape measure.

Step 4: Calculate the difference in vertical height (V) by subtracting the height of the short pole (A) from its equivalent height on the long pole (B): $V = B - A$.

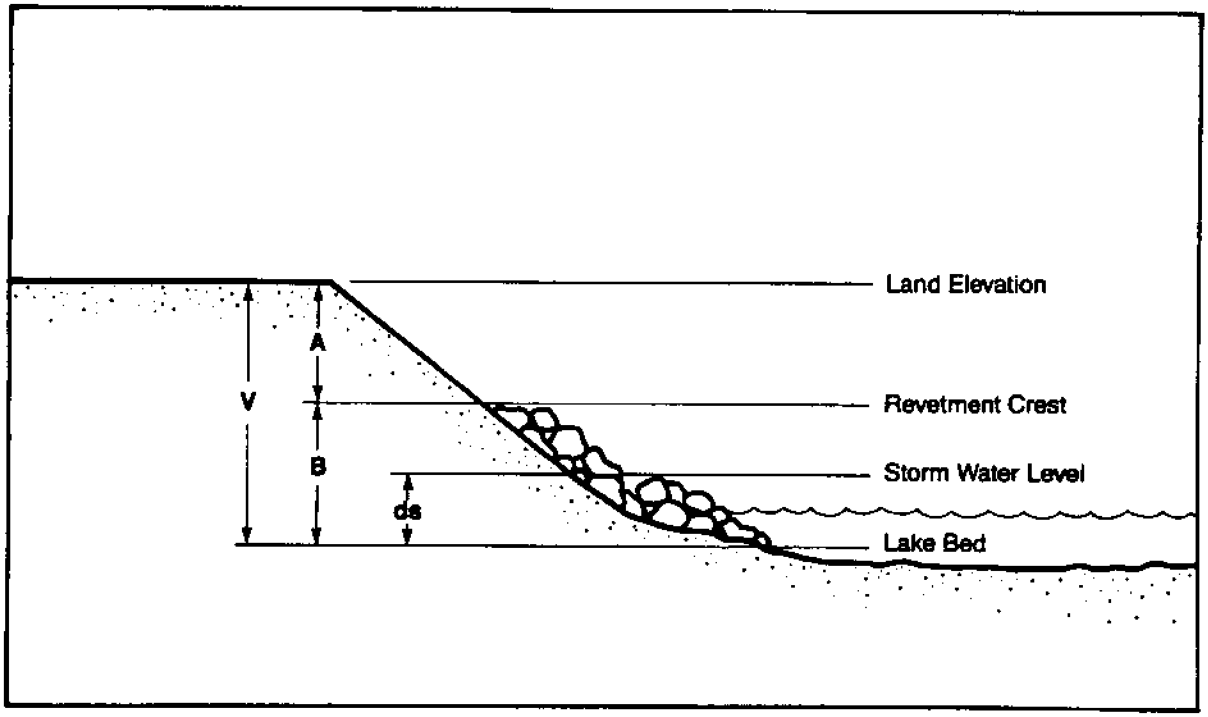
Step 5: Calculate the slope (S) by dividing the vertical height difference (V) and horizontal distance (H) between the poles: $S = H / V$. Tables 4-5 show the slope in terms of this ratio of horizontal to vertical distance (S:1).

Estimating the Depth of Water at the Base of Shore Protection Structures

Accurate estimates of wave runup on revetments and adequate crest elevations for seawalls require knowledge of the depth of water expected at the base or toe of the structure during storms. Any datum may be used, but all elevations must be in the same datum.

Figure 14

Estimating Storm Water Depth on Shore Protection Structures



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Step 1: Using a method similar to that just described for measuring a shoreline slope, determine the elevation of the lake bed at the base of the shore protection structure by subtracting the vertical distance to the lake bed (V) from the property's elevation as determined from a topographic map of the site (Figure 14). Similarly determine the elevation of the crest of the shore protection by subtracting the vertical distance to the crest of the structure (A) from the land elevation, or by adding the height of the structure (B) to the lakebed elevation, whichever is easiest.

Step 2: Using the method described in the "How to Evaluate the Risks of Flooding" section, estimate the property's storm water level elevation (highest still water level + typical storm surge + the equivalent land elevation for Great Lakes chart datum).

Step 3: Calculate the depth of water (ds) at the base of the structure by subtracting the lakebed elevation (step 1) from the highest storm water level elevation (step 2).

