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International Reference Group on Great Lakes Pollution from Land Use Activities

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INTERNATIONAL JOINT COMMISSION

THE DETERMINATION OF QUANTITY AND QUALITY OF GREAT LAKES UNITED STATES SHORELINE ERODED MATERIAL

TECHNICAL REPORT ON DETERMINATION OF QUANTITY AND QUALITY OF GREAT LAKES U.S. SHORELINE ERODED MATERIAL

by

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D I S C L A I M E R

To be used as a portion of the Reports for the International Reference Group on GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES of the International Joint Commission -- prepared in partial fulfillment of U.S. Environmental Protection Agency Contract No. 68-01-1598. Findings and conclusions are those of the authors and do not necessarily reflect the views of the Reference Group or its recommendations to the Commission.

SUMMARY

Over 3,438 kilometers (2,116 miles) of the U.S. Great Lakes shoreline have been classified as subject to erosion while another 780 kilometers (483 miles) are flood prone (U.S. Department of the Army, Corps of Engineers, 1971). Erodible bluffs and low plains occur along each of the U.S. Great Lakes coasts in varying degrees. The erosion process tends to be intensified during, or just after periods of high water level. High lake levels have prevailed during the early 1950's and again at the present time. While the effects of the increased recession rates are relatively unknown, one anticipated effect is an increase in the actual input of sediment to the Great Lakes from the U.S. shoreline. This study was undertaken as part of Activity 1.1 of the U.S. Task D section of the Pollution from Land Activities Reference Group which is organized under the aegis of the International Joint Commission. Activity 1 is designed to develop an estimate of the importance of shoreline erosion as a pollutant to the Great Lakes relative to other land associated pollutants.

Estimates of the annual volumetric contributions of eroded sediment, created by bluff recession, have been derived in this study for about 44 percent of the erodible U.S. Great Lakes shoreline. Approximations of the input of the chemical components of the eroded material, generated from specific reaches along the U.S. coasts, have also been calculated. Both sets of values are dependent on the recession rates which were obtained from various reports and agencies. The methods by which the bluff recession rates were determined and the time intervals over which they are recorded are significant factors when evaluating the validity of the values derived for the volumetric contribution and the chemical input of the eroded material. Further extrapolation of the data to obtain the total quantity and quality of shoreline material eroded into the Great Lakes will be attempted in Activity 1.2 of Task D.

The nearshore processes significantly affect the recession rates along the Great Lakes. The direction of the littoral current and the availability of source material largely determine the ability of a beach to rebuild itself. Major transport of drift within the littoral current will be in the direction of the predominant wind and wave action on shore. The greatest buildup of beach source material along the shores of Lake Michigan is at the southern tip where the littoral drift from both sides of the lake brings in source material. The beaches along the red clay bluffs of Lake Superior are quite narrow due to the lack of source material in the east-west littoral current. The lean drift is due to the absence of sand-sized particles in the eroded bluff

material; the smaller-sized particles are transported away from the nearshore zone. The narrow beaches along much of the Lake Erie and Lake Ontario shoreline are also a consequence of the lean drift in the littoral currents. The north-south littoral current and sand eroded from the updrift bluffs provide source material for the wide beaches at the south-western tip of Lake Huron. These wide beaches provide the shoreline with adequate natural protection from wave attack.

The relationships of other nearshore processes to bluff recession have been divided by Maresca (1975) into a three-part process and response model: (1) incoming energy, (2) distribution of incoming energy, and (3) energy dissipation reflected in the beach geometry. The incoming energy is dependent on the magnitude and duration of the storm waves, storm surge, and longshore currents. The distribution of the incoming energy is determined by the convergence or divergence of wave energy due to wave refraction, the unequal dissipation of wave energy before the wave breaks on the shore, and the balance or imbalance of the alongshore transport of material. The energy dissipation is reflected in the beach geometry because the beach acts as a buffer against wave attack to the adjacent shoreforms. Areas of wide beaches with large volumes of sand will better dissipate the incoming energy than narrow beaches with small volumes of sand. During low lake levels the large beaches will adequately protect the adjacent bluffs and little change will be created by the wave activity. However during high lake levels the narrow beaches cannot adequately dissipate the energy of the high intensity wave attack, and thus both the beach and the bluff are eroded. Consequently, beach erosion is reflected in the energy distribution while bluff recession is reflected in the interaction between the energy distribution and the beach geometry.

The recession rate data presented in this report were derived from the information available from agencies and individuals involved in recession rate determinations. A weighted average annual, maximum annual, and minimum annual recession rate have been estimated for each reach of the U.S. shoreline for which data were available. The average recession rate was calculated by a weighted average method using the following equation: $\Sigma r_i * l_i / \Sigma l_i$, when r_i was the recession rate and l_i the corresponding length of shoreline. The volume of material contributed to the Great Lakes from bluff recession along the U.S. shoreline was determined using the rectangular prism method. The horizontal recession served as one leg and the approximate vertical elevation of the bluff face at the initiation of the recession rate measurements was the second leg. The average recession rate multiplied by the bluff height multiplied by a linear meter (foot) of shoreline yields the cubic meter per meter (cubic foot per foot) of shoreline contributed to a lake. Where data were available, maximum and minimum erosion rates were similarly calculated.

Approximations for the input of the chemical components of the eroded material, produced from erosion along 58 percent of the erodible U.S. shoreline, were also derived as part of this study. The primary factors used to calculate these inputs were the chemical analysis of soil samples collected from the U.S. shoreline of the Great Lakes; the specific gravity of the soil samples; and the relevant recession rate data. The total input for each chemical component was initially derived for the shoreline reaches from which the soil samples had been obtained. These values were then categorized according to shoreform-material category. An inventory of similar reaches along the U.S. shoreline of each Great Lake was compiled for each shoreform-material category. An average annual input of the chemical constituents of the eroded material for each shoreform-material category was then calculated using a weighted average recession rate and a weighted average bluff height for each category and the specific gravity and chemical analysis of the representative soil sample for that category.

The distinctive patterns of the recession rates along the U.S. shoreline of each of the Great Lakes reflect the general wind and wave conditions and the shoreform characteristics. The rocky, rugged western and southern shorelines of Lake Superior incur relatively low recession rates, i.e., frequently less than 0.3 meters (1 foot) on an annual basis. The highest rates along the U.S. shoreline of Lake Superior occur in the extreme southwestern corner of the lake where red clay bluffs commonly experience annual recession rates which exceed 3 meters (9.8 feet). These highly erodible bluffs have little ability to withstand the frequent intense wave attack caused by northeasterly winds.

The western shores of both Lake Michigan and Lake Huron experience relatively low recession rates as a consequence of the weather patterns. In both cases the winds that would generate the most damaging waves, i.e., those from the east and northeast, occur infrequently and are of a low intensity. Thus these shorelines are not subjected to frequent storms of high intensity and often experience recession rates of less than 0.3 meters (1 foot) annually. In contrast, winds from the southerly and westerly quadrants frequently generate waves on the east coast of Lake Michigan which have a greater period and a breaker height that is about twice as high as that on the western coast of the lake. Hence, the eastern coast of Lake Michigan is subjected to frequent storms which create high energy waves that can cause annual recession rates which average greater than 1 meter (3.3 feet) annually.

Shoretype and material composition have also minimized the recession rates along the western shore of Lake Michigan and the northwestern shore of Lake Huron. The western coast of Lake Michigan is characterized by a high percentage of clay bluffs and banks whose somewhat more cohesive nature slightly increases the ability of these shorelands to withstand the occasionally intense wave attack. Similarly the limestone and dolomite bluffs and the nonerodible plains along the northwestern shore of Lake Huron tend to limit the effects of wave attack. The east coast of Lake Michigan, however, consists predominantly of high bluffs of unconsolidated glacial material and high dunes. Their high sand content, with its lack of cohesiveness, increases the ability of the attacking waves to carry away large amounts of material. Likewise, the sand, gravel, and clay bluffs of the southwestern shorelands along Lake Huron are also capable of offering little resistance to wave attack.

The maximum recession rates for the U.S. shoreline along Lake Erie occur along the western shoreline while quite low rates are experienced along the eastern shore. This situation is largely a consequence of the differences in shoreform and shore material composition. The shale content of many of the bluffs along the eastern shore increases the ability of these shorelands to withstand occasionally intense wave attack. Annual recession rates of less than 0.2 meters (0.7 feet) are common along this stretch of shoreline. However, the western shoreline is characterized by wetlands, barrier beaches, and low clay bluffs. Their low relief makes these shorelands highly susceptible to even small wave heights, while the clay and sand content are capable of giving little resistance to wave attack. Consequently, annual recession rates frequently exceed 1.5 meters (4.9 feet) along this end of Lake Erie.

While the entire Lake Ontario shoreline is subjected to relatively low recession rates, the higher rates are experienced along the southeastern and east coasts. The central and western segments of the southern Lake Ontario shore are primarily affected by waves generated by winds from the north, northeast, and east. However, storms from these directions are fairly infrequent. The southeastern and eastern coasts incur the greatest erosion damage from waves generated by storms from the westerly quadrants, and it is these winds which predominate on Lake Ontario. Consequently, the shorelands along the eastern end of Lake Ontario are subjected to a greater frequency and intensity of storms than the other areas adjacent to the lake and often incur annual recession rates which average greater than 0.2 meters (0.8 feet).

The erosion rates (volumetric contribution) of eroded sediment from the U.S. shoreline to the Great Lakes were determined from the recession rates. In general, the data for the erosion rates indicated the following: even low recession rates for a shoreform with high relief would yield relatively high erosion rates while high recession rates for a shoreform with low relief would create relatively low erosion rates. Thus, the controlling factor in erosion rates appears to be the height of the shoreform incurring some rate of recession.

The above conditions are best exemplified along the southern Lake Erie shoreline. The southeastern segments have often experienced relatively low annual recession rates, less than 0.2 meters (0.6 feet), due to the shale content of the bluffs. However, these bluffs were sufficiently high that even a low recession rate yielded a large volumetric contribution of sediment, i.e., annual erosion rates frequently exceed 5 cubic meters/year/meter (54 cubic feet/year/foot). In contrast, the southwestern portions have experienced relatively high recession rates, greater than 1.5 meters (4.9 feet), due to the low relief and nonresistant components of the shoreforms. However, the low relief of the shoreforms has also minimized the volume of sediment contributed to Lake Erie from these shorelands. Annual erosion rates are often less than 1 cubic meter/year/meter (11 cubic feet/year/foot).

Comparable situations exist for the U.S. shoreline along the other Great Lakes. The highest erosion rates for the U.S. shoreline of Lake Superior are found along the shoreline characterized by the high red clay bluffs. Annual erosion rates frequently exceed 15 cubic meters/year/meter (161.5 cubic feet/year/foot). These reaches are also where the highest recession rates have occurred; thus the height and the recession rates have combined to create very high erosion rates along these segments of the Lake Superior coast. The maximum rates for Lake Michigan occur along reaches consisting of high sand dunes; many of these dunes have experienced a relatively low recession rate. In one case, an average annual recession rate of 0.8 meters (2.6 feet) produced an average annual erosion rate of 72.9 cubic meters/year/meter (838.5 cubic feet/year/foot). Maximum erosion rates for Lake Ontario are apparently also along reaches consisting of high sand dunes; up to 7.3 cubic meters/year/meter (79 cubic feet/year/foot) were contributed to Lake Ontario along one dunal area. Eroded material from clay and sand bluffs along the U.S. shores of Lake Huron are generating maximum erosion rates for that lake; up to 7 cubic meters/year/meter (75 cubic feet/year/foot) have been experienced along some bluff stretches. However, these bluffs have incurred only moderate recession, with an average annual rate of 0.6 meters (2 feet).

Examination of all the available erosion and recession data for the Great Lakes clearly demonstrates that erosion is variable from one location to the next. When averaged over large segments or reaches of shoreline, the erosion and recession data will give a general indication of the erosive characteristics of a shoreform. However, for any one point within a particular shoreform along a given reach, the erosion and recession rates can vary significantly from the average values for that shoreform.

Approximations of the input of the chemical constituents of the eroded material from the U.S. shorelines to the Great Lakes have been derived for each lake using the available information. Soil samples, originally obtained for another project and analyzed by the U.S. Environmental Protection Agency, served as the basis for these approximations. A conjectured average annual input for chemical components of the eroded material from segments on the U.S. shoreline was calculated for each of the Great Lakes, see Table A. Due to the small amount of chemical data as well as the distribution of that data, the loading values should be considered at best as only first approximations.

TABLE A

TOTAL AVERAGE INPUT OF THE CHEMICAL CONSTITUENTS BY LAKE FOR THE U.S. GREAT LAKES SHORELINE

Chemical Constituent	Input Per Year (10^3kg)* Superior[1]	Michigan[2]	Huron[3]	Erie[4]	Ontario[5]
Phosphorus	5,800	2,500	350	600	150
Nitrogen	2,750	3,300	50		50
Calcium	249,000	1,461,950	52,400	40,000	9,850
Magnesium	114,750	318,900	17,800	20,000	2,800
Sodium	450	50	600	8,750	
Iron	149,000	179,150	6,900	73,150	5,900
Manganese	2,900	3,800	0	750	200
Aluminum	81,400	9,900	3,200	113,350	1,350
Boron	250				
Barium	950				
Copper	550	150			0
Lead	200	200	0	50	
Zinc	400	500	50	200	0
Vanadium	150		0		
Titanium	2,750	3,550	250	13,550	100
Organic Carbon	16,600	45,300	1,200	550	0

*Values rounded to the nearest 50,000 kg.
[1]Derived from 18% of the examined erodible shoreline (784.0 km, 487.2 mi).
[2]Derived from 56% of the examined erodible shoreline (1,688.9 km, 1,049.5 mi).
[3]Derived from 74% of the examined erodible shoreline (739.6 km, 459.6 mi).
[4]Derived from 85% of the examined erodible shoreline (538.5 km, 334.6 mi).
[5]Derived from 40% of the examined erodible shoreline (277.0 km, 172.1 mi).

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INTRODUCTION

Encompassing a total water area of approximately 246,000 square kilometers (95,000 square miles), the interconnected Great Lakes form one of the largest bodies of fresh water in the world. Yet less than a million years ago, no lake even existed. The area was traversed by the well-drained valleys and divides of several large rivers. In the geologic time scale, the five Great Lakes are a recent development; their present outlets and configurations probably date back less than 5,000 years.

A thick succession of sedimentary rocks underlies most of the Great Lakes Basin. The prominent structures include the extensive Michigan Basin and a long, narrow structural platform which extends from Indiana to the St. Lawrence Valley. Crystalline rocks outcrop in the western Lake Superior and Adirondack regions and form a subsurface structural high which separates the sedimentary basin and the platform structures. Surface deposits are of glacial and alluvial origin and obscure most of the preglacial geology.

During the Pleistocene or Ice Age a continental ice cap developed to a thickness of several thousand feet over much of Canada. The ice sheet then spread southward, completely covering what is now the Great Lakes Basin. While the present topography is the result of the alterations performed by the glacial activity, some evidence of the preglacial topography can still be found. Preglacial outcrops occur in the Marshall Upland in both northern and southern Michigan, in the Superior and Duluth Uplands, in the Niagara Cuesta and in a few areas of the scoured lowlands.

Portions of the major preglacial valleys were deepened by glacial scouring while other parts were filled by glacial deposits. For example, the maximum depth of Lake Michigan is greater than 275 meters (900 feet), and while bedrock is buried under 180 meters (600 feet) of glacial overburden along one reach of its east shoreline, bedrock is exposed along several reaches of its west shore. The preglacial well-drained divides were also scoured and then completely buried under glacial deposits. The degree or extent of glacial overburden varies throughout the basin. Glacial drift as thick as 335 meters (1,100 feet) has been recorded in Michigan. While vast areas are covered by 30 meters (100 feet) or more, there are scattered areas with only a thin cover of glacial overburden.

The Pleistocene epoch involved four major advances of the glaciers. While the first three probably formed glacial lakes, little is known of them as the effects of each advance of the ice sheet were obliterated by later and more extensive advances. The advance and recession stages of the Tazewell, Cary, Port Huron (Mankato), Two Creeks, and Valders substages of the Wisconsinian stage, the last glacial, define the time scale for the formation of the present Great Lakes.

As the ice sheet slowly melted and retreated progressively northward, the entrained debris was released, creating vast irregular deposits of overburden. The former drainage patterns were blocked during the various substages of the Wisconsinian glacial and new drainage patterns created a complex early history for the Great Lakes. The glacial lakes experienced many water levels, both higher and lower than the present-day levels and several major spillway-discharge points for the melt waters. Ponding of the melt waters caused the creation of large glacial lakes whose overflow outlets cut across present watershed divides. The earliest ponding formed Lakes Maumee and Chicago which discharged through the Wabash River, Indiana and the Des Plaines-Illinois Rivers, Illinois. Subsequent stages included Lakes Arkona and Whittlesey, drained by the Ubly-Grand River Channel, Michigan; Lake Wayne, which discharged eastward through the Mohawk Valley, New York, and Lake Warren which drained through the Grand River, Michigan.

At the time Lake Whittlesey was forming, melt waters also were ponding in front of the retreating glacial in the Lake Superior Basin. This lake, known as Lake Duluth, drained through the valley of the St. Croix River, Wisconsin. Consecutive glacial recession and melt water levels created Lake Algonquin which discharged both eastward and westward during four stages of development. A later stage, referred to as Lake Nipissing, discharged eastward through the North Bay-Ottawa River, Ontario and the St. Clair-Lake Erie outlet.

The occurrence of these early lake stages were dominant factors in determining the present relief and soil characteristics of the Great Lakes Basin. The resulting lake plains and outwash zones differ greatly from the nonimpoundment, morained deposits in terms of both slope and soil characteristics. The imprint of the former glacial lakes on the present shorelines is demonstrated by the following: (1) the perched wave-cut cliffs of Mackinac Island, (2) the lake-deposited clay flats of Chicago and Toledo, and (3) the sand tracts of the dune areas. In addition, regional uplift of the northern areas of the Great Lakes Basin has been occurring since the retreat of the last ice sheet. The weight of the heavy ice sheets upon the earth's crust had significantly depressed those areas it had covered. With the removal of this weight, isostatic recovery began. The entire region appears to be slowly tilting upward to the north and east at a rate of three-tenths meter per 160 kilometers per century (one-half foot to one foot per 100 miles). (Hite, 1971).

The advances, retreats, and readvances of the ice fronts, the outwash formed from the melting ice, the deposition of ground terminal moraines, and the pooled melt waters all helped to form the present complex land surface. Consequently, the Great Lakes Basin has an irregular and varied topography which includes depressions occupied by small lakes or marshes, level and sloping plains, and low rolling hills or ridges. The variety of slopes and gradients created by the glaciers form the relief patterns upon which erosion and sedimentation rates are based. The importation of soil materials and the mixing and sorting of these materials during the glaciation process form the basis of the erodibility characteristics of the soils found throughout the Basin. In general, the high precentage of erodible shoreline along the U.S. Great Lakes shorelands (71 percent) is due to the presence of glacially derived sediments which are relatively nonresistant to wave attack.

Accordingly, the approximately 5,580 kilometers (3,470 miles) of mainland and interconnecting shoreline range from high bluffs of clay, shale, and bedrock through the lower rocky shores and sandy beaches to low, marshy clay flats (Great Lakes Basin Commission, 1975). This variability of the shorelands created an obvious need for standard descriptive terminolgy. Hence, standard designations for the prevalent shoretypes along the U.S. Great Lakes shoreline were established as part of the Great Lakes Regional Inventory of the National Shoreline Study which was conducted by the U.S. Army Corps of Engineers in the early 1970's. Land form, topography, and relative degree of erodibility were incorporated into each designation. The ten basic shoretypes are as follows:

HBE - High bluff, 9 meters (30 feet)or higher, erodible material

HBN - High bluff, 9 meters (30 feet) or higher, nonerodible material

LBE - Low bluff, less than 9 meters (30 feet) high, erodible material

LBN - Low bluff, less than 9 meters (30 feet) high, nonerodible material

HD - High sand dune, 9 meters (30 feet) or higher

LD - Low sand dune, less than 9 meters (30 feet) high

PE - Low plain, erodible material

PN - Low plain, nonerodible material

A - Artificial lake fill or modification

W - Wetlands

Although the distribution of each of these shoretypes along the U.S. Great Lakes shoreline is highly erratic, some trends have been observed. Nonerodible high bluffs, 9 meters (30 feet) or higher, occur along much of the Lake Superior shoreline and in northern Door County, Wisconsin on Lake Michigan. Nonerodible low bluffs, less than 9 meters (30 feet) high, are more widely distributed along all of the Great Lakes. However, Lake Superior has the greatest number of kilometers of this shoretype, followed by Lake Ontario. Nonerodible low plains are found along the shores of the three upper Lakes—Huron, Michigan, and Superior—and are virtually ronexistent along Lakes Erie and Ontario.

Excluding the areas where bedrock is exposed, much of the glacial overburden comprising the shores of the U.S. Great Lakes is highly erodible. Along the U.S. shoreline, over 3,260 kilometers (2,026 miles) of shoreline are subject to significant erosion while an additional 1,500 kilometers (930 miles) are flood prone (Great Lakes Basin Commission, 1975). Erodible bluffs and low plains occur along each of the U.S. Great Lakes shores in varying degrees. Lake Michigan has the greatest number of kilometers of this shoretype and the U.S. shoreline of Lake Ontario the least. The ability of the shoreline to withstand water dynamics depends upon the composition of the shorefront. The rocky coasts of Minnesota possess greater resistance to wave forces than do the sandy beaches of Indiana and Michigan or the silty-clay bluffs of Ohio.

The recent increase in bluff recession rates along many shoreline reaches has led to speculation that the sediment input into the Great Lakes also has increased. The water quality effects of sediment loading from erosion-related coastal processes are relatively unknown. Consequently an assessment of shoreline erosion along the U.S. Great Lakes was included in Task D as defined by the Pollution from Land Use Activities Reference Group organized under the aegis of the International Joint Commission. The Reference Group was formed to conduct studies as a result of the 1972 Canada-United States Great Lakes Water Quality Agreement.

Task D has been defined as a diagnosis of the degree of impairment of water quality in the Great Lakes, including an evaluation of contaminants of concern in sediment and fish and other aquatic resources. Within Task D, Activity 1, shoreline erosion is recognized as a source of input to the U.S. coastal waters of the Great Lakes. The specific objectives of Activity 1 are: (1) to estimate the quantity of sediment entering the Great Lakes as a direct result of U.S. shoreline erosion, and (2) to estimate the levels of nutrients and trace elements in the erosive materials and to calculate their contribution to the Lakes.

Previous studies examining erosion and the related bluff recession rates along sections of the Great Lakes U.S. shoreline have provided valuable insight into the present erosion problems. The Great Lakes Regional Inventory of the National Shoreline Study by the Corps of Engineers (1971) was the first major attempt to collect and analyze all available information on erosion along the U.S. Great Lakes. The Study included the following information for each state bordering the Great Lakes: characteristics of its shoreland areas, its erosion and flooding history, and methods each state might use to control erosion problems. Utilizing the data generated from the Great Lakes Regional Inventory, the Great Lakes Basin Commission Framework Study (1975) assessed the problems of shore use and erosion along the Great Lakes. An inventory of shoreland resources, uses, and ownership was given for each lake. Recommendations for developing a strategy to reduce Great Lakes shoreland damages were also presented. Additional studies of bluff recession along the U.S. shoreline of the Great Lakes are presented in the discussions for each lake in the chapter on recession.

NEARSHORE PROCESSES

A schematic model of nearshore processes on the Great Lakes is given in Figure 1. In essence the processes that play the primary role in the nearshore zone are the effects of waves, the associated littoral currents, and the influence of the water levels on the intensity of these processes. Factors that are considered of secondary importance to overall shoreline changes include: the formation and movement of lake ice, the effects of local runoff, river discharge, shoreline orientation, beach and bluff composition, and the nearshore topography. The following presentation on the factors of primary importance is based upon previous discussions by Seibel (1972) and Maresca (1975).

WIND AND WAVES

Wind is the major source of energy that drives the overall nearshore system. The wind is responsible for the waves, indirectly influences littoral current through the waves, and may be considered a significant transporting agent on sand shorelines. With an onshore wind, sand is blown inland to form coastal dunes, but with an offshore wind the sand can be blown into the shallow water immediately offshore. Also, wind parallel with the shore moves sand along the shoreline on the dry beach. Wind, in addition to being responsible for the waves and its own action, will influence the lake levels by piling water on the shoreline in the direction it is blowing. It is intuitively obvious that the higher the wind velocity the greater the energy of the wind, and in general the greater will be the energy input into the water, thus greater wave heights are produced. A relationship between the deep water energy and the wave height from Seibel (1972) is presented in Figure 2. This figure suggests that as the wave height increases, the wave energy increases geometrically. For example, if the wave height is .9 meters (3 feet), the amount of energy that one can expect is approximately 1,058 joules per square meter (72 foot pounds per square foot). By increasing the wave height by a factor of three, i.e., 2.7 meter (9 foot) waves, the deep water wave energy is increased to 9,519 joules per square meter (648 foot pounds per square foot), or by a factor of nine. Therefore, the conclusion that Brater and Seibel (1973) reach, that wind generated water waves are the primary agent of shoreline erosion, seems plausible.

Brater and Seibel (1973) further indicate that the severity of wave energy input at any location depends on the prevalence of strong onshore winds, open water fetch, offshore topography, and the amount of natural and artificial protection present. The wave height that can be produced on the Great Lakes is controlled principally by the factor of limited fetch. However, the amount of energy that reaches the onshore bluff and beach at any location is significantly related to the offshore topography.

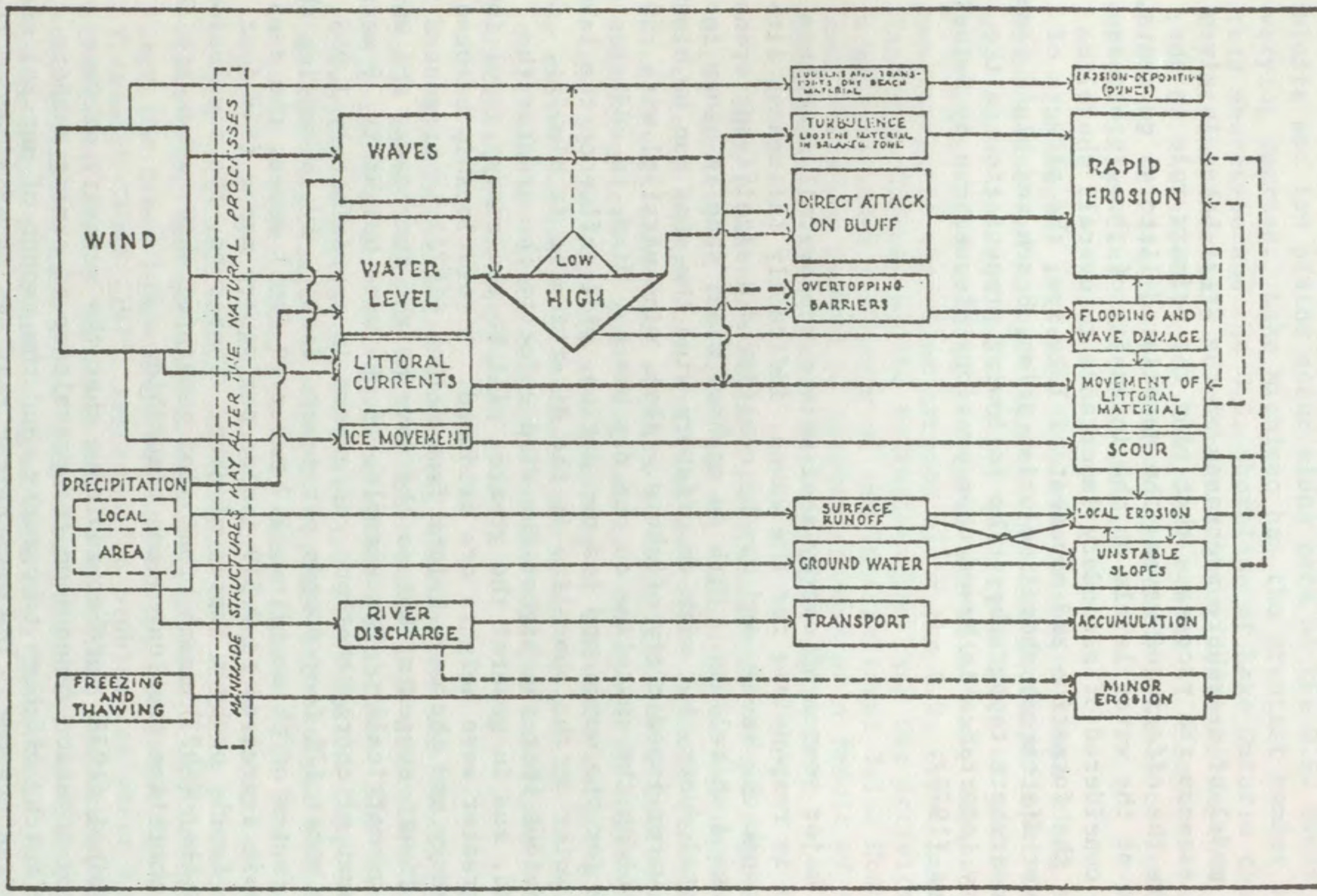


FIGURE 1. Diagrammatic representation of Nearshore Processes on the Great Lakes. Column one indicates the causative agent, the second column represents intermediary agents in the expenditure of energy and the third represents those effects of the intermediary agents which produce the results illustrated in column four. The size of each box suggests the relative significance of the factors depicted. The heavier lines and boxes indicate the critical path in this diagram.

SOURCE: Seibel, 1972.

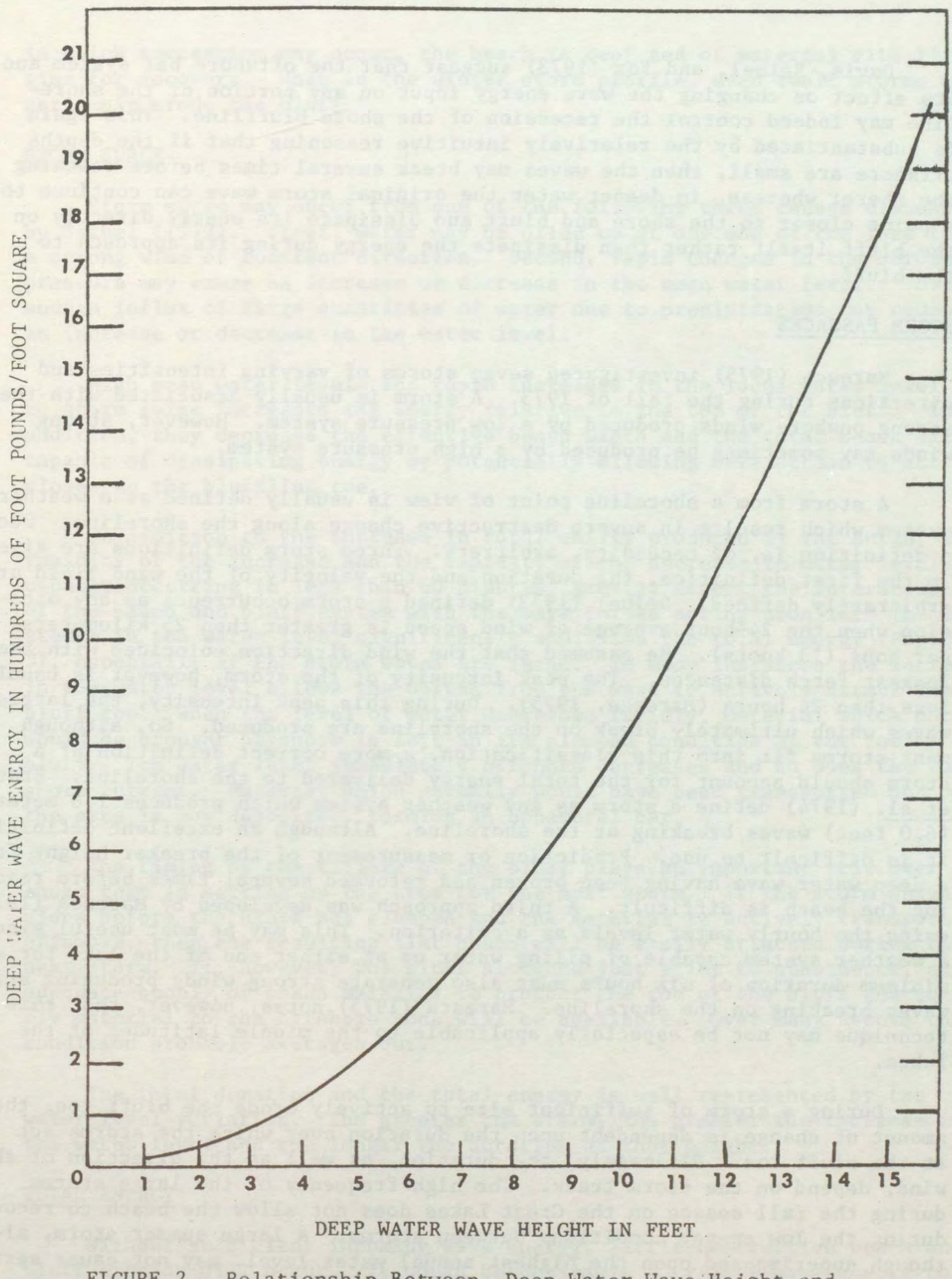


FIGURE 2. Relationship Between Deep Water Wave Height and Wave Energy.

SOURCE: Seibel, 1972

Davis, Seibel, and Fox (1973) suggest that the offshore bar system and its effect on changing the wave energy input on any portion of the shoreline may indeed control the recession of the shore bluffline. This again is substantiated by the relatively intuitive reasoning that if the depths offshore are small, then the waves may break several times before reaching the shore; whereas, in deeper water the original storm wave can continue to a point closer to the shore and bluff and dissipate its energy directly on the bluff itself rather than dissipate the energy during its approach to the bluff.

STORM PASSAGES

Maresca (1975) investigated seven storms of varying intensities and directions during the fall of 1973. A storm is usually associated with the strong onshore winds produced by a low pressure system. However, strong winds may sometimes be produced by a high pressure system.

A storm from a shoreline point of view is usually defined as a weather system which results in severe destructive change along the shoreline. Such a definition is, of necessity, arbitrary. Three storm definitions are given. In the first definition, the duration and the velocity of the wind field are arbitrarily defined. Seibel (1972) defined a storm occurrence as any occasion when the 24-hour average of wind speed is greater than 25 kilometers per hour (13 knots). He assumed that the wind direction coincided with the longest fetch distances. The peak intensity of the storm, however is usually less than 24 hours (Maresca, 1975). During this peak intensity, the largest waves which ultimately break on the shoreline are produced. So, although most storms fit into this classification, a more correct definition of a storm should account for the total energy delivered to the shoreline. Brater, et al. (1974) define a storm as any weather system which produces 1.8 meter (6.0 feet) waves breaking at the shoreline. Although an excellent definition, it is difficult to use. Prediction or measurement of the breaker height from a deep water wave having been broken and reformed several times before reaching the beach is difficult. A third approach was developed by Maresca (1975) using the hourly water levels as a criterion. This may be most useful since a weather system capable of piling water up at either end of the lake for a minimum duration of six hours must also generate strong winds producing strong waves breaking on the shoreline. Maresca (1975) notes, however, that this technique may not be especially applicable to the middle latitudes of the lakes.

During a storm of sufficient size to actively erode the bluff toe, the amount of change is dependent upon the duration over which the storms act at the bluff toe. Ultimately, the duration, as well as the direction of the wind, depend on the storm track. The high frequency of the large storms during the fall season on the Great Lakes does not allow the beach to recover during the low energy conditions between storms. A large summer storm, although superimposed upon the highest annual water level, may not cause serious damage to the bluff. A summer beach consisting of a wide berm serves as a buffer to dissipate the wave energy. During the fall season when many storms in quick succession may occur, the beach is depleted of material with little time for recovery. When in the winter storm profile, even small storms may seriously erode the bluff.

STORM SURGE

Storm surge may occur from one of the following three causes discussed by Seibel (1972). First, water may be piled up at one end of the lake from a strong wind of constant direction. Second, rapid changes in the barometric pressure may cause an increase or decrease in the mean water level. Third, sudden influx of large quantities of water due to precipitation may cause an increase or decrease in the water level.

High mean water levels and rapid increases in the local water level due to storm surge increases the energy relative to the toe of the bluff. In addition, they decrease the effective beach width and the total beach size capable of dissipating energy by potentially allowing wave action to act closer to the bluffline toe.

In addition to the increase in total energy produced by the surge, the rapidity of the increase and the rapidity of the decrease in water levels, usually occurring in less than 60 minutes, greatly affect the interaction of the beach and bluff system with the wave forces acting upon it. The increase in the water level significantly amplifies the total energy (Figure 3), especially if the storm waves are large. In many instances the increase in the water level allows the uprush from the wave to actively attack the bluff toe. When the level of water decreases rapidly, material which normally would be brought offshore is left in its slumped condition at the toe of the bluff. The water level immediately offshore decreases and so does the longshore current. Material which normally would have been transported out of the area is now deposited, forming an ephemeral bar.

The timing of the failure of the bluff plays an important role over the short term in setting up the area for the next storm. If the storm surge subsides before the bluff has slumped and the material is actively transported offshore, then the resulting flat beach will be easily attacked during the next storm. If, however, the bluff sloughed just prior to subsidence, an adequate supply of beach material to protect the toe of the bluff and to supply material to the offshore zone will be available. Over many events this condition probably averages out.

The total duration and the total energy is well represented by the water level variation. The greater the storm, the greater the increase in the water level and the longer the duration at that height.

TOTAL ENERGY

Without sufficient incoming wave energy, little destructive beach and bluff erosion will occur. It would be desirable to relate wave energy to the total volume of material eroded from the beach and bluff system. This is impossible unless quantitative measurements of the waves breaking on the shoreline are carried out continously along the shore. Thus, for example,

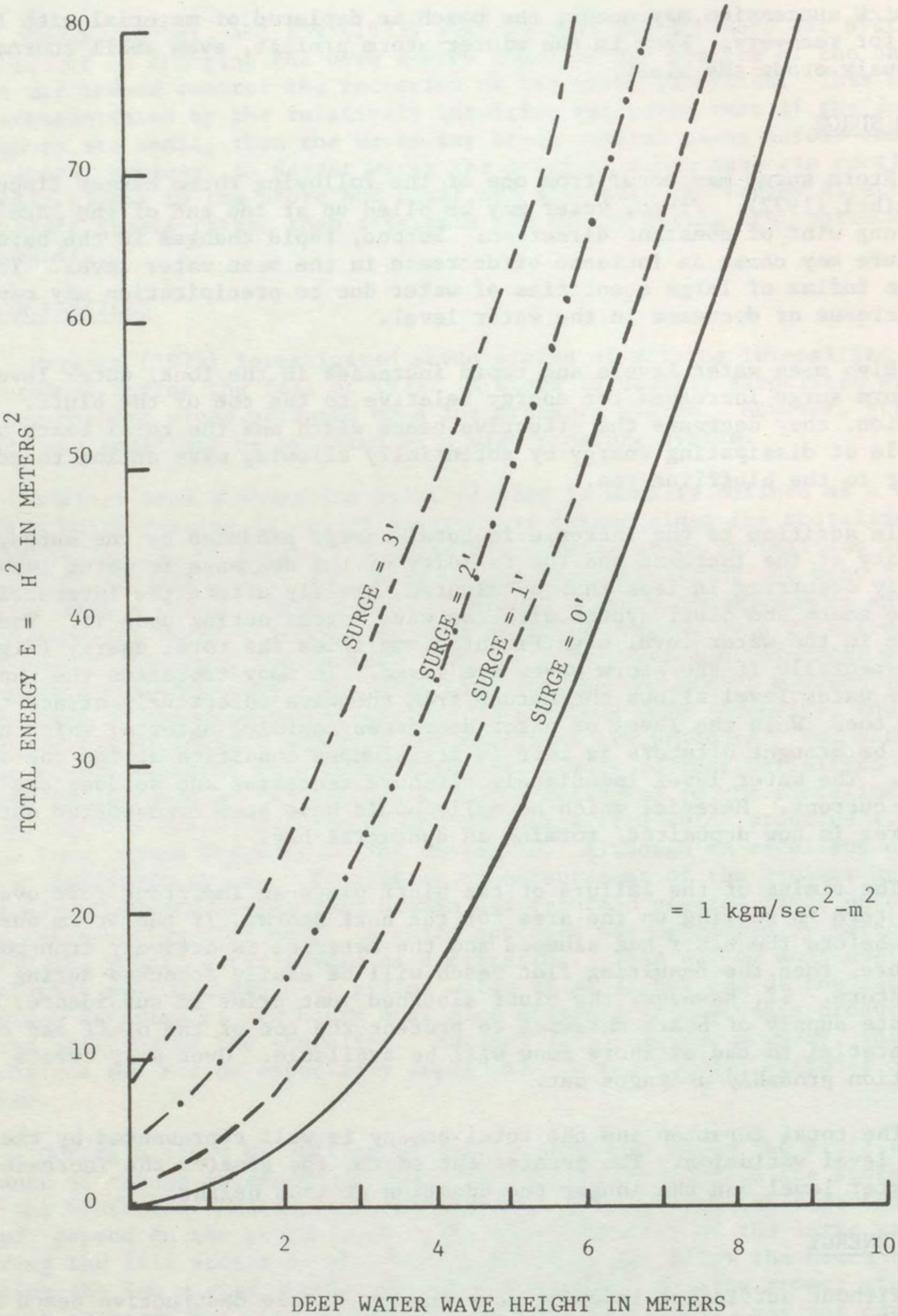


FIGURE: 3. Increase in the Total Wave Energy Due to Storm Surges.
SOURCE: Maresca, 1975

a deep water wave estimated at 2 meters (7 feet) will not affect all the areas evenly due to the factors distributing the wave energy such as wave refraction. Two areas with the same wave height may also show distinctly different rates of change along the shore. Nevertheless, the larger the storm, the larger the area that is affected by the large waves and high water levels.

LITTORAL CURRENTS

The nearshore processes also include the littoral currents which are generated by the nonnormal (nonperpendicular) wave approach to the shoreline. This current moves essentially parallel to the shore, and its velocity is controlled primarily by the size of the waves and the angle of wave approach. During storms longshore currents have been measured up to 1.5 meters per second (4.9 feet per second) in eastern Lake Michigan (Fox and Davis, 1971). Under these conditions Davis, Seibel, and Fox (1973) indicate that these currents carry tremendous quantities of sediment. It is known that the quantity of material that is moved varies, depending on the location, but on several portions of the eastern shore of Lake Michigan the amount is about 100,000 cubic meters (3.6 million cubic feet) per year. The littoral currents are considered the primary transporting agent of the beach and the bluff material along the coast, although the rate of littoral transport and its interrelationship with waves and currents that cause it are not clearly understood.

LAKE LEVEL

On the schematic diagram (Figure 4) lake levels are shown to be a dominant factor. Figure 4 illustrates the lake levels for the Lake Michigan-Huron basin since 1900. Factors that contribute to changing lake levels include precipitation on the lake's surface, runoff from the drainage basin, inflow from the lake above, and outflow from the lake itself through its natural channels. In addition to these natural factors, the artificial factors of diversion of the water to and from the lakes through manmade channels contribute to fluctuating lake levels. Megerian (1969) indicates that the effects of the artificial factors are relatively small when compared to those of the natural factors. Therefore, a change in the precipitation and evaporation on the Great Lakes basin is the major controlling factor in the fluctuating lake levels. This relationship is clearly shown in Figure 4. There is a difference of opinion as to whether there are any cycles in the lakes. In general, none but the annual cycle are found. However, Davis, Seibel, and Fox (1973) suggest a periodicity of between 8 and 14 years. Annual lake level fluctuations are relatively predictable with yearly maxima in midsummer and minima in February and March. This change is directly attributable to precipitation.

It is not valid to attribute all the coastal erosion to the level of the lakes. However, high lake levels, which cause both the decrease of beaches and the changes in nearshore topography, do play a major role in accelerating erosion. High mean annual water levels have been correlated with the bluffline recession by Maresca (1975), Seibel (1972, 1973, 1974), Brater and Seibel (1973), and Davis (1973). If the lake level remains high

LAKE LEVELS AND PRECIPITATION

LAKES MICHIGAN AND HURON

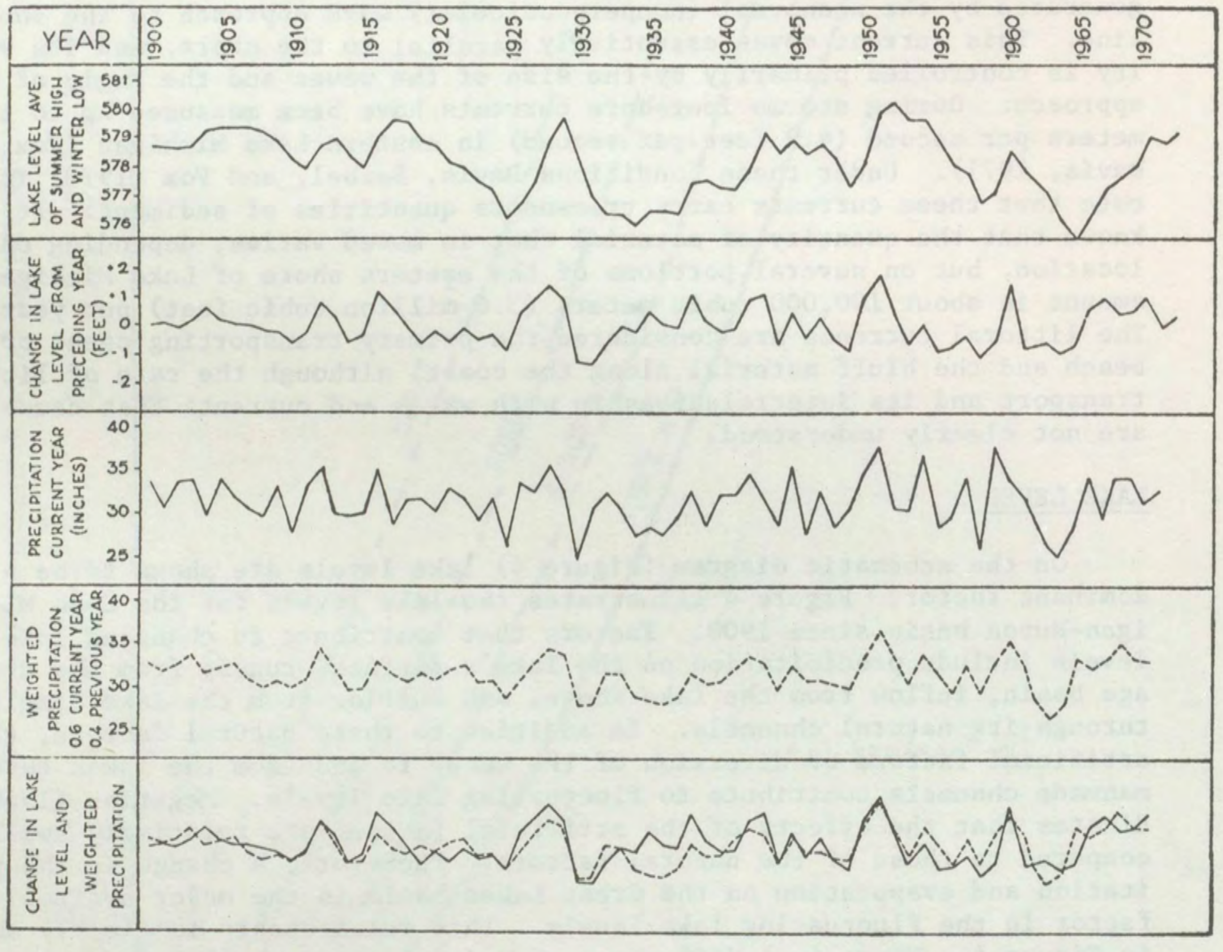


FIGURE 4. Relationship Between Precipitation and Lake Level Fluctuations for the Lake Michigan and Lake Huron Basin.

SOURCE: Seibel, 1972

for several years, then extensive bluffline recession distributed over a wider area can be expected. Studies by Laidly (1962), Megerian (1969), and Seibel (1972) indicate that there is no periodicity to the long-term water level fluctuations. Liu (1970) found a long-term period of fluctuation of eight years through spectral analysis, but was unable to explain the physical cause. The lake level rises during periods of increased precipitation. On an annual basis predictable seasonal fluctuations exist. Water level is highest during the summer months and lowest during the winter months.

Bluff recession analysis by aerial photographs suggests that a minimum mean water level relative to the beach and bluff system is required before active bluff recession can occur (Maresca, 1975). Davis (1973) suggested 177 meters (580 feet) above mean sea level while Seibel (1974) suggested 176.4 meters (578.5 feet) above mean sea level. Maresca (1975) showed that for his site on southeastern Lake Michigan a minimum level of about 176.8 meters (579.8 feet) above mean sea level was required before active bluff recession commenced. Once the beach is removed, bluff recession also will occur during the decreasing lake levels. Not only is the elevation of the mean water level important, but also the total time in which the lake level remains high.

High annual mean water levels are a necessary condition, but not a sufficient one to cause bluffline recession. Some areas along the shoreline are unaffected by bluffline recession even though mean lake levels are high.

METHODOLOGY

It is widely recognized that measurement of bluff recession rates is one of the best indicators for determining the volume of eroded shoreline sediment. Four principal sources have traditionally been utilized by coastal researchers to obtain relevant data: 1) historical observations, 2) field measurements, 3) maps and charts, and 4) aerial photographs. Historical observations are rarely of sufficient accuracy or detail. Field studies are the most direct method of measuring the bluff line change and thus are most accurate. However, over long time spans and long distances of shoreline, this is also the most expensive method. The aerial photographs are most useful as they are still a primary data source and are relatively inexpensive. While researchers have extrapolated the linear measurements derived from air photos to volumetric calculations of erosion through an empirically derived relationship, it must be recognized that this relationship can only be considered a first approximation and must be redetermined for each set of shoreline characteristics.

In addition, the average rate of bluffline recession is dependent on the interval between measurements. The simultaneous occurrence of high mean lake levels and large storm passages produce a maximum bluffline change. Since the bluffline shift is not continuous through time, an average number calculated over an arbitrary time interval may be misleading. More realistic data may result from calculating the recessions occurring during periods of high lake level only and assuming an upper limit for the number of these maxima during a future time period.

Thus, the method by which bluff recession rates have been measured and the time interval over which they have been recorded are significant factors when determining the validity of calçulated values for the volumetric contribution of sediment from the shoreline into the lakes.

The recession rate measurements that are documented in this report are those that are available and obtainable from the agencies and individuals involved in recession rate determinations. For each U.S. shoreline reach which had data, an average rate of recession was calculated. This average rate will naturally apply only to the time period of the measurements. A clear understanding of the shorebluff is imperative because the recession measurements made for different lakes are dependent on the shoretype. The following definition of a bluff was utilized in this study:

> The bluffline is the elevated segment of the shoreline above the beach or beach terrace subject to the periodic wave attack and presenting a precipitous front with the deposits making up the bank inclining more or less steeply on the water side. For the purposes of bluffline recession measurements an eroding and

accreting dunal terrace should not be considered as a bluff, but rather simply as a transient feature to the lakeward side of the bluffline.

The above definition eliminates the possibility of using beach recession as a measure of shoreline recession. Beach material must, for the sake of this study, be considered the result of local bluff recession.

A maximum annual, minimum annual, and weighted average annual recession rate have been derived for each sampling location. These data are classified in a tabular format for each individual lake and broken down into reaches delineated by shoretype and height. The current annual recession rate has been calculated only from recent data sampling in order to obtain a reasonably valid value. In general, recession rates were documented in the literature as averages over time; thus, the maximum annual and minimum annual values given in this report were compiled using that information. All locations from which data were analyzed in this study are represented on a map for each lake which gives an indication of the sampling distribution.

The determination of the volume of material contributed to the lakes by means of bluffline recession is, in most cases, only a first approximation. In order to determine accurate volumes, it was essential that vertical and horizontal controls (reference points) were available. It is quite obvious that these controls were at best rare. Therefore, the volume of material contributed to the lakes from bluffline recession was determined using the trapezoidal method. Where more accurate data was available, such as slopes and exact starting and finishing elevations, the volume measurements for those areas are naturally more precise.

The input of the chemical components of the eroded materials entering the Great Lakes waters as part of the eroded U.S. shore material were estimated using the volumetric bluff erosion calculations. Sediment samples, collected for another project and analyzed by the U.S. Environmental Protection Agency, were provided for the calculations. Using the density of each sample in conjunction with the chemical analyses, the percentages of the eroded material that constitute components of interest were approximated.

To accomplish the above objectives a literature search was conducted in an attempt to accumulate the existing information and data on bluff recession along the U.S. Great Lakes. Relevant materials were solicited from the following through a mail survey and follow-up telephone calls: attendees of a workshop on recession rates sponsored by the Standing Committee on Coastal Zone Management of the Great Lakes Basin Commission in December of 1975, the pertinent division and district offices of the U.S. Army Corps of Engineers and various environmentally oriented state agencies in the eight Great Lakes states. As a consequence of the relatively recent scientific interest in recession rate projects, 1950 was frequently chosen as the cutoff date. A bibliography of relevant articles is found on page 255.

DETERMINING BLUFF HEIGHTS AND REACHES

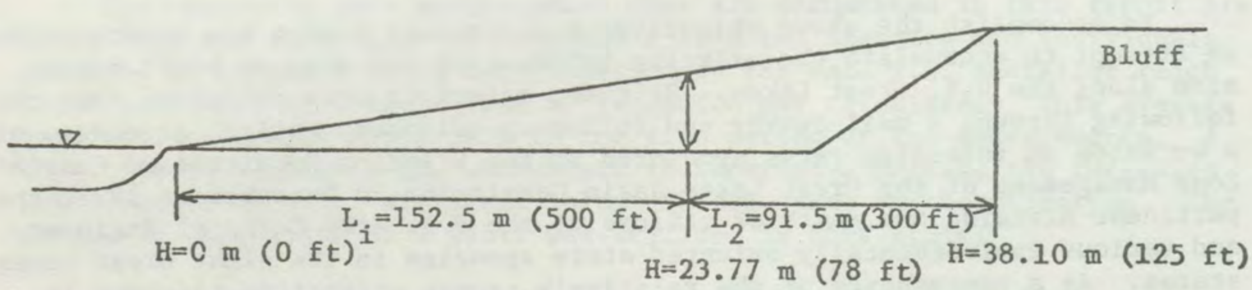
Bluff heights along the U.S. shore of the Great Lakes were determined from the U.S.G.S. topographic maps. The bluff height information was recorded on sepia copies of maps produced by the U.S. Army Corps of Engineers for the Great Lakes shoreline as part of the National Shoreline Study (1971).

The basic procedure for determining the bluff heights entailed use of the contour lines on the topographic maps. A bluff was identified by closely spaced contour lines along the shore. The maximum height of the bluff was signaled when the contours began to spread apart.

The bluff heights were recorded in 1.5 meter (5 foot) intervals. An exeeption was where 3.0 meter (10 foot) intervals were used in an area of high (greater than 9 meters or 30 feet) sand dunes in the northern lower peninsula of Michigan. Due to the small scale of the sepias, the minimum length of any one bluff height was restricted to 1.6 kilometers or 1 mile (1.27 centimeters or .5 inches on a sepia). Where rivers, creeks, and gullies and their floodplains were encountered, the change in elevation, if any, was only noted if the floodplain was greater than 1.6 kilometer (1 mile).

An effort was made to correlate the bluff height indicated on the topographic maps with the U.S. Army Corps of Engineers' shoreform designations. Where discrepancies in bluff height occurred between U.S.G.S. and the Army Corps, the U.S.G.S. data were used.

The above description applies to bluffs along the shore which reach their maximum height within a distance of 153 meters (500 feet). When bluffs extended more than 153 meters (500 feet) landward from shore, the maximum height was derived from the contour lines regardless of the depth of the bluff. When the toe of a bluff was 153 meters (500 feet) or more from the shore, the height was assumed. This assumption was based on a linear rise from the shore to the top of the bluff, resulting in a triangular relationship. The height was then calculated using this relationship, see the diagram below.



H = Height
L = Length

FIGURE 5. Bluff Height Determination When Bluff is Set Back From Shore.

Reaches were defined by bluff height and the U.S. Army Corps of Engineers shoreform designations. Reaches were identified by an 8-digit number, for an example, 15-012-018. The first 2 digits represent the county. This particular code was developed by the U.S. Army Corps of Engineers and provides a number for all 83 Great Lakes Coastal counties in the United States. The next 2 sets of numbers indicate where the reach began and ended. The numbers represent an identified political boundary.

The states of Minnesota, Wisconsin, Illinois, Indiana, Michigan and Western Ohio have political land boundaries in the form of Township-Range-Section (U.S. Public Land Surveys). A Section is generally a 2.6 kilometer square or a 1-mile square segment of land. An identification number was given to each Section bordering on the Great Lakes. The Section identification was numbered east to west. Occasionally the Township-Range-Section system would be preempted by Land Grant segments in these states. The Land Grant segments were treated as individual areas and numbered similar to Sections.

Eastern Ohio's political land boundaries were of a Township-Range nature, but the 2.6 kilometer (1-mile) square Sections were not available. This resulted in an area defined by Township-Range numbers, representing an 8 to 11 kilometer segment or a 5 to 7 mile segment of shoreline.

Pennsylvania, New York, isolated areas of Ohio, and Detroit, Michigan were without a Township-Range-Section system. Therefore, with the use of the U.S.G.S. 7.5 minute topographic maps, an identification system was derived using degrees of longitude and latitude. A 2.5 minutes "square" resulted in the basic unit corresponding to an identification number.

HISTOGRAM METHODOLOGY

Histograms were drafted for each reach to give a graphical representation of recession and erosion data. They reflect long-term, and short-term where available, recession and erosion data by county.

A county's shoreline was divided into reaches defined by bluff height and shoreform. Moving west to east along the shore, each reach length was derived from maps. For each reach with data, the maximum and minimum recession rates and their locations were noted and the average recession rate was calculated.

Two methods of calculating the recession rate averages were used due to the difference in the raw data for the states of Michigan (except Monroe County, Michigan), Wisconsin, Illinois and Indiana and Lake Erie (including Monroe County, Michigan).

The recession data used for the States of Wisconsin, Illinois, Indiana, and Michigan include data from E. Seibel and M. Jannereth; Water Development Services Division, Michigan Department of Natural Resources; A Power Plant Study in Berrien County, Michigan; W. E. Powers, Northwestern University; U.S. Army Corps of Engineers, Chicago District; C. S. Hess, University of Wisconsin;

and R. C. Berg and C. Collinson, Illinois State Geological Survey. The above data were recorded in a point value form. An example being, a data point on the lakeshore, where River Road ends, having a recession rate of 1.0 meter per year (3.3 feet per year). Data were concentrated on Lake Michigan south of Benzie County, Michigan and Green Bay, Wisconsin, and on Lake Superior in western Wisconsin and Michigan with some data available on Lake Huron. The data were plotted on Sepia copies of the U.S. Army Corps of Engineers maps. The plotting of data points was straight forward because locations were identified by roads or T-R-S. The plotting on the sepias resulted in a line drawn to indicate the data location and provided space to label the point. The labeling included the original identification number or letter, the recession rate, and the time span. All data points were plotted except in the case of a few areas in Michigan with 20 or more data points in a 1.6 kilometer or 1 mile stretch. In the attempt to avoid a number jungle, adjacent rates that were similar in value (within ±0.15 meters or ±0.5 feet per year) were averaged together.

The average recession rate for a reach was based upon the number of data points within the reach. The calculation followed this formula: $\Sigma r_i/\Sigma i$, where r_i was the individual recession rate. These rates were determined in English units and rounded to tenths; the values were then converted to metric units and rounded to hundredths due to the accuracy of the conversion factor (feet * 0.3048 = meters). If accretion data were available the values were entered in the calculation with an opposite sign.

The recession data for Lake Erie from C. H. Carter were in a form which gave a value for a specific segment of shoreline. An example being 1,000 meters (3,280 feet) of shoreline had a recession rate of 1.0 meter per year (3.3 feet per year). Carter's recession data were comprehensive, providing data for most of the southern Lake Erie shoreline. His recession rates were in two forms. One where the rate was given in an alphebetic code, e.g., VS, 0-0.3 meters per year (0-1 feet per year); S, 0.3-.9 meters per year (1-3 feet per year); M, 0.9-1.5 meters per year (3-5 feet per year); R, 1.5-2.1 meters per year (5-7 feet per year); and VR, 2.1-2.7 meters per year (7-9 feet per year). The other form gave specific numbers for the recession rates to supplement the alphabetic code.

The average recession rate was calculated by a weighted average method using the following equation: $\Sigma r_i * \ell_i/\Sigma \ell_i$ where r_i was the recession rate and ℓ_i the corresponding length of shoreline. These rates were also determined in English units and rounded to tenths; the values were then converted to metric units and rounded to hundredths due to the accuracy of the conversion factor (feet * 0.3048 = meters). Carter's data included identification of areas of accretion, protection (artificial fill), and floodplains, but did not indicate any recession rate. Therefore, areas of accretion and floodplains were given a recession rate of 0 meters per year (0 feet per year).

Erosion rate (volumetric contribution) data were then derived from the calculated recession rate data. A rectangular prism method, based on a linear erosion relationship, was used to assume the average volumetric contribution to the lake for a linear meter or foot of shore. The diagram on page 19 illustrates the method. The average recession rate multiplied by the bluff height multiplied by a linear meter (foot) of shoreline yields the cubic meter per meter (cubic foot per foot) of shoreline contributed to the lake. The erosion values derived in this study were calculated in cubic feet per year per foot and rounded to tenths; these values were then converted to cubic meters per year per meter and rounded to hundredths due to the accuracy of the conversion factor (cubic feet per year per foot * 0.09290 = cubic meters per year per meter). The maximum and minimum erosion rates, if available, were calculated in the same manner. Negative recession rates, indicating accretion in the form of beach buildup or low foredune material buildup during low water level periods, were not utilized to derive erosion rates. Since the height of the accreted material is unknown, realistic values for negative erosion cannot be calculated.

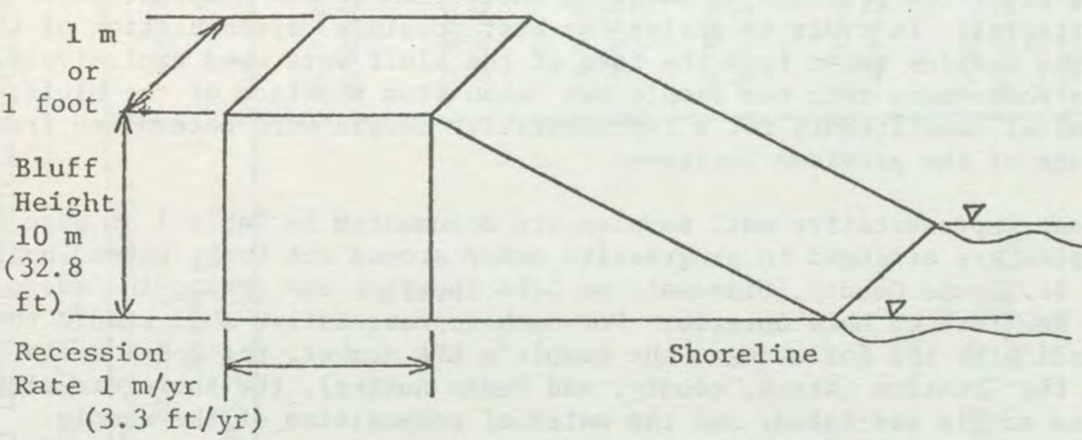


FIGURE 6. Rectangular Prism Method of Deriving Erosion Rates.

The reach boundaries were identified along with the reach mileage, reach identification number, average bluff height for the reach, shoreform for the reach, and the time span the data covered.

DETERMINING CHEMICAL INPUTS TO THE GREAT LAKES

The primary tool used to derive the chemical inputs of bluff material from eroded U.S. shorelands into the Great Lakes was the soil sample analysis provided by the U.S. Environmental Protection Agency (EPA). Three to four shoreline profiles, indicating bluff heights and materials, were determined in several coastal counties in the states of Minnesota, Wisconsin, Michigan and New York. Along these profile lines several soil samples were taken and the visual description of the bluff material by horizon was compiled by the U.S. Corps of Engineers and the Soil Conservation Service. The sampling procedure has been previously documented and will not be discussed here.

The analyzed soil samples have provided this study with chemical data for the following counties: St. Louis, Minnesota; Douglas, Brown, and Racine, Wisconsin; Alcona, Chippewa, Huron, Manistee, Muskegon, and Schoolcraft, Michigan; and Oswego, New York. U.S. EPA examined the soil samples for the dissolved and total percentages of 29 different elements. Only the values for the total quantities were used in this study. Many elements were nondetectable in the analyses resulting in 15 elements being frequently present in each of the samples taken: Phosphorus, Nitrogen, Calcium, Magnesium, Sodium, Iron, Manganese, Aluminum, Barium , Vanadium, Copper, Lead, Zinc, Titanium, and Organic Carbon. The specific gravity for these soil samples ranged between 1.56 to 2.97 g/cc. The number of soil samples taken in relation to the total Great Lakes shoreline was very small. In order to give some indication of the input of the chemical constituents of the eroded material to the Great Lakes, representative samples for a particular bluff height and material were considered descriptive for all the areas of the same bluff composition along the shoreline.

Initially, one or more representative soil samples for each profile were chosen and documented. Each profile usually provided three or more soil samples. Neither the samples from the top of the bluff nor those from near the bluff toe provided an adequate indication of the composition of the bluff material. In order to derive the best possible representation of the bluff, the samples taken from the face of the bluff were used exclusively. In cases where more than one sample was taken from the face of the bluff, the chemical constituents for a representative sample were determined from an average of the provided analyses.

These representative soil samples are documented in Table 1 on page 21. The samples are arranged in progressive order around the Great Lakes, beginning in St. Louis County, Minnesota on Lake Superior and ending in Oswego County, New York on Lake Ontario. For each representative soil sample the table indicates the following: the sample's EPA number, the local state number, the location (state, county, and reach number), the shoreform along which the sample was taken, and the material composition of the sample. When erosion data were available, the average annual input of the chemical constituents of the eroded material to the Great Lakes were calculated for each profile using the average erosion rate of the reach. If EPA soil samples from different lakes were available, only the samples from the same general location of the similar reaches were used. This was done as an attempt to achieve the best possible data. Categories for which no representative EPA soil sample was available were not given further consideration. The representative sample was identified by its EPA number, county, state, and local number.

The average annual input for each chemical constituent of the eroded material for each shoreform-material category was calculated similarly to the input data for the individual reaches from which the EPA soil samples were taken. Specifically, the calculation was derived using an average recession rate, an average bluff height, the reach length, the specific gravity of the representative sample and the component weight percents.

To obtain the best indication of the recession rate of a shoreform-material category, a weighted average recession rate was derived from those of the similar reaches. This calculation depended solely on the availability of recession data for each of the similar reaches. The form of the weighted average calculation was $\Sigma r_i l_i / \Sigma l_i$ where r_i was the recession for one of the similar reaches and l_i was its length. When recession rate data were not available for a few of the similar reaches, a weighted average of the recession data for the other similar reaches was used. If recession rate data

TABLE 1

REPRESENTATIVE SOIL SAMPLES*: LOCATION AND INPUT OF CHEMICAL CONSTITUENTS DERIVED FROM THE AVERAGE EROSION OF THE REACH

EPA No. State No.	Location: State County Reach	Shoreform Material	Total Ave. Mat'l. Eroded From Reach ** m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material*** ($10^3 kg/year$)
EPA-76-14493 Sample 1 56" - 252"	Minnesota St. Louis Co. 3-001-003	LBN Glatial till		No recession data available for calculation.
EPA-76-14498 Sample 2 114" - 150"	Minnesota St. Louis Co.	LBN Glatial till		No recession data available for calculation.
EPA-76-14503 Sample 3 108"-109"	Minnesota St. Louis Co. 3-019-026	LBE Glatial till		No recession data available for calculation.
EPA-76-14504 Sample 4 3'	Minnesota St. Louis Co. 3-026-036	PE Glatial till		No recession data available for calculation.
EPA-76-14506 Sample 5 2'	Minnesota St. Louis Co. 3-026-036	PE Sand		No recession data available for calculation.
EPA-76-14558 D-4-2	Wisconsin Douglas Co. 4-005-012	HBE Clay	169,150 (6,040,750)	P-205.0, N-222.0, CA-16,148.0; MG-2718.0, FE-20,418.0, MN-320, AL-11,922.0, BA-33.0, CU-24.0, PB-11.0, ZN-37, TI-318.0, OC-1246.0

* Samples taken directly from the face of the bluff.

** Values calculated in English units, converted to metric units and rounded to nearest 50.

***Organic Carbon is referred to as OC.

TABLE 1--Continued

EPA No. State No.	Location: State County Reach	Shoreform Material	Total Ave. Mat'l. Eroded From Reach ** m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material*** (10^3kg/year)
EPA-76-144556 0-3-2	Wisconsin Douglas Co. 4-015-019	HBE Clay	188,450 (6,729,700)	P-136.0, N-985.0, CA-1212.0, MG-273.0, FE-10,984.0, MN-172.0, AL-6400, ZN-26.0, TI-80.0, OC-10,605.0
EPA-76-14554 D-2-2	Wisconsin Douglas Co. 4-022-023	HBE Clay	30,900 (1,103,500)	P-32.0, N-11.0; CA-2129.0, MG-367.0, FE-10.984.0, MN-47.0, AL-157.0, BA-17.0, CU-3.4, PB-1.5, ZN-5.5, TI-47.0, OC-40
EPA-76-14552 D-1-2	Wisconsin Douglas Co. 4-027-030	HBE Clay	68,200 (2,435,550)	P-78.0, N-89.0, CA-4468.0, MG-832.0, FE-7912.0, MN-107.0, AL-4300.0, BA-48.0, CU-8.6, PB-3.9, ZN-14.0, TI-99.0, OC-484.0
EPA-76-14410 033-4-4	Michigan Chippewa Co. 16-009-013	LBN Sand	55,300 (1,975,150)	P-13.0, N-9.4, CA-94.0, MG-57.0, FE-4003.0, AL-96.0, TI-126.0
EPA-76-14405 033-3-7	Michigan Chippewa Co. 16-025-026	LBE Sand	1,900 (68,750)	P-0.54, N-0.32, CA-1.10, MG-1.20, FE-3.70, AL-3.90, TI-0.31, OC-5.50

* Samples taken directly from the face of the bluff.

** Values calculated in English units, converted to metric units and rounded to nearest 50.

***Organic Carbon is referred to as OC.

TABLE 1 -- Continued

EPA No. State No.	Location: State County Reach	Shoreform Material	Total Ave. Mat'l. Eroded From Reach** m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material*** (10^3kg/year)
EPA-76-14398 033-2-2	Michigan Chippewa Co. 16-046-056	PE Sand		No recession data available for calculation.
EPA-76-14471 153-1-3	Michigan Schoolcraft Co. 18-038-045	LD Sand		No recession data available for calculation.
EPA-76-14472 73 153-2-1,2	Michigan Schoolcraft Co. 18-031-035	PN Sand		No recession data available for calculation.
EPA-76-14475 153-3-2	Michigan Schoolcraft Co. 18-029-031	LD Sand		No recession data available for calculation.
EPA-76-14481 153-4-1	Michigan Schoolcraft Co. 18-023-026	LD Sand		No recession data available for calculation.
EPA-76-14486 153-5-1,3	Michigan Schoolcraft Co. 18-006-008	PN Sand		No recession data available for calcuation.
EPA-76-14545 B. 3-1-2	Wisconsin Brown Co. 37-025-028	PN Clay		No recession data available for calculation.

*Samples taken directly from the face of the bluff.
**Values calculated in English units, converted to metric units and rounded to nearest 50.
***Organic Carbon is referred to as OC.

TABLE 1-Continued

EPA No. State No.	Location: State County Reach	Shoreform Material	Total Ave. Mat'l. Eroded From Reach** m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material *** (10^3kg/year)
EPA-76-14546 B-4-1	Wisconsin Brown Co. 37-028-029	W/PE Sand		No recession data available for calculation.
EPA-76-14550 B-6-1-2	Wisconsin Brown Co. 37-038-038	LBE Clay		No recession data available for calculation.
EPA-76-14528 R-1-2	Wisconsin Racine Co. 44-001-006	HBE Glacial till	59,750 (2,133,350)	P-44.0, N-79.0, CA-9738.0, MG-5689.0, FE-4168.0, MN-89.0, AL-1930.0, CU-3.6, PB-3.8, ZN-9.6, TI-3.8, OC-1315.0
EPA-76-14531 R-2-2	Wisconsin Racine Co. 44-001-006	HBE Glatial till	59,750 (2,133,350)	P-51.0, N-21.0, CA-10,226.0, MG-6031.0, FE-1931.0, MN-52.0, AL-829.0, CU-1.7, PB-3.5, TI-41.0, OC-222.0
EPA-76-14534 R-3-2	Wisconsin Racine Co. 44-006-011	HBE Sand till		No recession data available for calculation.
EPA-76-14536 R-4-2	Wisconsin Racine Co. 44-013-017	HBE Glatial till		No recession data available for calculation.

* Samples taken directly from the face of the bluff.
** Values calculated in English units, converted to metric units and rounded to nearest 50.
***Organic Carbon is referred to as OC.

TABLE 1-Continued

EPA No. State No.	Location: State County Reach	Shoreform Material	Total Ave. Mat'l. Eroded From Reach ** m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material*** (10^3kg/year)
EPA-76-14539 R-5-2	Wisconsin Racine Co. 44-013-017	HBE Glatial till		No recession data available for calculation.
EPA-76-14452 121-2-1	Michigan Muskegon Co. 25-004-006	HD Sand	54,100 (1,910,100)	P-6.7, N-2.4, CA-225.3, MG-139.9, FE-514.2, MN-5.0, AL-83.4, TI-31.6, OC-74.1
EPA-76-14459-60 121-4-2,3	Michigan Muskegon Co. 25-013-020	LBE Sand	14,350 (506,900)	P-2.5, N-3.8, CA-1027.1, MG-384.7, FE-82.5, MN-1.6, AL-28.3, BA-0.3, TI-2.8, OC-19.2
EPA-76-14464 121-6-1	Michigan Muskegon Co. 25-025-029	HBE Sand	59,100 (2,087,700	P-8.0, CA-623.2, MG-267.6, FE-769.0, MN-4.5, AL-47.9, TI-17.3
EPA-76-14467 121-8-1	Michigan Muskegon Co. 25-025-029	HBE Sand	59,100 (2,087,700	P-6.6, CA-21.3, MG-221.0, FE-171.5, AL-46.2, TI-4.4
EPA-76-14438-39 101-2-1,2	Michigan Manistee Co. 28-001-005	HBE Glatial till	40,500 (1,430,950)	P-23.7, N-2.4, CA-5683.3, MG-2655.0, FE-727.1, MN-22.0, AL-534.2, PB-1.9, TI-25.4, OC-105.2

* Samples taken directly from the face of the bluff.
** Values calculated in English units, converted to metric units and rounded to nearest 50.
***Organic Carbon is referred to as OC.

TABLE 1--Continued

EPA No. State No.	Location: State County Reach	Shoreform Material	Total Ave. Mat'l. Eroded From Reach ** m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material*** (10^3kg/year)
EPA-76-14442-3 101-4-1,2	Michigan Manistee Co. 28-002-024	LBE Sand till	8,700 (307,500)	P-2.0, N-0.6, CA-531.3, MG-203.7, FE-117.5, AL-13.3, PB-0.1, TI-4.6, OC-39.3
EPA-76-14448 101-6-1	Michigan Manistee Co. 28-028-029	HBE Sand till	2,850 (99,800)	P-0.37, N-0.19, CA-43.26, MG-26.02, FE-9.08, MN-0.13, AL-3.52, TI-0.23, OC-8.39
EPA-76-14396 001-5-2	Michigan Alcona Co. 54-001-006	PE Sand till	1,500 (53,850)	P-2.25, N-0.68, CA-35.34, NA-0.09, MG-17.33, FE-7.92, MN-0.12, AL-3.44, ZN-0.04, TI-0.62, OC-22.13
EPA-76-144394 001-4-1	Michigan Alcona Co. 54-006-009	PE/W Sand		No recession data available for calculation.
EPA-76-144390 001-2-1	Michigan Alcona Co. 54-023-028	PE Sand		No recession data available for calculation.
EPA-76-14411-13 063-1-1,3	Michigan Huron Co. 59-001-020	W Glacial till		No recession data available for calculation.

* Samples taken directly from the face of the bluff.
** Values calculated in English units, converted to metric units and rounded to nearest 50.
***Organic Carbon is referred to as OC.

TABLE 1-Continued

EPA No. State No.	Location: State County Reach	Shoreform Material	Total Ave. Mat'l. Eroded From Reach ** m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material*** (10^3kg/year)
EPA-76-14416 063-3-1	Michigan Huron Co. 59-020-025	LBE Sand		No recession data available for calculation.
EPA-76-144420 063-5-1	Michigan Huron Co. 59-037-050	LD Glatial till		No recession data available for calculation.
EPA-76-14421-23 063-6-1,3	Michigan Huron Co. 59-050-054	LBN Sand		No recession data available for calculation.
EPA-76-14427-28 063-8-1,2	Michigan Huron Co. 59-063-084	PE Clay		No recession data available for calculation.
EPA-76-14432-3 063-10-1,2	Michigan Huron Co. 59-090-092	HBE Clay		No recession data available for calculation.
EPA-76-14525 Profile 4 67"C	New York Oswego Co. 81-002-003	LBE Glacial till	3,900 (136,950)	P-5.34, N-0.93, CA-391.20, MG-98.51, FE-160.19, MN-3.98, AL-47.18, CU-0.13, PB-0.13, TI-4.00

* Samples taken directly from the face of the bluff.
** Values calculated in English units, converted to metric units and rounded to nearest 50.
***Organic Carbon is referred to as OC.

TABLE 1--Continued

EPA No. State No.	Location: State County Reach	Shoreform Material	Total Ave. Mat'l. Eroded From Reach ** m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material*** ($10^3 kg/year$)
EPA-76-14520 Profile 3 31" B3	New York Oswego Co. 81-009-010	LBE Glatial till	8,350 (295,500)	P-9.90, N-1.87, CA-40.49, MG-78.78, FE-400.49, MN-130.93, AL-135.55, TI-2.60, OC-9.20
EPA-76-14516 Profile 2 42" II-C	New York Oswego Co. 81-013-017	LD/W Sand	86,300 (3,046,900)	P-48.0, N-13.7, CA-139.5, MG-596.8, FE-3132.4, MN-107.5, AL-1138.6, CU-5.26, TI-15.1
EPA-76-14560 Profile 1 11"	New York Oswego Co. 81-013-017	LD/W Sand	86,300 (3,046,900)	P-35.5, CA-125.3, MG-127.7, FE-669.0, AL-191.5, TI-8.5

* Samples taken directly from the face of the bluff.
** Values calculated in English units, converted to metric units and rounded to nearest 50.
***Organic Carbon is referred to as OC.

were not available for any of the similar reaches, the recession rate connected with the representative reach, for which chemical data are available, was used to fill the void.

An average bluff height for each shoreform-material category was also derived. This bluff height was also a weighted average calculated in the following form: $\Sigma h_i l_i / \Sigma l_i$, where h_i was the average bluff height of a reach and l_i the reach length. An average total volumetric contribution for the shoreform-material category was then derived: Average recession rate (ft/yr) * average bluff height (ft) * reach lengths (ft) * 0.028317 (m^3/ft^3) = Total Average Volume (m^3/yr).

As before, the average total weight of the eroded material was determined using the specific gravity of the representative sample. If more than one sample was available, an average of the specific gravity of the samples was used.

The average annual input for each of the chemical constituents of the eroded material was derived from the average total weight of the eroded material and the weight percent of the components. The method for this particular calculation was similar to that previously described for the representative EPA soil samples. Tables were compiled for each of the Great Lakes to indicate the total average annual input of the chemical constituents of the eroded material to the lake. These tables included the percentage of the erodible shoreline mileage which was able to be examined. A summary table for all the Great Lakes was compiled from these tables to present the total average input per year of the chemical constituents in the eroded material from 58 percent of the erodible U.S. Great Lakes shoreline.

The average annual input of the chemical constituents of the eroded material for Lake Erie was also compiled. The data used were taken from Sediment Load Measurements Along the U.S. Shore of Lake Erie by C.H. Carter. While these input values were similar in calculation and presentation to those for the other lakes, they were derived by a somewhat different procedure. This procedure is presented in the discussion of the input of the chemical components of the eroded material for Lake Erie on page 244. The average annual input of the constituents of the eroded material from the U.S. Lake Erie shoreline was included in the summary table for all the Great Lakes.

BLUFF RECESSION ALONG THE GREAT LAKES U.S. SHORELINE

Historically, high lake levels are associated with high rates of bluff recession. Since 1964, the lake levels of the Great Lakes have increased and are currently near or above the high lake levels experienced in the early 1950's. At the present high lake levels, bluffline recession and shoreline erosion is actively occurring. Qualitative observations have been made by the beach visitor, the lakeshore landowner, and the scientist of the cause-and-effect relationships of bluffline recession, beach erosion, and coastal processes.

Interactions between the various coastal processes and the sediment which occupies the beach and nearshore zones are quite complex. Beach profiles in the Great Lakes take one of two general forms depending on lake level and storm activity. During periods of low lake level and/or extended periods of low energy coastal conditions, the beach is in an accretion stage. A relatively wide beach with a pronounced berm and rather steeply inclined foreshore is developed. The opposite situation occurs during high lake level and/or storm periods. The beach takes an erosional or storm profile with a uniform slope and the absence of a berm. During the past five years the latter situation has prevailed throughout the Great Lakes.

The nearshore zone of the Great Lakes is occupied by longshore sandbars which are nearly parallel to the shore at most localities. There are typically two of these sandbars: the shoreward one crests 100-125 meters (328-410 feet) from shore and is near 2 meters (6.6 feet) below lake level, and the outer bar is commonly 165-200 meters (540-655 feet) from shore with a crest about 3 meters (10 feet) below lake level. The outer sandbars are essentially permanent. They show little modification after severe storms (Davis and Fox, 1971) although their crests have been shown to migrate slowly.

Sandbars are of considerable importance to coastal erosion in that storm waves steepen and break over them. As a result, longshore bars act as baffles, preventing portions of the wave energy from reaching the shore. Consequently, the position and depth of each bar is a factor in determining the total amount of wave energy at a given location. In this respect, it is obvious that local variation in erosion must largely be due to subtle differences in nearshore topography.

The movement of this nearshore bar system, especially the emphemeral bar, has been suggested as the prime factor in determining shoreline recession by Davis (1964, 1970, 1972), Fox and Davis (1970, 1971, 1973), Davis et al. (1971, 1973, and Davis and Fox (1971, 1972). However, the correlation between the offshore bar system and beach and bluff change still requires further investigation.

Bluffline recession investigations to determine the rates and severity of recession along the Great Lakes shorelines have been conducted by numerous scientists using original survey notes, aerial photographs, and field surveys. The first large quantitative study determining average annual bluff recession rates for a portion of the Great Lakes U.S. shoreline was done by Powers (1958). He established rates by resurveying the shoreline in 1956 and 1957 along the survey lines originally taken between 1829 and 1839.

Although one beach profile may not be representative of changes occurring in an area, statistical information over a long period of time should be meaningful. Short term field investigations which include measurement of waves, currents, and beach changes have been conducted along the Great Lakes at Stephensville and Holland, Michigan in time series studies similar to the ones of Fox and Davis (1970) and Davis and Fox (1971). These studies were conducted during the summer or early fall so information obtained is more typical of the summer beach changes. Coakley and Cho (1972) discussed beach and nearshore interaction along Lake Ontario in a study similar to Maresca (1975).

The study by Maresca (1975) is probably the most intensive examination of any portion of the Great Lakes in an attempt to determine and establish the detailed interaction between the nearshore processes and the subsequent shoreline recession. Both the short term and long term effects of the parameters that influence the shoreline of the Great Lakes were examined. A similar study along Lake Erie by Gelinas and Quigley (1973) related the change of the shoreline over a 100 year period with the total energy distribution. They obtained a good correlation between total annual energy and bluffline recession. However, using the total energy is questionable since little change occurs during nonstorm days. Additional beach studies on Lake Ontario by Cohn (1973) showed change at five profile sites over a one year period.

Even though the largest storms produce the greatest changes, it is not known if the sum of several smaller storm events cause change that compares in magnitude to one large event. The variation of change along the shoreline suggests that other factors are involved in the distribution of wave energy dissipated on the shoreline.

The total bluffline recession and beach erosion are dependent upon the complex interaction of the total energy distributed along the shoreline and the resulting transport of sediment offshore and alongshore. Storm waves, storm surges, and longshore currents superimposed upon high mean water levels are the principal agents of destructive change along the shoreline. The offshore topography controls the distribution of energy along the shoreline, while the beach topography affects the degree of change at the bluff. The dynamics of bluff recession depends upon the interaction of the energy distribution and the energy dissipation by the beach.

In the case of sand bluffs, re-building of the beach may occur from the material supplied to it from a bluff which has slumped or from the accretion at the waterline. The re-building of the beach using material from the bluff provides a measure of protection from storm waves. Clay till bluffs, another principal bluff system, interact with the lake differently than sand bluffs. Upon failure, material from the bluff is not available to re-build the beach. Consequently, further protection of the bluff is not provided until accretion occurs at the waterline during the quiescent lake conditions after the storm. However, a clay till bluff system with a large cohesive strength does not fail instantaneously when attacked by storm waves as a sand bluff system does. Thus, there is a lag time between the cause of failure and the actual failure, making it difficult to directly link the cause and the effect. For example, several storms may occur during which the waves are actively attacking the toe of a clay till bluff system with little or no failure. Several days, weeks, or months later, large sections of the bluff may fail during apparent quiescent conditons. Accordingly, the correlation of the storm or storms, and the failure of the bluff is difficult to assess; the total dynamics are unique to the location of a specific site.

During storms, a sand bluff and beach system will be acted upon by the lake in three ways. First, waves may break directly on the toe of the bluff, effecting extensive change. This type of attack is most severe on narrow beaches with a concave upward profile and a deep water condition lakeward of the plunge step. This condition is predominant in areas where the beaches are depleted of sand material. Second, the run-up from breaking waves may rush against the toe of the bluff. This becomes especially destructive when superimposed upon high annual mean lake levels and the increased lake levels experienced due to storm surge. In this case the type of breaker, the water level, the profile shape, the beach width, the beach slope, and the permeability of the beach are critical factors in determining the effect of the run-up. The effects of run-up are evident in the areas of wide beaches, but most destructive in areas of narrow beaches. Third, the up-rush may run over the berm crest and flow within the channel present between the bluff toe and the berm crest. This condition may result in limited erosion of the bluff toe but generally it will not result in bluff crest recession.

The processes responsible for the beach and bluff change have been divided by Maresca (1975) into a three part process and response model: one, incoming energy; two, distribution of incoming energy; and three, energy dissipatiion reflected in the beach geometry, see Figure 7. The input energy (part one) necessary to effect change is derived from intense low pressure cell passages. If the magnitude and duration of the storm waves, storm surge, and longshore currents are sufficient, destructive beach change may occur. Severe beach erosion may result during the time of low annual mean water levels. However, both beach erosion and bluff recession may occur during times of high annual mean water levels.