Estimating Nearshore Lakebed Slopes

Nearshore lakebed slope is a crucial factor in estimating the adequacy of the height of a seawall. If the differences in seawall height due to nearshore lakebed slope are important, you may wish to consider measuring the nearshore slope. Here is a simple method that requires only one person but is easier with two. Note that this method ignores nearshore bars within 50 feet of shore, and it should be done on a calm day.

Step 1: Make the measurements shown in Figure 15: Attach one end of a measuring tape to the seawall. Unreeling the tape measure as you go, walk or row a small boat straight out from shore until you are about 50 feet offshore (H in Figure 15), and then measure the water depth (B) with one of the marked poles. Also measure the water depth about 10 feet lakeward and 10 feet shoreward of the 50-foot position to make sure that you are not on top of a bar. If you find that the 50-foot position was measured on a bar, move off of the bar either lakeward or shoreward and remeasure both B and H.

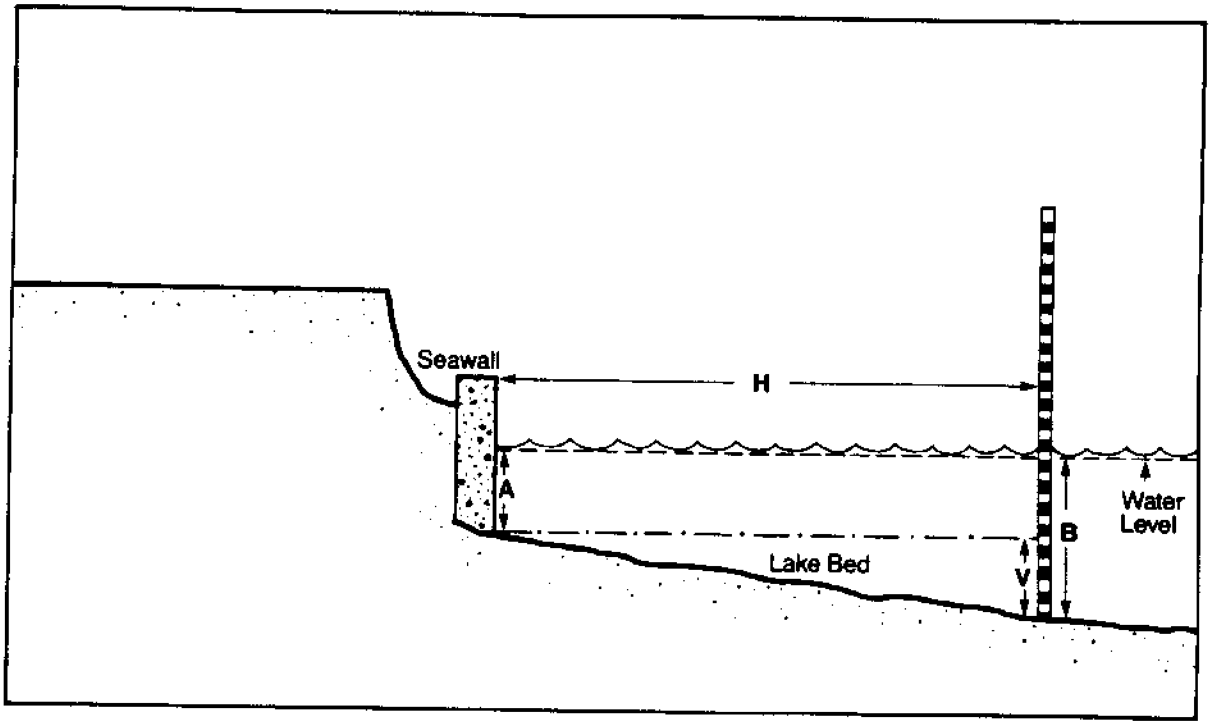
Step 2: Calculate the nearshore lakebed slope (S) by dividing the horizontal distance (H) by the difference (V) between the depth of the water offshore (B) and the water depth at the base of the seawall (A): $V = B - A$ and $S = H / V$. In Table 6, the lakebed slope is described as S:1.