The lateral extent and magnitude of the beach change is controlled by the distribution (part two) of the incoming energy. The distribution of this total energy may be highly irregular, even over short lengths of shoreline, or may be uniformly distributed along the shoreline. The distribution of wave energy along the shoreline depends on the convergence or divergence of wave energy due to wave refraction, the unequal dissipation of the wave energy before the wave breaks on the shore, and the balance and imbalance of the

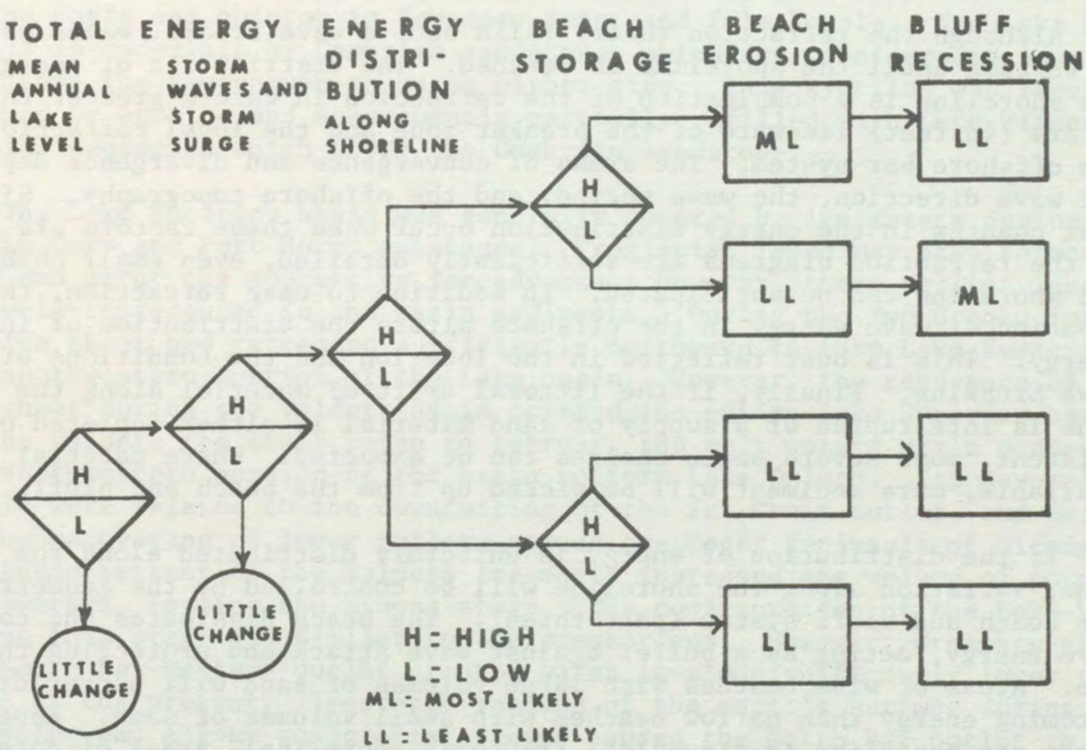


FIGURE 7. Bluff Recession Model. Given the total incoming energy, the distribution of this energy along the shoreline, and the beach erosion and bluff recession can be predicted. For example, given a high mean annual lake level, high storm waves and storm surges, and high beach storage, it is most likely that high beach erosion and low bluff recession will occur for a given storm.

SOURCE: Maresca, 1975.

alongshore transport of material. Normally, wave refraction controls the general distribution of energy. Areas of convergence and divergence of wave energy along the shoreline for a given offshore topography should coincide with the beach and bluffline change.

Although the refraction theory fails once a wave breaks, waves continue to refract until the shoreline is reached. The distribution of energy along the shoreline is a combination of the refraction in waters greater than 10 meters (48 feet) lakeward of the breaker zone and the local refraction inside the offshore bar system. The areas of convergence and divergence depend on the wave direction, the wave period, and the offshore topography. Significant changes in the energy distribution occur when these factors are varied. If the refraction diagrams are sufficiently detailed, even small changes along the shoreline can be anticipated. In addition to wave refraction, the dissipation of wave energy in the offshore alters the distribution of incoming energy. This is best reflected in the location and the conditions affecting wave breaking. Finally, if the littoral drift of material along the shoreline is interrupted or a supply of sand material is either depleted or nonexistent, more severe beach changes can be expected. Where material is not available, more sediment will be picked up from the beach and bluff.

If the distribution of energy is uniformly distributed along the shoreline, variation along the shoreline will be controlled by the geometry of the beach and bluff system (part three). The beach dissipates the coming wave energy, acting as a buffer against wave attack and protecting the bluff toe. Areas of wide beaches with large volumes of sand will better dissipate incoming energy than narrow beaches with small volumes of sand. Especially where the shoreline is sinusoidal (rhythmic shoreline), areas of potential destructive change will be controlled by the beach geometry for a uniform distribution of incoming energy. However, even uniformly wide beaches may experience severe beach erosion and bluff recession in areas where the greatest concentrations of energy are encountered. Beach erosion is reflected in the energy distribution, while bluff recession is reflected in the interaction of the energy distribution and the beach geometry.

LAKE SUPERIOR

The largest and northernmost Great Lake, Lake Superior has a water surface of 82,000 square kilometers (31,700 square miles). While its average depth is 150 meters (490 feet), the maximum recorded depth is 406 meters (1,333 feet). The Lake Superior basin contains 12.2×10^{12} cubic meters (2,935 cubic miles) of water when at the low water datum; water drains through its outlet, the St. Marys River, at an average rate of 2,100 cubic meters per second (74,500 cubic feet per second).

Lake Superior is bordered by the most rugged, uninhabited, and inaccessible shorelands of all the Great Lakes. The shoreline ranges from the steep rock cliffs of the Pictured Rocks National Lakeshore area to the sandy beaches of Whitefish Bay; from the low-lying clay and gravel bluffs near Duluth, Minnesota and in Wisconsin to the marshlands of Munuscong, Michigan. These shoretypes demonstrate their varied geologic settings.

The Lake Superior basin is primarily developed along the length of a syncline, a structural sag, which formed in this portion of the Canadian Shield. The syncline formed during the Late Precambrian when the area was subjected to folding, faulting, and lava flows. The resistant Keweenawan rocks, volcanics generated during the Precambrian, partially form the sides of the basin and outcrop in Keweenaw Point and Isle Royale. The Lake basin itself is underlain by Cambrian sandstones which are considerably less resistant than the Keweenawan rocks on either side. This syncline was largely exhumed by erosion and subsequently partially refilled with Late Wisconsin glacial sediments which cover the Cambrian sandstone.

The Lake Superior basin was generally covered by ice sheets during most of the Cary and Port Huron substages. Proglacial lakes may have formed before and after the successive ice advances; however, these earlier lakes are not well-represented in the basin sediments. During the Two Creeks interval the ice sheet had retreated sufficiently northward to form Lake Keweenaw in the southwestern portion of the Lake basin. However, the readvance of the ice sheet during the Valders again covered the entire Lake Superior basin. As the Valders ice sheet began to retreat, the melt waters again ponded in the southwestern portion of the basin to form Lake Duluth. Its several water levels were related to the downcutting of the St. Croix outlet, and later, to the uncovering of lower outlets across the Upper Peninsula of Michigan. Continued retreat of the Valders ice sheet increased the volume of ponded melt waters, forming the Minong stage. The configuration of the Lake basin during this stage was similar to the present one. However, drainage through the North Bay-Mattawa outlet created water levels significantly lower than those of the present. Isostatic rebound of the earth's surface during the Nipissing and Algoma postglacial stages caused the North Bay outlet to be raised 126 meters (415 feet) (Hough, 1958). Consequently the previous outlet for the Lake Superior basin was blocked, producing increased drainage through the St. Marys outlet. Isostatic rebound is still continuing.

Over ninety percent of the Lake Superior shoreline is classified as bluff; the remaining ten percent is divided about equally into marsh and beach. While the north shore is characterized by rugged, rocky cliffs, the south shore is generally low bluff or beach. Approximately 800 kilometers (490 miles) of these shorelands are erodible.

The northeastern shores of Minnesota are characterized by the steep rugged cliffs of the resistant Keweenawan rocks and the somewhat less resistant Cambrian sandstones of the Jacobsville Formation. Bluff heights range from over 30 meters (100 feet) in elevation in this area to about 9 meters (30 feet) along the shoreline just north of Duluth. Low-lying clay and gravel covered banks are prevalent in the Duluth-Superior area. Minnesota Point, a natural sandbar about 8 kilometers (5 miles) long, separates the Duluth-Superior Harbor from Lake Superior. Except for the sandy beach along Minnesota Point, the remaining beaches along the Minnesota shoreline consist of small scattered sand and gravel areas found in small coves and at the mouths of the tributary rivers.

A major portion of what is known as the Red Clay Area lies within the plain of the Lake Superior Lowland and extends from the Duluth-Superior area to Ashland, Wisconsin. This plain is the former lakebed of Lake Duluth. The shoreline of this area is characterized by red clay bluffs which range in height from 9 to 30 meters (30 to 100 feet) and are highly erodible. The ferric oxide content of the clay accounts for its predominantly red color.

Bedrock outcrops in the vicinities of the mouth of the Iron River, Port Wing, Herbster, and Bark Point at an elevation slightly above the present lake level. The bedrock is thought to be Cambrian sandstones and shales. The high bank deposits found east of Port Wing range from 9 to 21 meters (30 to 70 feet) in elevation and appear to be a glacial till as they contain large quantities of sand, gravel, and boulders. Their "flat iron" texture, produced by gullying, distinguishes them from the concave banks of the Red Clay area to the west. Low, flat areas of peat and muck and slough occur along Chequamegon Point, the tip of Chequamegon Bay, and scattered along the eastern shore of the Bayfield Peninsula. Beaches, primarily composed of sand and gravel, vary in width significantly. In some areas, there is no dry beach adjacent to the steep sandstone bluffs, while along Chequamegon Point in Ashland County, 15 to 21 meters (50 to 70 feet) of beach exists.

Shoretypes along Michigan's Lake Superior coast range from sheer rock cliffs to agate beaches and from high sand dunes to marshes. The presence of the Superior Upland along the southern coast of Lake Superior is evidenced by outcrops of Precambrian Keweenawan rocks in the Porcupine Mountains and along the northwestern shore of the Keweenaw Peninsula. These ragged bluffs range from 5 to 50 meters (15 to 160 feet) in elevation. The Cambrian sandstones of the Jacobsville Formation form steep cliffs along the southeastern shore of the Keweenaw Peninsula and the western shore of Marquette County. These bluffs range in height from 3 to 30 meters (10 to 100 feet). Cambrian marine sandstones of the Munising Formation form the precipitous cliffs along the Pictured Rocks reach and range in height from 15 to 60 meters (50 to 200 feet). Between Au Sable Point and Tahquamenon Falls the shoreline is generally characterized by low-lying bluffs of glacial sand and gravel. Another glacial deposit, the towering Grand Sable sand dunes are located along a 8 kilometer (5 mile) stretch just west of Grand Marais and reach elevations of up to 60 meters (200 feet). Beach widths along the Michigan Lake Superior shoreline vary from submerged shingle rock beaches to no beach along the rocky bluffs; from 3 to 27 meters (10 to 90 feet) of sand and gravel beaches along the shore of Ontonagon County; and from 9 to 12 meters (30 to 40 feet) along the eastern Marquette County shoreline.

Approximately 57 percent of the U.S. Lake Superior shoreline is subjected to erosion or flooding, see Table 2. The red clay bluffs of Minnesota and Wisconsin and the low-lying sand and gravel bluffs of Eagle Harbor, Bete Grise Bay, Marquette, and Whitefish Bay, Michigan are particularly susceptible to erosion. Shorelands more resistant to erosion include the volcanic and sandstone bluffs of Minnesota and of the Keweenaw Peninsula, Michigan as well as the sandstone bluffs of the Pictured Rocks area in Michigan. Flooding is a major problem along the low-lying shorelands of the Duluth-Superior region and along Keweenaw Bay and Ontonagon County in Michigan, see Figure 8.

The probability of extensive erosion and flooding is greatly increased by the presence of high lake levels. Record water levels occurred during the

TABLE 2

SHORETYPES ALONG THE U.S. SHORELINE OF LAKE SUPERIOR

SHORETYPES	MILES	KILOMETERS	PERCENTAGE
Artificial fill area	6.1	9.82	0.67
Erodible high bluff	59.5	95.75	6.52
Nonerodible high bluff	225.2	362.40	24.69
Erodible low bluff	257.0	413.58	28.18
Nonerodible low bluff	170.1	273.58	18.65
High sand dune	4.0	6.44	0.44
Low sand dune	77.6	124.88	8.51
Erodible low plain	61.7	99.29	6.77
Nonerodible low plain	23.4	37.66	2.57
Wetlands	27.4	44.09	3.00
Wetlands/Erodible plain	0.0	0.00	0.00
Wetlands/Erodible low bluff	0.0	0.00	0.00
Total Shore Length	912.0	1467.49	100.0

Source: Great Lakes Basin Commission, 1975.

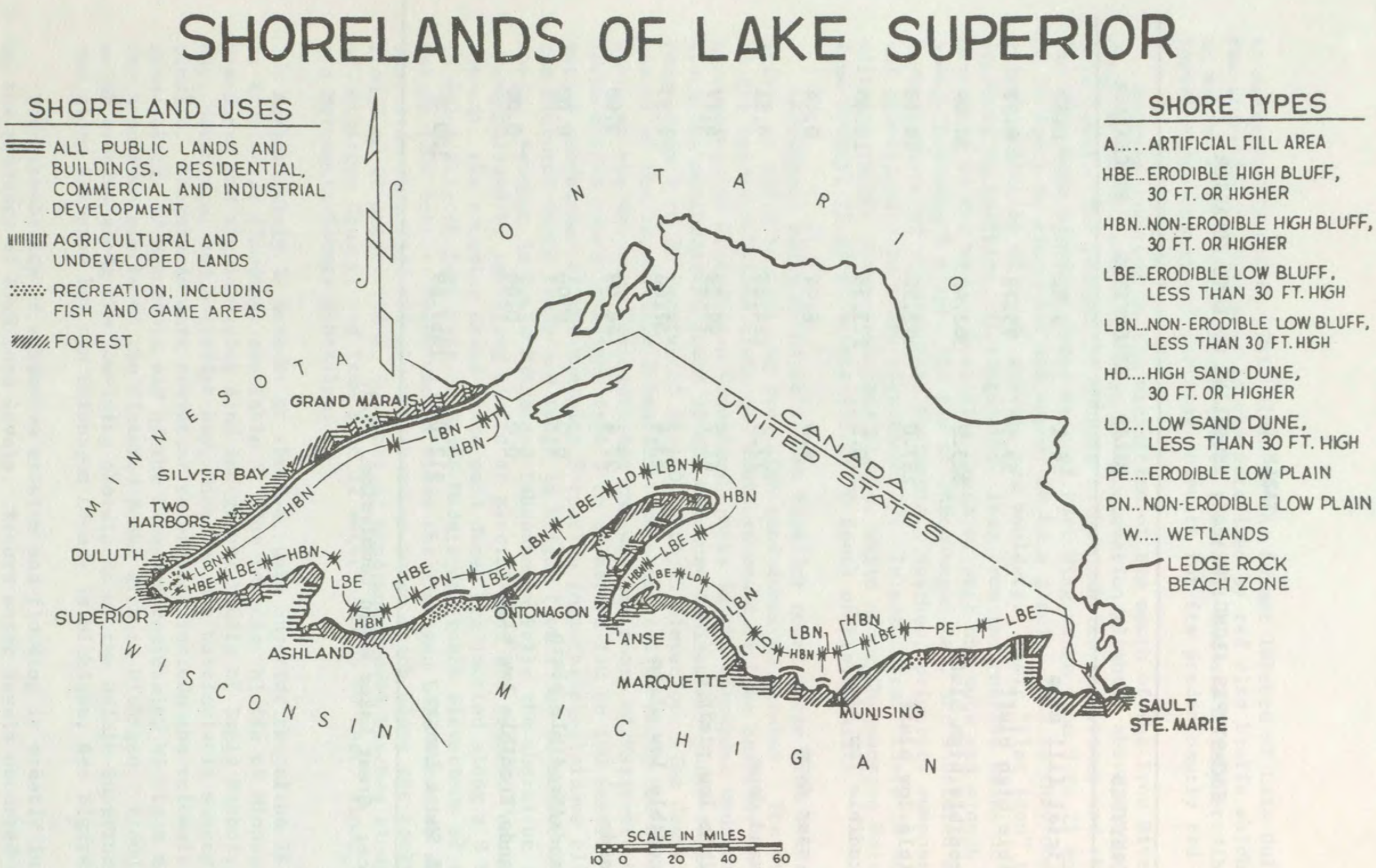


FIGURE 8. Shorelands of Lake Superior.

SOURCE: U.S. Department of the Army, Corps of Engineers, 1971.

late 1870's, 1951 to 1952, and the late 1960's to the mid-1970's, see Figures 9 and 10. Although residential, industrial, and commercial uses account for only 21 percent of the Lake Superior shoreline, the latter two high lake level periods caused extensive damage to public and private property. The following damages, based on the 1970 value of a dollar, were incurred by public and private property owners due to erosion during the 1951 to 1952 period: $1.6 million in Minnesota, $1.5 million in Wisconsin, and $2.4 million in Michigan. An additional $1.5 million damages due to flooding were incurred in the Duluth-Superior area. Prior to 1951 the erosion rate along the shoreline just east of the Grand Marais Harbor in Michigan averaged 3 meters per year (10 feet per year); during the 1951 to 1952 high water period the rate increased to 6 meters per year (20 feet per year). During this same period the erosion rate along sections of the Eagle Harbor, Bete Grise, Marquette, and Whitefish Bay shorelands experienced erosion rates of 1.2 meters per year (4 feet per year). The high lake levels of 1968 combined with a severe storm in the fall of 1968 to cause extensive erosion damages near Saxon, Wisconsin and along Ashland County. Flooding damages amounting to $54,000 also were incurred by property owners along the Keweenaw Bay shorelands during the 1968 high water period. These values were derived for the Great Lakes Regional Inventory of the National Shoreline Study which was conducted by the U.S. Corps of Engineers.

The degree that a storm will damage a shoreline is largely dependent on the intensity and direction of the wind and the height of the waves. In the western portion of Lake Superior winds come from the northeast or southwest about 40 percent of the time. The eastern sections of Lake Superior receive winds from the north to northwest or south to south east about 58 percent of the time. Daily winds range between 16 to 32 kilometers per hour (9-17 knots) approximately 50 percent of the time and exceed 32 kilometers per hour (17 knots) approximately 26 percent of the time. Winds from the northerly quadrants generate waves over the largest fetches. Wind roses for western, west-central, east-central and eastern Lake Superior are found on pages 42 to 45. The probable once-a-year wave heights for several locations on Lake Superior are as follows: 4.6 meters (15 feet) with an east or northeast wind for the shoreline of Minnesota; 6.1 meters (20 feet) with a northeast wind for Brule River, Wisconsin; 8.8 meters (29 feet) with a north or northeast wind for Eagle Harbor, Michigan and 7.6 meters (25 feet) with a northeast wind for Grand Marais, Michigan. These conditions commonly occur over 6 to 8 hour periods. When these wave heights are combined with high lake levels, the extensive erosion and flooding damages caused in the early 1950's and during the 1970's are likely to occur.

The direction of the littoral drift is another factor involved in the loss or accretion of beach material. The drift pattern in Lake Superior is somewhat complex. Although it varies along the Minnesota coast, it is generally from west to east between Grand Marais and Grand Portage, and east to west in the area south of Grand Marais. The drift again trends from east to west along the southern shore from Duluth to near Cornucopia. It reverses direction from Cornucopia to Copper Harbor as it generally flows from west to east. From Copper Harbor to Sault Ste. Marie the littoral drift direction is quite strongly from west to east.

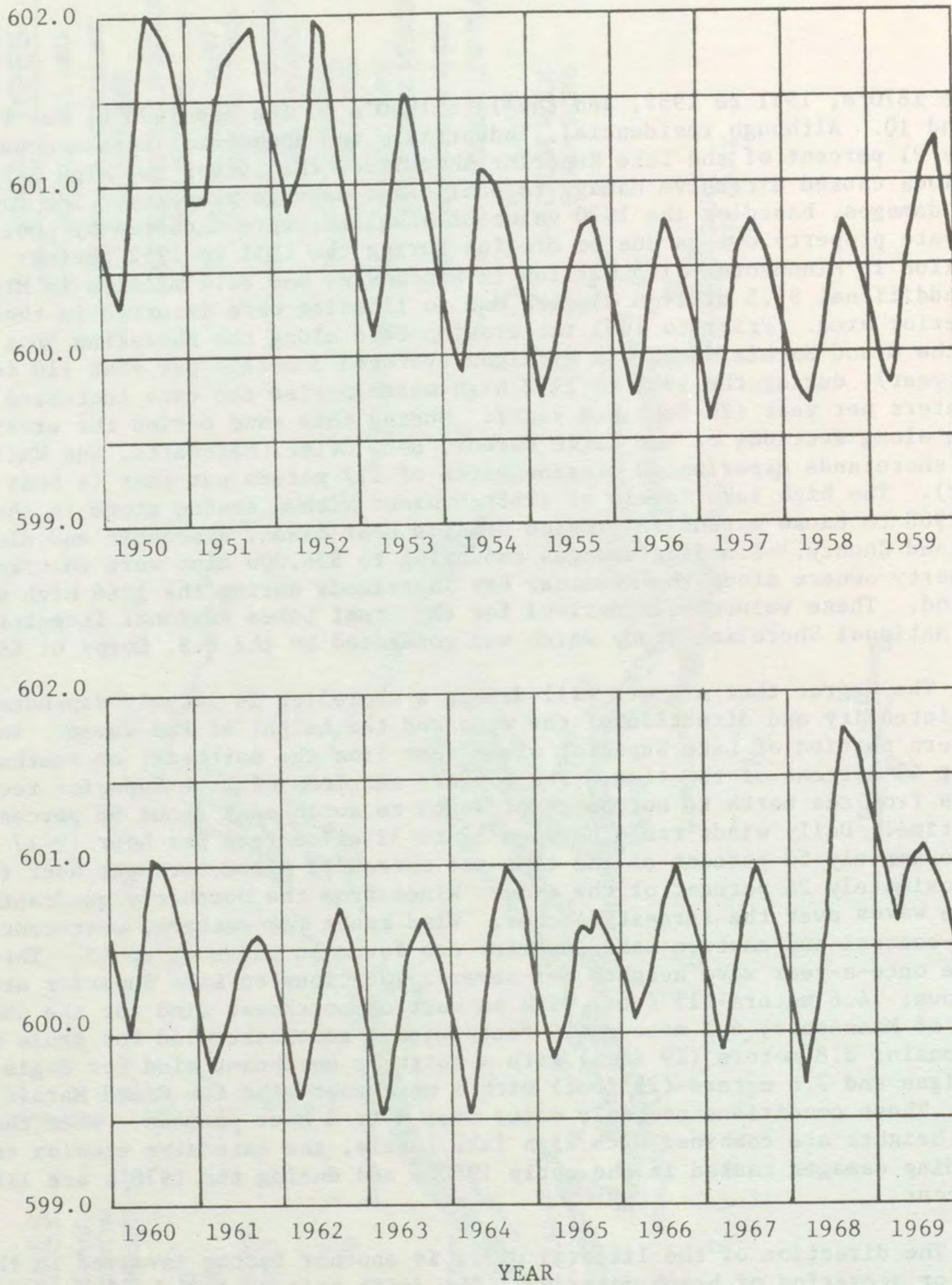


FIGURE 9. Lake Superior Stage Hydrograph.

NOTE: Stages represent monthly mean levels.

SOURCE: U.S. Department of the Army, Corps of Engineers, 1970.

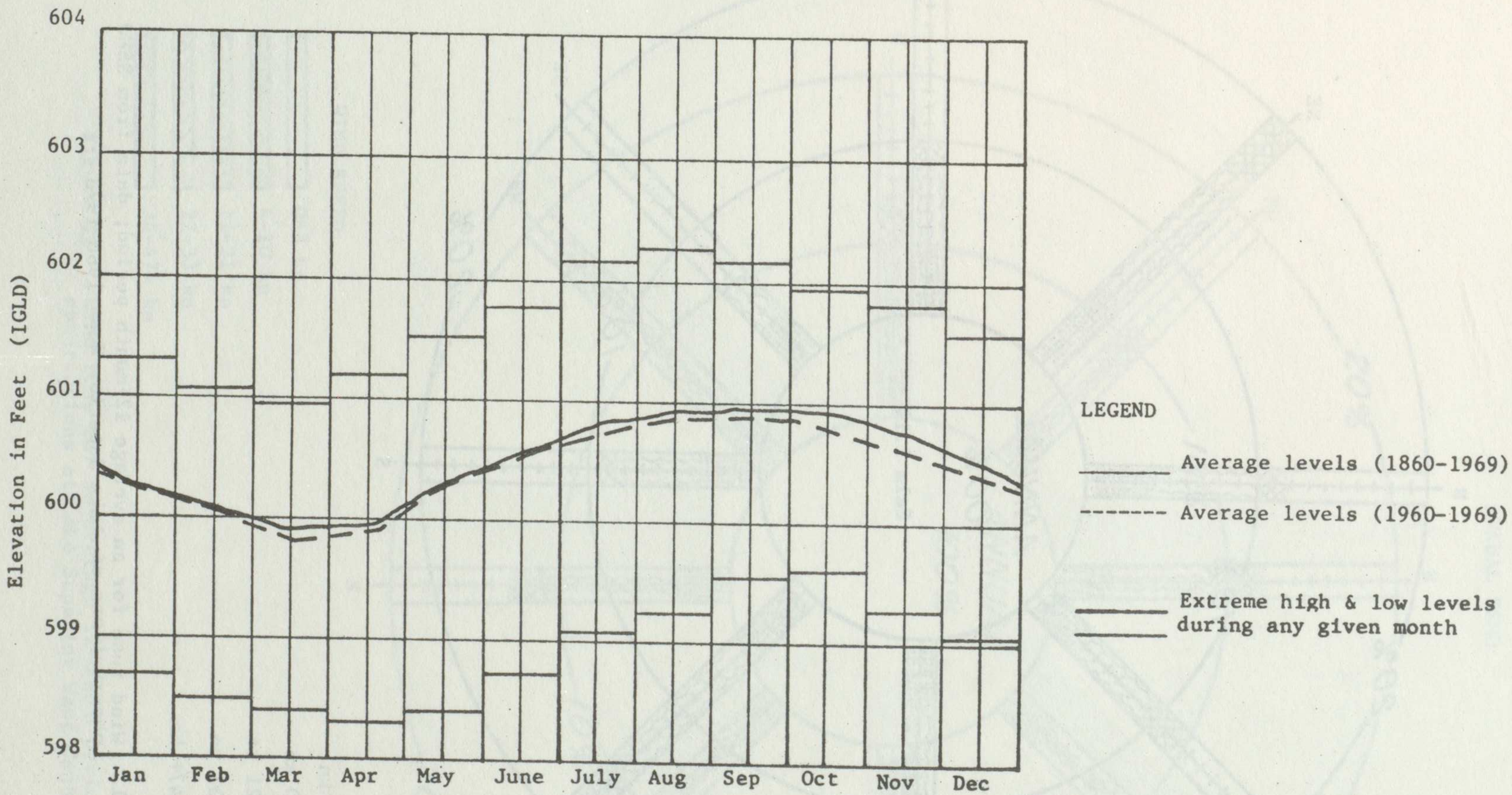


FIGURE 10. Mean monthly lake levels.

SOURCE: U.S. Department of the Army, Corps of Engineers, 1970

LAKE SUPERIOR WEST

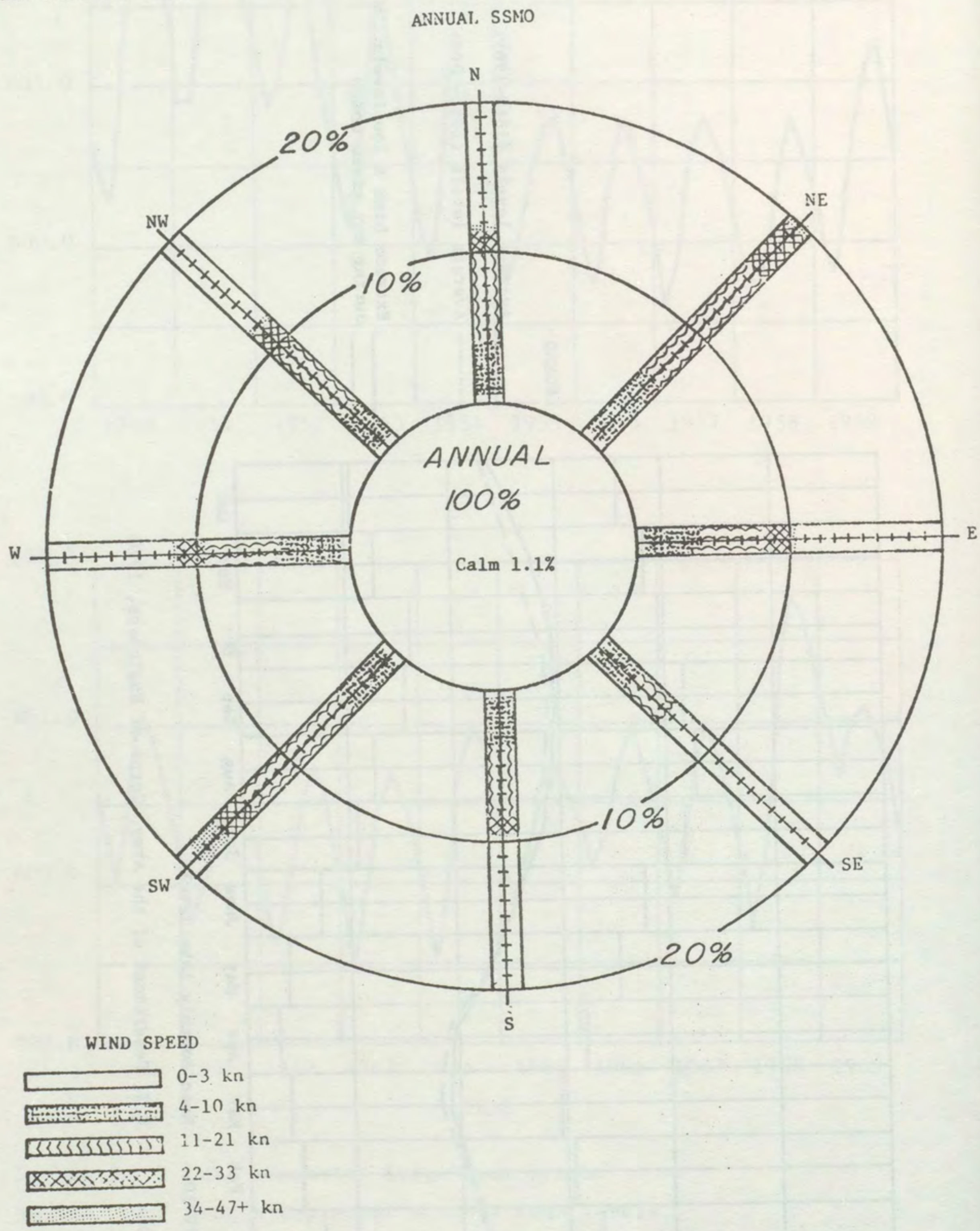


Figure 11. Wind rose for an average 12-month period; data from SSMO observations at Lake Superior West 1960-1973

LAKE SUPERIOR WEST CENTRAL

WIND ROSE

ANNUAL SSMO

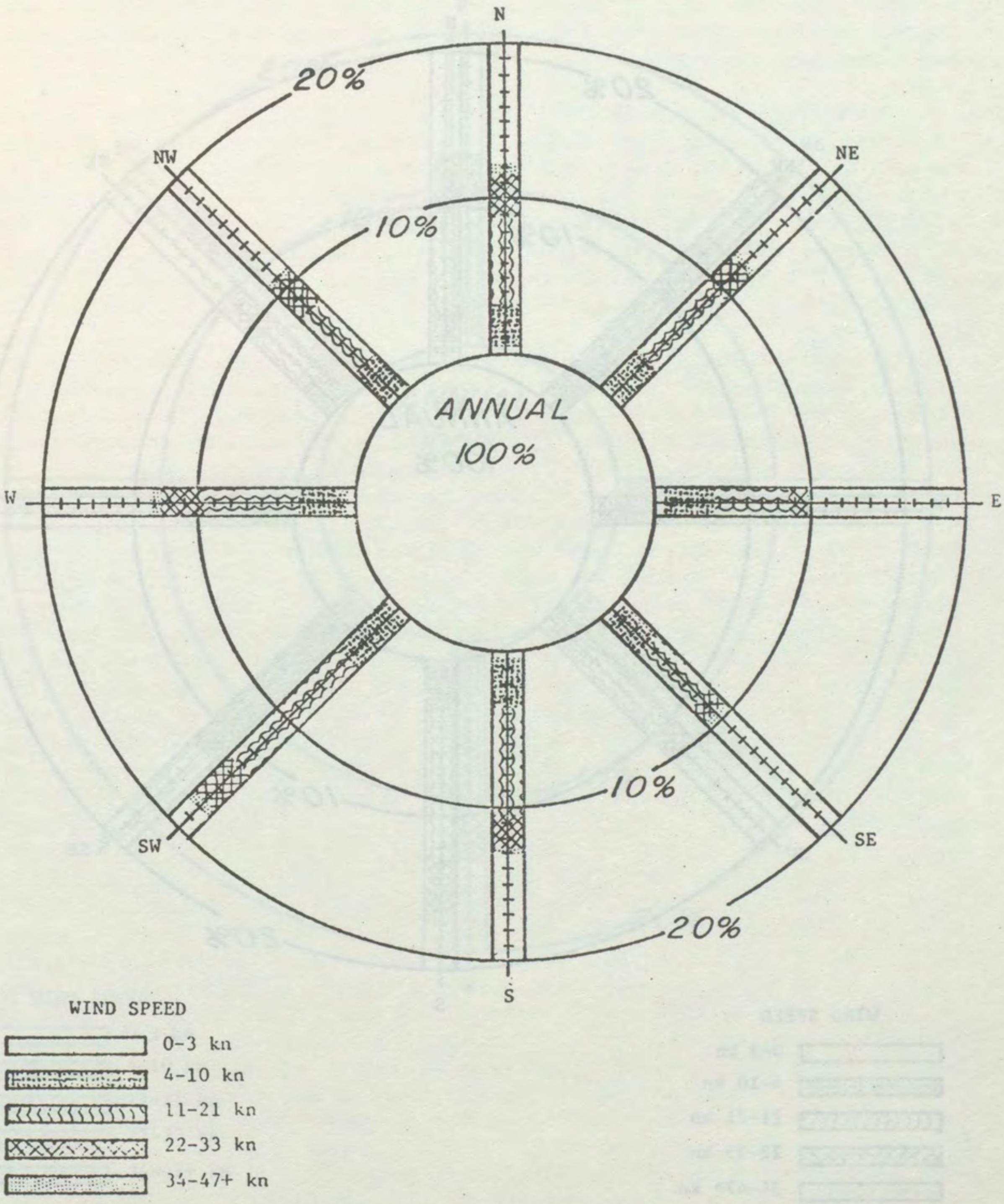


Figure 12. Wind rose for an average 12-month period; data from SSMO observations at Lake Superior West Central 1960-1973

LAKE SUPERIOR EAST CENTRAL

ANNUAL SSMO

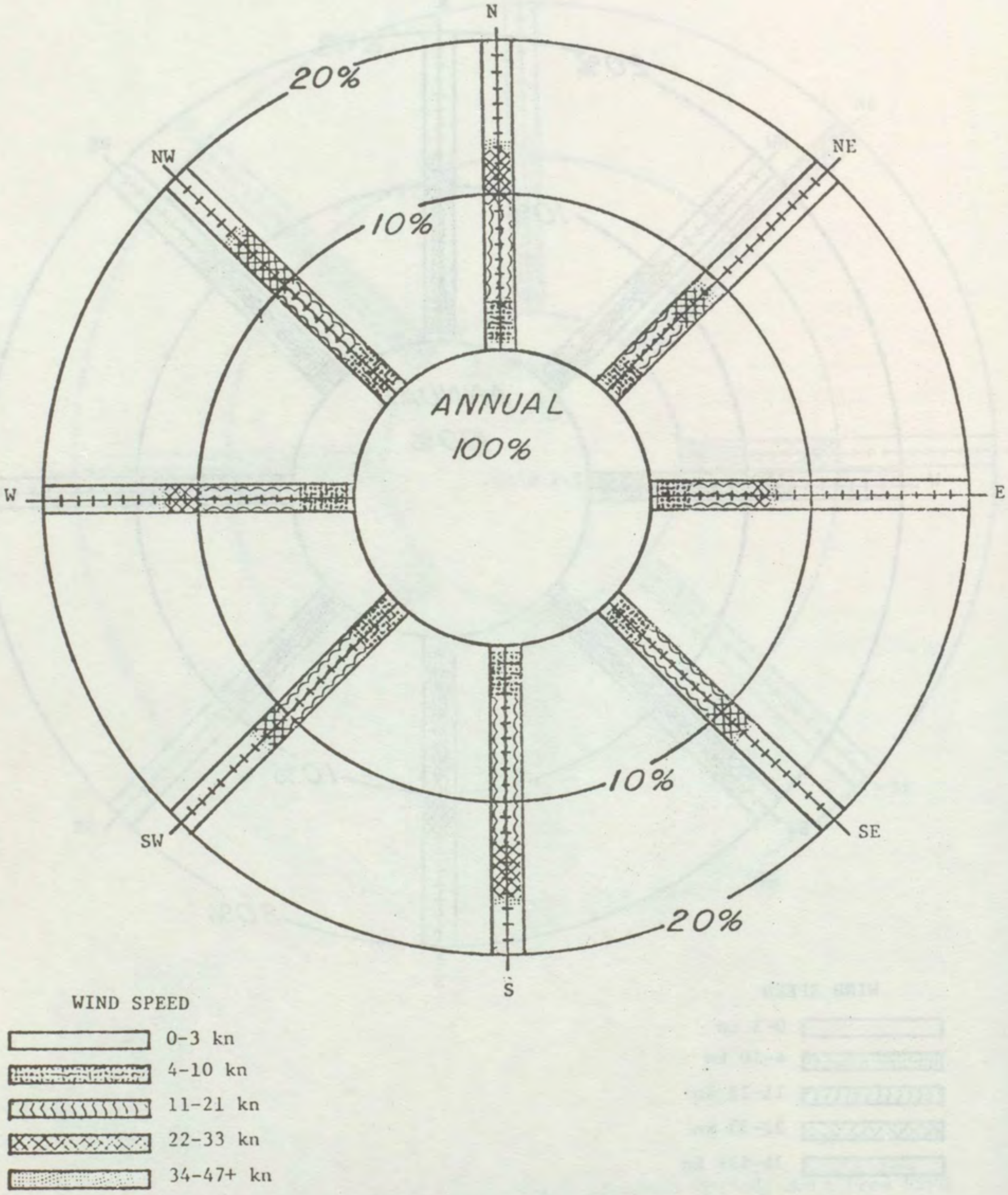


Figure 13. Wind rose for an average 12-month period; data from SSMO observations at Lake Superior East Central 1960-1973

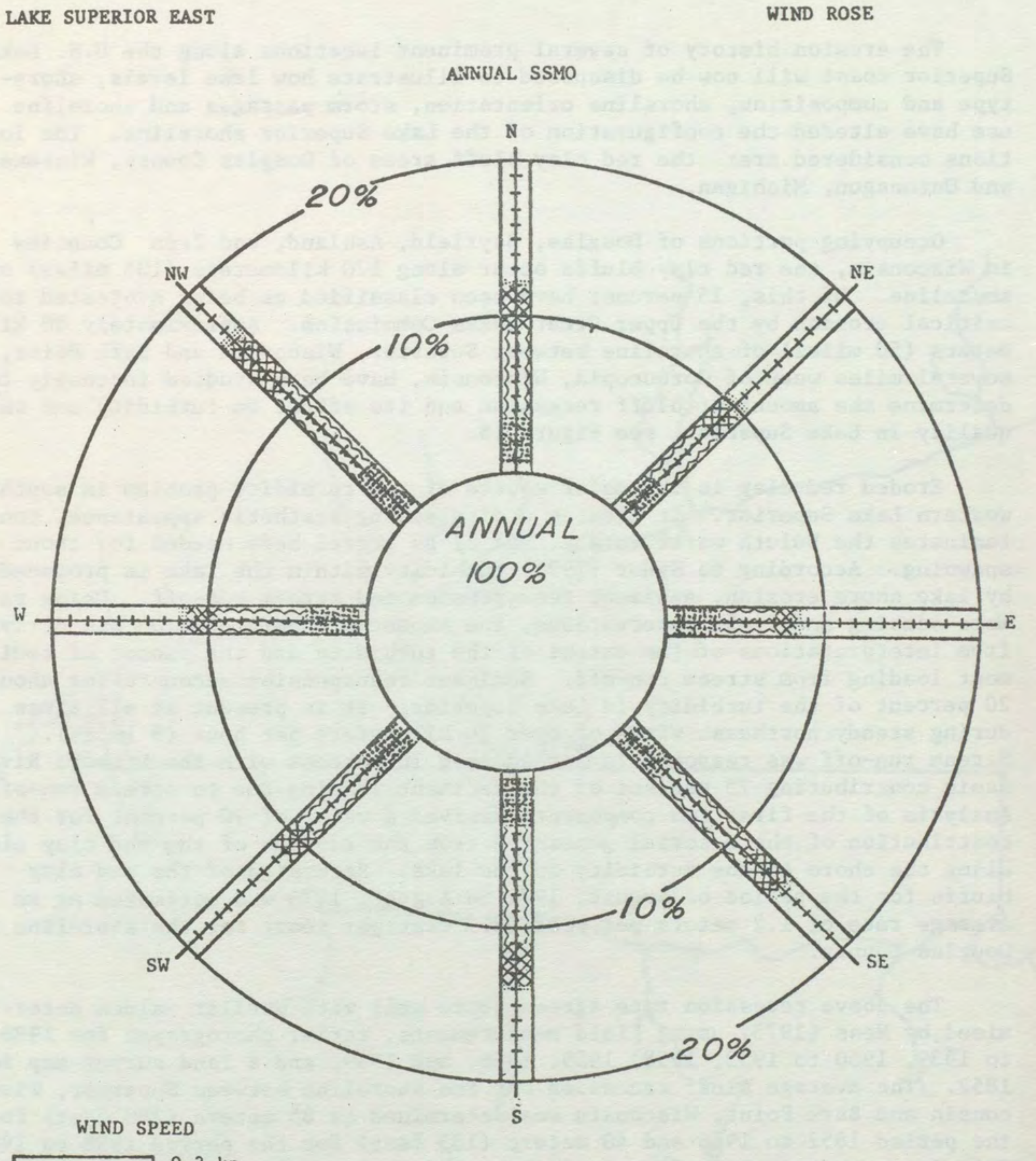


Figure 14. Wind rose for an average 12-month period; data from SSMO observations at Lake Superior East 1960-1973

The erosion history of several prominent locations along the U.S. Lake Superior coast will now be discussed to illustrate how lake levels, shore-type and composition, shoreline orientation, storm passages and shoreline use have altered the configuration of the Lake Superior shoreline. The locations considered are: the red clay bluff areas of Douglas County, Wisconsin and Ontonagon, Michigan.

Occupying portions of Douglas, Bayfield, Ashland, and Iron Counties in Wisconsin, the red clay bluffs occur along 170 kilometers (105 miles) of shoreline. Of this, 15 percent have been classified as being subjected to critical erosion by the Upper Great Lakes Commission. Approximately 80 kilometers (50 miles) of shoreline between Superior, Wisconsin and Bark Point, several miles west of Cornucopia, Wisconsin, have been studied intensely to determine the amount of bluff recession and its effect on turbidity and water quality in Lake Superior, see Figure 15.

Eroded red clay is the major source of the turbidity problem in southwestern Lake Superior. It creates a displeasing aesthetic appearance, contaminates the Duluth water intake, and clogs gravel beds needed for trout spawning. According to Sydor (1975) turbidity within the lake is produced by lake shore erosion, sediment resuspension and stream run-off. Using remote sensing and field observations, the amount of shore erosion was derived from interpretations of the extent of the turbidity and the amount of sediment loading from stream run-off. Sediment resuspension accounts for about 20 percent of the turbidity in Lake Superior; it is present at all times during steady northeast winds of over 16 kilometers per hour (9 knots). Stream run-off was responsible for another 10 percent with the Nemadji River Basin contributing 75 percent of the sediment loading due to stream run-off. Analysis of the first two components derived a value of 70 percent for the contribution of the material generated from the erosion of the red clay bluffs along the shore to the turbidity in the lake. Recession of the red clay bluffs for the period of August, 1972 to August, 1975 was estimated at an average rate of 1.2 meters per year (3.9 feet per year) for the shoreline in Douglas County.

The above recession rate agrees quite well with earlier values determined by Hess (1973) using field measurements, aerial photographs for 1938 to 1939, 1950 to 1953, 1958, 1959, 1966, and 1969, and a land survey map for 1852. The average bluff recession for the shoreline between Superior, Wisconsin and Bark Point, Wisconsin was determined as 85 meters (280 feet) for the period 1852 to 1966 and 40 meters (133 feet) for the period 1938 to 1966. This is an average annual rate of about 0.8 meters per year (2.5 feet per year) for 114 years and 1.5 meters per year (4.8 feet per year) for the last 28 years of the period. The volume of eroded material was calculated at about 1.1 million cubic meters per year (1.4 million cubic yards per year) for the 114-year period and 2.9 million cubic meters per year (3.8 million cubic yards per year) for the last 28 years of that period.

Considerable portions of eroded material disperse into Lake Superior as particles less than 2 microns forming suspensions of lengthy stability. Particles of this size are also more readily available for resuspension.

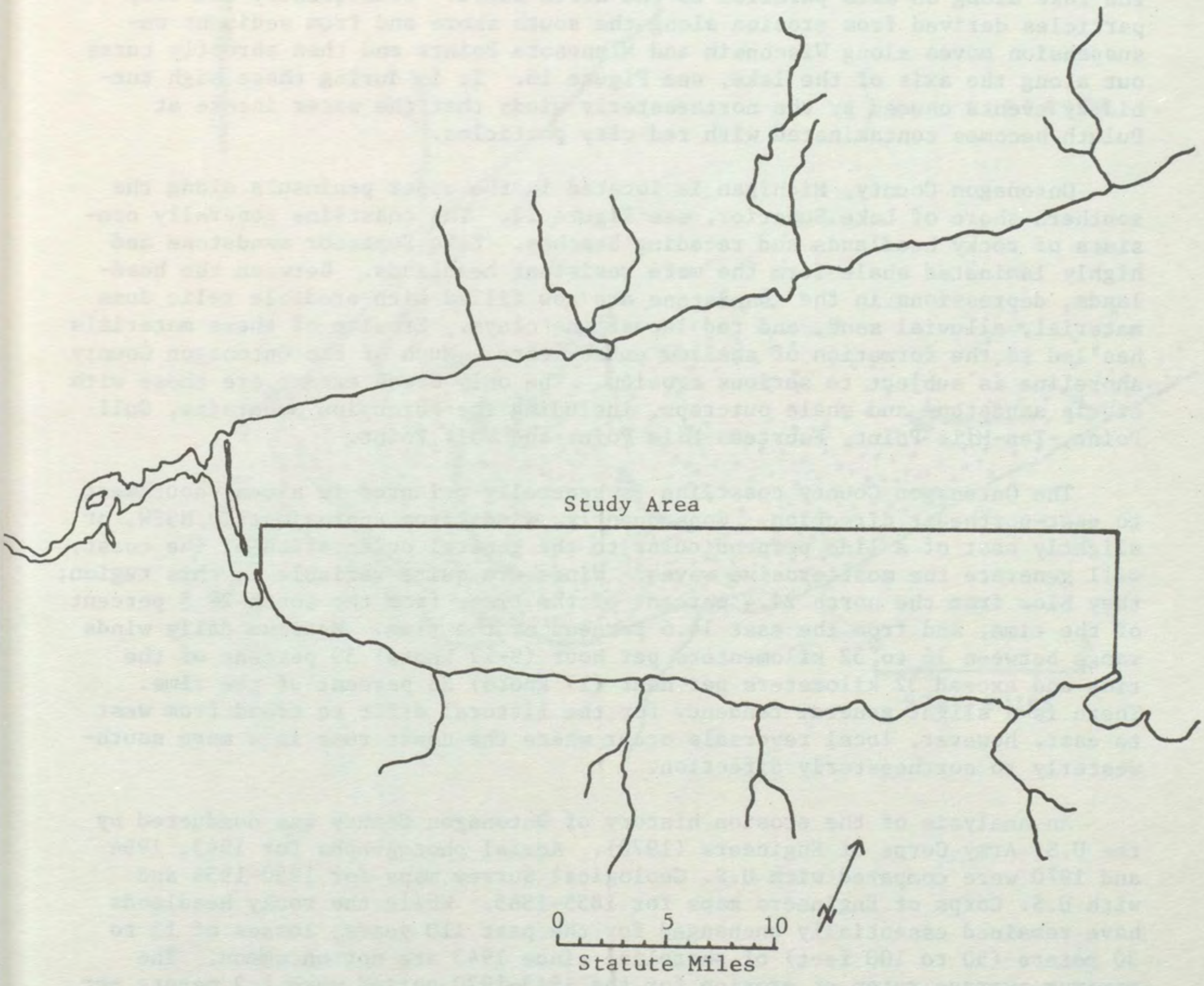


FIGURE 15. Lake Superior Shoreline Along Douglas and Bayfield Counties.

SOURCE: Hess, 1973

The transport patterns of the suspended red clay particles are of significance due to their pollutant nature. Drift studies indicate a generally counterclockwise summer circulation with eddying effects generated off of Minnesota and Wisconsin Points. Northeasterly winds create a strong southerly current along the north shore from Silver Bay to Duluth, Minnesota and a westerly current along the south shore. The southerly and westerly currents appear to turn and meet at Minnesota Point and turn out into the middle of the lake along an axis parallel to the north shore. Consequently red clay particles derived from erosion along the south shore and from sediment resuspension moves along Wisconsin and Minnesota Points and then abruptly turns out along the axis of the lake, see Figure 16. It is during these high turbidity events caused by the northeasterly winds that the water intake at Duluth becomes contaminated with red clay particles.

Ontonagon County, Michigan is located in the upper peninsula along the southern shore of Lake Superior, see Figure 17. The coastline generally consists of rocky headlands and receding beaches. Lake Superior sandstone and highly laminated shale form the more resistant headlands. Between the headlands, depressions in the sandstone are now filled with erodible relic dune material, alluvial sand, and red lacustrine clays. Erosion of these materials has led to the formation of shallow embankments. Much of the Ontonagon County shoreline is subject to serious erosion. The only areas exempt are those with stable sandstone and shale outcrops, including the Porcupine Mountains, Gull Point, Ten-Mile Point, Fourteen-Mile Point and Wolf Point.

The Ontonagon County coastline is generally oriented in a west-southwest to east-northeast direction. Consequently, winds from approximately N32W, or slightly east of a line perpendicular to the general orientation of the coast, will generate the most erosive waves. Winds are quite variable in this region; they blow from the north 24.4 percent of the time, from the south 28.5 percent of the time, and from the east 14.6 percent of the time. Maximum daily winds range between 16 to 32 kilomenters per hour (9-17 knots) 50 percent of the time and exceed 32 kilometers per hour (17 knots) 26 percent of the time. There is a slight general tendency for the littoral drift to trend from west to east, however, local reversals occur where the coast runs in a more southwesterly to northeasterly direction.

An analysis of the erosion history of Ontonagon County was conducted by the U.S. Army Corps of Engineers (1970). Aerial photographs for 1943, 1964 and 1970 were compared with U.S. Geological Survey maps for 1950-1956 and with U.S. Corps of Engineers maps for 1855-1865. While the rocky headlands have remained essentially unchanged for the past 110 years, losses of 15 to 30 meters (50 to 100 feet) of shoreline since 1943 are not uncommon. The maximum average rates of erosion for the 1943-1970 period were 1.2 meters per year (4.0 feet per year) at an embankment near the mouth of Pine Creek and 0.9 meters (3.0 feet) per year just east of Green. The only shoreline to experience appreciable accretion was along the two jetties which protect the entrance to Ontonagon Harbor; accretion occurred at an average rate of 2.4 meters per year (8.0 feet per year) along the western side of the harbor entrance.

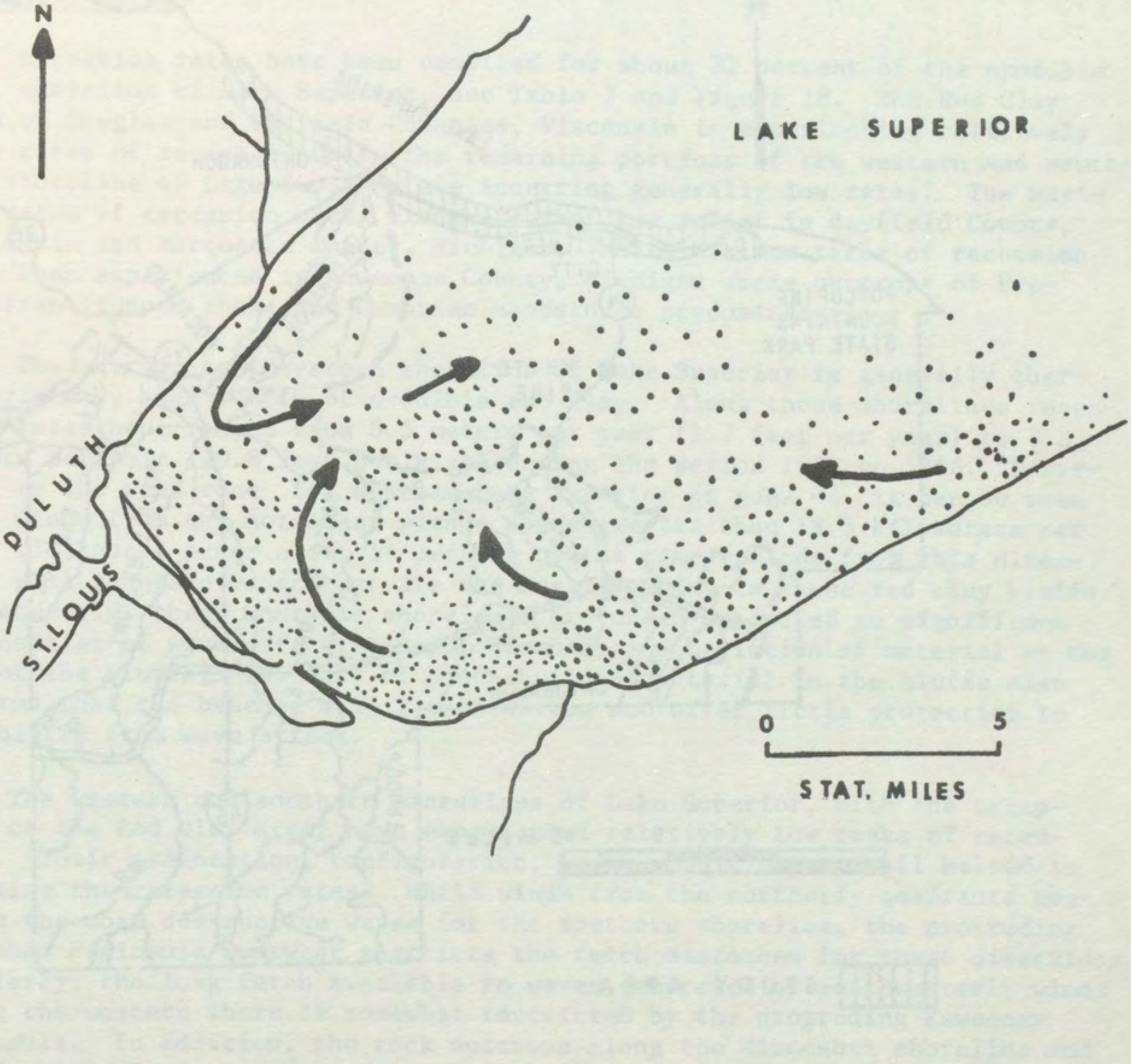


FIGURE 16. Red Clay Turbidity Transport for Northeasterly Storm.

SOURCE: Sydor, 1975

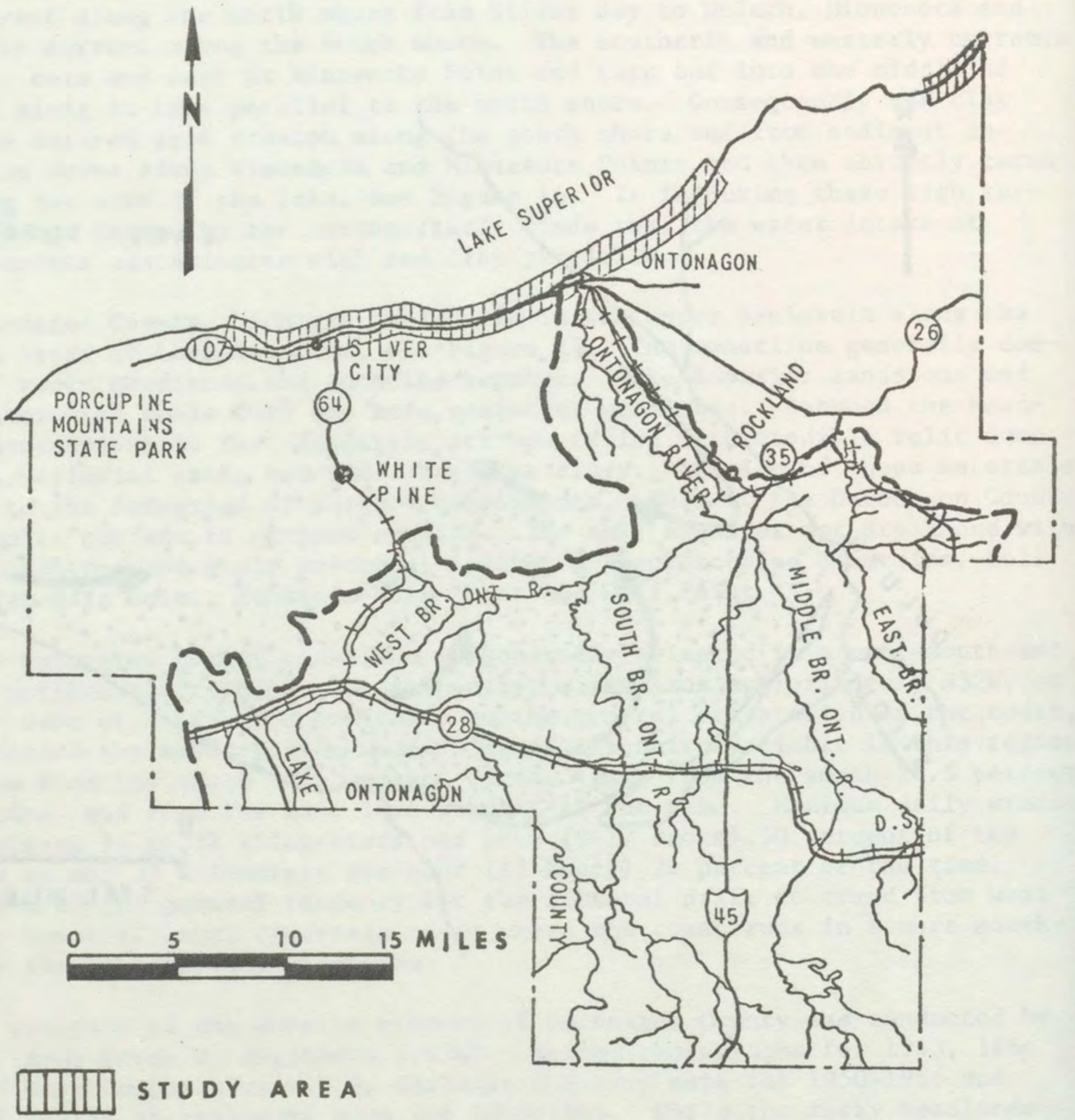


FIGURE 17. Lake Superior Shoreline Along Ontonagon County, Michigan.

SOURCE: U.S. Department of the Army, Corps of Engineers, 1970.

This stretch of shoreline is also subjected to extensive flooding. The greatest flood on the Ontonagon River occurred in April 1963 when the river reached a level that was 0.6 meters (2 feet) above any previous level. During a storm in December 1963, winds gusting up to 80 kilometers per hour (43 knots) generated waves which eroded large stretches of shoreline and washed out and destroyed sections of Michigan Highway M 107.

Recession Rates

Recession rates have been compiled for about 32 percent of the erodible U.S. shoreline of Lake Superior, see Table 3 and Figure 18. The Red Clay Area of Douglas and Bayfield Counties, Wisconsin is experiencing relatively high rates of recession while the remaining portions of the western and southern shoreline of Lake Superior are incurring generally low rates. The maximum rates of recession occur along areas of low relief in Bayfield County, Wisconsin and Marquette County, Michigan. While minimum rates of recession have been experienced in Keweenaw County, Michigan where outcrops of Precambrian igneous rocks and Cambrian sandstones predominate.

The extreme southwestern shoreline of Lake Superior is generally characterized by high bluffs of erodible red clay. Along these shorelines recession rates have ranged from 0.5 meters per year (1.7 feet per year) to 3.3 meters per year (10.8 feet per year) during the period 1938 to 1966. Referring to the wind rose for western Lake Superior on page 42, it can be seen that winds from the northeast with a speed greater than 18.5 kilometers per hour (10 knots) occur about 14 percent of the time. Winds from this direction will generate waves that are the most damaging to these red clay bluffs. Consequently, these unstable shorelands are often subjected to significant intensities of wave attack, causing slumping and depletion of material at the toe of the bluffs. The lack of beach building material in the bluffs also insures that the beaches will remain narrow and offer little protection to the bluffs from wave attack.

The western and southern shorelines of Lake Superior, with the exception of the Red Clay Area, have experienced relatively low rates of recession. Their orientation, configuration, and composition have all helped to minimize the recession rates. While winds from the northerly quadrants generate the most destructive waves for the southern shoreline, the protruding Keweenaw Peninsula somewhat restricts the fetch distances for these directions. Similarly, the long fetch available to waves generated by southwesterly winds along the western shore is somewhat restricted by the protruding Keweenaw Peninsula. In addition, the rock outcrops along the Minnesota shoreline and the Keweenaw Peninsula are quite resistant to wave attack. The irregularity of the southern shoreline also helps to diminish the effects of waves breaking along the coast.

The maximum rates of recession occur along reaches of low relief which are subjected to waves generated over the longest available fetches. A 3.5 kilometer (2.2 mile) reach along western Bayfield County, Wisconsin has experienced an average annual recession rate of 4.8 meters per year (15.9 feet per year) during the 1938 to 1966 period. This shore consists of a low sand

TABLE 3

RECESSION RATES ALONG U.S. SHORELINE OF LAKE SUPERIOR

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Douglas Co. Wisconsin											
4-001-002	3.22	(2.0)	LD	2.29	(7.5)	-1.80	(-5.9)	0.34	(1.1)	-4.57	(-15.0)
4-002-005	1.61	(1.0)	PE/W	2.29	(7.5)	0.40	(1.3)	0.64	(2.1)	0.09	(0.3)
4-005-012	9.01	(5.6)	HBE	14.48	(47.5)	1.31	(4.3)	3.29	(10.8)	-0.03	(-0.1)
4-012-015	4.18	(2.6)	HBE	17.53	(57.5)	0.88	(2.9)	1.46	(4.8)	-0.52	(-1.7)
4-015-019	5.15	(3.2)	HBE	20.57	(67.5)	1.80	(5.9)	2.80	(9.2)	0.91	(3.0)
4-019-022	2.57	(1.8)	HBE	17.53	(57.5)	1.80	(5.9)	3.60	(11.8)	0.94	(3.1)
4-022-023	1.61	(1.0)	HBE	14.48	(47.5)	1.34	(4.4)	2.35	(7.7)	0.79	(2.6)
4-023-024	3.54	(2.2)	HBE	11.43	(37.5)	1.19	(3.9)	1.83	(6.0)	0.85	(2.8)
4-024-027	1.60	(1.0)	HBE	8.38	(27.5)	2.07	(6.8)	3.29	(10.8)	0.94	(3.1)
4-027-030	4.83	(3.0)	HBE	5.33	(17.5)	2.59	(8.5)	3.60	(11.8)	1.23	(3.7)
Bayfield Co. Wisconsin											
5-001-008	9.17	(5.7)	LBE	5.33	(17.5)	1.40	(4.6)	3.05	(10.0)	.31	(1.0)
5-008-009	0.08	(0.5)	HBE	5.33	(17.5)						
5-009-010	2.09	(1.3)	LBE/LBN	5.33	(17.5)	0.94	(3.1)	1.62	(5.3)	0.12	(0.4)
5-010-013	3.54	(2.2)	PE	0.76	(2.5)	4.85	(15.9)	14.54	(47.7)	1.65	(5.4)
5-013-015	2.09	(1.3)	HBE	23.62	(77.5)	1.07	(3.5)	1.46	(4.8)	0.52	(1.7)
5-015-017	2.57	(1.6)	HBE	29.72	(97.5)	1.85	(6.1)	3.20	(10.5)	0.52	(1.7)
5-017-018	1.61	(1.0)	HBE	41.91	(137.5)	3.29	(10.8)	3.84	(12.6)	2.44	(8.5)
5-018-020	0.08	(0.5)	HBN	41.91	(137.5)	0.82	(2.7)	1.28	(4.2)	0.49	(1.6)
5-020-021	1.61	(1.0)	HBE	17.53	(57.5)	0.52	(1.7)	1.34	(4.4)	0.09	(0.3)
5-021-023	2.90	(1.8)	PE	0.76	(2.5)	1.19	(3.9)	1.83	(6.0)	0.55	(1.8)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 3--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Bayfield Co. (continued)											
5-023-025	3.54	(2.2)	LBE	11.43	(37.5)	1.31	(4.3)	2.26	(7.4)	0.61	(2.0)
5-025-025	2.74	(1.7)	HBE	20.57	(67.5)						
5-025-027	1.45	(0.9)	LBE	5.33	(17.5)	1.68	(5.5)	2.29	(7.5)	1.07	(3.5)
5-027-109 (42 reaches)	102.98	(64.0)									
Gogebic Co. Michigan											
08-001-002	2.74	(1.7)	HBN	23.62	(77.5)						
08-002-006	4.34	(2.7)	HBN	17.53	(57.5)						
08-006-007	1.45	(0.9)	LBN	5.33	(17.5)						
08-007-009	0.97	(0.6)	LBE	5.33	(17.5)	0.98	(3.2)	1.28	(4.2)	0.67	(2.2)
08-009-009	1.13	(0.7)	LBE	11.43	(37.5)	1.37	(4.5)	1.86	(6.1)	0.79	(2.6)
08-009-013	4.67	(2.9)	HBN	11.43	(37.5)	0.30	(1.0)	0.43	(1.4)	0.09	(0.3)
08-013-016	3.22	(2.0)	HBN	17.53	(57.5)						
08-016-018	1.93	(1.2)	HBN	11.43	(37.5)						
08-018-020	3.05	(1.9)	HBN	5.33	(17.5)						
08-020-020	0.48	(0.3)	HBE	5.33	(17.5)						
08-020-022	1.61	(1.0)	HBE	11.43	(37.5)						
08-022-024	4.50	(2.8)	HBE	23.62	(77.5)						
08-024-027	2.57	(1.6)	HBE	35.81	(117.5)	1.80	(5.9)	2.53	(8.3)	0.24	(0.8)
08-027-028	1.61	(1.0)	HBE	17.53	(57.5)	0.30	(1.0)	0.58	(1.9)	0.12	(0.4)

* Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 3--Continued

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Gogebic Co. (continued)											
08-029-032	4.99	(3.1)	HBE	11.43	(37.5)						
08-032-036	2.57	(1.6)	HBE	23.62	(77.5)						
08-036-037	1.29	(0.8)	LBN	23.62	(77.5)						
08-037-038	4.02	(2.5)	LBN	11.43	(37.5)						
08-038-040	3.70	(2.3)	PN	11.43	(37.5)						
Ontonagon Co. Michigan											
9-001-004	3.06	(1.9)	PN	11.43	(37.5)						
9-004-018	19.63	(12.2)	PN	5.33	(17.5)						
9-018-019	4.18	(2.6)	LBE	0.76	(2.5)	0.55	(1.8)	0.67	(2.2)	0.46	(1.5)
9-019-021	1.45	(0.9)	PN	0.76	(2.5)	0.55	(1.8)	0.82	(2.7)	0.30	(1.0)
9-021-022	0.97	(0.6)	W	0.76	(2.5)	0.24	(0.8)	0.46	(1.5)	0.00	(0.0)
9-022-026	5.15	(3.2)	PN	0.76	(2.5)	0.70	(2.3)	2.13	(7.0)	-1.10	(-3.6)
9-026-040	17.54	(10.9)	LBE	0.76	(2.5)	0.67	(2.2)	2.16	(7.1)	-0.37	(-1.2)
9-040-041	1.13	(0.7)	LBN	0.79	(2.6)	0.39	(1.3)	0.81	(2.6)	0.21	(0.7)
9-041-043	1.61	(1.0)	LBE	0.76	(2.5)	0.58	(1.9)	0.73	(2.4)	0.40	(1.3)
9-043-044	1.61	(1.0)	LBN	0.76	(2.5)	0.76	(2.5)	1.22	(4.0)	0.52	(1.7)
9-044-051	8.05	(5.0)	LBE	0.76	(2.5)	0.73	(2.4)	1.43	(4.7)	-0.76	(-2.5)
9-051-051	0.48	(0.3)	LBN	0.76	(2.5)						
9-051-053	2.25	(1.4)	LBN	5.33	(17.5)	1.07	(3.5)	1.28	(4.2)	0.85	(2.8)
9-053-053	0.64	(0.4)	LBE	5.33	(17.5)	1.31	(4.3)	1.43	(4.7)	1.19	(3.9)
9-053-054	1.77	(1.1)	LBE	0.76	(2.5)	1.95	(6.4)	2.32	(7.6)	1.77	(5.8)

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 3--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession Average m/yr	(ft/yr)	Maximum m/yr	(ft/yr)	Minimum m/yr	(ft/yr)
Ontonagon Co. (continued)											
9-054-057	4.02	(2.5)	LBN	0.76	(2.5)						
9-057-059	2.74	(1.7)	LBE	0.76	(2.5)						
9-059-062	2.90	(1.8)	PN	0.76	(2.5)						
9-062-064	1.45	(0.9)	LBN	0.76	(2.5)						
9-064-064	1.13	(0.7)	PN	0.76	(2.5)						
9-064-067	3.54	(2.2)	LBE	0.76	(2.5)	0.18	(0.6)	0.40	(1.3)	0.09	(0.3)
9-067-069	4.18	(2.6)	LBE	5.33	(17.5)	0.91	(3.0)	1.65	(5.4)	0.43	(1.4)
Keweenaw Co. Michigan											
11-001-003	2.74	(1.7)	LBE	0.76	(2.5)	0.49	(1.6)	0.85	(1.6)	0.24	(0.8)
11-003-007	4.67	(2.9)	LBE	5.33	(17.5)	0.52	(1.7)	0.70	(2.3)	0.40	(1.3)
11-007-009	2.74	(1.7)	LBE	0.76	(2.5)						
11-009-015	6.44	(4.0)	LBN	5.33	(17.5)	0.12	(0.4)	0.37	(1.2)	-0.09	(-0.3)
11-015-015	1.61	(1.0)	LBN	11.43	(37.5)						
11-015-016	1.61	(1.0)	LD	11.43	(37.5)	0.73	(2.4)	1.16	(3.8)	0.27	(0.9)
11-016-019	3.06	(1.9)	LD	28.19	(92.5)						
11-019-021	1.61	(1.0)	LD	11.43	(37.5)						
11-021-022	2.41	(1.5)	LD	0.76	(2.5)	0.82	(2.7)	1.01	(3.3)	0.64	(2.1)
11-022-023	1.77	(1.1)	LD	2.29	(7.5)	1.04	(3.4)	1.04	(3.4)	1.04	(3.4)
11-023-027	6.76	(4.2)	LD	25.14	(82.5)	0.24	(0.8)	0.43	(1.4)	0.06	(0.2)
11-027-028	2.57	(1.6)	LBN	0.76	(2.5)	0.21	(0.7)	0.21	(0.7)	0.21	(0.7)
11-028-029	2.09	(1.3)	LBN	5.33	(17.5)						

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 3--Continued

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Keweenaw Co. (continued)											
11-029-029	0.32	(0.2)	LBE	5.33	(17.5)						
11-029-033	3.38	(2.1)	LBE	3.81	(12.5)						
11-033-033	5.63	(3.5)	LBN	3.81	(12.5)						
11-033-035	3.86	(2.4)	LBN	5.33	(17.5)						
11-035-036	4.51	(2.8)	LBN	28.19	(92.5)						
11-036-039	5.63	(3.5)	LBN	5.33	(17.5)						
11-039-043	8.05	(5.0)	LBN	8.38	(27.5)						
11-043-111 (18 reaches)	75.46	(46.9)									
Marquette Co. Michigan											
13-001-057 (29 reaches)	78.51	(48.8)									
13-057-057	0.80	(0.5)	LD	9.91	(32.5)	0.06	(0.2)	0.15	(0.5)	-0.06	(-0.2)
13-057-057	1.13	(0.7)	HBN	9.91	(32.5)	0.00	(0.0)	0.21	(0.7)	-0.12	(-0.4)
13-057-058	2.90	(1.8)	LD	0.76	(2.5)						
13-058-058	0.48	(0.3)	LBN	0.76	(2.5)						
13-058-058	1.79	(1.1)	LBN	28.19	(92.5)						
13-058-059	1.93	(1.2)	LBN	0.76	(2.5)						
13-059-062	2.74	(1.7)	LD	0.76	(2.5)						
13-062-064	1.29	(0.8)	LBN	0.76	(2.5)						
13-064-069	4.83	(3.0)	LBN	2.29	(7.5)						

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 3--Continued

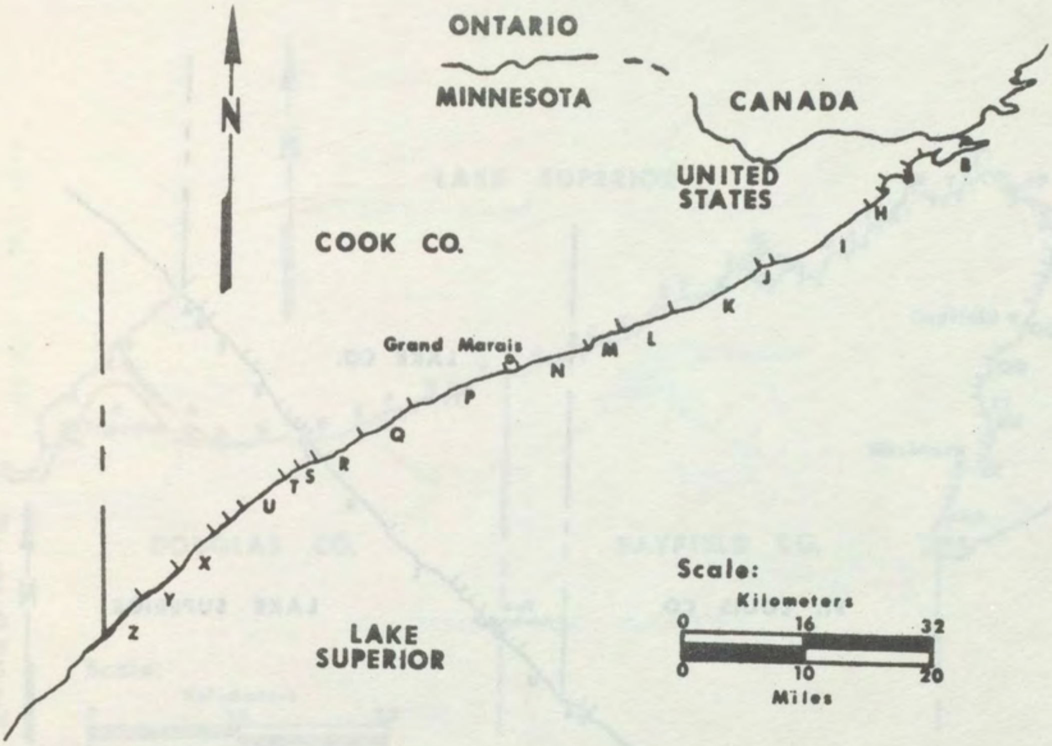
Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Marquette Co. (continued)											
13-069-069	1.29	(0.8)	LD	2.29	(7.5)						
13-069-076	7.56	(4.7)	LD	0.76	(2.5)	0.91	(3.0)	1.98	(6.5)	-0.24	(-0.8)
13-076-079	7.08	(4.4)	LD	5.33	(17.5)	0.29	(0.95)	0.46	(1.5)	0.00	
13-079-082	5.95	(3.7)	LD	0.76	(2.5)						
Luce Co. Michigan											
15-001-002	2.41	(1.5)	PE	3.81	(12.5)	0.58	(1.9)	0.70	(2.3)	0.49	(1.6)
15-002-019	22.37	(13.9)	PE	2.29	(7.5)	0.24	(0.8)	0.49	(1.6)	0.00	(0.0)
15-019-020	2.09	(1.3)	HBE	2.29	(7.5)						
15-020-021	1.45	(0.9)	LBE	2.29	(7.5)						
15-021-025	5.95	(3.7)	LBE	5.33	(17.5)						
15-025-027	1.45	(0.9)	PE	5.33	(17.5)						
15-027-030	4.51	(2.8)	PE	6.86	(22.5)						
15-030-034	4.18	(2.6)	HBE	14.48	(47.5)	0.76	(2.5)	1.58	(5.2)	0.24	(0.8)
15-034-039	7.56	(4.7)	LBE	2.29	(7.5)						

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 3--Continued

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Chippewa Co. Michigan											
16-001-009 (2 reaches)	14.80	(9.2)	-	0.76	(2.5)						
16-009-015	9.01	(5.6)	LBE	2.29	(7.5)	1.43	(4.7)	2.71	(8.9)	0.09	(0.3)
16-015-025 (2 reaches)	12.07	(7.5)	-	2.29	(7.5)						
16-025-026	2.25	(1.4)	LBE	0.76	(2.5)	0.73	(2.9)	1.13	(3.7)	0.52	(1.7)
16-026-031 (2 reaches)	6.92	(4.3)	LBN								
16-031-046	11.99	(11.8)	LBN	0.76	(2.5)	0.98	(3.2)	1.46	(4.8)	0.43	(1.4)
16-046-179 (30 reaches)	130.17	(80.9)									
16-179-181	3.70	(2.3)	LBE	2.29	(7.5)	0.09	(0.3)	0.46	(1.5)	-0.30	(-1.0)
16-181-184	3.54	(2.2)	PN	2.29	(7.5)	0.46	(1.5)	1.01	(3.3)	0.12	(0.4)
16-184-188	8.05	(5.0)	LBE	2.29	(7.5)	0.52	(1.7)	0.94	(3.1)	-0.18	(-0.6)
16-188-189	1.93	(1.2)	LBN	2.29	(7.5)						

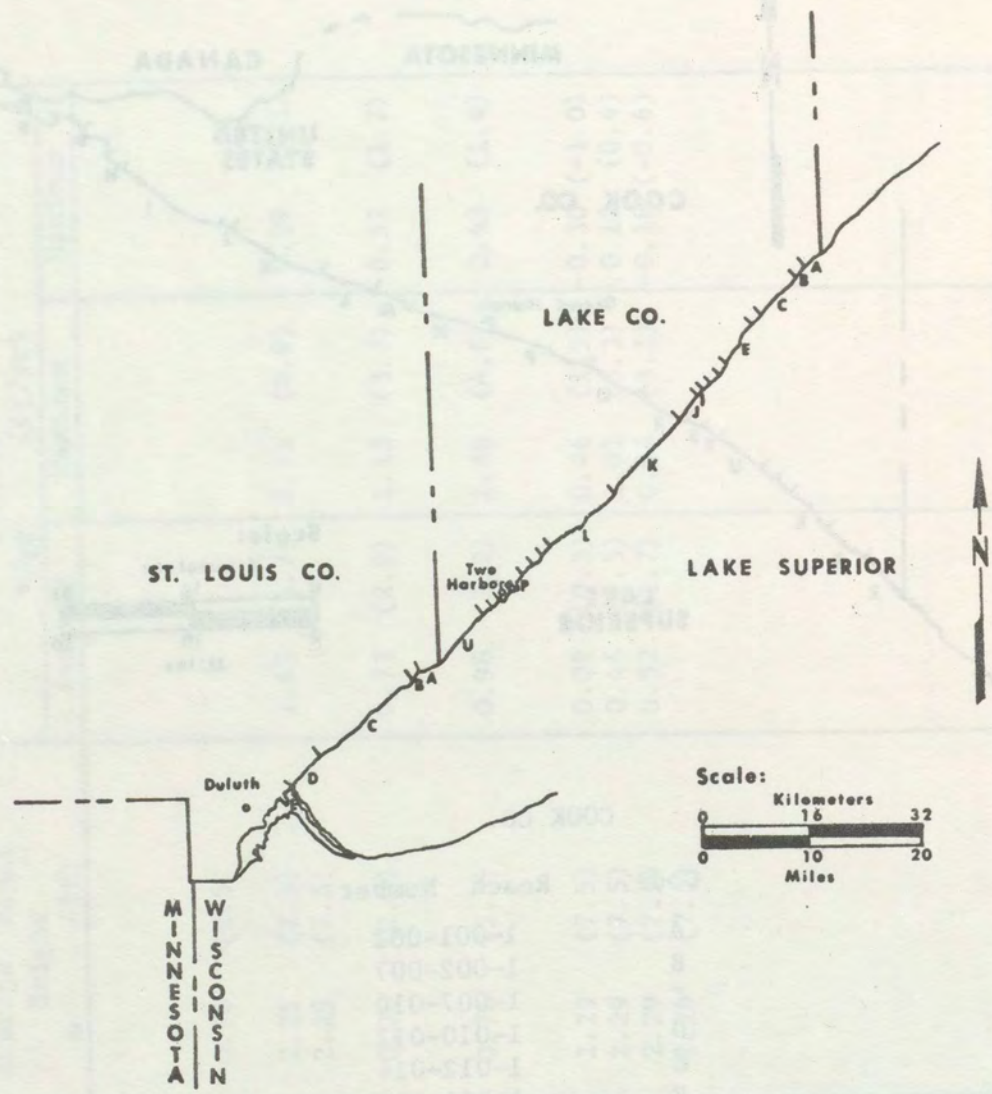
*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.



COOK CO.

Code	Reach Number
A	1-001-002
B	1-002-007
C	1-007-010
D	1-010-012
E	1-012-014
F	1-014-017
G	1-017-019
H	1-019-022
I	1-022-034
J	1-034-036
K	1-036-047
L	1-047-951
M	1-051-055
N	1-055-064
O	1-064-066
P	1-066-077
Q	1-077-086
R	1-086-091
S	1-091-093
T	1-093-096
U	1-096-101
V	1-101-103
W	1-103-105
X	1-105-108
Y	1-108-114
Z	1-114-116

FIGURE 18. LAKE SUPERIOR: Cook County Reach Locations.



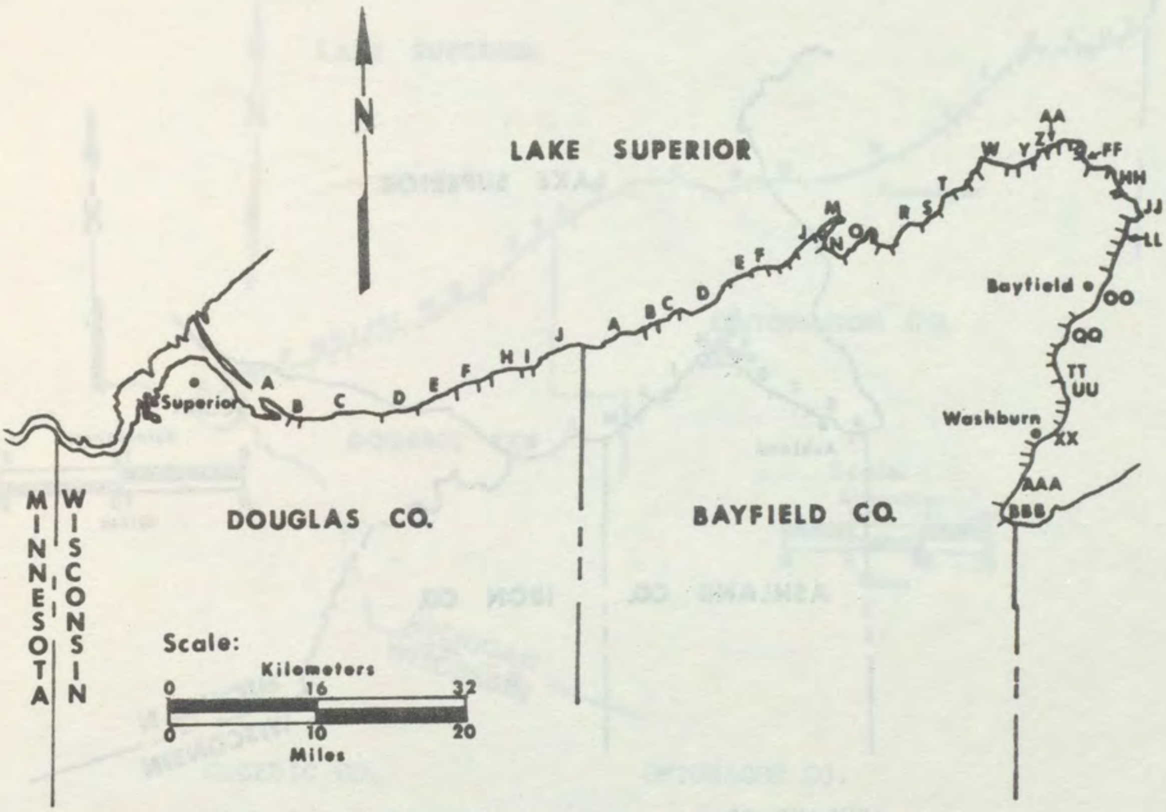
LAKE CO.

Code	Reach Number
A	2-001-003
B	2-003-004
C	2-004-008
D	2-008-009
E	2-009-017
F	2-017-019
G	2-019-020
H	2-020-021
I	2-021-023
J	2-023-029
K	2-029-042
L	2-042-049
M	2-049-051
N	2-051-053
O	2-053-055
P	2-055-058
Q	2-058-059
R	2-059-061
S	2-061-063
T	2-063-066
U	2-066-072

ST. LOUIS CO.

Code	Reach Number
A	3-001-003
B	3-003-005
C	3-005-019
D	3-019-026
E	3-026-036

LAKE SUPERIOR: Lake and St. Louis County Reach Locations.



DOUGLAS CO.

Code	Reach Number
A	4-001-002
B	4-002--005
C	4-005-012
D	4-012-015
E	4-015-019
F	4-019-022
G	4-022-023
H	4-023-024
I	4-024-027
J	4-027-030

BAYFIELD CO.

Code	Reach Number
A	5-001-008
B	5-008-009
C	5-009-010
D	5-010-013
E	5-013-015
F	5-015-017
G	5-017-018
H	5-018-020
I	5-020-021
J	5-021-023
K	5-023-025
L	5-025-025
M	5-025-027

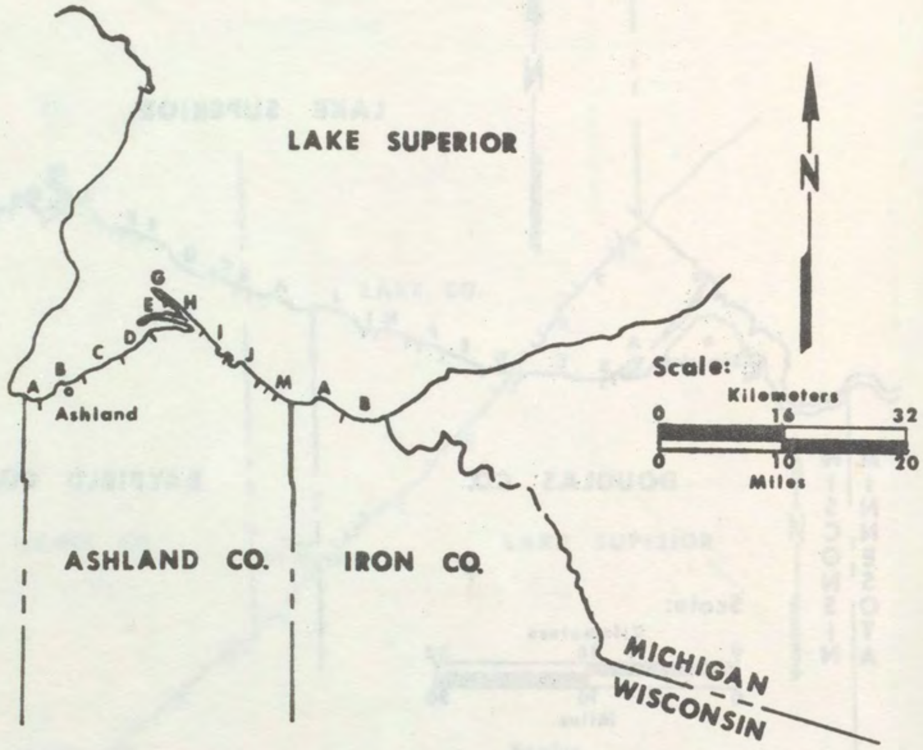
BAYFIELD CO. (Cont.)

Code	Reach Number
N	5-027-034
O	5-034-036
P	5-036-037
Q	5-037-038
R	5-038-039
S	5-039-041
T	5-041-043
U	5-043-044
V	5-044-047
W	5-047-049
X	5-049-050
Y	5-050-052
Z	5-052-053
AA	5-053-055
BB	5-055-056
CC	5-056-058
DD	5-058-058
EE	5-058-061
FF	5-061-062
GG	5-062-063
HH	5-063-065

BAYFIELD CO. (Cont.)