Estimating Wave Runup Based on Design Storms

In evaluating runup on shorelines or shore protection structures, coastal engineers use wave conditions representative of those found in so-called "design storms." The runup data in this appendix are based on a "10-year design storm" -- a storm expected to be exceeded once in 10 years over several decades. This means there is a 10 percent chance that such storm conditions would be exceeded in any given year, a 65 percent chance of exceedance in a 10-year interval, and a 93 percent chance of exceedance in a 25-year period.[26] It is an artificial and sometimes unrealistic simplification: Two or three 10-year design storms may occur in a single year. Nonetheless, this approach is useful in estimating the likelihood that a storm of a given minimum severity will occur within the year, within the term of a mortgage or during the lifetime of a building.

Figure 15

A Simple Method for Measuring the Slope of Nearshore Lakebeds



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Wave Runup on Beaches

Wave runup on gentle slopes, like beaches, is a complex process. Wave runup depends on the heights of incoming waves, the time between successive waves and the grouping of the waves approaching the beach. Maximum wave runup occurs when the preceding backwash of water is small and a large incoming wave can run unhindered up the slope. On gently sloping beaches, an incoming wave may begin its run up the beach before the water from the preceding wave has washed back into the lake. If the backwash is large, the incoming wave simply may not run up the beach, so the number of waves running up the beach are fewer than the number of incoming waves. This can easily be verified by careful observation.

A method has been recently developed for estimating maximum wave runup on natural beaches during storms.[27,28] It is based on analysis of storm wave and wave runup data for wave conditions that include those typical of Great Lakes storms. This method uses nearshore wave conditions just outside the breaker zone to predict runup -- a departure from laboratory studies, which describe wave runup in terms of deepwater wave conditions.[29] Table 4 gives Great Lakes wave runup values computed from equations suggested in References 27 and 28. These figures should be considered interim values, however, because the methodology is based on a small sample of storm wave data.

The lower and higher values for each location and beach slope in Table 4 are for the lower and higher estimated wave period of maximum storm wave energy, respectively. For

Lakes Michigan and Superior, these periods are 8 and 10 seconds.[30] The width of the nearshore breaker zone where waves are expected to break was estimated using methods described in the U.S. Army Corps of Engineers Shore Protection Manual[31] and the wave conditions shown in Table 7 (Appendix 3).

TABLE 4
INTERIM ESTIMATED RANGES OF MAXIMUM WAVE RUNUP ON BEACHES

Wisconsin Coast	Maximum Range of Wave Runup (feet) Slope of Beach (horizontal:vertical) 20:1	 15:1	 10:1
Lakes Superior and Michigan	2.0-5.0	2.7-6.0	3.9-8.0
Green Bay, Lake Michigan	1.2-2.1	1.6-2.8	2.4-4.3

EXAMPLE 4: Estimating Wave Runup for Property with a Beach

A 30-year-old house is located on a coastal lot in Sheboygan County on Lake Michigan. It has a basement, the floor of which is about 6 feet below ground level. A topographic map of the area indicates that the ground around the house is about 592 feet above mean sea level (MSL). The shoreline consists of a sandy beach less than 100 feet wide and a vegetated ridge about 4 feet higher than the ground around the house. What is the likelihood that the house will be flooded by storms during high water periods?

Step 1: Estimate the slope of the beach.

In the fall of the year (when the beach is most likely at its steepest and wave runup is greatest), the beach slope was measured as shown in Figure 13, where A = 4 feet, B = 6 feet and H = 30 feet:

$$V = B - A = 2 \text{ feet}$$

$$S = H / V = 30/2 = 15$$

The beach slope was thus estimated to be about 15:1.

Step 2: Estimate the highest predicted still water level and convert it to an equivalent land elevation.

The highest monthly mean water level for Lake Michigan was 4.8 feet above chart datum in October 1986, according to the Corps of Engineers' lake level bulletin (see Figure 3); however, a maximum level of 5.0 feet above chart datum is predicted. According to Table 2, the Lake Michigan Chart Datum is 578.1 feet above MSL (or NGVD).

Equivalent chart datum elevation	578.1 feet above MSL
Highest monthly mean lake level	+ 5.0 feet
Highest still water level elevation	583.1 feet above MSL

Step 3: Determine the local storm surge.

The coast at Sheboygan has a typical storm surge of 1.2 feet (Figure 5).

Step 4: Estimate the storm water level elevation.

Still water level elevation (step 2)	583.1 feet above MSL
Typical storm surge (step 3)	+ 1.2 feet
Storm water level elevation	584.3 feet above MSL

Step 5: Estimate the range of wave runup.