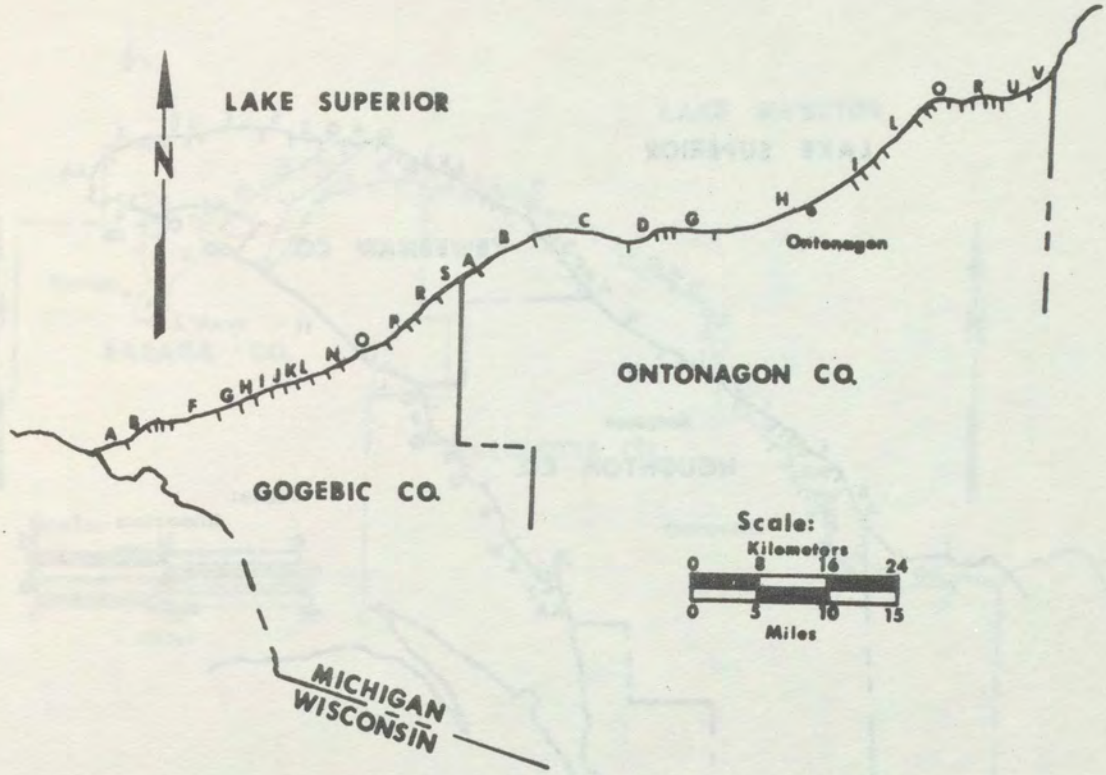
Code	Reach Number
II	5-065-067
JJ	5-067-069
KK	5-069-070
LL	5-070-074
MM	5-074-075
NN	5-075-077
OO	5-077-080
PP	5-080-083
QQ	5-083-085
RR	5-085-087
SS	5-087-089
TT	5-089-091
UU	5-091-093
VV	5-093-096
WW	5-096-097
XX	5-097-100
YY	5-100-101
ZZ	5-101-101
AAA	5-101-102
BBB	5-102-105
CCC	5-105-109

LAKE SUPERIOR: Douglas and Bayfield County Reach Locations



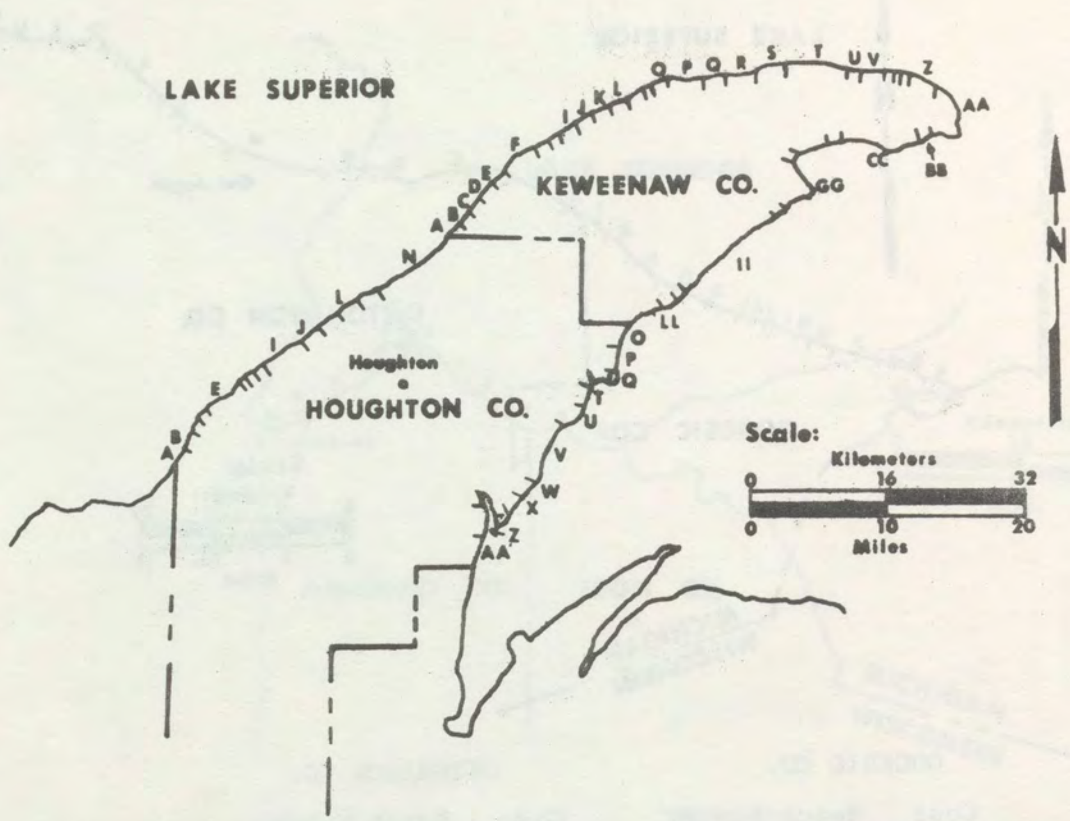
ASHLAND CO.		IRON CO.	
Code	Reach Number	Code	Reach Number
A	6-001-002	A	7-001-006
B	6-002-006	B	7-006-010
C	6-006-007		
D	6-007-010		
E	6-010-012		
F	6-012-019		
G	6-019-023		
H	6-023-026		
I	6-026-029		
J	6-029-033		
K	6-033-033		
L	6-033-036		
M	6-036-037		

LAKE SUPERIOR: Ashland and Iron County Reach Locations.



GOGEBIC CO.		ONTONAGON CO.	
Code	Reach Number	Code	Reach Number
A	8-001-002	A	9-001-004
B	8-002-006	B	9-004-018
C	8-006-007	C	9-018-019
D	8-007-009	D	9-019-021
E	8-009-009	E	9-021-022
F	8-009-013	F	9-022-026
G	8-013-016	G	9-026-040
H	8-016-018	H	9-040-041
I	8-018-020	I	9-041-043
J	8-020-020	J	9-043-044
K	8-020-022	K	9-044-051
L	8-022-024	L	9-051-051
M	8-024-027	M	9-051-053
N	8-027-028	N	9-053-053
O	8-029-032	O	9-053-054
P	8-032-036	P	9-054-057
Q	8-036-037	Q	9-057-059
R	8-037-038	R	9-059-062
S	8-038-040	S	9-062-064
		T	9-064-064
		U	9-064-067
		V	9-067-069

LAKE SUPERIOR: Gogebic and Ontonagon County Reach Locations.



HOUGHTON CO

Code	Reach Number
A	10-001-002
B	10-002-004
C	10-004-005
D	10-005-006
E	10-006-013
F	10-013-015
G	10-015-016
H	10-016-018
I	10-018-022
J	10-022-024
K	10-024-026
L	10-026-029
M	10-029-030
N	10-030-037
O	10-038-040
P	10-040-043
Q	10-043-044
R	10- 044-047
S	10-047-048
T	10-048-051
U	10-051-054
V	10-054-059
W	10-059-061

HOUGHTON CO. (Cont.)

Code	Reach Number
X	10-061-064
Y	10-064-065
Z	10-065-067
AA	10-067-068

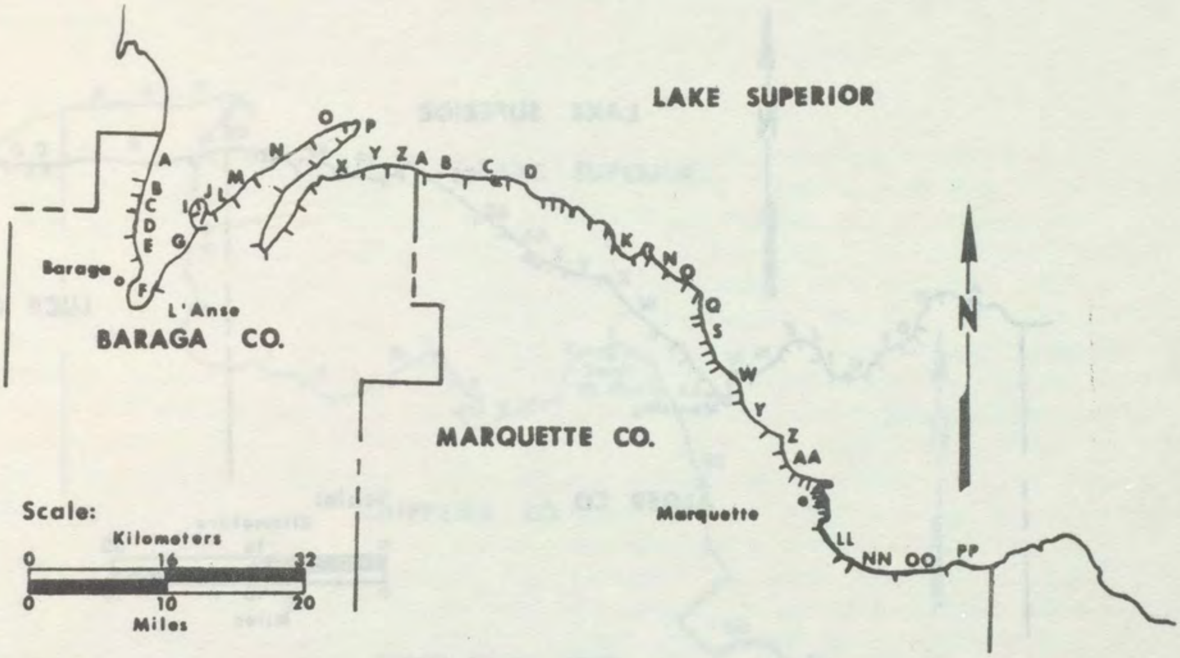
KEWEENAW CO.

Code	Reach Number
A	11-001-003
B	11-003-007
C	11-007-009
D	11-009-015
E	11-015-015
F	11-015-016
G	11-016-019
H	11-019-021
I	11-021-022
J	11-022-023
K	11-023-027
L	11-027-028
M	11-028-029
N	11-029-029
O	11-029-033
P	11-033-033

KEWEENAW CO. (Cont.)

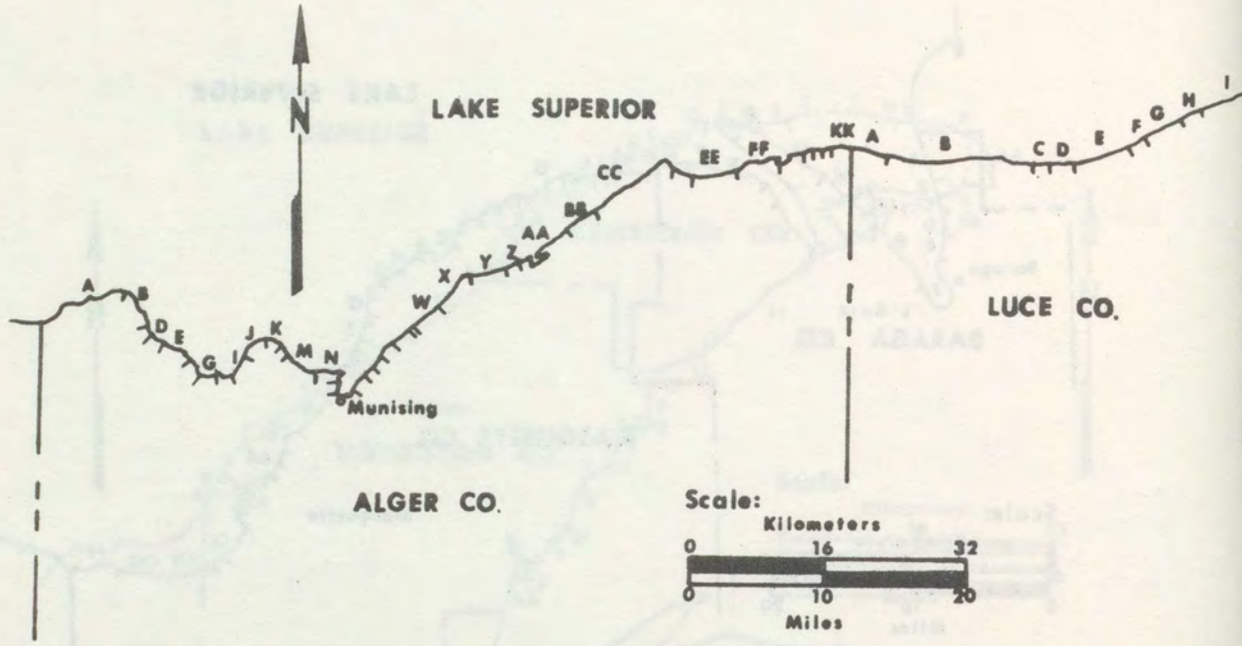
Code	Reach Number
Q	11-033-035
R	11-035-036
S	11-036-039
T	11-039-043
U	11-043-047
V	11-047-048
W	11-048-052
X	11-052-052
Y	11-052-052
Z	11-052-055
AA	11-055-063
BB	11-063-065
CC	11-065-071
DD	11-071-072
EE	11-072-076
FF	11-076-077
GG	11-077-094
HH	11-094-094
II	11-094-103
JJ	11-103-105
KK	11-105-105
LL	11-105-111

LAKE SUPERIOR: Keweenaw and Houghton County Reach Locations.



BAGARA CO.		MARQUETTE CO.		MARQUETTE CO. (Cont.)	
Code	Reach Number	Code	Reach Number	Code	Reach Number
A	12-001-004	A	13-001-003	AA	13-052-052
B	12-004-005	B	13-003-008	BB	13-052-052
C	12-005-006	C	13-008-010	CC	13-052-057
D	12-006-008	D	13-010-014	DD	13-057-057
E	12-008-011	E	13-014-015	EE	13-057-057
F	12-011-021	F	13-015-017	FF	13-057-058
G	12-021-029	G	13-017-018	GG	13-058-058
H	12-029-032	H	13-018-020	HH	13-058-058
I	12-032-035	I	13-020-021	II	13-058-059
J	12-035-037	J	13-021-023	JJ	13-059-062
K	12-037-038	K	13-023-025	KK	13-062-064
L	12-038-041	L	13-025-026	LL	13-064-069
M	12-041-044	M	13-026-026	MM	13-069-069
N	12-044-051	N	13-026-030	NN	13-069-076
O	12-051-055	O	13-030-034	OO	13-076-079
P	12-055-057	P	13-034-035	PP	13-079-082
Q	12-057-061	Q	13-035-036		
R	12-061-067	R	13-036-037		
S	12-067-072	S	13-037-041		
T	12-072-071	T	13-041-041		
U	12-072-074	U	13-041-043		
V	12-074-075	V	13-043-043		
W	12-075-076	W	13-043-047		
X	12-076-080	X	13-047-049		
Y	1]-080-082	Y	13-049-050		
Z	12-082-084	Z	13-050-052		

LAKE SUPERIOR: Baraga and Marquette County Reach Locations.



ALGER CO.

Code	Reach Number
A	14-001-009
B	14-009-012
C	14-012-012
D	14-012-014
E	14-014-015
F	14-015-020
G	14-020-023
H	14-023-025
I	14-025-028
J	14-028-031
K	14-031-034
L	14-034-035
M	14-035-039
N	14-039-040
O	14-040-041
P	14-041-045
Q	14-045-046
R	14-046-049
S	14-049-051

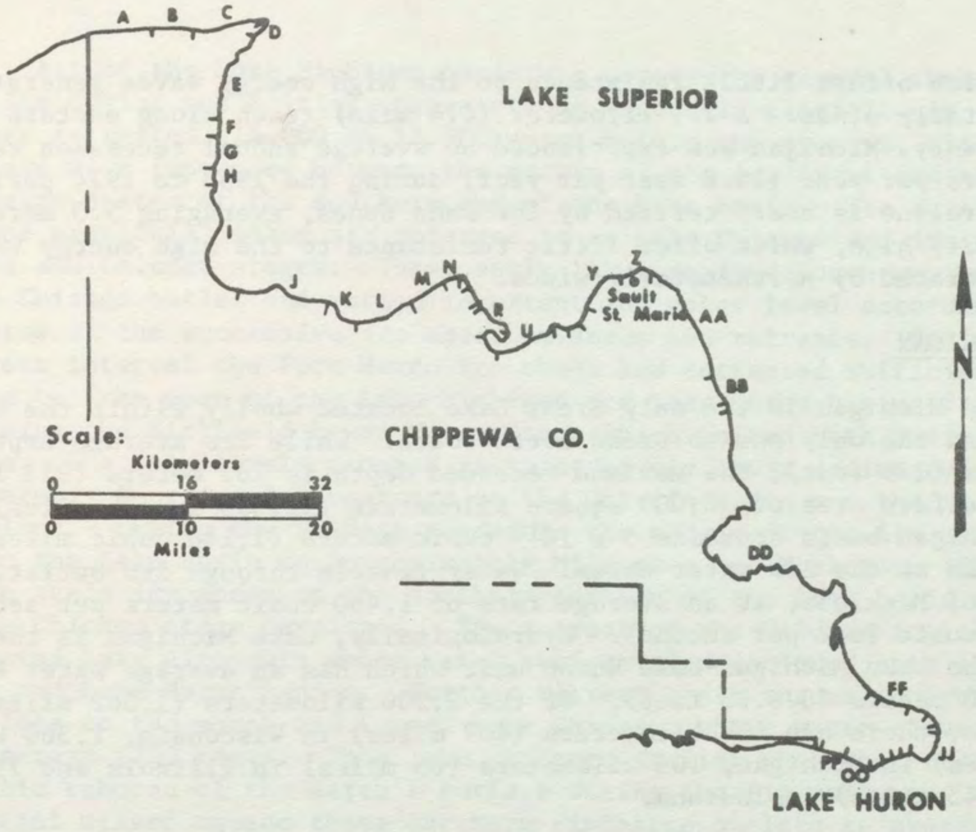
ALGER CO. (Cont.)

Code	Reach Number
T	14-051-053
U	14-053-054
V	14-054-055
W	14-055-057
X	14-057-059
Y	14-059-067
Z	14-067-069
AA	14-069-074
BB	14-074-079
CC	14-079-087
DD	14-087-090
EE	14-090-094
FF	14-094-096
GG	14-096-100
HH	14-100-101
II	14-101-101
JJ	14-101-102
KK	14-102-103

LUCE CO.

Code	Reach Number
A	15-001-002
B	15-002-019
C	15-019-020
D	15-020-021
E	15-021-025
F	15-025-027
G	15-027-030
H	15-030-034
I	15-034-039

LAKE SUPERIOR: Alger and Luce County Reach Locations.



CHIPPEWA CO.

Code	Reach Number	Code	Reach Number
A	16-001-006	W	16-087-089
B	16-006-009	X	16-089-091
C	16-009-015	Y	16-091-093
D	16-015-018	Z	16-093-094
E	16-018-025	AA	16-094-106
F	16-025-026	BB	16-106-110
G	16-026-030	CC	16-110-110
H	16-030-031	DD	16-110-162
I	16-031-046	EE	16-162-164
J	16-046-056	FF	16-164-169
K	16-056-059	GG	16-169-171
L	16-059-066	HH	16-171-173
M	16-066-069	II	16-173-174
N	16-069-069	JJ	16-174-176
O	16-069-070	KK	16-176-177
P	16-070-072	LL	16-177-178
Q	16-072-073	MM	16-178-179
R	16-073-076	NN	16-179-181
S	16-076-079	OO	16-181-184
T	16-079-081	PP	16-184-188
U	16-081-086	QQ	16-188-189
V	16-086-087		

LAKE SUPERIOR AND LAKE HURON: Chippewa County Reach Locations.

plain which offers little resistance to the high energy waves generated by northeasterly winds. A 7.1 kilometer (4.4 mile) reach along eastern Marquette County, Michigan has experienced an average annual recession rate of 4.8 meters per year (15.8 feet per year) during the 1938 to 1974 period. This shoreline is characterized by low sand dunes, averaging 5.3 meters (17.5 feet) high, which offer little resistance to the high energy waves also generated by northeasterly winds.

LAKE MICHIGAN

Lake Michigan is the only Great Lake located wholly within the United States and the only one to trend north-south. While its average depth is 85 meters (279 feet), the maximum recorded depth is 282 meters (923 feet). With a surface area of 58,000 square kilometers (22,300 square miles), the Lake Michigan basin contains 5 x 10^{12} cubic meters (1,180 cubic miles) of water when at the low water datum. Water travels through its outlet, the Straits of Mackinac, at an average rate of 1,460 cubic meters per second (52,000 cubic feet per second). Hydrologically, Lake Michigan is the western arm of the Lake Michigan-Lake Huron unit which has an average water elevation of 176.50 meters (578.68 feet). Of the 2,200 kilometers (1,362 miles) of shoreline, there are 660 kilometers (407 miles) in Wisconsin, 1,360 kilometers (845 miles) in Michigan, 105 kilometers (65 miles) in Illinois and 75 kilometers (45 miles) in Indiana.

Lake Michigan contains the largest number of embayments of any of the Great Lakes and has the least number of islands and island groups, all of which are located in the northern one-third of the Lake. Large embayments include Green Bay, Little Bay de Noc, Big Bay de Noc, Little Traverse Bay and Grand Traverse Bay. The southern two-thirds of the Lake basin is defined by smoothly curved shores, with no bays and almost no large natural harbors. The shoreline ranges from the extensive dunes of the Indiana Dunes National Lakeshore to the marshlands of Green Bay; from the rock cliffs of the Door Peninsula, Wisconsin and of Seul Choix Point, Michigan to the steep unconsolidated bluffs at Muskegon, Michigan.

The Lake Michigan basin was formerly a pre-glacial stream valley that developed along the west and northwest flanks of a shallow structural basin, the Michigan Basin. The configuration of the Lake basin is generally defined by the curved outcrops of rocks of relatively weak formations, mainly shales and limestones of Devonian age. Formed in sedimentary rocks and centered in southern Michigan, the Michigan Basin is an intracratonic structural sag or depression that formed during the early Paleozoic. The sediments that filled the Michigan intracratonic basin were derived from neighboring highlands such as the Adirondack Highlands to the east and northeast, the Findlay, Kankakee, and Cincinatti arches to the south, the Wisconsin Highlands to the west and northwest and the Canadian Shield to the north. The sedimentary strata in the downwarped Michigan Basin are similar to bowls whose eroded edges reach the surface in a series of concentric rings. The younger strata outcrop near the center of the basin and the older layers around the edges. However, bedrock outcrops along the Lake basin are relatively rare as the effects of the Pleistocene glaciers have masked the former geologic history of much of the surfacial features in this region.

All of the Lake Michigan basin was covered by several thousand feet of ice during the initial stages of the Wisconsin glacial. As the Cary ice sheet retreated, 16,000 to 13,500 years before the present, glacial melt waters were impounded between the margin of the ice front and the Valparaiso moraine system at the southern end of the Lake basin. The several stages of these proglacial lakes are referred to as Lake Chicago and include the Glenwood and Calumet stages. These early lakes drained south-westward through the Chicago outlet and varied in extent and water level according to the status of the successive ice sheet advances and retreats. During the Two Creeks interval the Port Huron ice sheet had retreated sufficiently northward to free most of the Lake Michigan and Lake Huron basins from ice cover, forming the Kirkfield Lower Water Stage which united both basins into a single lake. The lake levels dropped as successively lower drainageways were uncovered: Georgian Bay eastward to the Ontario basin and the St. Lawrence Lowland. During the Valders readvance the margin of the ice sheet extended down the Lake basin to approximately Milwaukee and Muskegon. The melt waters were again impounded in the southern portion of the Lake basin and another Lake Chicago stage developed. The retreat of the Valders ice sheet eventually created Lake Algonquin whose water surface also included both the Lake Michigan and Lake Huron basins. Further retreat again uncovered lower discharge outlets to the north and formed Lake Chippewa whose water elevation was only 70 meters (230 feet). This lake was much smaller than the present one. Isostatic rebound of the earth's surface during the Nipissing and Algoma postglacial stages caused these northern discharge outlets to eventually become inoperative, forming the present Lake Michigan configuration. Differential uplift between the southern end of Lake Michigan and the Michigan-Huron outlet is still continuing, causing a submergence at Chicago of .4 meter (1.48 feet) per century.

South of Milwaukee and Muskegon, the glacial moraines at or near the shore were formed as part of the Lake Border moraine system which was generated during the Cary substage. Also deposited during the Cary substage were Tinley and Valparaiso moraines which are located inland of the Lake Border system. When exposed in bluffs along the shore, Tinley or Valparaiso drift may underlie Lake Border drift. North of Milwaukee and Muskegon the moraines along the shore are composed of drift deposited during the Valders substage. The predominantly red color indicates that the ice picked up and incorporated red silt and clay from the bottom sediments of Lake Superior and fragments of the Precambrian iron formations of the western part of the Michigan Upper Peninsula.

Bluffs of unconsolidated material form steep embankments along approximately one-third of Lake Michigan's shoreline. The entire southeastern coast alternates between bluffs, extending tens of kilometers along the shore, and dune fields of similar dimensions. Further, there is a close correlation of present shoretypes and glacial deposits along the Lake Michigan coast. Most bluffs occur at the intersection of a glacial moraine with the present shoreline. Some of the low bluffs along the northern shore may be cut in lacustrine sediments that are covered with only a thin veneer of wind blown sand. There are relatively few bedrock outcrops along these shores. Except for two stretches of outcrops of Niagaran limestone along the Door Peninsula, most bedrock sections have been eroded to present lake levels and form broad beaches extending from the shore. Marshes, swamps, and dry, low plains constitute a quarter of the shoreline. Some of these gentle, undulating plains represent strand lines, i.e., the shorelines of former lakes whose water elevation was higher than the present one. Marginal lakes, not associated with major rivers, are another relic of higher lake levels. As the level of Lake Michigan decreased, littoral deposits isolated these former embayments from the lake proper. The emerged landscape was subsequently buried by aeolian deposition. Silver, Hamlin, Crystal, and Glen Lakes are presently separated from Lake Michigan by broad tracts of transverse dunes.

The sand dunes are the most impressive natural feature of the Lake Michigan shoreline. They extend almost continuously along the eastern shore from the Indiana Dunes National Lakeshore northward to the top of the Leelanau Peninsula. Two extensive tracts also occur along the northern coast. There are two types of coastal dunes: foredune ridges and high dunes. Foredune ridges are younger as they are related to the relatively low water levels and shorelines of the modern Great Lakes and usually range from 9 to 15 meters (30 to 50 feet) in height. The high dunes are related to the water levels during the Nipissing postglacial stage and are commonly over 30 meters (100 feet) in height. High dunes deposited on the tops of glacial moraines are termed perched dunes. The Sleeping Bear Dune is an example of a perched dune; the dunes found at Warren, Michigan are high dunes; and the dunes found near Michigan City, Indiana are foredunes.

The west coast of Green Bay, Wisconsin consists of wetlands and a low, erodible plain which gently ascends to the west. The east coast of the Bay is characterized by the rocky limestone cliffs of the Door Peninsula. The lake side of the peninsula and the remainder of the Wisconsin shoreline of Lake Michigan generally consist of sloping, unconsolidated bluffs of glacial sediments. Exceptions are the foredunes found near Two Rivers and Cheyboygan, Wisconsin. The sand and gravel beaches at the base of these highly erodible bluffs remain narrow as the littoral drift carries the eroded materials away.

Low, sand-gravel plains characterize the Illinois shoreline from the Wisconsin-Illinois State line to Waukegan. High bluffs composed of glacial till and outwash deposits are present from Waukegan to Glencoe. Artificial fill is present along the coast from Glencoe to the Illinois-Indiana State line. The entire coastline, where unprotected, is highly erodible. The beaches, ranging from 15 to 107 meters (50 to 350 feet) in width, extend the length of the coast.

Artificial industrial lake fills extend along the Indiana shoreline from the Illinois-Indiana State line to the western limit of Marquette Park in Gary. Low sand plains fronted by wide sand beaches characterize the coast from Marquette Park to the mouth of the Burns Waterway. From this point to the Indiana-Michigan State line, the shoreline consists of high sand dunes fronted by sand beaches. It is estimated that 21 (13) of these 72 kilometers (45 miles) of shoreline sustain critical erosion processes.

As previously stated, unconsolidated bluffs and sand dunes alternate along most of the shoreline from the Indiana-Michigan State line to Grand Traverse Bay. From Grand Traverse Bay to the Straits of Mackinac the coast is generally characterized by narrow, cobble beaches backed by erodible bluffs and low plains. Scattered wetlands are present from Sturgeon Bay to Mackinac City. Along the southern edge of the Upper Peninsula from the Straits of Mackinac to Gladstone the shoreline is generally irregular and contains many small bays. Low limestone bluffs are found at the points of these bays while the bay heads are commonly sand beaches. From Gladstone to the Michigan-Wisconsin State line the shorelands mainly consist of gently sloping sand and gravel beaches, frequently backed by low sand bluffs. Wetlands and marshes are found along the shores of both Big and Little Bay de Noc. Approximately 52 percent of Michigan's Lake Michigan shoreline has been categorized as erodible high bluff, erodible low bluff, and erodible low plain. About 20 percent of this shoreline consists of sand dunes and wetlands account for nearly 10 percent of the coast.

Approximately 77 percent of the Lake Michigan coastline is subjected to erosion and flooding, see Table 4. Extensive erosion is occurring along the Michigan shoreline from Leelanau through Berrien Counties, along the entire Indiana and Illinois shoreline and along the Wisconsin shoreline from Kenosha through Ozaukee Counties. These highly erodible areas include high unconsolidated bluffs, high dunes, and low plains, see Figures 19 and 20. Erosion is negligible along the coasts of Delta County, Michigan and northern Door County, Wisconsin due to the rocky shoreline. Flooding is the major problem along the Lake Michigan coast from northern Menominee County, Michigan to Green Bay, Wisconsin where wetlands and low erodible plains predominate, see Figures 19 and 21.

High lake levels greatly enhance the probability of flooding and erosion. While the maximum recorded lake level was reached in the 1880's, high water levels have occurred during the early 1950's and the early through mid-1970's, see Figure 4. During the more recent periods, extensive erosion and flooding damages were incurred by public and private property owners. Based on the 1970 value of the dollar, the damages resulting from flooding and erosion during the 1951 to 1952 period were: $7.8 million in Wisconsin, $17.7 million in Illinois, $10.0 million in Indiana, and $13.8 million in Michigan. These values were derived for the Great Lakes Regional Inventory of the National Shoreline Study which was conducted by the U.S. Corps of Engineers. The highly developed and urbanized nature of the Indiana and Illinois shorelands accounts for the large monetary damage per mile of shoreline. During the high levels of the 1970's, over $30 million damage has been caused by erosion and flooding along Wisconsin's Lake Michigan coast. Monetary estimates for damages to the remainder of the Lake Michigan shorelands during the 1970's have not been compiled.

The degree of damage that is produced by any one storm is largely dependent on the intensity and direction of the wind and the height of the waves which are generated. Winds greater than 34 kilometers per hour (18 knots) generally come from the south, southwest, west, and northwest, creating waves which are directed against the east coast of Lake Michigan. Davis and Fox (1974) determined that wind from these directions frequently generate waves on the east coast which have a greater period and a breaker height that is about twice as high as that on the western coast of Lake Michigan. Wind roses for southern and northern Lake Michigan are found on pages 76 and 77.

TABLE 4

SHORETYPES ALONG THE SHORELINE OF LAKE MICHIGAN

SHORETYPES	MILES	KILOMETERS	PERCENTAGE
Artificial fill area	67.4	108.46	4.95
Erodible high bluff	273.6	440.30	20.09
Nonerodible high bluff	46.9	75.47	3.44
Erodible low bluff	118.9	191.34	8.73
Nonerodible low bluff	24.7	39.75	1.81
High sand dune	139.6	224.65	10.25
Low sand dune	73.4	118.12	5.39
Erodible low plain	287.5	462.66	21.11
Nonerodible low plain	173.5	279.21	12.74
Wetlands	94.5	152.08	6.94
Wetlands/Erodible plain	51.8	83.36	3.80
Wetlands/Erodible low bluff	10.2	16.41	0.75
Total Shore Length	1362.0	2191.8	100.00

Source: Great Lakes Basin Commission, 1975.

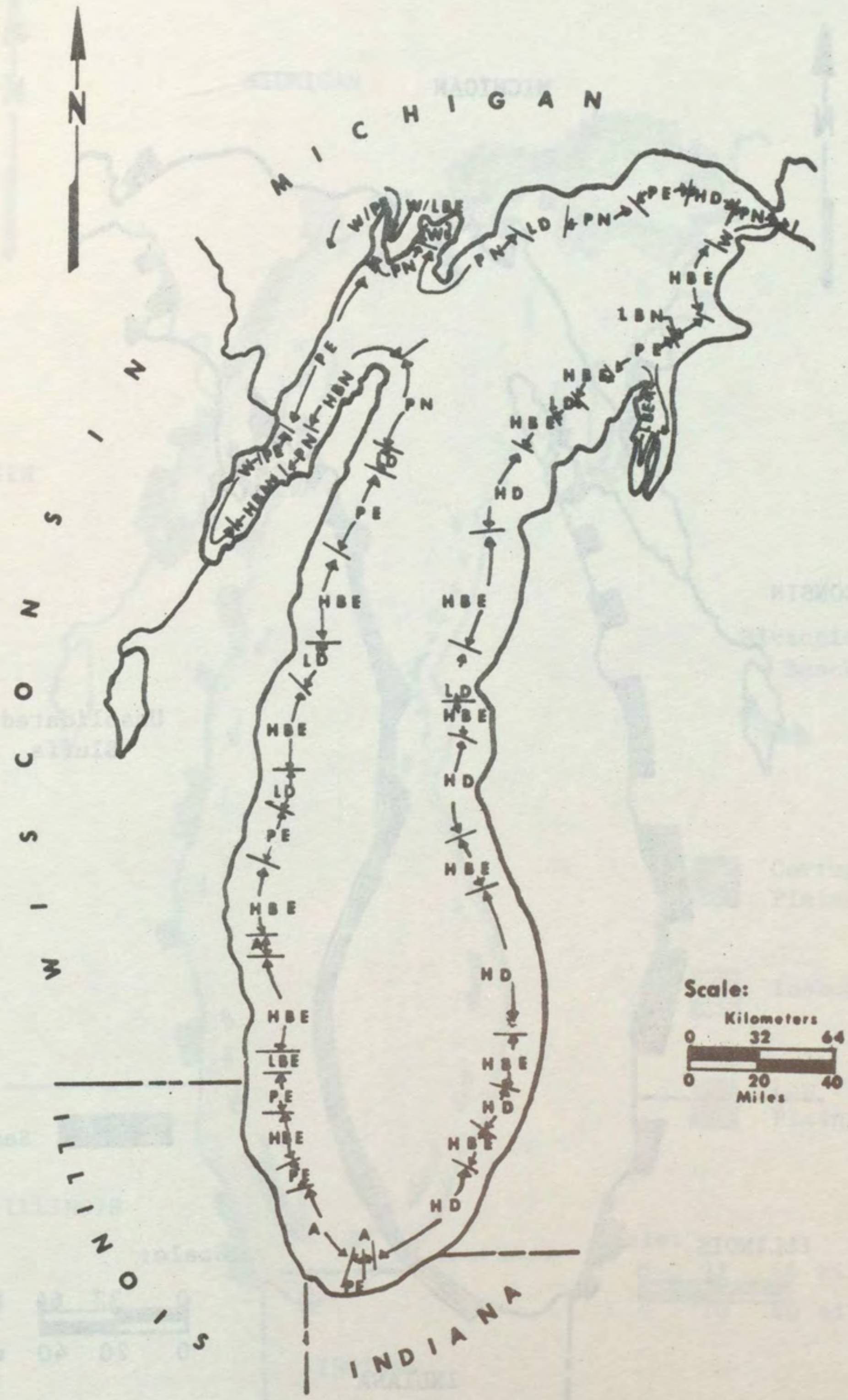


FIGURE 19. Shorelands of Lake Michigan.
SOURCE: U.S. Department of the Army, Corps of Engineers, 1971.

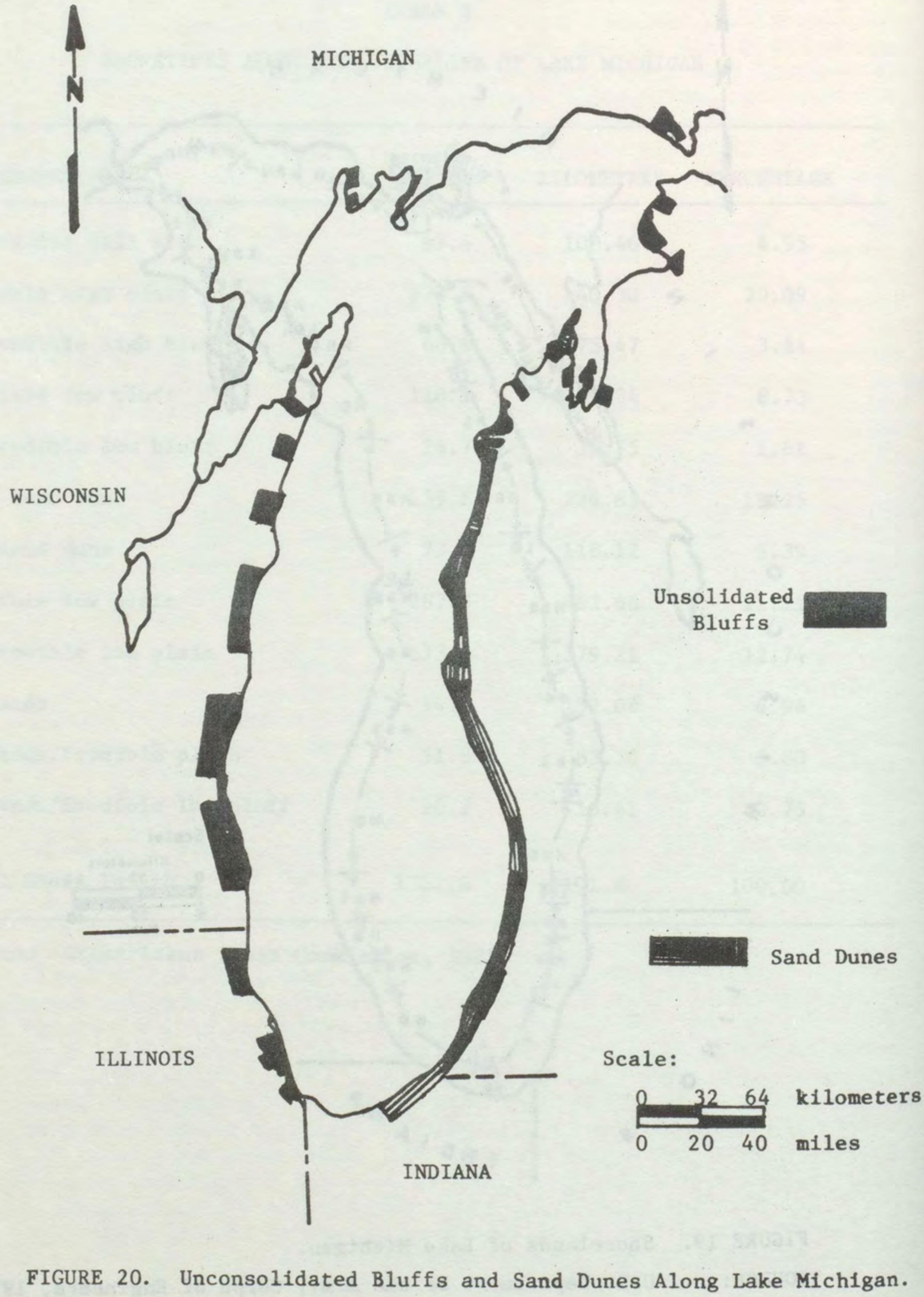


FIGURE 20. Unconsolidated Bluffs and Sand Dunes Along Lake Michigan.
SOURCE: Hands, 1970.

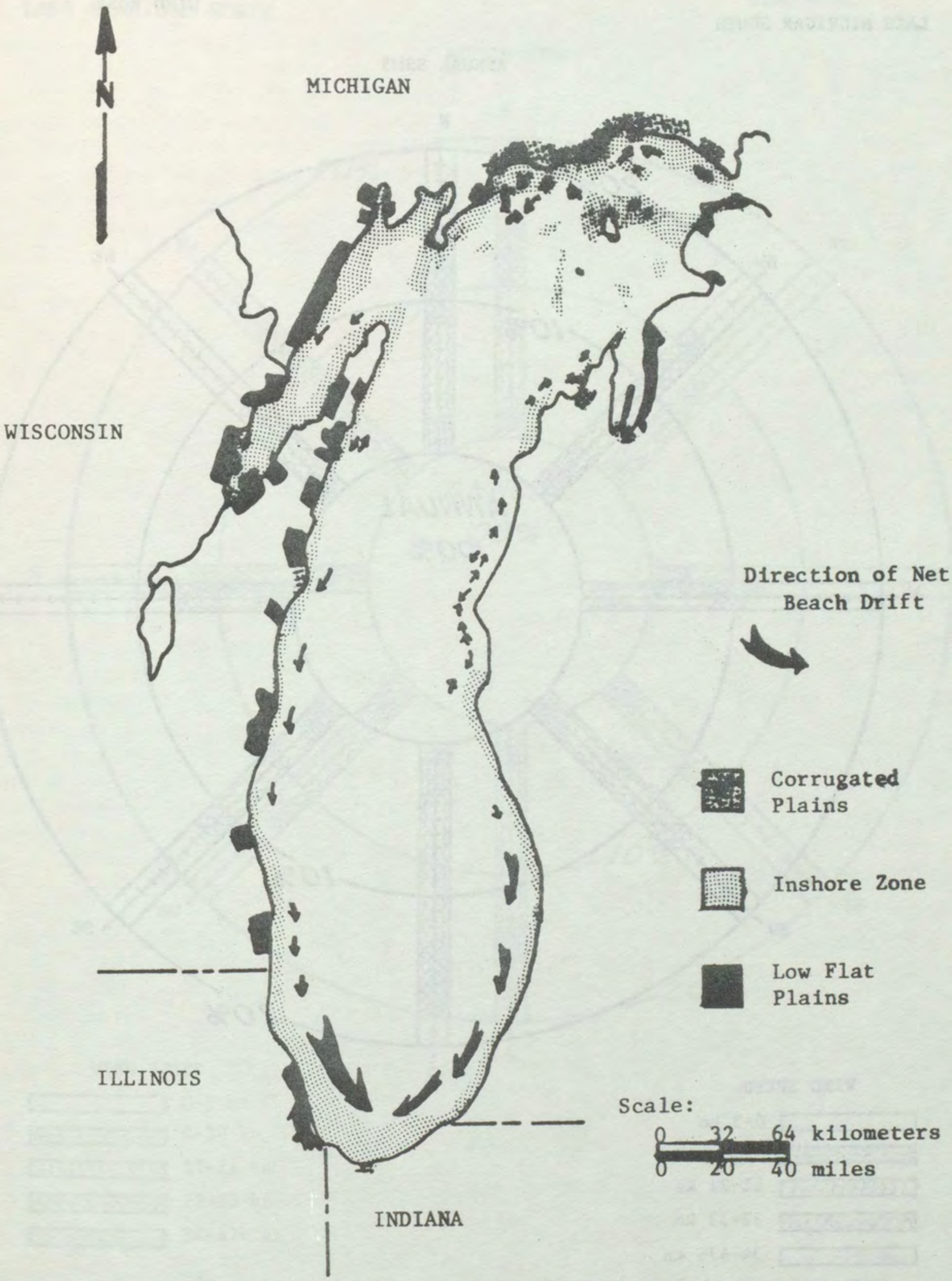


FIGURE 21. Plains Along Lake Michigan and Direction of Net Beach Drift.

SOURCE: Hands, 1970.

LAKE MICHIGAN SOUTH

WIND ROSE

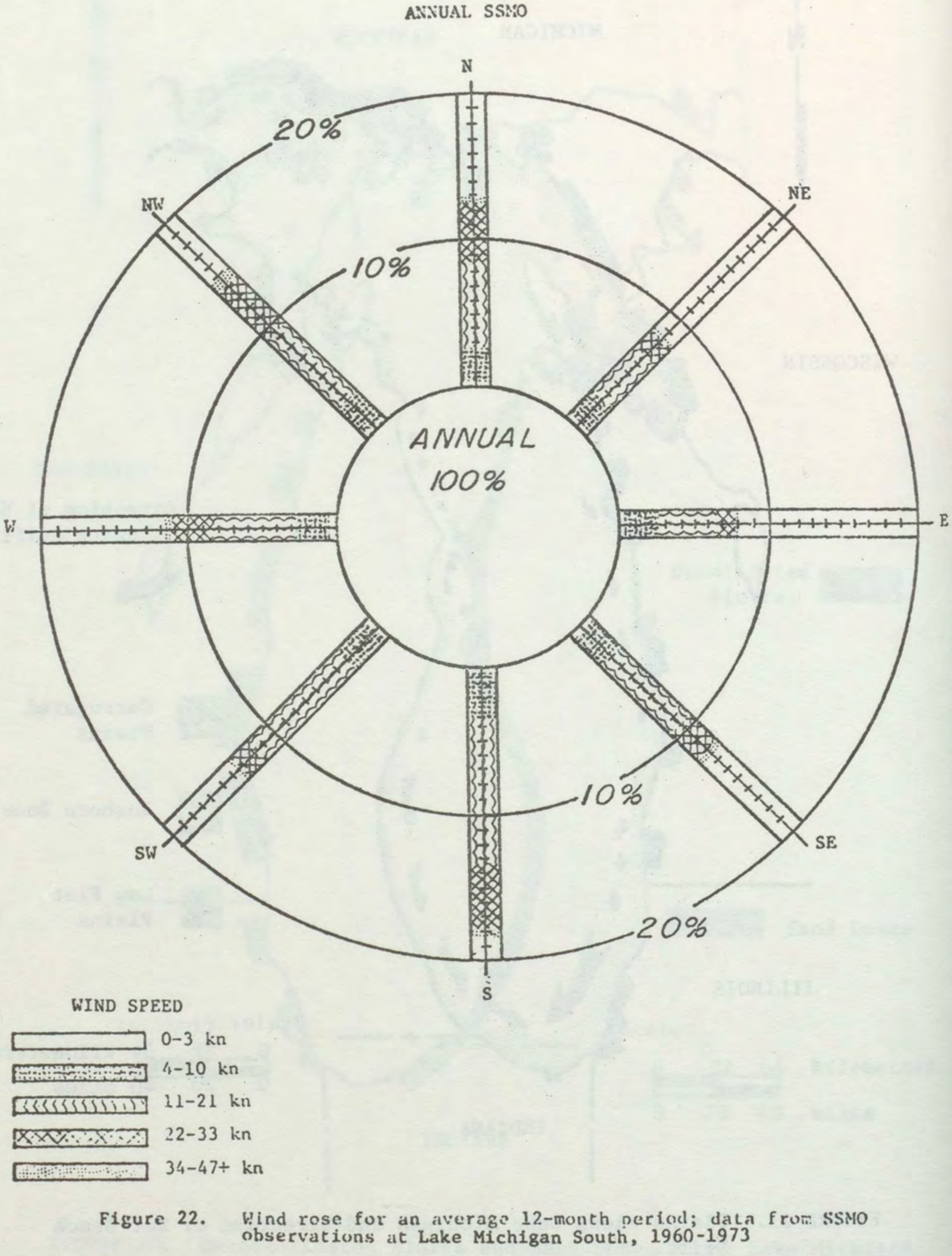


Figure 22. Wind rose for an average 12-month period; data from SSMO observations at Lake Michigan South, 1960-1973

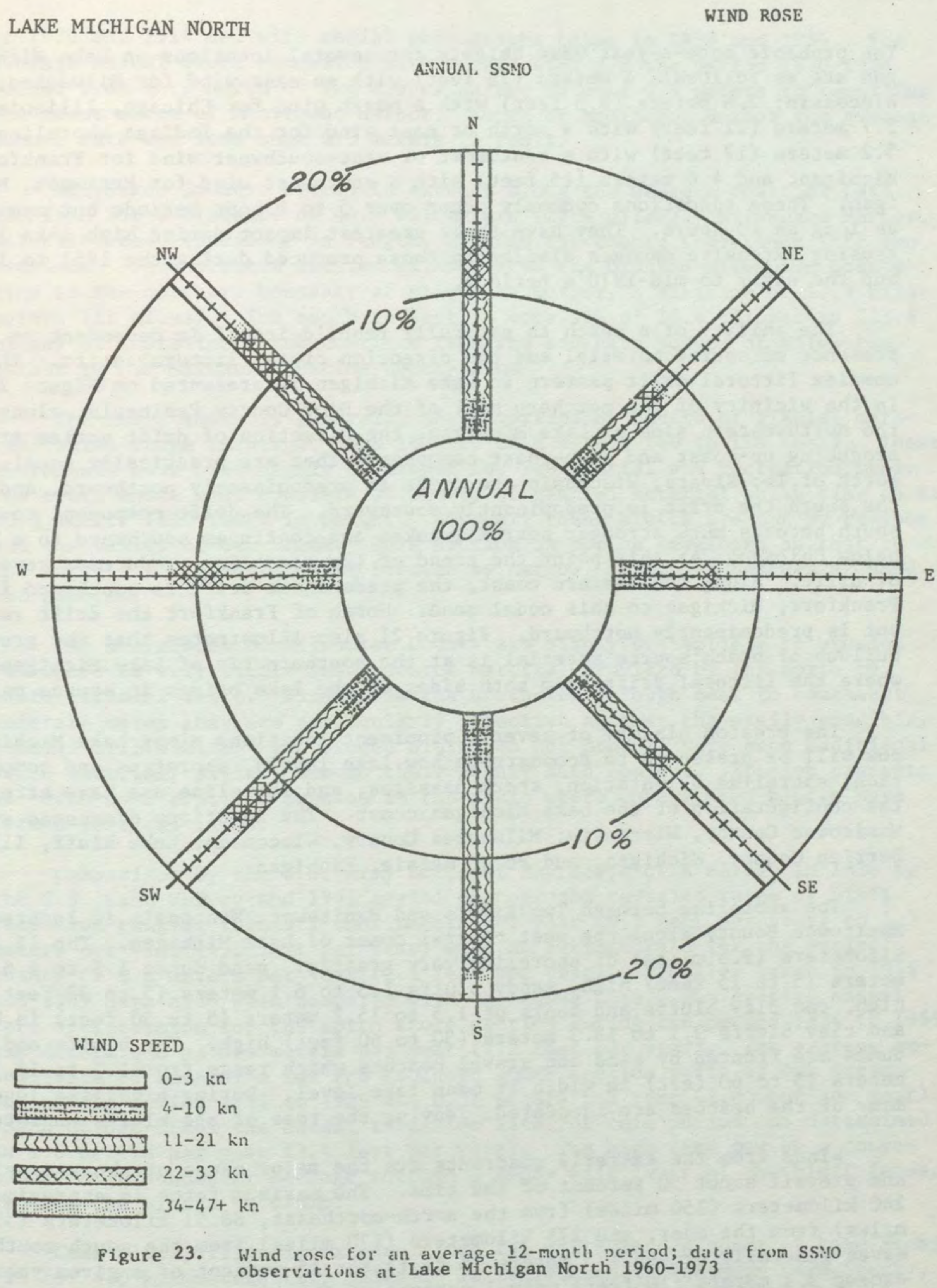


Figure 23. Wind rose for an average 12-month period; data from SSMO observations at Lake Michigan North 1960-1973

The probable once-a-year wave heights for several locations on Lake Michigan are as follows: 4 meters (13 feet) with an east wind for Milwaukee, Wisconsin; 2.6 meters (8.5 feet) with a north wind for Chicago, Illinois; 3.7 meters (12 feet) with a north or east wind for the Indiana shoreline; 5.2 meters (17 feet) with a southwest or west-southwest wind for Frankfort, Michigan; and 4.6 meters (15 feet) with a southwest wind for Muskegon, Michigan. These conditions commonly occur over 5 to 6 hour periods but can last as long as 10 hours. They have their greatest impact during high lake levels, causing extensive damages similar to those produced during the 1951 to 1952 and the early to mid-1970's periods.

The ability of a beach to naturally rebuild itself is dependent on the presence of source material and the direction of the littoral drift. The complex littoral drift pattern in Lake Michigan is presented on Figure 21. In the vicinity of the northern half of the Door County Peninsula, along the northwestern side of Lake Michigan, the direction of drift varies greatly, producing up-coast and down-coast components that are practically equal. North of Two Rivers, Wisconsin the drift is predominantly northward, and to the south the drift is predominantly southward. The drift component to the south becomes much stronger near Milwaukee and continues southward to a point below Chicago. At this point the trend of the coastline produces a reversal of drift. Along the eastern coast, the predominant drift is southward from Frankfort, Michigan to this nodal zone. North of Frankfort the drift varies but is predominantly northward. Figure 21 also illustrates that the greatest buildup of beach source material is at the southern tip of Lake Michigan where the littoral drift from both sides of the lake brings in source material.

The erosion history of several prominent locations along Lake Michigan now will be presented to demonstrate how lake levels, shoretype and composition, shoreline orientation, storm passages, and shoreline use have affected the configuration of the Lake Michigan coast. The locations discussed are: Manitowoc County, Wisconsin; Milwaukee County, Wisconsin; Lake Bluff, Illinois; Berrien County, Michigan; and Point Betsie, Michigan.

The shoreline between Two Rivers and Manitowoc, Wisconsin is located in Manitowoc County along the west central coast of Lake Michigan. The 15.3 kilometers (9.5 miles) of shoreline vary greatly: sand dunes 1.5 to 4.6 meters (5 to 15 feet) high, sandy bluffs 1.5 to 6.1 meters (5 to 20 feet) high, red clay bluffs and banks of 1.5 to 15.2 meters (5 to 50 feet) in height, and clay bluffs 9.1 to 18.3 meters (30 to 60 feet) high. The bluffs and dunes are fronted by sand and gravel beaches which range from 1.5 to 18.3 meters (5 to 60 feet) in width at mean lake level. During high lake levels many of the beaches are inundated, leaving the toes of the bluffs unprotected.

Winds from the easterly quadrants are the major cause of shore erosion and prevail about 50 percent of the time. The maximum fetch is approximately 240 kilometers (150 miles) from the north-northeast, 88.51 kilometers (55 miles) from the east, and 275 kilometers (170 miles) from the south-southeast. Waves generally exceed 1.5 meters (5 feet) for 15 percent of a given year but exceed 3.1 meters (10 feet) only 1 percent of the time. Recession rates were determined for this area by the U.S. Army Corps of Engineers (1957). Soundings taken in 1953 were compared with contours from U.S. Lake Survey charts of 1870 and 1914 and with aerial photographs taken in 1938 and 1954. The average annual bluff recession within this area for the period 1870-1954 varied from zero north of Two Rivers Harbor to over 0.9 meters (3 feet) for the coast north of Manitowoc Harbor. South of Manitowoc Harbor the average annual rate was less than 0.3 meters (1 foot).

Milwaukee County, Wisconsin extends along the western coast of Lake Michigan for a distance of 44.1 kilometers (27.4 miles). Milwaukee Harbor, 8.1 kilometers (5 miles) in length, divides the county shorelands into two sections. The northern section extends from the Ozaukee-Milwaukee County line to the northern boundary of Milwaukee Harbor, a distance of 17.7 kilometers (11 miles). The southern section consists of 18.4 kilometers (11.4 miles) of shoreline which continue from the southern border of Milwaukee Harbor to the Milwaukee-Racine County line.

The north shore is generally characterized by bluffs of glacial material which range in height from 18.3 to 36.6 meters (60 to 120 feet). These shorelands have been highly developed for residential and recreation uses. The south shore also consists of bluffs of glacial material which rise up to 30.5 meters (100 feet) in height. However, these bluffs are cut by ravines and the valley of Oak Creek. This section is not as developed as that to the north. Both sections are fronted by narrow, irregular beaches of sand and pebbles.

The shorelands of Milwaukee County are highly susceptible to erosion and there is very little beach source material provided by the north to south littoral drift. Winds from the northeast through east to southeast generate waves that are particularly effective against the easily erodible, glacial till bluffs. The eroded bluffs do not produce very much additional beach material, either, due to their scanty sand content. Erosion presents an even more critical problem in the areas where unvegetated bluffs have formed vertical faces.

Comparison by the U.S. Army Corps of Engineers of a survey in 1836 by the U.S. Land Survey and 1941 aerial photographs revealed rates of bluff recession ranging from 6.1 centimeters per year (0.2 feet per year) to 1.2 meters per year (4.0 feet per year) with an average rate for the entire county of 0.6 meters per year (2.1 feet per year). Profiles taken in 1944 and 1969 have also been compared with the above data. The average annual rate of recession for the north shore section during the period 1836 to 1969 was determined as 0.4 meters per year (1.2 feet per year). The average annual rate of recession for the southern shore section north of Oak Creek during the period 1944 to 1969 was 0.31 meters per year (1.0 foot per year). South of Oak Creek the annual recession rate for this period was determined as 1.0 meters per year (3.4 feet per year). The high rate may be a consequence of groundwater seepage through a sandy silt layer of the bluff faces, causing the bluffs to slump.

Lake Bluff, Illinois extends along the southwestern coast of Lake Michigan for 4.0 kilometers (2.5 miles). It is located in southern Lake County, immediately south of the Great Lakes Naval Training Center. The shore is characterized by bluffs approximately 21 meters (70 feet) high. Several deep ravines cut the southern one-third of the shore, providing good drainages. However, the northern two-thirds is uninterrupted and has poor drainage. Occasional narrow beaches line approximately one-third of the shoreline.

The upper one-third to one-half of the bluffs consists of soft, porous glacial outwash sand, silts, gravel, and silty till that are exceedingly weak. The sands and gravels are excellent conductors of groundwater, enabling it to seep into a bluff face and cause slumping. The lower one-half to two-thirds of the bluffs are composed of stable, homogeneous, gray silty till.

Over one-half of this shoreline has been classified as suffering severe erosion and rapid recession. An additonal 26 percent of the shorelands are denuded and actively eroding. Berg and Collinson (1975) have derived recession rates for the Lake Bluff shoreline by comparing topographic maps from the U.S. Army Corps of Engineers for 1872 and 1910 with aerial photographs for 1947, 1964, 1969, 1970, 1973, 1974, and 1975. Since 1964 the eroding sections have receded an average of 8.9 meters (29.2 feet) and contributed more than 520,200 cubic meters (680,000 cubic yards) of material to Lake Michigan. The bluffs have receded an average of 12.3 meters (40.5 feet) during the last 25 years and an average of 25.8 meters (84.5 feet) during the last 50 years. Since 1872 the bluffs have receded an average of 78.9 meters (259 feet) and contributed over 4.59 million cubic meters (6 million cubic meters (6 million cubic yards) to Lake Michigan.

Berrien County, Michigan extends along the southeastern coast of Lake Michigan for 67.6 kilometers (42 miles). High bluffs of sand and clay ranging from 24.4 to 33.5 meters (80 to 110 feet) in height and fronted by sand beaches, line the shore from the Van Buren-Berrien County line to the northern limits of Benton Harbor, a distance of 15.6 kilometers (9.7 miles). From Benton Harbor south 2.3 kilometers (1.4 miles) to the north edge of the entrance to St. Joseph Harbor, the shore consists of low sand dunes and wide sand beaches. Sand beach continues from the south edge of the harbor to the Chesapeake and Ohio Railway Company's protective structures. Clay bluffs, up to 27.4 meters (90 feet) in height, extend along the shore from the Michigan State Highway's protective works to the southern limit of the Village of Shoreham, a distance of 4.4 kilometers (2.7 miles). The shorelands of Lincoln Lake, Chikaming, and New Buffalo townships, 42.7 kilometers (26.5 miles) in length, are characterized by alternating sand and clay bluffs which range up to 61 meters (200 feet) in height and are fronted by narrow beaches.

Winds from the south through west to north prevail about 60 percent of the time with a average intensity of 20.4 kilometers per hour (11 knots). Winds from the north through east to southeast prevail the remaining 40 percent of the time with an average intensity of 13.4 kilometers per hour (7.2 knots). These winds generate waves on Lake Michigan over the following fetches: about 360 kilometers (225 miles) from the north, 225 kilometers (140 miles) from the north to northwest, 160 kilometers (100 miles) from the northwest, 96 kilometers (60 miles) from the west, and 80 kilometers (50 miles) from the southwest. While waves from the northwest and southwest cause movement of beach material, the predominant littoral drift is southward at an estimated rate of 76,500 cubic meters per year (100,000 cubic yards per year).

Recession rates for segments of the Berrien County shoreline were determined in 1958 by the U.S. Army Corps of Engineers. Topographic maps for 1830, 1872, and 1907 were compared with aerial photographs for 1950 and 1954 and shore profiles for 1954. The maximum average recession rate for the period 1830-1954 was 0.7 meters per year (2.3 feet per year) for the coastline just south of Grand Marais Lakes in Lincoln Township. Maximum accretion for the period 1830-1954 was 1.3 meters per year (4.4 feet per year) in the vicinity just north of the St. Joseph Harbor entrance. Average bluff recession from the harbor entrance to south of the Village of Shoreham was determined as 0.6 meters per year (2.1 feet per year) with an average contribution of 198,900 cubic meters (260,000 cubic yards) of bluff materials to the lake each year.

Profiles taken in 1971 at 24 locations which ranged from north of the city limits of Benton Harbor to Shoreham have been compared with the previous data. The shoreline located north of Benton Harbor to the north edge of St. Joseph Harbor has changed from an area of accretion to an area of recession during the 1954 to 1971 period: from an average accretion rate of 0.8 meters per year (2.6 feet per year) for the period 1830 to 1954 to an average recession rate of 0.4 meters per year (1.2 feet per year) for the period 1954 to 1971. The average recession rate for the shoreline south of St. Joseph Harbor to south of the Village of Shoreham was determined as 0.3 meters (1.1 feet) per year for the 1954 to 1971 period.

Seibel (1972) determined recession rates for 9.66 kilometers (6 miles) of shoreline in the vicinity of Bridgman in Lake Township, see Figure 24. The sand dunes along this segment average 9.1 meters (30 feet) in height but decrease to less than 1.8 meters (6 feet) and are fronted by beaches less than 15.2 meters (50 feet) wide. Aerial photographs for 1938, 1950, 1955, 1960, 1967, and 1970 were compared for 18 sites. The average recession rates were found to be as follows: 0.8 meters per year (2.5 feet per year) for 1938 to 1950, 2.8 meters per year (9.1 feet per year) for 1967 to 1970, and 2.8 meters per year (9.1 feet per year) for 1970 to 1972.

The shoreline at Point Betsie, Michigan, located just north of Frankfort in Benzie County, is characterized by low lying sand dunes which are fronted by narrow sand and gravel beaches, see Figure 24. The foreshore is frequently composed of coarse gravel and cobbles while the back shore consists of sand. Although the dunes are vegetated, blowouts are numerous.

Winds from the north to northwest are generally the most destructive. This direction provides a long fetch and generates waves which approach the coast at a substantial angle, creating rapid longshore currents which are capable of transporting large quantities of sediment. In additon, the steep inner nearshore profile enables a relatively high amount of wave energy to attack the shore.

Davis (1976) profiled a site on Point Betsie at monthly intervals during the period 1970 to 1973 to study the erosion processes. During the fall of 1970 the lakeward face of the low lying dunes eroded 2.1 meters (7 feet) without a corresponding change in the beach position. It appeared that the beach was capable of restoring itself within the four-week surveying

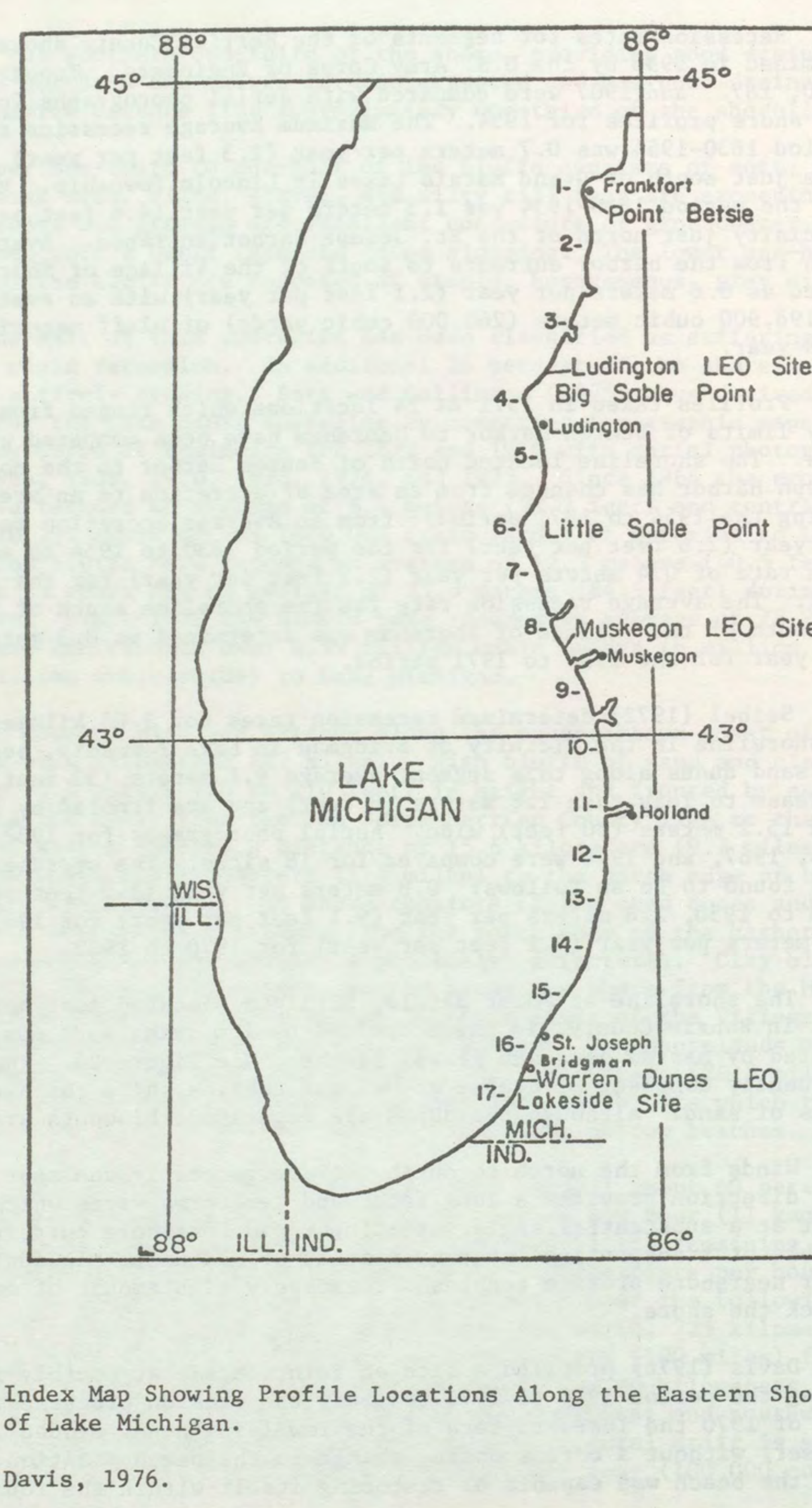


FIGURE 24. Index Map Showing Profile Locations Along the Eastern Shore of Lake Michigan.

SOURCE: Davis, 1976.

interval. The dune face lost 3.4 meters (11 feet) during a spring storm in 1973 and the beach area was completely destroyed in June, 1973. During this last storm 6.3 cubic meters (222 cubic feet) of sediment were contributed to the lake.

Recession Rates

Recession rates have been determined for 54 percent of the erodible shoreline of Lake Michigan, see Table 5 and Figure 25. In general, the eastern coast of Lake Michigan is experiencing higher recession rates than those along the western coast. The relatively lower resistance of the eastern shorelands is largely a consequence of the weather patterns, shoreform, and shore material composition. Winds from the east are lowest in the percentage of occurrence and intensity. Thus, the western shoreline is not subjected to the same frequency of storms, nor the intensity. In contrast, winds greater than 40.8 kilometers per hour (22 knots) come from the south, southwest, west, and northwest and occur 20 percent of the time; refer to the wind roses on pages 76 and 77. The winds from these directions frequently generate waves on the east coast which have a greater period and a breaker height that is about twice as high as that on the western coast of Lake Michigan (Davis and Fox, 1974). In addition, the eastern coast is generally characterized by high bluffs of unconsolidated glacial material and high dunes. Their high sand content, with its lack of cohesiveness, increases the ability of the attacking waves to carry away large amounts of shore material. However, this process also provides the north-south littoral drift with a considerable quantity of beach rebuilding material, as evidenced by the wider beaches of the eastern coast. The west coast, on the other hand, consists of a greater percentage of clay bluffs and banks whose somewhat more cohesive nature slightly increases the ability of the shorelands to withstand the occasionally intense wave attack.

The maximum recession rate, however, occurs in Kenosha County, Wisconsin. A 4.0 kilometer (2.5 mile) reach along the southwestern shore of Lake Michigan has experienced an average recession rate of 2.6 meters per year (8.4 feet per year) for the 1834 to 1957 period. This shore consists of low sand banks. Their low relief makes this stretch of shoreline highly susceptible to wave attack while the sand content lacks the ability to offer resistance to even minor wave attack. Consequently, this reach along the western coast of Lake Michigan is easily eroded, creating the relatively high annual rate of recession.

Due to the north-south orientation of Lake Michigan, the waves potentially generated over the longest fetch distances are located at the north and south ends of the lake. Accordingly, one might have expected the highest recession rates to be generated at these ends. However, shoreforms and wind patterns have minimized the effects of these waves. Winds from the north occur only about 14 percent of the time and are generally less than 40.8 kilometers per hour (22 knots). Thus, the southern tip of the lake is seldom subjected to strong winds for an extended period of time, resulting in fairly low recession rates. This is evidenced by annual average recession rates of 0.5 meter per year (1.6 feet per year) for the period 1947-1975 along a 25.8 kilometer (16 mile) stretch of shoreline consisting of high

TABLE 5

RECESSION RATES ALONG U.S. SHORELINE OF LAKE MICHIGAN

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Kewaunee Co. Wisconsin											
38-001-004	4.18	(2.6)	LBE	2.29	(2.5)						
38-004-007	3.22	(2.0)	LBE	2.29	(7.5)						
38-007-010	3.86	(2.4)	PE	2.29	(7.5)						
38-010-014	2.90	(1.8)	HBE	11.43	(37.5)	0.15	(0.5)	0.15	(0.5)	0.15	(0.5)
38-014-015	2.41	(1.5)	LBE	5.33	(17.5)	-0.03	(-0.1)	-0.03	(-0.1)	-0.03	(-0.1)
38-015-018	3.5	(2.2)	LBE	5.33	(17.5)						
38-018-023	5.79	(3.6)	HBE	11.43	(37.5)	0.12	(0.4)	0.18	(0.6)	0.09	(0.3)
38-023-025	4.99	(3.1)	HBE	11.43	(37.5)	0.24	(0.8)	0.34	(1.1)	0.18	(0.6)
38-025-034	11.26	(7.0)	HBE	17.53	(57.5)	0.24	(0.8)	0.52	(1.7)	0.12	(0.4)
38-034-037	2.57	(1.6)	HBE	5.33	(17.5)						
38-037-037	0.96	(0.6)	LBE	11.43	(37.5)	0.66	(2.2)	0.66	(2.2)	0.66	(2.2)
Manitowoc Co. Wisconsin											
40-001-007	8.85	(5.5)	LBE	5.33	(17.5)	0.61	(2.0)	0.85	(2.8)	0.12	(0.4)
40-007-007	0.96	(0.6)	LBE	2.29	(7.5)						
40-007-018	12.87	(8.0)	LD	2.29	(7.5)						
40-018-018	0.80	(0.5)	PE	2.29	(7.5)						
40-018-019	0.80	(0.5)	PE	0.76	(2.5)						
40-019-022	4.67	(2.9)	LBE	0.76	(2.5)						
40-022-026	4.83	(3.0)	LBE	5.33	(17.5)						
40-026-027	2.41	(1.5)	A	5.33	(17.5)						
40-027-027	0.96	(0.6)	HBE	5.33	(17.5)						

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Manitowoc Co. (continued)											
40-027-030	4.02	(2.5)	HBE	17.53	(57.5)	0.49	(1.6)	0.61	(2.0)	0.34	(1.1)
40-030-037	9.01	(5.6)	HBE	11.43	(37.5)	0.06	(0.2)	0.09	(0.3)	0.06	(0.2)
40-037-043	8.85	(5.5)	HBE	14.48	(47.5)	0.40	(1.3)	0.61	(2.0)	0.12	(0.4)
Sheboygan Co. Wisconsin											
41-001-005	7.24	(4.5)	HBE	14.48	(47.5)	0.37	(1.2)	0.49	(1.6)	0.27	(0.9)
41-005-006	1.93	(1.2)	HBE	11.43	(37.5)	0.40	(1.3)	0.52	(1.7)	0.30	(1.0)
41-006-009	2.41	(1.5)	HBE	14.48	(47.5)						
41-009-012	4.34	(2.7)	HBE	11.43	(37.5)	0.00	(0.0)	0.00	(0.0)	0.00	(0.0)
41-012-013	1.45	(0.9)	A	0.76	(2.5)						
41-013-014	1.45	(0.9)	PE	0.76	(2.5)						
41-014-014	1.45	(0.9)	HBE	9.91	(32.5)	0.30	(1.0)	0.30	(1.0)	0.30	(1.0)
41-014-015	1.45	(0.9)	LBE	9.91	(32.5)						
41-015-022	8.21	(5.1)	LD	2.29	(7.5)						
41-022-023	1.61	(1.0)	LD	0.76	(2.5)						
41-023-030	12.87	(8.0)	PE	0.76	(2.5)	0.06	(0.2)	0.15	(0.5)	-0.12	(-0.4)
Ozaukee Co. Wisconsin											
42-001-004	4.99	(3.1)	PE	0.76	(2.5)	0.03	(0.1)	0.03	(0.1)	0.03	(0.1)
42-004-008	6.28	(3.9)	LBE	2.29	(7.5)	0.03	(0.1)	0.03	(0.1)	0.00	(0.0)

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Ozaukee Co. (continued)											
42-008-015	7.88	(4.9)	HBE	23.62	(77.5)	0.40	(1.3)	0.40	(1.3)	0.40	(1.3)
42-015-015	2.41	(1.5)	A	0.76	(2.5)						
42-015-020	5.63	(3.5)	HBE	29.72	(97.5)	0.52	(1.7)	0.52	(1.7)	0.52	(1.7)
42-020-027	10.94	(6.8)	HBE	35.81	(117.5)	0.94	(3.1)	1.04	(3.4)	0.91	(3.0)
42-027-031	6.60	(4.1)	HBE	29.72	(97.5)						
Milwaukee Co. Wisconsin											
43-001-006	7.24	(4.5)	HBE	29.72	(97.5)	0.12	(0.4)	0.15	(0.5)	0.03	(0.1)
43-006-007	2.74	(1.7)	HBE	35.81	(117.5)	0.55	(1.8)	0.58	(1.9)	0.52	(1.7)
43-007-014	5.63	(3.5)	HBE	32.77	(107.5)	0.61	(2.0)	0.94	(3.1)	0.40	(1.3)
43-014-014	0.80	(0.5)	A	0.76	(2.5)						
43-014-015	2.41	(1.5)	PE	0.76	(2.5)						
43-015-021	9.66	(6.0)	A	0.76	(2.5)						
43-021-023	3.06	(1.9)	HBE	11.43	(37.5)	0.49	(1.6)	0.52	(1.7)	0.46	(1.5)
43-023-024	0.80	(0.5)	A	0.76	(2.5)						
43-024-029	8.85	(5.5)	HBE	29.72	(97.5)	0.24	(0.8)	0.37	(1.2)	0.04	(0.3)
43-029-030	1.77	(1.1)	HBE	26.67	(87.5)	0.21	(0.7)	0.21	(0.7)	0.21	(0.7)
43-030-031	0.80	(0.5)	A	0.76	(2.5)	0.52	(1.7)	0.52	(1.7)	0.52	(1.7)
43-031-034	3.86	(2.4)	HBE	26.67	(87.5)	0.79	(2.6)	0.85	(2.8)	0.76	(2.5)
43-034-034	1.45	(0.9)	A	0.76	(2.5)	0.67	(2.2)	0.67	(2.2)	0.67	(2.2)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession Average m/yr	(ft/yr)	Maximum m/yr	(ft/yr)	Minimum m/yr	(ft/yr)
Racine Co. Wisconsin											
44-001-006	5.95	(3.7)	HBE	14.48	(47.5)	0.70	(2.3)	1.07	(3.5)	0.37	(1.2)
44-006-011	9.82	(6.1)	HBE	8.38	(27.5)						
44-011-013	3.22	(2.0)	A	0.76	(2.5)						
44-013-017	5.47	(3.4)	HBE	11.43	(37.5)						
44-017-017	1.77	(1.1)	HBE	8.38	(27.5)						
Kenosha Co. Wisconsin											
45-001-005	6.44	(4.0)	HBE	8.38	(27.5)	0.94	(3.1)	1.16	(3.8)	0.73	(2.4)
45-005-006	3.22	(2.0)	A	0.76	(2.5)	0.06	(0.2)	0.06	(0.2)	0.06	(0.2)
45-006-009	2.41	(1.5)	LBE	0.76	(2.5)						
45-009-010	2.25	(1.4)	A	2.29	(7.5)	1.28	(4.2)	1.28	(4.2)	1.28	(4.2)
45-010-012	4.83	(3.0)	LBE	2.29	(7.5)						
45-012-014	4.02	(2.5)	PE	0.76	(2.5)	2.56	(8.4)	2.56	(8.4)	2.56	(8.4)
Lake Co. Illinois											
46-001-010	11.70	(11.0)	PE	0.76	(2.5)						
46-010-012	1.61	(1.0)	HBE	2.29	(7.5)						
46-012-013	2.25	(1.4)	HBE	5.33	(17.5)						
46-013-029	25.75	(16.0)	HBE	20.57	(67.5)	0.49	(1.6)	0.76	(2.5)	0.21	(0.7)

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession Average m/yr	(ft/yr)	Maximum m/yr	(ft/yr)	Minimum m/yr	(ft/yr)
Porter Co. Indiana											
49-001-003	4.67	(2.9)	LD	5.33	(17.5)						
49-003-007	5.63	(3.5)	A	5.33	(17.5)						
49-007-009	4.18	(2.6)	HD	20.57	(67.5)						
49-009-011	2.90	(1.8)	PE/HD	20.57	(67.5)						
49-011-014	5.80	(3.6)	HD	20.57	(67.5)						
49-014-019	4.83	(3.0)	LD	5.33	(17.5)	0.82	(2.7)	1.19	(3.9)	0.64	(2.1)
49-019-021	4.02	(2.5)	HD	20.57	(67.5)	0.94	(3.1)	1.22	(4.0)	0.70	(2.3)
La Porte Co. Indiana											
50-001-002	1.93	(1.2)	HD	20.57	(67.5)						
50-002-004	2.57	(1.6)	HD	0.76	(2.5)						
50-004-004	1.13	(0.7)	A	2.29	(7.5)						
50-004-006	4.02	(2.5)	LD	2.29	(7.5)						
50-006-008	1.61	(1.0)	LD	8.38	(27.5)	0.67	(2.2)	0.67	(2.2)	0.67	(2.2)

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Berrien Co. Michigan											
21-001-002	3.38	(2.1)	LD	5.33	(17.5)	0.73	(2.4)	1.22	(4.0)	0.00	(0.0)
21-002-007	6.76	(4.2)	LD	8.38	(27.5)	0.70	(2.3)	1.40	(4.6)	0.37	(1.2)
21-007-013	6.60	(4.1)	LD	11.43	(37.5)	0.24	(0.8)	0.46	(1.5)	0.09	(0.3)
21-013-015	2.09	(1.3)	LD	8.38	(27.5)	0.55	(1.8)	0.79	(2.6)	0.15	(0.5)
21-015-019	3.38	(2.1)	HBE	11.43	(37.5)						
21-019-020	1.45	(0.9)	HBE	16.00	(52.5)						
21-020-020	0.64	(0.4)	HD	16.00	(52.5)						
21-020-032	14.97	(9.3)	HD	23.62	(77.5)	0.61	(2.0)	0.98	(3.2)	0.40	(1.3)
21-032-033	1.45	(0.9)	HD	9.91	(32.5)	0.55	(1.8)	0.73	(2.4)	0.40	(1.3)
21-033-036	2.09	(1.3)	HBE	9.91	(32.5)	0.94	(3.1)	1.43	(4.7)	0.49	(1.6)
21-036-039	4.83	(3.0)	HBE	17.53	(57.5)	1.04	(3.4)	1.65	(5.4)	0.27	(0.9)
21-039-043	5.15	(3.2)	LBE	0.76	(2.5)	1.25	(4.1)	1.25	(4.1)	1.25	(4.1)
21-043-050	9.98	(6.2)	HBE	23.62	(77.5)	0.37	(1.2)	0.76	(2.5)	0.00	(0.0)
21-050-051	1.93	(1.2)	HD	23.62	(77.5)	0.00	(0.0)	0.00	(0.0)	0.00	(0.0)
21-051-055	6.12	(3.8)	HD	11.43	(37.5)	0.18	(0.6)	0.27	(0.9)	0.09	(0.3)
Allegan Co. Michigan											
23-001-001	0.80	(0.5)	HBE	11.43	(37.5)						
23-001-008	8.69	(5.4)	HBE	23.62	(77.5)	1.04	(3.4)	1.65	(5.4)	0.49	(1.6)
23-008-012	17.06	(10.6)	HBE	17.53	(57.5)	0.91	(3.0)	1.65	(5.4)	0.40	(1.3)
23-012-015	4.83	(3.0)	HD	5.33	(17.5)	1.22	(4.0)	2.59	(8.5)	0.43	(1.4)
23-015-020	9.98	(6.2)	HD	23.62	(77.5)	1.25	(4.1)	1.71	(5.6)	0.82	(2.7)

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Van Buren Co. Michigan											
22-001-010	10.46	(6.5)	HD	23.62	(77.5)	0.52	(1.7)	0.79	(2.6)	0.15	(0.5)
22-010-010	1.45	(0.9)	HBE	23.62	(77.5)						
22-010-017	10.14	(6.3)	HBE	11.43	(37.5)	0.79	(2.6)	2.35	(7.7)	0.00	(0.0)
Ottawa Co. Michigan											
24-001-002	3.54	(2.2)	HD	17.53	(57.5)	0.85	(2.8)	1.43	(4.7)	0.30	(1.0)
24-002-009	10.30	(6.4)	HBE	17.53	(57.5)	0.40	(1.3)	1.43	(4.7)	0.00	(0.0)
24-009-019	13.04	(8.1)	HD	17.53	(57.5)	0.73	(2.4)	1.28	(4.2)	0.15	(0.5)
24-019-021	9.17	(5.7)	HD	23.62	(77.5)	0.67	(2.2)	1.31	(4.3)	0.12	(0.4)
24-021-028	6.92	(4.3)	HD	22.10	(72.5)	0.27	(0.9)	0.73	(2.4)	0.00	(0.0)
Muskegon Co. Michigan											
25-001-004	4.83	(3.0)	HD	26.67	(87.5)	0.30	(1.0)	0.88	(2.9)	-0.12	(-0.4)
25-004-006	4.02	(2.5)	HD	12.95	(42.5)	0.82	(2.7)	1.25	(4.1)	-0.12	(-0.4)
25-006-009	3.70	(2.3)	HD	26.67	(87.5)						
25-009-013	3.54	(2.2)	HD	12.95	(42.5)	0.30	(1.0)	0.79	(2.6)	-0.03	(-0.1)
25-013-013	2.41	(1.5)	HD	23.62	(77.5)	0.36	(1.2)	0.79	(2.6)	-0.09	(-0.3)
25-013-020	8.05	(5.0)	LBE	5.33	(17.5)	0.33	(1.1)	0.70	(2.3)	-0.98	(-3.2)
25-020-021	1.45	(0.9)	LBE	11.43	(37.5)	0.52	(1.7)	1.16	(3.8)	-0.06	(-0.2)
25-021-024	4.18	(2.6)	HD	11.43	(37.5)	1.13	(3.7)	1.77	(5.8)	0.67	(2.2)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric and rounded .