According to Table 4, the estimated maximum wave runup for the beach will be 2.7 to 6.0 feet on a slope of 15:1. To be safe, use 6 feet.

Step 6: Determine the elevation that storm wave runup is likely to reach on the property.

Storm water level elevation (step 4)	584.3 feet above MSL
Maximum wave runup (step 5)	+ 6.0 feet
Storm wave runup elevation	590.3 feet above MSL

Step 7: Compare the property elevations to the estimated storm wave runup elevation (round off all elevations to the nearest foot).

Storm wave runup elevation (step 6)	590 feet above MSL
Land/house elevation	592 feet above MSL
Beach ridge elevation (592 + 4 =)	596 feet above MSL
Basement elevation (592 - 6 =)	586 feet above MSL

Answer: The beach ridge seems adequate for handling storm waves on top of storm water levels. The land around the house is not likely to flood under the assumed lake level and storm conditions.

Estimating Wave Runup on Sloping Stone Revetments

Table 5 shows the approximate limits of irregular wave runup on stone riprap laid over an impervious underlayer to form a sloping revetment. The table was developed using nearshore wave conditions expected during a 10-year design storm, with wave heights limited by nearshore water depths. The laboratory work from which this table was developed is presently undergoing technical review for publication.[32] Therefore, Table 5 should be regarded as an interim indicator of likely wave runup. The experimental laboratory revetments were constructed with nonporous underlayers, while most revetments have a porous underlayer, which generally results in less wave runup because some of the water is absorbed by the structure.

TABLE 5
INTERIM ESTIMATED RANGES OF WAVE RUNUP ON RIPRAP REVETMENTS

Maximum Estimated Water Depth (ds) at Base of Revetment (feet)	Estimated Maximum Ranges of Wave Runup (feet) Slope of Revetment (Horizontal:Vertical) 2:1	3:1	4:1
Wisconsin Coasts of Lakes Superior and Michigan			
1	1.7 - 2.4	1.4 - 2.0	1.1 - 1.6
2	3.1 - 4.4	2.4 - 3.4	2.0 - 2.8
3	4.4 - 6.2	3.4 - 4.8	2.7 - 3.9
4	5.5 - 7.9	4.3 - 6.1	3.5 - 4.9
5	6.7 - 9.5	5.1 - 7.3	4.1 - 5.9
Wisconsin Coast of Green Bay			
1	1.4 - 2.1	1.1 - 1.6	0.9 - 1.3
2	2.6 - 3.6	1.9 - 2.8	1.6 - 2.2
3	3.5 - 5.1	2.7 - 3.8	2.1 - 3.1
4	4.6 - 6.4	3.3 - 4.8	2.7 - 3.8
5	5.3 - 7.6	4.0 - 5.7	3.2 - 4.5

EXAMPLE 5: Estimating Wave Runup on a Riprap Revetment

A coastal property in Door County south of Bailey's Harbor has a stone riprap revetment 6 feet high with a crest elevation that is level with the ground on which the house is built. The house elevation is about 589 feet above mean sea level (MSL), according to topographic maps of the property. Nothing is known about the nearshore lake bed nor its slope. Does the revetment and ground elevation appear adequate to protect the house from storm water levels and waves?

Step 1: Measure the revetment slope using the method shown in Figure 13.

In this case, the horizontal distance (H) is measured to be 6 feet and the vertical difference (V) in height between A and B is 3 feet.

$$S = H / V = 6 / 3 = 2$$

The slope of the revetment is estimated to be 2:1.

Step 2: Estimate the highest still water level.

Like the property in Example 4, this property is on Lake Michigan, so the highest still water elevation again is 583.1 feet above MSL (chart datum elevation of 578.1 feet above MSL + 5.0 feet, the highest predicted monthly mean lake level).

Step 3: Determine the local storm surge.

Figure 5 shows the typical storm surge along the Door County coast to be 1.1 feet.

Step 4: Estimate the highest likely storm water level elevation.

Highest still water level (step 2)	583.1 feet above MSL
Local storm surge (step 3)	+ 1.1 feet
Highest storm water level elevation	584.2 feet above MSL

Step 5: Estimate the maximum depth of water at the base of the revetment using the method shown in Figure 14. In this case, the lakebed elevation is about 6 feet below the land elevation.