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shoreform	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Muskegon Co. (continued)											
25-024-025	1.93	(1.2)	HD	5.33	(17.5)	0.24	(0.8)	0.55	(1.8)	0.06	(0.2)
25-025-029	4.83	(3.0)	HBE	23.62	(77.5)	0.52	(1.7)	1.52	(5.0)	-0.40	(-1.3)
25-029-033	5.95	(3.7)	HD	23.62	(77.5)	0.67	(2.2)	1.68	(5.5)	0.03	(0.1)
Oceana Co. Michigan											
26-001-001	1.13	(0.7)	HD	23.62	(77.5)	0.64	(2.1)	0.85	(2.8)	0.24	(0.8)
26-001-008	8.69	(5.4)	HBE	23.62	(77.5)	0.52	(1.7)	1.28	(4.2)	-0.24	(-0.8)
26-008-014	11.10	(6.9)	HD	11.43	(37.5)	0.91	(3.0)	2.35	(7.7)	-0.03	(-0.1)
26-014-020	6.92	(4.3)	HD	5.33	(17.5)	0.61	(2.0)	1.28	(4.2)	0.34	(1.1)
26-020-027	8.53	(5.3)	HD	11.43	(37.5)	0.43	(1.4)	1.43	(4.7)	-0.03	(-0.1)
26-027-032	8.05	(5.0)	HD	14.48	(47.5)	0.27	(0.9)	0.43	(1.4)	0.15	(0.5)
Mason Co. Michigan											
27-001-003	4.35	(2.7)	HD	14.48	(47.5)	0.18	(0.6)	0.61	(2.0)	-0.06	(-0.2)
27-003-009	7.89	(4.9)	HBE	14.48	(47.5)	0.43	(1.4)	1.07	(3.5)	-0.03	(-0.1)
27-009-009	0.64	(0.4)	LD	14.48	(47.5)	0.15	(0.5)	0.40	(1.3)	-0.24	(-0.8)
27-009-011	4.18	(2.6)	LD	3.81	(12.5)	0.61	(2.0)	1.28	(4.2)	0.06	(0.2)
27-011-022	17.38	(10.8)	LD	5.33	(17.5)	0.76	(2.5)	1.46	(4.8)	0.00	(0.0)
27-022-033	14.16	(8.8)	HBE	17.53	(57.5)	0.82	(2.7)	2.56	(8.4)	-0.18	(-0.6)

* Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Manistee Co. Michigan											
28-001-005	6.60	(4.1)	HBE	17.53	(57.5)	0.37	(1.2)	0.49	(1.6)	0.12	(0.4)
28-005-008	3.54	(2.2)	LBE	0.76	(2.5)	0.21	(0.7)	0.61	(2.0)	0.00	(0.0)
28-008-012	5.47	(3.4)	HBE	17.53	(57.5)	0.49	(1.6)	1.28	(4.2)	-0.03	(-0.1)
28-012-013	2.90	(1.8)	LBE	5.33	(17.5)	1.19	(3.9)	1.46	(4.8)	0.98	(3.2)
28-013-016	3.70	(2.3)	HBE	17.53	(57.5)	0.67	(2.2)	1.25	(4.1)	0.40	(1.3)
28-016-016	0.64	(0.4)	LBE	17.53	(57.5)	0.46	(1.5)	0.49	(1.6)	0.40	(1.3)
28-016-018	3.54	(2.2)	LBE	5.33	(17.5)	0.64	(2.1)	0.73	(2.4)	0.55	(1.8)
28-018-022	4.67	(2.9)	HBE	35.81	(117.5)	0.43	(1.4)	0.91	(3.0)	-0.03	(-0.1)
28-022-024	4.51	(2.8)	LBE	5.33	(17.5)	0.37	(1.2)	0.64	(2.1)	0.15	(0.5)
28-024-026	3.70	(2.3)	LBE	35.81	(117.5)	0.30	(1.0)	0.88	(2.9)	-0.03	(-0.1)
28-026-028	2.25	(1.4)	LBE	5.33	(17.5)	0.49	(1.6)	0.79	(2.6)	0.06	(0.2)
28-028-029	1.45	(0.9)	HBE	5.33	(17.5)	0.37	(1.2)	0.61	(2.0)	0.06	(0.2)
Benzie Co. Michigan											
29-001-002	3.22	(2.0)	HBE	35.81	(117.5)	0.40	(1.3)	1.10	(3.6)	0.00	(0.0)
29-002-003	0.97	(0.6)	HBE	5.33	(17.5)	0.12	(0.4)	0.24	(0.8)	0.06	(0.2)
29-003-004	3.54	(2.2)	LBE	5.33	(17.5)	0.09	(0.3)	0.21	(0.7)	0.00	(0.0)
29-004-007	5.15	(3.2)	HBE	35.81	(117.5)	0.55	(1.8)	1.16	(3.7)	-0.03	(-0.1)
29-007-007	0.97	(0.6)	LBE	35.81	(117.5)						
29-007-010	1.93	(1.2)	LBE	5.33	(17.5)						
29-010-013	5.95	(3.7)	HD	35.81	(117.5)	0.46	(1.5)	1.19	(3.8)	-0.15	(-0.5)
29-013-018	6.60	(4.1)	LD	5.33	(17.5)	0.61	(2.0)	1.65	(5.4)	-0.12	(-0.4)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach km	Length (mi)	Shoreform	Average Bluff Height m	(ft)	Recession Average m/yr	(ft/yr)	Maximum m/yr	(ft/yr)	Minimum m/yr	(ft/yr)
Benzie Co. (continued)											
29-018-023	7.56	(4.7)	HD	5.33	(17.5)	0.40	(1.3)	0.67	(2.2)	0.27	(0.9)
29-023-026	3.54	(2.2)	HD	0.76	(2.5)	0.34	(1.1)	1.48	(4.8)	-0.06	(-0.2)
29-026-027	1.61	(1.0)	HD	5.33	(17.5)	1.04	(3.4)	1.58	(5.2)	0.30	(1.0)
29-027-028	1.93	(1.2)	LBE	98.30	(322.5)	0.24	(0.8)	0.49	(1.6)	0.03	(0.1)
Leelanau Co. Michigan											
30-001-002	3.22	(2.0)	HBE	98.30	(322.5)	0.79	(2.6)	1.92	(6.3)	0.12	(0.4)
30-002-003	0.97	(0.6)	HBE	5.33	(17.5)	0.46	(1.5)	0.67	(2.2)	0.30	(1.0)
30-003-004	0.64	(0.4)	LD	5.33	(17.5)	0.70	(2.3)	1.43	(4.7)	0.58	(1.9)
30-004-005	2.57	(1.6)	LD	15.24	(50.0)	0.61	(2.0)	1.07	(3.5)	0.18	(0.6)
30-005-006	0.97	(0.6)	LD	5.33	(17.5)						
30-006-009	5.31	(3.3)	HD	100.58	(330.0)						
30-009-010	2.41	(1.5)	HD	15.24	(50.0)						
30-010-011	2.90	(1.8)	HD	5.33	(17.5)						
30-011-011	0.32	(0.2)	HBE	5.33	(17.5)						
30-011-014	5.15	(3.2)	HBE	0.76	(2.5)						
30-014-016	2.90	(1.8)	HBE	76.20	(250.0)	0.49	(1.6)	1.13	(3.7)	0.09	(0.3)
30-016-019	2.74	(1.7)	HBE	21.34	(70.0)	0.64	(2.1)	1.34	(4.4)	0.09	(0.3)
30-019-019	1.93	(1.2)	HBE	5.33	(17.5)	0.27	(0.9)	0.27	(0.9)	0.12	(0.4)
30-019-021	1.77	(1.1)	HBE	88.39	(290.0)	0.15	(0.5)	0.43	(1.4)	0.06	(0.2)
30-021-021	0.64	(0.4)	PE	88.39	(290.0)						
30-021-027	8.37	(5.2)	PE	0.76	(2.5)						
30-027-033	8.85	(5.5)	PE	27.43	(90.0)	0.09	(0.3)	0.27	(0.9)	-0.03	(-0.1)
30-033-034	2.90	(1.8)	PE	67.82	(222.5)	0.37	(1.2)	0.76	(2.5)	0.18	(0.6)
30-034-037	4.18	(2.6)	LBE	5.33	(17.5)	0.15	(0.5)	0.34	(1.1)	0.00	(0.0)

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Leelanau Co. (continued)											
30-037-041	2.74	(1.7)	HBE	29.72	(97.5)	0.27	(0.9)	0.40	(1.3)	0.03	(0.1)
30-041-043	4.02	(2.5)	PE	5.33	(17.5)	0.43	(1.4)	0.55	(1.8)	0.21	(0.7)
30-043-045	2.90	(1.8)	PE	9.91	(32.5)	0.27	(0.9)	0.37	(1.2)	0.15	(0.5)
30-045-045	1.13	(0.7)	HBE	9.91	(32.5)	0.88	(2.9)	1.34	(4.4)	0.88	(2.9)
30-045-049	6.76	(4.2)	HBE	67.82	(222.5)	0.18	(0.6)	0.70	(2.5)	0.00	(0.0)
30-049-054	2.74	(1.7)	HBE	25.15	(82.5)	0.43	(1.4)	1.07	(3.5)	0.03	(0.2)
30-054-056	2.90	(1.8)	PE	5.33	(17.5)	0.43	(1.4)	0.67	(2.2)	0.00	(0.0)
30-056-057	3.22	(2.0)	PE	15.25	(50.0)	0.49	(1.6)	0.70	(2.3)	0.24	(0.8)
30-057-058	2.74	(1.7)	PE	5.33	(17.5)						
30-058-063	8.05	(5.0)	PE	0.76	(2.5)	0.55	(1.8)	0.79	(2.6)	0.18	(0.6)
30-063-067	6.44	(4.0)	PE	2.29	(7.5)						
30-067-068	2.74	(1.7)	PE	5.33	(17.5)	0.52	(1.7)	0.85	(2.8)	0.12	(0.4)
30-068-069	2.74	(1.7)	PE	2.29	(7.5)						
30-069-070	2.74	(1.7)	PE	5.33	(17.5)						
30-070-072	1.45	(0.9)	LBE	5.33	(17.5)						
30-072-074	4.51	(2.8)	LBE	0.76	(2.5)						
30-074-078	5.47	(3.4)	LBE	5.33	(17.5)						
30-078-078	0.97	(0.6)	PE	5.33	(17.5)						
30-078-079	3.06	(1.9)	PE	2.29	(7.5)						
30-079-080	2.41	(1.5)	PE	5.33	(17.5)						
30-080-086	6.12	(3.8)	LBE	5.33	(17.5)						
30-086-089	2.09	(1.3)	PE	0.76	(2.5)	0.09	(0.3)	0.27	(0.9)	-0.03	(-0.1)
30-089-090	3.22	(2.0)	PE	2.29	(7.5)						
30-090-091	2.57	(1.6)	PE	0.76	(2.5)						

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Leelanau Co. (continued)											
30-091-091	1.77	(1.1)	PE	33.53	(110.0)						
30-091-092	1.45	(0.9)	PE	29.72	(97.5)						
30-092-094	2.74	(1.7)	PE	6.86	(22.5)						
30-094-095	2.09	(1.3)	PE	0.76	(2.5)						
30-095-097	3.70	(2.3)	LBE	5.33	(17.5)	0.43	(1.4)	0.94	(3.1)	0.06	(0.2)
30-097-102	9.33	(5.8)	LBE	77.72	(255.0)	0.27	(0.9)	0.52	(1.7)	0.00	(0.0)
30-102-103	3.54	(2.2)	LBE	33.53	(110.0)	0.24	(0.8)	0.58	(1.9)	0.00	(0.0)
30-103-104	1.29	(0.8)	LBE	5.33	(17.5)						
30-104-105	1.61	(1.0)	LBE	2.29	(7.5)						
Grand Traverse Co. Michigan											
31-001-004	4.02	(2.5)	PE	0.76	(2.5)	0.24	(0.8)	0.43	(1.4)	-0.61	(-2.0)
31-004-009	6.60	(4.1)	LBE	48.77	(160.0)						
31-009-013	4.67	(2.9)	LBE	5.33	(17.5)						
31-013-015	3.06	(1.9)	LBE	2.29	(7.5)						
31-015-017	3.38	(2.1)	LBE	0.76	(2.5)	0.58	(1.9)	0.61	(2.0)	0.00	(0.0)
31-017-020	2.41	(1.5)	LBE	5.33	(17.5)						
31-020-021	1.93	(1.2)	LBE	2.29	(7.5)						
31-021-024	3.22	(2.0)	LBE	5.33	(17.5)						
31-024-025	1.77	(1.1)	LBE	2.29	(7.5)						
31-025-025	1.13	(0.7)	LBE	5.33	(17.5)						

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Grand Traverse Co. (continued)											
31-025-029	5.47	(3.4)	PE	5.33	(17.5)	0.03	(0.1)	0.12	(0.4)	-0.27	(-0.9)
31-029-029	3.38	(2.1)	PE	0.76	(2.5)	0.37	(1.2)	0.52	(1.7)	0.12	(0.4)
31-029-029	0.48	(0.3)	PE	29.72	(97.5)						
31-029-033	4.35	(2.7)	HBE	29.72	(97.5)						
31-033-033	2.74	(1.7)	PE	0.79	(2.5)						
31-033-033	1.29	(0.8)	PE	5.33	(17.5)						
31-033-034	1.13	(0.7)	LBE	5.33	(17.5)						
31-034-035	1.93	(1.2)	LBE	39.62	(130.0)						
31-035-036	1.13	(0.7)	LBE	9.14	(30.0)						
31-036-039	5.15	(3.2)	LBE	5.33	(17.5)	0.18	(0.6)	0.82	(2.7)	-0.27	(-0.9)
31-039-040	2.41	(1.5)	HBE	23.62	(77.5)						
31-040-050	11.10	(6.9)	LBE	5.33	(17.5)						
31-050-056	10.78	(6.7)	PE	0.76	(2.5)						
31-056-058	2.90	(1.8)	LBE	0.76	(2.5)						
31-058-059	1.45	(0.9)	LBE	17.53	(57.5)						
31-059-061	2.09	(1.3)	PE	0.76	(2.5)						
31-061-063	1.29	(0.8)	PE	16.00	(52.5)	0.18	(0.6)	0.40	(1.3)	0.03	(0.1)
31-063-063	1.29	(0.8)	PE	0.76	(2.5)						
Antrim Co. Michigan											
32-001-004	3.70	(2.3)	PE	3.05	(10.0)	0.58	(1.9)	0.76	(2.5)	0.09	(0.3)
32-004-011	9.33	(5.8)	PE	1.52	(5.0)	0.21	(0.7)	0.52	(1.7)	0.00	(0.0)

*Reach defined by bluff height and shoreform.
Values calculated in English units, conwerted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession Average m/yr	(ft/yr)	Maximum m/yr	(ft/yr)	Minimum m/yr	(ft/yr)
Antrim Co. (continued)											
32-011-027	28.00	(17.4)	PE	0.76	(2.5)	0.27	(0.9)	0.64	(2.1)	-0.03	(-0.1)
Charlevoix Co., Michigan											
33-001-004	4.02	(2.5)	PE	5.33	(17.5)	0.12	(0.4)	0.49	(1.6)	-0.03	(-0.1)
33-004-008	6.60	(4.1)	PE	0.76	(2.5)						
33-008-010	2.25	(1.4)	PE	5.33	(17.5)						
33-010-012	3.38	(2.1)	PN	5.33	(17.5)	0.37	(1.2)	1.19	(3.9)	0.03	(0.1)
33-012-013	1.77	(1.1)	PN	0.76	(2.5)						
33-013-014	0.80	(0.5)	PE	0.76	(2.5)						
33-014-017	4.02	(2.5)	PE	5.33	(17.5)						
33-017-017	0.80	(0.5)	PE	0.76	(2.5)						
33-017-025	9.50	(5.9)	PN	0.76	(2.5)						
33-025-026	3.54	(2.2)	LBN	5.33	(17.5)						
Emmet Co. Michigan											
34-001-005	1.61	(1.0)	LBN	21.34	(70.0)						
34-005-012	11.59	(7.2)	LBN	2.29	(7.5)						
34-012-014	3.70	(2.3)	HD	2.29	(7.5)						
34-014-017	1.93	(1.2)	W	2.29	(7.5)						
34-017-022	10.30	(6.4)	HBE	2.29	(7.5)						
34-022-025	3.70	(2.3)	HBE	67.82	(222.5)						

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession Average m/yr	(ft/yr)	Maximum m/yr	(ft/yr)	Minimum m/yr	(ft/yr)
Emmet Co. (continued)											
34-025-028	4.83	(3.0)	HBE	82.30	(270.0)						
34-028-030	2.09	(1.3)	HBE	21.34	(70.0)	0.09	(0.3)	0.12	(0.4)	0.06	(0.2)
34-030-036	8.53	(5.3)	HBE	28.96	(95.0)						
34-036-039	1.93	(1.2)	HBE	7.62	(25.0)						
34-039-042	5.95	(3.7)	HBE	21.34	(70.0)						
34-042-044	2.57	(1.6)	HBE	7.62	(25.0)						
34-044-047	3.54	(2.2)	HBE	13.72	(45.0)						
34-047-048	0.97	(0.6)	HBE	13.72	(45.0)						
34-048-055	6.44	(4.0)	HD	6.86	(22.5)	0.18	(0.6)	0.34	(1.1)	0.09	(0.3)
34-055-058	3.22	(2.0)	HD	0.76	(2.5)	0.58	(1.9)	0.85	(2.8)	0.09	(0.3)
34-058-063	17.22	(10.7)	W	0.76	(2.5)						
34-063-062	2.90	(1.8)	PE	0.76	(2.5)						
34-062-066	2.74	(1.7)	PE	2.29	(7.5)						
34-066-066	2.90	(1.8)	W	5.33	(17.5)						
34-066-067	1.77	(1.1)	W	2.29	(7.5)						
34-067-068	0.97	(0.6)	PE	2.29	(7.5)						
34-068-073	2.41	(1.5)	PE	0.76	(2.5)						
34-073-075	3.38	(2.1)	W	2.29	(7.5)						
34-075-076	1.93	(1.2)	PE	2.29	(7.5)						
34-076-081	5.15	(3.2)	W	1.52	(5.0)						
34-081-082	1.77	(1.1)	HD	1.52	(5.0)						
34-082-085	4.99	(3.1)	HBE	2.29	(7.5)	0.06	(0.2)	0.15	(0.5)	0.00	(0.0)

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Mackinac Co. Michigan	NO DATA										
Schoolcraft Co., Michigan											
18-001-003	5.31	(3.3)	PN	0.76	(2.5)						
18-003-004	0.64	(0.4)	PN	6.86	(22.5)						
18-004-004	1.29	(0.8)	W	6.86	(22.5)						
18-004-005	0.80	(0.5)	PN	6.86	(22.5)						
18-005-006	1.29	(0.8)	PN	11.43	(37.5)						
18-006-008	1.13	(0.7)	PN	0.76	(2.5)						
18-008-009	1.93	(1.2)	W	0.76	(2.5)						
18-009-009	0.48	(0.3)	PN	0.76	(2.5)						
18-009-011	2.25	(1.4)	W	0.76	(2.5)						
18-011-011	0.64	(0.4)	W	6.86	(22.5)						
18-011-012	2.25	(1.4)	PN	6.86	(22.5)	0.61	(2.0)	0.73	(2.4)	0.34	(1.1)
18-012-013	1.77	(1.1)	HBE	0.76	(2.5)	0.37	(1.2)	0.41	(1.3)	0.34	(1.1)
18-013-013	0.16	(0.1)	PN	0.76	(2.5)						
18-013-014	1.29	(0.8)	PN	2.29	(7.5)	0.18	(0.6)	0.18	(0.6)	0.18	(0.6)
18-014-016	1.13	(0.7)	HBE	0.76	(2.5)	0.06	(0.2)	0.09	(0.3)	0.00	(0.0)
18-016-023	5.63	(3.5)	PN	0.76	(2.5)	0.24	(0.8)	0.46	(1.5)	0.00	(0.0)
18-023-026	3.54	(2.2)	LD	0.76	(2.5)						
18-026-027	1.45	(0.9)	PN	0.76	(2.5)						
18-027-028	2.90	(1.8)	PE	0.76	(2.5)						
18-028-028	0.64	(0.4)	LD	0.76	(2.5)						
18-028-029	1.61	(1.0)	PE	0.76	(2.5)						

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Schoolcraft Co. (continued)											
18-029-031	3.22	(2.0)	LD	0.76	(2.5)						
18-031-035	7.72	(4.8)	PN	0.76	(2.5)						
18-035-036	1.61	(1.0)	LD	0.76	(2.5)						
18-036-038	1.61	(1.0)	PE	0.76	(2.5)						
18-038-045	2.57	(6.1)	LD	3.81	(12.5)						
18-045-048	4.02	(2.5)	PN	2.29	(7.5)						
18-048-051	7.24	(4.5)	PN	0.76	(2.5)						
18-051-053	2.09	(1.3)	PN	3.81	(12.5)						
18-053-053	0.81	(0.5)	PN	0.76	(2.5)						
Delta Co. Michigan											
19-001-001	1.45	(0.9)	PN	0.76	(2.5)						
19-001-003	1.77	(1.1)	PN	2.29	(7.5)						
19-003-004	3.70	(2.3)	LBE	2.29	(7.5)	0.34	(1.1)	0.43	(1.4)	0.21	(0.7)
19-004-014	6.28	(3.9)	PE	2.29	(7.5)	0.18	(0.6)	0.27	(0.9)	0.06	(0.2)
19-014-017	10.14	(6.3)	PE	0.76	(2.5)						
19-017-019	2.41	(1.5)	PE	2.29	(7.5)	0.43	(1.4)	0.46	(1.5)	0.37	(1.2)
19-019-021	3.22	(2.2)	LD	0.76	(2.5)						
19-021-027	10.30	(6.4)	W	0.76	(2.5)						
19-027-027	2.57	(1.6)	PE	0.76	(2.5)						
19-027-028	1.61	(1.0)	A	0.76	(2.5)	0.31	(1.0)	0.37	(1.2)	0.24	(0.8)

* Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Delta Co. (continued)											
19-028-028	1.29	(0.8)	W	0.76	(2.5)						
19-028-029	1.93	(1.2)	LBE	0.76	(2.5)						
19-029-030	0.97	(0.6)	PE	0.76	(2.5)						
19-030-030	0.97	(0.6)	W	5.33	(17.5)						
19-030-033	2.41	(1.5)	W	5.33	(17.5)	0.31	(1.0)	0.37	(1.2)	0.24	(0.8)
19-033-037	2.09	(1.3)	HBE	11.43	(37.5)						
19-037-038	2.41	(1.5)	PEW	11.43	(37.5)						
19-038-047	18.51	(11.5)	W	0.76	(2.5)	0.43	(1.4)	0.61	(2.0)	0.27	(0.9)
19-047-175 (54 reaches)	236.56	(147.0)									
Menominee Co. Michigan											
20-045-048	4.99	(3.1)	PE	0.76	(2.5)						
20-043-045	1.77	(1.1)	LBE	0.76	(2.5)						
20-041-043	2.90	(1.8)	PE	0.76	(2.5)						
20-040-041	1.61	(1.0)	PN	0.76	(2.5)						
20-036-040	4.67	(2.9)	PE	0.76	(2.5)						
20-034-036	2.74	(1.7)	PN	0.76	(2.5)						
20-032-034	1.93	(1.2)	PE	0.76	(2.5)						
20-031-032	1.61	(1.0)	LBE	2.29	(7.5)						
20-030-031	1.77	(1.1)	LBE	0.76	(2.5)						
20-023-030	9.66	(6.0)	PE	0.76	(2.5)	0,24	(0.8)	0.43	(1.4)	0.06	(0.2)
20-022-023	2.25	(1.4)	PN	2.29	(7.5)						
20-020-022	3.22	(2.0)	PE	0.76	(2.5)						
20-018-020	1.77	(1.1)	PN	0.76	(2.5)						
20-016-018	4.35	(2.7)	PE	0.76	(2.5)	0.15	(0.5)	0.15	(0.5)	0.15	(0.5)

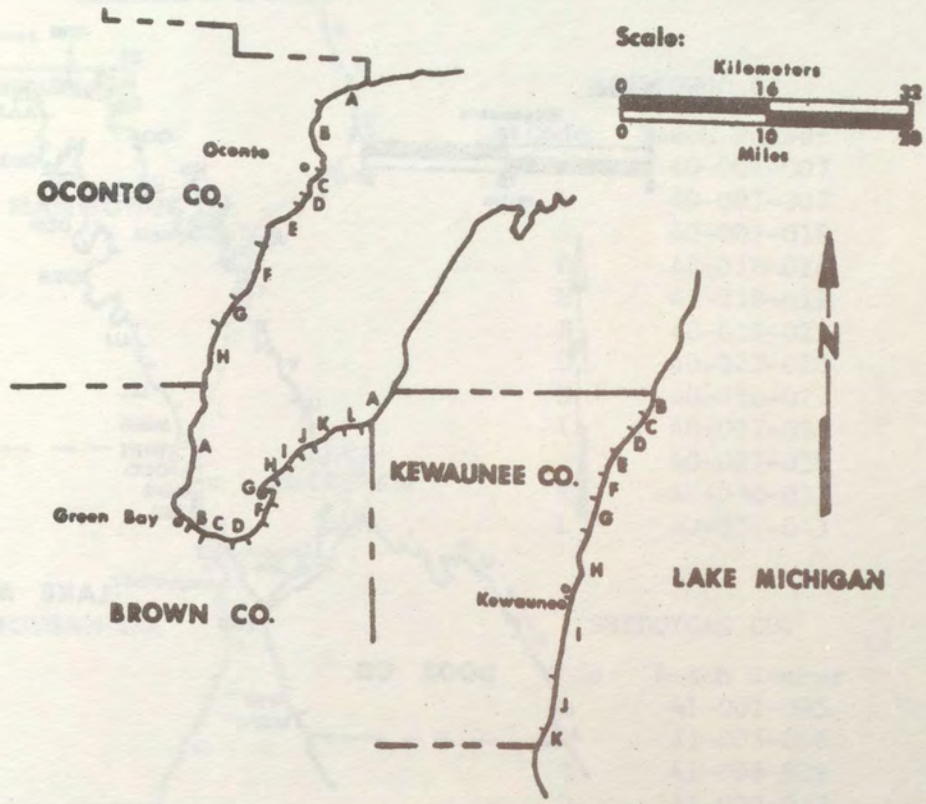
*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 5--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Menominee Co. (continued)											
20-014-016	4.02	(2.5)	LBE	0.76	(2.5)	0.37	(1.2)	0.58	(1.9)	0.15	(0.5)
20-005-014	12.55	(7.8)	PE	0.76	(2.5)	0.21	(0.7)	0.40	(1.3)	0.09	(0.3)
20-005-005	2.09	(1.3)	A	0.76	(2.5)	0.82	(2.7)	1.43	(4.7)	0.43	(1.4)
20-001-005	4.83	(3.0)	PE	0.76	(2.5)						

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.



OCONTO CO.

Code	Reach Number
A	36-001-003
B	36-003-011
C	36-011-014
D	36-014-016
E	36-016-020
F	36-020-024
G	36-024-025
H	36-025-033

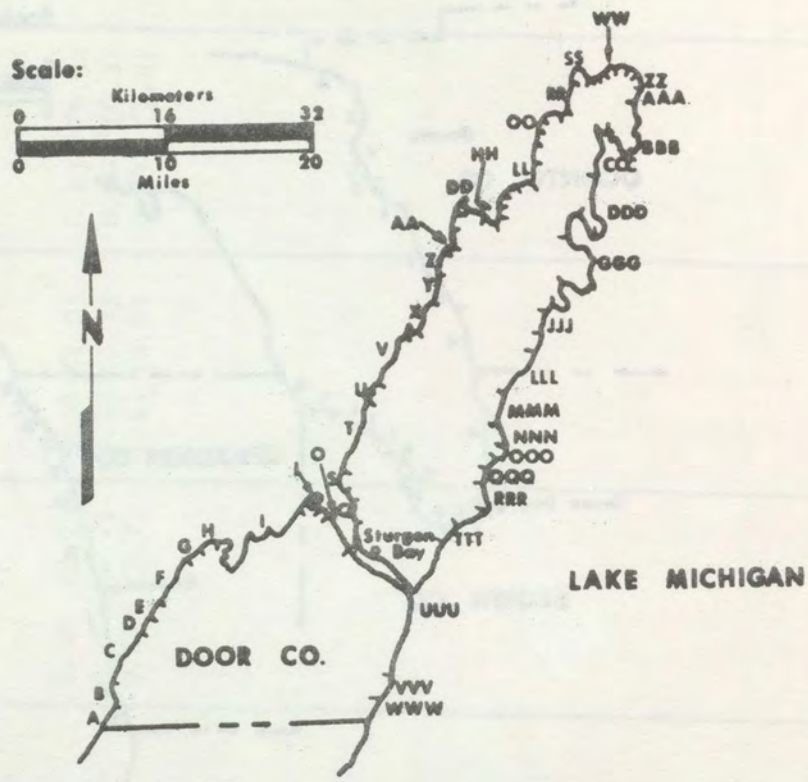
BROWN CO.

Code	Reach Number
A	37-001-017
B	37-017-019
C	37-019-023
D	37-023-024
E	37-024-024
F	37-024-028
G	37-028-029
H	37-029-031
I	37-031-031
J	37-031-033
K	37-033-034
L	37-034-038
M	37-038-038

KEWAUNEE CO.

Code	Reach Number
A	38-001-004
B	38-004-007
C	38-007-010
D	38-010-014
E	38-014-015
F	38-015-018
G	38-018-023
H	38-023-025
I	38-025-034
J	38-034-037
K	38-037-037

FIGURE 25. LAKE MICHIGAN: Oconto, Brown, and Kewaunee County Reach Locations.



DOOR CO.

Code	Reach Number	Code	Reach Number	Code	Reach Number
A	39-001-004	Z	39-066-068	YY	39-100-101
B	39-004-006	AA	39-068-070	ZZ	39-101-102
C	39-006-011	BB	39-070-072	AAA	39-102-103
D	39-011-013	CC	39-072-072	BBB	39-103-110
E	39-013-015	DD	39-072-073	CCC	39-110-114
F	39-015-019	EE	39-073-075	DDD	39-114-119
G	39-019-019	FF	39-075-077	EEE	39-119-120
H	39-019-022	GG	39-077-079	FFF	39-120-124
I	39-022-035	HH	39-079-081	GGG	39-124-132
J	39-035-035	II	39-081-083	HHH	39-132-137
K	39-035-036	JJ	39-083-084	III	39-137-139
L	39-036-036	KK	39-084-085	JJJ	39-139-141
M	39-036-037	LL	39-085-086	KKK	39-141-143
N	39-037-038	MM	39-086-086	LLL	39-143-147
O	39-038-041	NN	39-086-088	MMM	39-147-149
P	39-041-044	OO	39-088-090	NNN	38-149-151
Q	39-044-045	PP	39-090-090	OOO	39-151-151
R	39-045-046	QQ	39-090-092	PPP	39-151-154
S	39-046-049	RR	39-092-093	QQQ	39-154-158
T	39-049-054	SS	39-093-094	RRR	39-158-159
U	39-054-057	TT	39-094-096	SSS	38-159-162
V	39-057-061	UU	39-096-096	TTT	38-162-164
W	39-061-063	VV	49-096-097	UUU	39-164-177
X	39-063-065	WW	39-097-099	VVV	39-177-179
Y	39-065-066	XX	39-099-100	WWW	39-170-180

LAKE MIGHIGAN: Door County Reach Locations

MANITOWOC CO.

Code	Reach Number
A	40-001-007
B	40-007-007
C	40-007-018
D	40-018-018
E	40-018-019
F	40-019-022
G	40-022-026
H	40-026-027
I	40-027-027
J	40-027-030
K	40-030-037
L	40-037-043

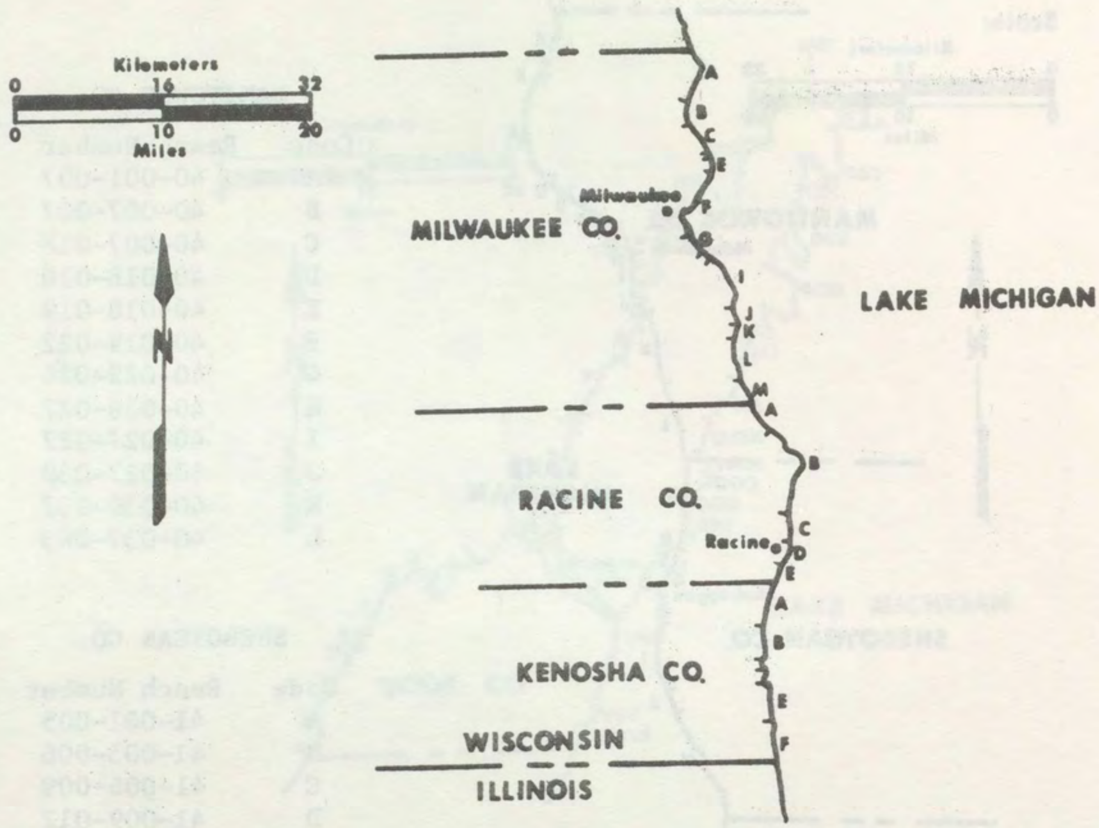
SHEBOYGAN CO.

Code	Reach Number
A	41-001-005
B	41-005-006
C	41-006-009
D	41-009-012
E	41-012-013
F	41-013-014
G	41-014-014
H	41-014-015
I	41-015-022
J	41-022-023
K	41-023-030

OZAUKEE CO.

Code	Reach Number
A	42-001-004
B	42-004-008
C	42-008-015
D	42-015-015
E	42-015-020
F	42-020-027
G	42-027-031

LAKE MICHIGAN: Manitowoc, Sheboygan, and Ozaukee County Reach Locations.



MILWAUKEE CO.

Code	Reach Number
A	43-001-006
B	43-006-007
C	43-007-014
D	43-014-014
E	43-014-015
F	43-015-021
G	43-021-023
H	43-023-024
I	43-024-029
J	43-029-030
K	43-030-031
L	43-031-034
M	43-034-034

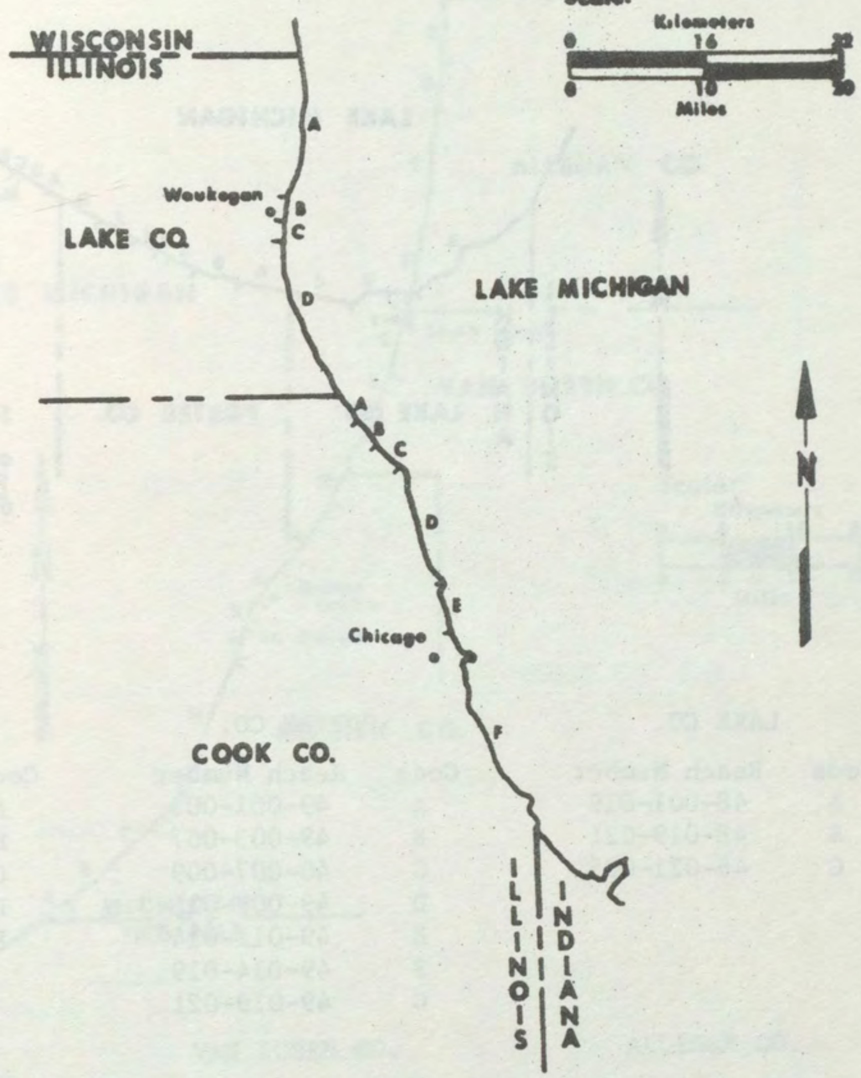
RACINE CO.

Code	Reach Number
A	44-001-006
B	44-006-011
C	44-011-013
D	44-013-017
E	44-017-017

KENOSHA CO.

Code	Reach Number
A	45-001-005
B	45-005-006
C	45-006-009
D	45-009-010
E	45-010-012
F	45-012-014

LAKE MICHIGAN: Milwaukee, Racine, and Kenosha County Reach Locations.



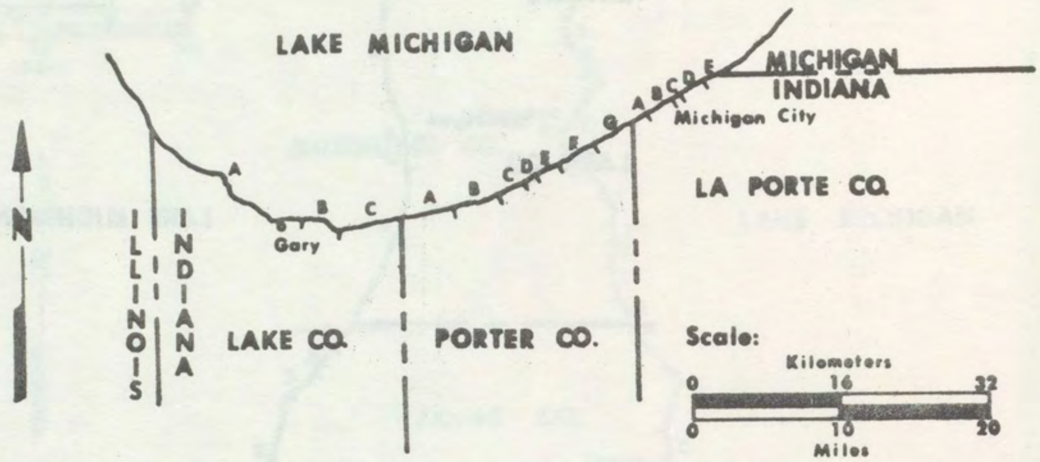
LAKE CO.

Code	Reach Number
A	46-001-010
B	46-010-012
C	46-012-013
D	46-013-029

COOK CO.

Code	Reach Number
A	47-001-005
B	47-005-007
C	47-007-009
D	47-009-019
E	47-019-023
F	47-023-043

LAKE MICHIGAN: Lake and Cook County Reach Locations.

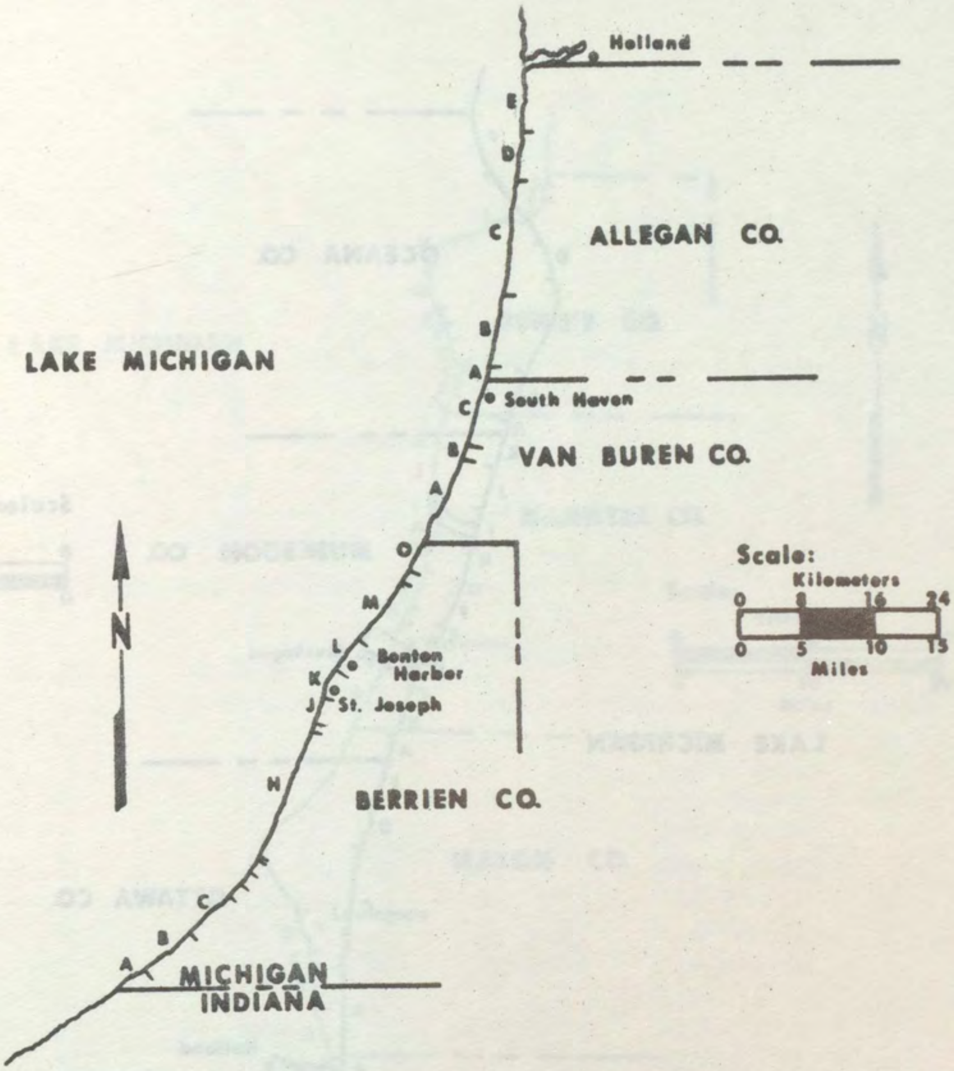


LAKE CO.	
Code	Reach Number
A	48-001-019
B	48-019-021
C	48-021-025

PORTER CO.	
Code	Reach Number
A	49-001-003
B	49-003-007
C	40-007-009
D	49-009-011
E	49-011-014
F	49-014-019
G	49-019-021

LA PORTE CO.	
Code	Reach Number
A	50-001-002
B	50-002-004
C	50-004-004
D	50 004-006
E	50-006-008

LAKE MICHIGAN: Lake, Porter, and La Porte County Reach Locations.



BERRIEN CO.

Code	Reach Number
A	21-001-002
B	21-002-007
C	21-007-013
D	21-013-015
E	21-015-019
F	21-019-020
G	21-020-020
H	21-020-032
I	21-032-033
J	21-033-036
K	21-036-039
L	21-039-043
M	21-043-050
N	21-050-051
O	21-051-055

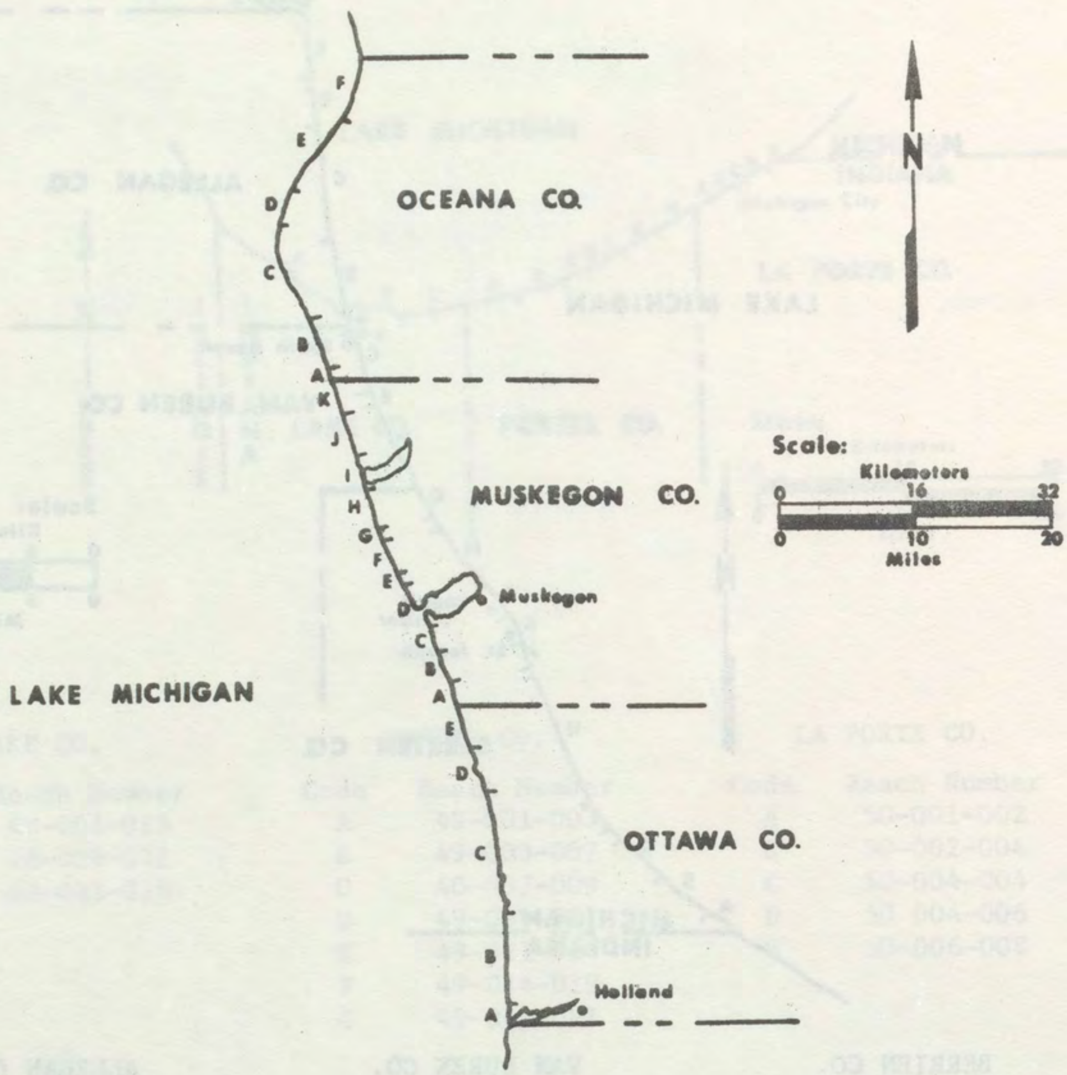
VAN BUREN CO.