Land elevation	589 feet above MSL
Vertical distance to lake bed (V)	- 6 feet
Lakebed elevation	583 feet above MSL

Storm water level elevation (step 4)	584.2 feet above MSL
Lakebed elevation	-583.0 feet above MSL
Maximum depth of water at base (ds)	1.2 feet

Step 6: Estimate the range of likely wave runup.

Table 5 indicates that wave runup on a revetment with a slope of 2:1 and about a foot of water at its base ranges from 1.7 to 2.4 feet. To be safe, use 2.4 feet.

Step 7: Estimate the likely elevation of storm wave runup.

Storm water level elevation (step 4)	584.2 feet above MSL
Highest estimated wave runup (step 6)	+ 2.4 feet
Storm wave runup elevation	586.6 feet above MSL

Step 8: Compare the land, revetment crest and storm wave runup elevations.

Land/revetment crest elevation	589 feet above MSL
Storm wave runup elevation (step 7)	-587 feet above MSL
	2 feet

Answer: The land appears high enough so that flooding will not be a problem, and the revetment crest appears adequate to prevent overtopping and damage by waves.

Estimating Adequate Crest Elevations on Vertical Seawalls

The approach to estimating the adequacy of a seawall in terms of wave runup is different than the approach used for beaches and revetments. Recent coastal engineering work offers an approach that recognizes that waves striking a seawall rise much higher in the air than waves running up slopes under comparable conditions.[25,33] Adequate crest elevations are estimated for "acceptable" overtopping rates of water that can be drained away without jeopardizing the stability of the seawall. This approach assumes that provisions have or will be made to drain away water without erosion of the bank or bluff behind the wall.

TABLE 6
INTERIM ESTIMATED RANGES OF ADEQUATE FREEBOARD FOR SEAWALLS

Slope of Nearshore Lake Bed	Estimated Maximum Storm Water Depth at Base of Seawall	Freeboard for Acceptable Storm Overtopping Rates (in feet above maximum water depth at seawall base)			
		Wisconsin Coasts of Lake Michigan and Lake Superior		Wisconsin Coast of Green Bay, Lake Michigan	
		0.01 cfs/ft (4.5 gpm/ft)	0.1 cfs/ft (45 gpm/ft)	0.01 cfs/ft (4.5 gpm/ft)	0.1 cfs/ft (45 gpm/ft)
30:1	1	2.3	1.7	2.2	1.5
	2	3.8	2.8	3.5	2.5
	3	5.1	3.8	4.7	3.4
	4	6.4	4.8	5.7	4.1
	5	7.5	5.7	6.6	4.9
10:1	1	3.3	2.5	3.1	2.3
	2	5.7	4.3	5.2	3.9
	3	7.5	5.8	6.7	5.1
	4	9.2	7.1	8.0	6.0
	5	10.6	8.2	9.2	6.9

Table 6 lists estimated adequate seawall "freeboard" (the vertical distance from the storm water level to the top of the seawall) for two nearshore lakebed slopes, two overtopping rates and five depths of water (ds) at the base of a seawall.

The two assumed acceptable overtopping rates are for storm waves breaking against the wall. The larger of the two rates is 0.10 cubic feet per second per shoreline foot (cfs/ft) of seawall, which is equivalent to 45 gallons per minute per foot (gpm/ft) of wall, or about 0.01 cubic meters per second per foot of wall -- an overtopping rate used in Japan as a general guideline for port design where large drainage channels are provided.[25] The smaller rate is 0.01 cfs/ft of seawall, equivalent to 4.5 gpm/ft of wall or approximately 0.001 cubic meters per second per foot of wall -- the recommended maximum overtopping rate in cases where wide drainage channels at the top of or behind the seawall are impractical.[25] The latter (smaller) overtopping rate is more suitable for residential property.

EXAMPLE 6: Estimating Adequate Freeboard (or Crest Elevation) for Seawalls

A lakeside house in Bayfield County on Lake Superior has an elevation of 612.5 feet above NGVD and a yard that slopes down towards the lake, where there is a seawall with a crest that is about 3 feet lower than the house elevation. The top of the seawall is about 9 feet above the lake bed. Does the height of the seawall and the elevation of the home appear to be adequate to prevent flooding during a storm?

Step 1: Estimate the highest still water level.

From the Corps of Engineers' monthly lake level bulletin (Figure 3), the highest monthly mean level for Lake Superior was 2.2 feet above chart datum in 1985. No higher levels are predicted. From Table 2, chart datum is 601.0 feet NGVD.

Highest monthly mean lake level	2.2 feet above chart datum
Equivalent elevation of chart datum	+601.0 feet NGVD
Highest still water level	603.2 feet NGVD

Step 2: Determine the local storm surge.

Figure 5 shows the typical storm surge along the coast of Bayfield County to be 1.0 feet.

Step 3: Estimate the storm water level elevation.

Highest still water level (step 1)	603.2 feet NGVD
Storm surge (step 2)	+ 1.0 feet
Storm water level elevation	604.2 feet NGVD

Step 4: Estimate the maximum depth of water at the base of the seawall (see Figure 14).

Elevation of house	612.5 feet NGVD
Seawall crest below elevation (A)	- 3.0 feet
Elevation of seawall crest	609.5 feet NGVD
Height of seawall above lake bed (B)	- 9.0 feet
Lakebed elevation	600.5 feet NGVD

Storm water level elevation (step 3)	604.2 feet NGVD
Lakebed elevation	-600.5 feet NGVD
Maximum depth of water at base (ds)	3.7 feet

Step 5: Estimate the amount of freeboard needed for the seawall.

Table 6 indicates the recommended freeboard is 6.4 to 9.2 feet for an overtopping rate of 4.5 gpm/ft, the recommended maximum rate for a residential property.

Step 6: Compare the elevation of the land and seawall with the storm water level and recommended freeboard (height of seawall crest above maximum storm water depth).

Land elevation of house	612.5 feet NGVD
Elevation of seawall crest (step 4)	609.5 feet NGVD
Storm water level elevation (step 3)	-604.2 feet NGVD
Existing freeboard	5.3 feet
Recommended freeboard (Table 6)	6.4 to 9.2 feet

Answer: Storms during high lake levels will result in excessive overtopping of this seawall. The top of the seawall will have to be raised so that the freeboard can be maintained at 6 to 9 feet above storm water levels, and some accommodation for drainage will also be needed.

APPENDIX 3

Assumptions and Sources Used in Preparing This Manual

Comparing Great Lakes Water Levels to Land Elevations

Land elevations in the U.S. portion of the Great Lakes Basin are available in feet above National Geodetic Vertical Datum (NGVD) or Mean Sea Level of 1929 (MSL 1929), which was the earlier term for the present NGVD datum. Land elevations in the Canadian portion of the basin are based on Canadian Geodetic Datum. Water elevations in the Great Lakes are referenced to a different datum, the International Great Lakes Datum of 1955 (IGLD 1955).

The difference between the land-based datums and the water-based datum is not constant, but varies with latitude and elevation.[34] However, on each lake this variation is a few tenths of a foot (no more than a few tenths of a meter). For the purposes of this manual, it is assumed that such variation is unimportant, given the other uncertainties involved (storm surge, future lake levels, wave runup). Consequently, a single value is given in Table 2 for converting IGLD to NGVD and Canadian Geodetic Datum on each lake. The conversion value appropriate for each lake's U.S. and Canadian master gauge sites is assumed sufficiently accurate for the other locations on each lake.[10,11]

Design Wave Information

No comprehensive source of design wave information for the entire Great Lakes Basin exists. The most complete source of design wave information for the U.S. portion of the Great Lakes shoreline is a set of reports published in the mid-1970s by the U.S. Army Corps of Engineers Waterways Experiment Station entitled "Design Wave Information for the Great Lakes," by Donald Resio and Charles Vincent.[35] Another source of wave information is the data from the National Oceanic and Atmospheric Administration wave buoys in each of the Great Lakes.[36]

A "10-year" reoccurrence interval storm was selected for the purposes of this manual as being sufficiently severe and common enough to be encountered more than once within the period of a mortgage or the lifetime of a Great Lakes coastal house. The Resio and Vincent reports for Lakes Michigan and Superior give significant wave heights and periods for 29 deepwater sites along these Wisconsin coasts for storms expected to occur on the average once in 10 years.[35] Significant wave heights are the average of the highest one-third of all waves present and are a commonly used engineering parameter. The wave height data in this manual are based on Reference 35.

The wave periods data used for this manual are generally from References 30 and 35. Deepwater wave data available from NOAA's two NOMAD buoys in each lake also provide a good indication of the wave periods associated with maximum wave energy during storms.[36] For Lakes Michigan-Huron and Superior, the largest wave periods of maximum storm wave energy are about 8 to 10 seconds; for Lakes Erie and Ontario, the largest wave periods are about 8 seconds.[30] For Green Bay, the authors assumed the largest wave periods of maximum storm wave energy to be 5 to 7 seconds based on shallow-water wave forecasting curves in Reference 31. Table 7 shows the assumed 10-year design storm wave conditions used in this manual.

TABLE 7
10-YEAR DESIGN STORM WAVE CONDITIONS

Wisconsin Coasts	Wave Periods (seconds)	Deepwater Wave Heights (feet)
Lakes Michigan and Superior	10	18
	9	13
	8	13
	7	12
Green Bay, Lake Michigan	7	9
	6	8
	5	10

Wave Runup on Beaches

Most beach runup equations appear to follow the form developed by Hunt, which uses deepwater wave conditions and beach slope to predict wave runup.[29] The approach used in this manual is based on Resio and Holman's methods, which use actual storm wave conditions lakeward of the breaker zone to estimate extreme wave runup during storm events.[27,28] Their methods were developed using ocean wave and runup conditions similar to those for the Great Lakes. The range of runup values represents the maximum and minimum runup calculated for beach slopes extending into 5- and 10-foot-deep water and nearshore lakebed slopes of 10:1 and 50:1, as observed in Racine County, Wisconsin.[37] The maximum depth of water where wave breaking begins was determined by deepwater wave conditions in Table 7 and the methods of Reference 31. Nearshore wavelengths were assumed to change according to linear wave theory, and wave heights were assumed to be limited by nearshore water depths.[9,32] For convenience, the range of beach slopes was limited to 10:1 to 20:1. The methodology of References 27 and 28 could be used to produce a broader range of beach slopes, from 5:1 to 30:1, if needed. Milwaukee County, for example, is reported to have beaches with slopes ranging from 3:1 to 14:1.[38]

Wave Runup on Revetments

The method selected for estimating wave runup was the method developed by Ahrens and Heimbaugh for estimating the upper limit of runup of irregular waves on sloping riprap revetments with little or no porosity.[32,39] Ahrens and Heimbaugh base their runup values on nearshore wave heights and wave lengths. Under this approach, waves were assumed to shoal, with wave lengths changing according to linear wave theory. Wave heights were assumed to be limited by nearshore water depths.[9]

Each water depth (ds) and revetment slope in Table 5 of Appendix 2 has a minimum and a maximum runup value. The minimum value is the value calculated from the runup equation. The maximum value is calculated to be 1.4 times the minimum value to account for some variation in Ahrens and Heimbaugh's laboratory results. There was no substantial difference in runup values for wave periods of 7 and 9 seconds.

Wave Runup on Vertical Seawalls

An approach suggested by Ahrens was used.[33,39] Instead of runup, the selected equation calculates freeboard (the crest elevation minus the storm water level) for a given acceptable rate of overtopping water from waves. Two "acceptable" rates of overtopping water were assumed. The larger rate of 0.10 cubic feet per second per foot (cfs/ft) of seawall is a general guideline for harbor dockwalls in Japan where large drainage channels are provided to drain off the water.[25] The lesser rate of 0.01 cfs/ft is recommended where large drainage channels are impractical -- the situation for most residential coastal properties.[25]

Table 6 in Appendix 2 has minimum and maximum values of seawall freeboard for each depth of water (ds) at the base of the seawall. The minimum value of freeboard for each value of ds is for a nearshore lakebed slope of 30:1. The maximum freeboard value is for a nearshore lakebed slope of 10:1. The assumption is that most lakebed slopes fall somewhere between those two slopes.

Recession Rates

The principal source of the recession rates used in this manual is the 1977 series of Technical Appendices from the Wisconsin Coastal Management Program (WCMP) Shore Erosion Study.[16] The WCMP study did not include an analysis of error in estimating rates. Peters estimated recession rate errors of plus or minus 0.5 to 0.8 feet per year in estimating long-term recession rates from aerial photographs in Manitowoc County.[17] Keillor and DeGroot estimated errors of plus or minus 0.3 to 0.8 feet per year in obtaining recent short-term (decade or less) recession rates from Racine County maps that had been prepared from aerial photos.[40] Aerial photos are available only for the last 50 years. Recession rates for periods longer than 50 years are obtainable from old survey notes (principally at section corners) dating back more than a century. Recession rates based on surveys should have substantially less error than the plus or minus 1 foot per year that appears to be the error in deriving long-term recession rates from aerial photos.

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