Code	Reach Number
A	22-001-010
B	22-010-010
C	22-010-017

ALLEGAN CO.

Code	Reach Number
A	23-001-001
B	23-001-008
C	23-008-012
D	23-012-015
E	23-015-020

LAKE MICHIGAN: Berrien, Van Buren, and Allegan County Reach Locations.



OTTAWA CO.

Code	Reach Number
A	24-001-002
B	24-002-009
C	24-009-019
D	24-019-021
E	24-021-028

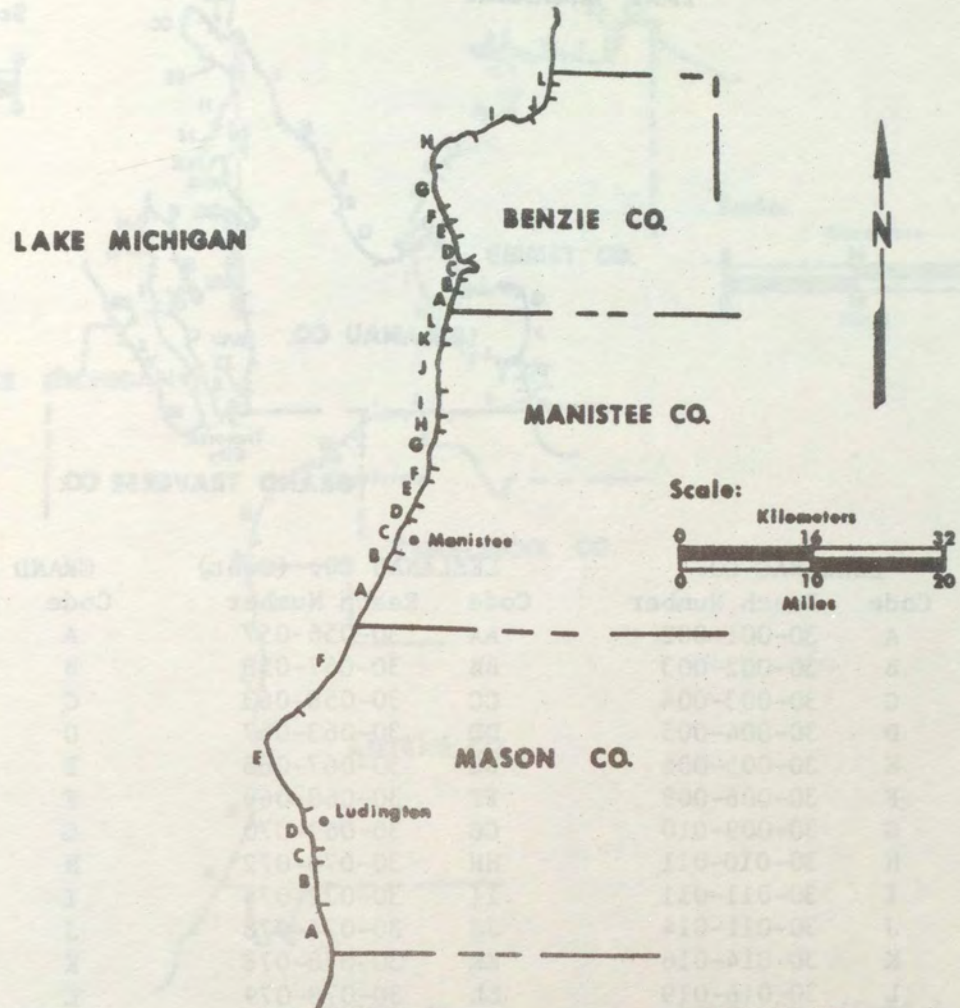
MUSKEGON CO.

Code	Reach Number
A	25-001-004
B	25-004-006
C	25-006-009
D	25-009-013
E	25-013-013
F	25-013-020
G	25-020-021
H	25-021-024
I	25-024-025
J	25-025-029
K	25-029-033

OCEANA CO.

Code	Reach Number
A	26-001-001
B	26-001-008
C	26-008-014
D.	26-014-020
E	26-020-027
F	26-027-032

LAKE MICHIGAN: Ottawa, Muskegan, and Oceana County Reach Locations.



MASON CO.

Code	Reach Number
A	27-001-003
B	27-003-009
C	27-009-009
D	27-009-011
E	27-011-022
F	27-022-033

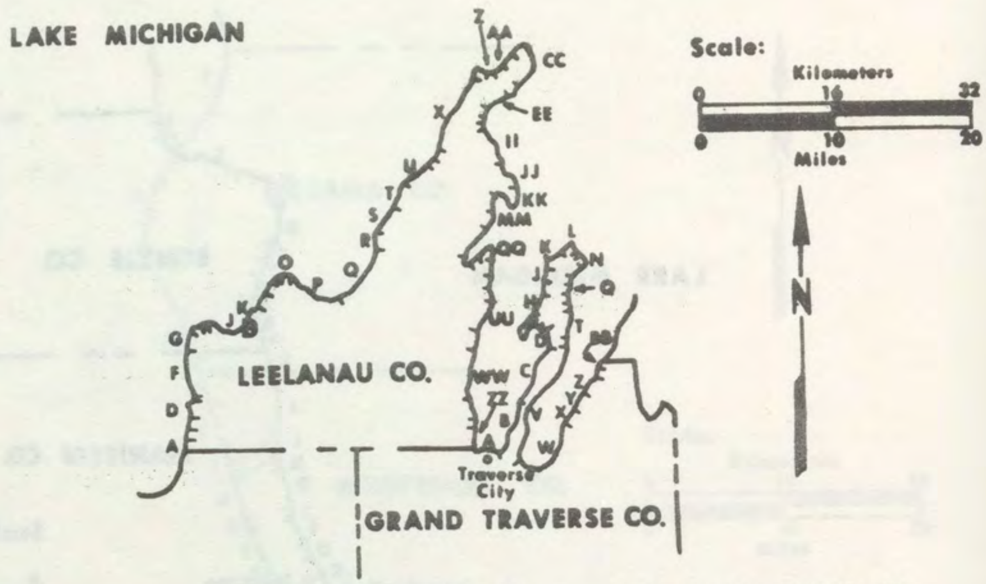
MANISTEE CO.

Code	Reach Number
A	28-001-005
B	28-005-008
C	28-008-012
D	28-012-013
E	28-013-016
F	28-016-016
G	28-016-018
H	28-018-022
I	28-022-024
J	28-024-026
K	28-026-028
L	28-028-029

BENZIE CO.

Code	Reach Number
A	29-001-002
B	29-002-003
C	29-003-004
D	29-004-007
E	29-007-007
F	29-007-010
G	29-010-013
H	29-013-018
I	29-018-023
J	29-023-026
K	29-026-027
L	29-027-028

LAKE MICHIGAN: Mason, Manistee, and Benzie County Reach Locations.

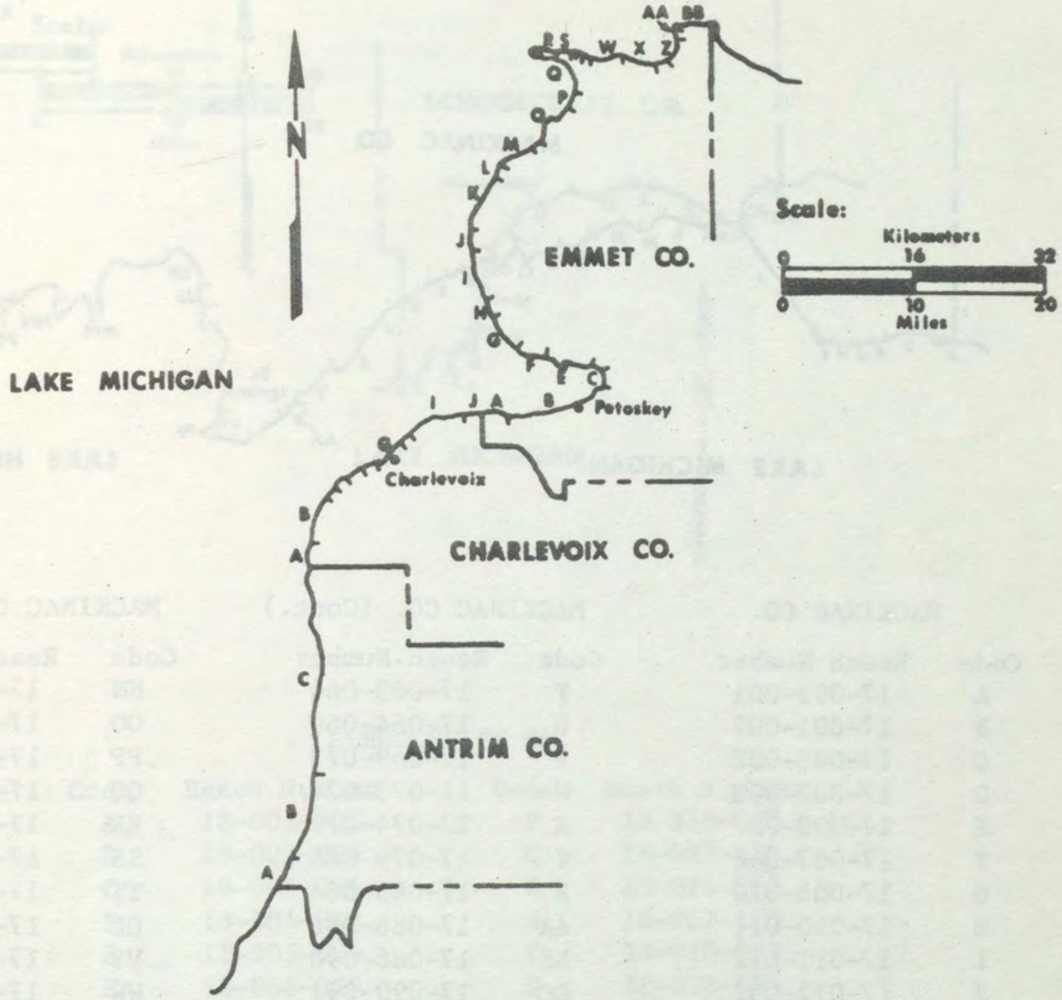


LEELANAU CO.	
Code	Reach Number
A	30-001-002
B	30-002-003
C	30-003-004
D	30-004-005
E	30-005-006
F	30-006-009
G	30-009-010
H	30-010-011
I	30-011-011
J	30-011-014
K	30-014-016
L	30-016-019
M	30-019-019
N	30-019-021
O	30-021-021
P	30-021-027
Q	30-027-033
R	30-033-034
S	30-034-037
T	30-037-041
U	30-041-043
V	30-043-045
W	30-045-045
X	30-045-049
Y	30-049-054
X	30-054-056

LEELANAU CO. (Cont.)	
Code	Reach Number
AA	30-056-057
BB	30-057-058
CC	30-058-063
DD	30-063-067
EE	30-067-068
FF	30-068-069
GG	30-069-070
HH	30-070-072
II	30-072-074
JJ	30-074-078
KK	30-078-078
LL	30-078-079
MM	30-079-080
NN	30-080-086
OO	30-086-089
PP	30-089-090
QQ	30-090-091
RR	30-091-091
SS	30-091-092
TT	30-092-094
UU	30-094-095
VV	30-095-097
WW	30-097-102
XX	30-102-103
YY	30-103-104
ZZ	30-104-105

GRAND TRAVERSE CO.	
Code	Reach Number
A	31-001-004
B	31-004-009
C	31-009-013
D	31-013-015
E	31-015-017
F	31-017-020
G	31-020-021
H	31-021-024
I	31-024-025
J	31-025-025
K	31-025-029
L	31-029-029
M	31-029-029
N	31-029-033
O	31-033-033
P	31-033-033
Q	31-033-034
R	31-034-035
S	31-035-036
T	31-036-039
U	31-039-040
V	31-040-050
W	31-050-056
X	31-056-058
Y	31-058-059
Z	31-059-061
AA	31-061-063
BB	31-063-063

LAKE MICHIGAN: Leelanau and Grand Traverse County Reach Locations.



ANTRIM CO.

Code	Reach Number
A	32-001-004
B	32-004-011
C	32-011-027

CHARLEVOIX CO.

Code	Reach Number
A	33-001-004
B	33-004-008
C	33-008-010
D	33-010-012
E	33-012-013
F	33-013-014
G	33-014-017
H	33-017-017
I	33-017-025
J	33-025-026

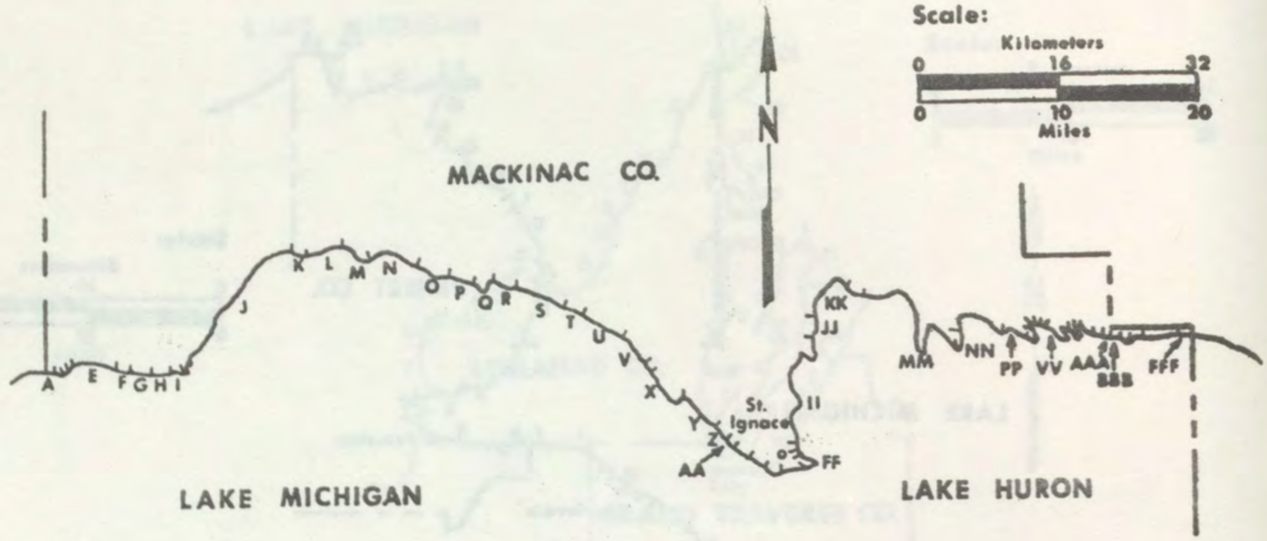
EMMET CO.

Code	Reach Number
A	34-001-005
B	34-005-012
C	34-012-014
D	34-014-017
E	34-017-022
F	34-022-025
G	34-025-028
H	34-028-030
I	34-030-036
J	34-036-039
K	34-039-042
L	34-042-044
M	34-044-047
N	34-047-048

EMMET CO. (Cont.)

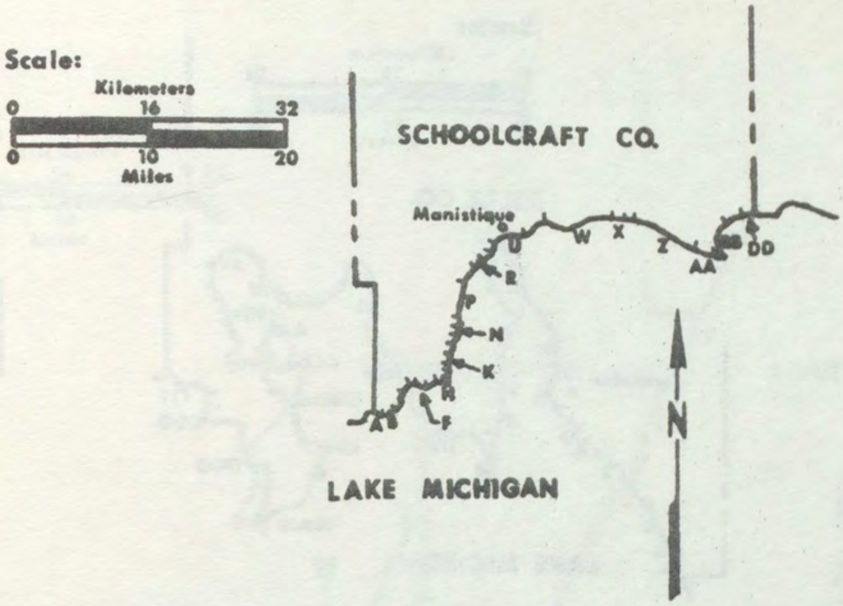
Code	Reach Number
O	34-048-055
P	34-055-058
Q	34-058-063
R	34-063-062
S	34-062-066
T	34-066-066
U	34-066-067
V	34-067-068
W	34-068-073
X	34-073-075
Y	34-075-076
Z	34-076-081
AA	34-081-082
BB	34-082-085

LAKE MICHIGAN: Antrim, Charlevoix, and Emmet County Reach Locations.



MACKINAC CO. Code	Reach Number	MACKINAC CO. (Cont.) Code	Reach Number	MACKINAC CO. (Cont.) Code	Reach Number
A	17-001-001	T	17-063-064	NN	17-136-138
B	17-001-002	U	17-064-069	OO	17-138-145
C	17-002-002	V	17-069-073	PP	17-145-148
D	17-002-003	W	17-073-074	QQ	17-148-147
E	17-003-007	X	17-074-079	RR	17-147-148
F	17-007-008	Y	17-079-085	SS	17-148-149
G	17-008-010	Z	17-085-086	TT	17-149-149
H	17-010-011	AA	17-086-088	UU	17-149-151
I	17-011-012	BB	17-088-090	VV	17-151-154
J	17-012-032	CC	17-090-091	WW	17-154-154
K	17-032-034	DD	17-091-091	XX	17-154-155
L	17-034-038	EE	17-091-094	YY	17-155-155
M	17-038-040	FF	17-094-095	ZZ	17-155-157
N	17-040-045	GG	17-095-095	AAA	17-157-158
O	17-045-049	HH	17-095-097	BBB	17-158-158
P	17-049-052	II	17-097-110	CCC	17-158-161
Q	17-052-056	JJ	17-110-111	DDD	17-161-161
R	17-056-057	KK	17-111-116	EEE	17-161-166
S	17-057-063	LL	17-116-122	FFF	17-166-167
		MM	17-122-136		

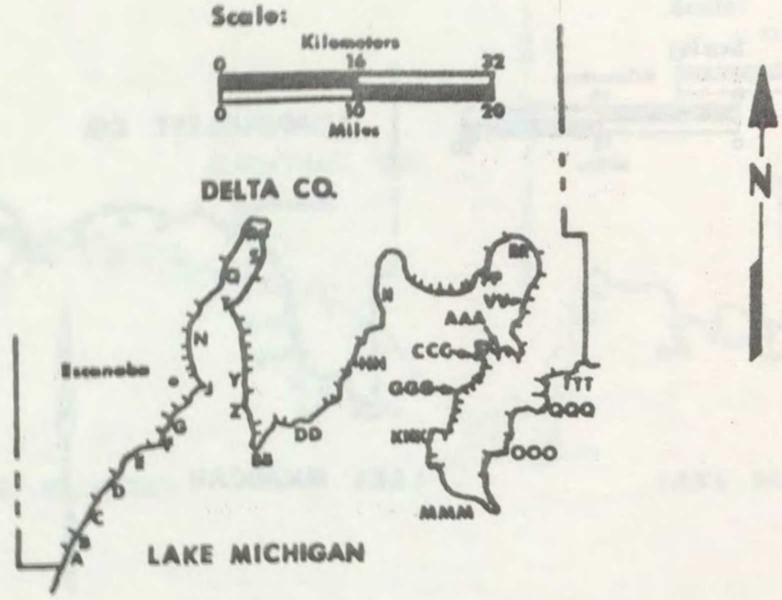
LAKE MICHIGAN AND LAKE HURON: Mackinac County Reach Locations.



SCHOOLCRAFT CO.

Code	Reach Number	Code	Reach Number
A	18-001-003	P	18-016-023
B	18-003-004	Q	18-023-026
C	18-004-004	R	18-026-027
D	18-004-005	S	18-027-128
E	18-005-006	T	18-028-028
F	18-006-008	U	18-028-029
G	18-008-009	V	18-029-031
H	18-009-009	W	18-031-035
I	18-009-011	X	18-035-036
J	18-011-011	Y	18-036-038
K	18-011-012	Z	18-038-045
L	18-012-013	AA	18-045-048
M	18-013-013	BB	18-048-051
N	18-013-014	CC	18-051-053
O	18-014-016	DD	18-053-053

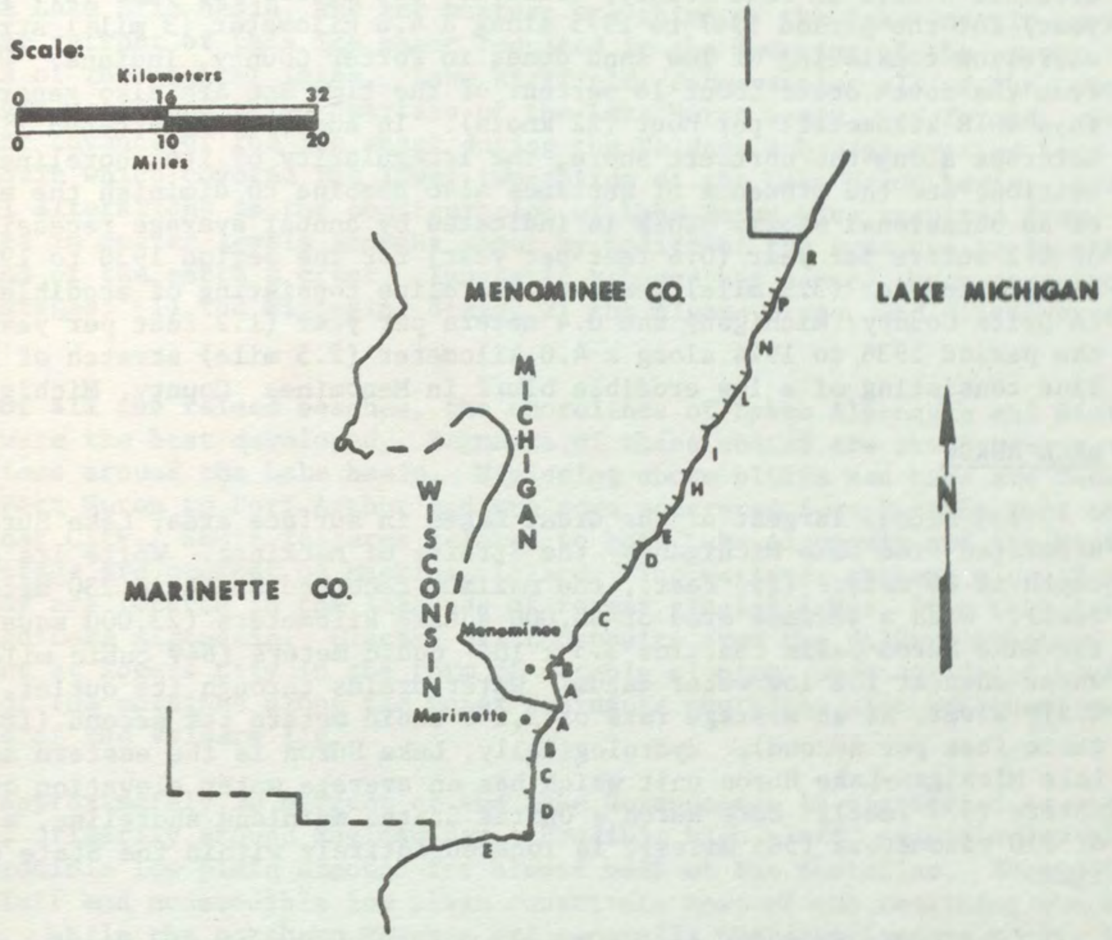
LAKE MICHIGAN: Schoolcraft County Reach Location.



DELTA CO.

Code	Reach Number	Code	Reach Number	Code	Reach Number
A	19-001-001	Y	19-064-067	WW	19-120-122
B	19-001-003	Z	19-067-070	XX	19-122-122
C	19-003-004	AA	19-070-071	YY	19-122-124
D	19-004-014	BB	19-071-074	ZZ	19-124-126
E	19-014-017	CC	19-074-075	AAA	19-126-127
F	19-017-019	DD	19-075-080	BBB	19-127-129
G	19-019-021	EE	19-080-081	CCC	19-129-130
H	19-021-027	FF	19-081-082	DDD	19-130-131
I	19-027-027	GG	19-082-086	EEE	19-131-135
J	19-027-028	HH	19-086-087	FFF	19-135-136
K	19-028-028	II	19-087-097	GGG	19-136-136
L	19-028-029	JJ	19-097-098	HHH	19-136-138
M	19-029-030	KK	19-098-100	III	19-138-137
N	19-030-030	LL	19-100-101	JJJ	19-139-142
O	19-030-033	MM	19-101-102	KKK	19-142-145
P	19-033-037	NN	19-102-102	LLL	19-145-146
Q	19-037-038	OO	19-102-104	MMM	19-146-155
R	19-038-047	PP	19-104-105	NNN	19-155-159
S	19-047-058	QQ	19-105-109	OOO	19-159-164
T	19-058-061	RR	19-109-114	PPP	19-164-165
U	19-061-062	SS	19-114-116	QQQ	19-165-167
V	19-062-063	TT	19-116-118	RRR	19-167-170
W	19-063-063	UU	19-118-119	SSS	19-170-171
X	19-063-064	VV	19-119-120	TTT	19-171-175

LAKE MICHIGAN: Delta County Reach Locations.



MARINETTE CO. Code	Reach Number
A	35-001-004
B	35-004-005
C	35-005-008
D	35-008-011
E	35-011-018

MENOMINEE CO. Code	Reach Number
A	20-001-005
B	20-005-005
C	20-005-014
D	20-014-016
E	20-016-018
F	20-018-020
G	20-020-022
H	20-022-023
I	20-023-030

MENOMINEE CO. (Cont.) Code	Reach Number
J	20-030-031
K	20-031-032
L	20-032-034
M	20-034-036
N	20-036-040
O	20-040-041
P	20-041-043
Q	20-043-045
R	20-045-048

LAKE MICHIGAN: Marinette and Menominee County Reach Locations.

erodible bluffs in Lake County, Illinois, 0.8 meters per year (2.7 feet per year) for the period 1947 to 1975 along a 4.8 kilometer (3 mile) stretch of shoreline consisting of low sand dunes in Porter County, Indiana. Winds from the south occur about 18 percent of the time and are also generally less than 40.8 kilometers per hour (22 knots). In addition, scattered limestone outcrops along the northern shore, the irregularity of its shoreline configuration, and the presence of wetlands also combine to diminish the effects of an occasional storm. This is indicated by annual average recession rates of 0.2 meters per year (0.6 feet per year) for the period 1938 to 1974 along a 6.3 kilometer (3.9 mile) reach of shoreline consisting of erodible plain in Delta County, Michigan, and 0.4 meters per year (1.2 feet per year) for the period 1938 to 1974 along a 4.0 kilometer (2.5 mile) stretch of shoreline consisting of a low erodible bluff in Menominee County, Michigan.

LAKE HURON

The second largest of the Great Lakes in surface area, Lake Huron is separated from Lake Michigan by the Straits of Mackinac. While its average depth is 60 meters (195 feet), the maximum recorded depth is 230 meters (750 feet). With a surface area of 60,000 square kilometers (23,000 square miles), the Lake Huron basin contains 3.5×10^{12} cubic meters (849 cubic miles) of water when at the low water datum. Water drains through its outlet, the St. Clair River, at an average rate of 5,240 cubic meters per second (187,000 cubic feet per second). Hydrologically, Lake Huron is the eastern arm of the Lake Michigan-Lake Huron unit which has an average water elevation of 177 meters (577 feet). Lake Huron's United States mainland shoreline, a total of 910 kilometers (565 miles), is located entirely within the State of Michigan.

Lake Huron contains more islands than any of the other Great Lakes; two of the larger islands within Michigan's jurisdiction are Drummond and Mackinac Islands. The Lake Huron shoreline has an exceptionally gradual relief which is characterized by sand and gravel beaches, marsh, clay bluffs, and sporadic rock outcrops. The offshore areas adjacent to the coast consist of limestone overlain by glacial deposits.

The Lake Huron basin was formerly a preglacial stream valley that developed along the east and northeast flanks of the Michigan Basin. The configuration of the stream valley was generally defined by the outcrops of rocks of relatively weak formations, mainly shales and limestones of Devonian Age. This preglacial stream valley was a locus for the considerable glacial activity that occurred during the Pleistocene and created the present Lake Huron basin. Accordingly, the characteristic shoretypes present along the perimeter of Lake Huron are derivatives of the Pleistocene glaciation.

Successive glacial advances and retreats during the Cary, Port Huron, Two Creeks and Valders substages left their imprints on the present shores of Lake Huron. The retreat of the Cary ice sheet formed Lake Arkona which encompassed parts of the Erie, Huron, and Saginaw basins. The readvance of the ice sheet during the Port Huron substage formed Lake Saginaw which was confined to Saginaw Bay. The retreat of the ice sheet during the Two Creeks created Lake Lundy which covered the lower half of the Lake Huron basin, all of the Lake Erie basin, and the western one-third of the Lake Ontario basin. Further retreat of this ice sheet resulted in the lowering of the water levels of the glacial lakes. Lake Kirkfield, encompassing all of the Lake Michigan basin and three-quarters of the Lake Huron basin, was formed. Subsequent advance of the ice sheet during the Valders substage created Lake Algonquin which covered the lower two-thirds of the Lake Huron basin. Additional alterations in the configuration of Lake Huron have resulted from changes in outlet levels brought about by uplift of the area due to isostatic rebound of the earth's crust. Isostatic rebound has caused three postglacial lake stages: 1) the Nipissing Stage, 2) the Algoma Stage, and 3) the present stage.

Of all the raised beaches, the shorelines of Lakes Algonquin and Nipissing were the best developed. Segments of these shores are present at many locations around the Lake basin. Nipissing shore bluffs and bars are found from Port Huron to Port Arthur and are more scattered from Port Lookout to Mackinac City. Shore features related to both Lake Algonquin and the Nipissing stage are present on Mackinac Island. The wetlands present along Saginaw Bay are located in the lakebeds of former glacial lakes, from Lake Arkona through Lake Algonquin. Glacial drift deposits from the Valders substage are present at Rogers City in the form of steeply sloping, unconsolidated bluffs. Some of the moraines along the Upper Peninsula shoreline also represent retreats of the Valders ice.

Approximately 30 percent of the Lake Huron coast is classified as wetlands, primarily around Saginaw Bay. Erodible high bluff, erodible low bluff, and erodible low plain account for almost half of the shoreline. Nonerodible low bluff and nonerodible low plain constitute most of the remaining shorelands. While the northern reaches are generally characterized as rocky, the southern ones consist mostly of sand beaches backed by low bluffs.

The U.S. Lake Huron shoreline along the Upper Peninsula from Point Detour to St. Ignace is generally composed of alternating nonerodible plains of clay and marshes with occasional outcrops of Silurian limestone and dolomite. A stone and boulder shore, backed by high bank beaches, is prevalent along the coast from Mackinac City to Harrisville. However, much of the shorelands in the Thunder Bay area consist of marshes and wetlands. Outcrops of Devonian limestone form low bluffs which are relatively nonerodible in the Rogers City and Alpena areas. Sand beaches, usually low and occasionally backed by bluffs, predominate from Harrisville to the southern part of Arenac County. Marsh lands extend along most of the Saginaw Bay area. On the northeastern edge of Saginaw Bay, Sand Point juts westward into the Bay and divides it from Wildfowl Bay. Sand beaches, backed by bluffs of irregular sand ridges, are present along the shore from Sand Point to Port Austin. From Port Austin to Grindstone City, bedrock composed of Mississippian sandstone forms a bluff which averages 3 meters (10 feet) in height. Southeastward from Grindstone City to 11 kilometers (7 miles) south of Lexington the shore area is mainly boulder-strewn and clay bluffs gradually become prevalent and increase in height. A wide sand beach, backed by sand, gravel, and clay bluffs up to 12 meters (40 feet) high, extends along the shoreline from this point to Port Huron.

Approximately 81 percent of the U.S. Lake Huron shoreline is susceptible to erosion or flooding, see Table 6. The southern portion of the western coast of Lake Huron, from Harrisville to Port Huron, Michigan is generally characterized by erodible sand, gravel, and clay bluffs fronted by sand and cobble beaches. During high lake levels the beaches are considerably depleted, enabling the waves to directly attack the nonresistant bluff toes. Erosion is negligible along the northern portion of the coast, from Point Detour to Harrisville, Michigan due to the presence of limestone and dolomite bluffs and nonerodible clay plains. Flooding is a serious problem along the western Lake Huron shoreline as wetlands comprise 29 percent of the shorelands. It is particularly acute in the Saginaw Bay region which consists entirely of wetlands and low lying sand bluffs, see Figure 26.

Extensive flooding and erosion along the western Lake Huron shoreline create serious economic consequences since 42 percent of the coast is devoted to residential use. The potential for these conditions is greatly increased during periods of high lake levels. While the maximum recorded lake level was reached in the 1880's, high water levels have occurred during the early 1950's and the 1970's, see Figure 4. During the more recent periods, extensive damages were incurred by public and private property owners. Based on the 1970 value of the dollar, the damages resulting from flooding and erosion during the 1951 to 1952 period were $2.4 million. Flooding in Saginaw Bay was severe and its eastern end eroded from 3.1 to 12.2 meters (10 to 40 feet) during that period. Erosion of the shoreline from Harbor Beach to the St. Clair County line amounted to 3.1 to 4.6 meters (10 to 15 feet) in the northern portion and up to 7.6 meters (25 feet) in the southern portion. A 16.1 kilometer (10 mile) stretch of shoreline north of Point Lookout experienced 9.1 to 12.2 meters (30 to 40 feet) of recession while the coast 4.8 kilometers (3 miles) south of the Point eroded an average of 3.1 meters (10 feet). These values were determined for the Great Lakes Regional Inventory of the National Shoreline Study which was conducted by the U.S. Corps of Engineers. During the high lake levels of the 1970's, millions of dollars of flooding damage are caused along the Saginaw Bay shorelands whenever strong easterly winds occur.

The amount of damage that is produced by any one storm is primarily dependent on the intensity and direction of the wind and the height of the waves which are generated. Although winds from the northwest, west, and southwest dominate along the western shore of Lake Huron, it is the easterly quadrant winds that generate the waves that are most effective against the shorelands. Not only do they attack the coast head-on but they are also formed over the longer fetch distances. Wind roses for south, central, and northwest Lake Huron are found on pages 123 to 125. The probable once-a-year wave heights for several locations on Lake Huron are as follows: 2.7 meters (9 feet) with a northeast or southeast wind for North Point, Michigan; 4.0 meters (13 feet) with an east wind for Harbor Beach; and 2.4 meters (8 feet) with a north wind for Port Huron. These conditions commonly occur over 6 to 9 hour periods. When these wave heights are combined with high lake levels, the extensive erosion and flooding damages caused in the early 1950's and during the 1970's are likely to occur.

TABLE 6

SHORETYPES ALONG THE U.S. SHORELINE OF LAKE HURON

SHORETYPES	MILES	KILOMETERS	PERCENTAGE
Artificial fill area	0.0	0.00	0.00
Erodible high bluff	34.7	55.84	6.14
Nonerodible high bluff	0.0	0.00	0.00
Erodible low bluff	59.7	96.07	10.57
Nonerodible low bluff	60.0	96.56	10.62
High sand dune	0.0	0.00	0.00
Low sand dune	18.4	29.61	3.26
Erodible low plain	183.6	295.46	32.50
Nonerodible low plain	45.4	73.06	8.03
Wetlands	163.2	262.63	28.88
Wetlands/Erodible plain	0.0	0.00	0.00
Wetlands/Erodible low bluff	0.0	0.00	0.00
Total Shore Length	565.0	909.20	100.00

Source: Great Lakes Basin Commission, 1975.

FIGURE 26. Shorelands of Lake Huron.

SOURCE: U.S. Department of the Army, Corps of Engineers, 1971.

ANNUAL SSMO

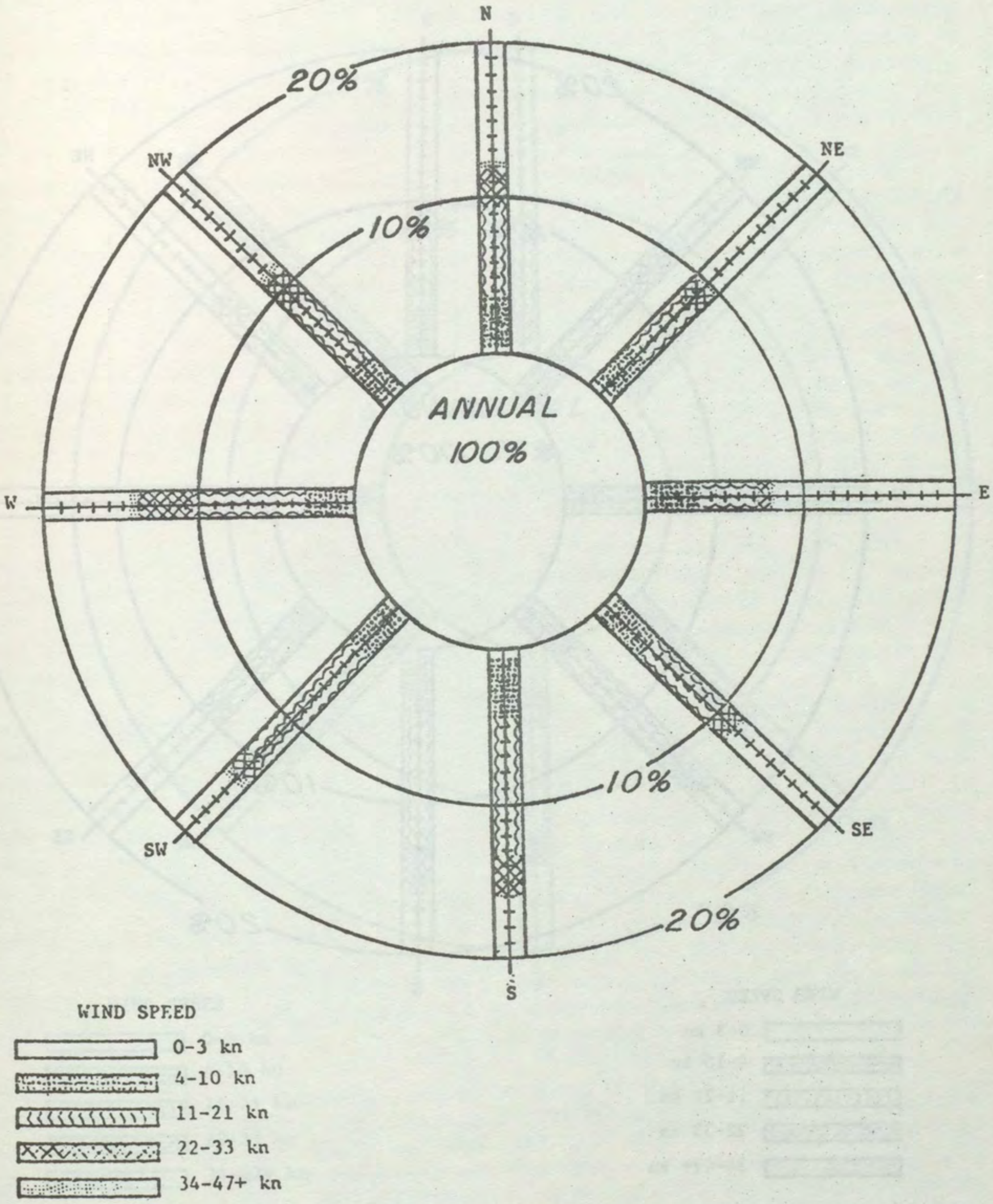


Figure 27. Wind rose for an average 12-month period; data from SSMO observations at Lake Huron South 1960-1973

ANNUAL SSMO

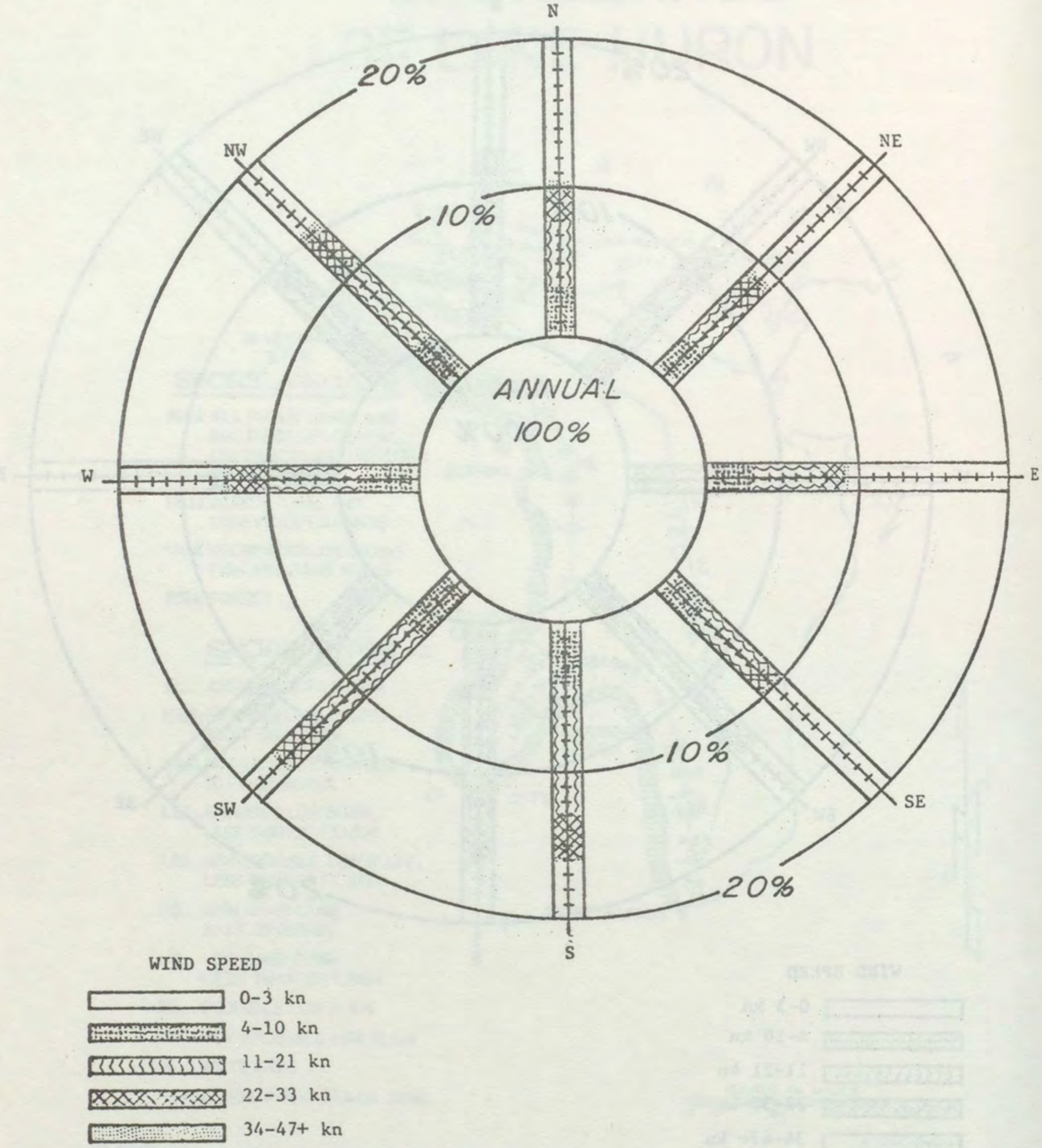


Figure 28. Wind rose for an average 12-month period; data from SSMO observations at Lake Huron Central 1960-1973

LAKE HURON NORTHWEST

WIND ROSE

ANNUAL SSMO

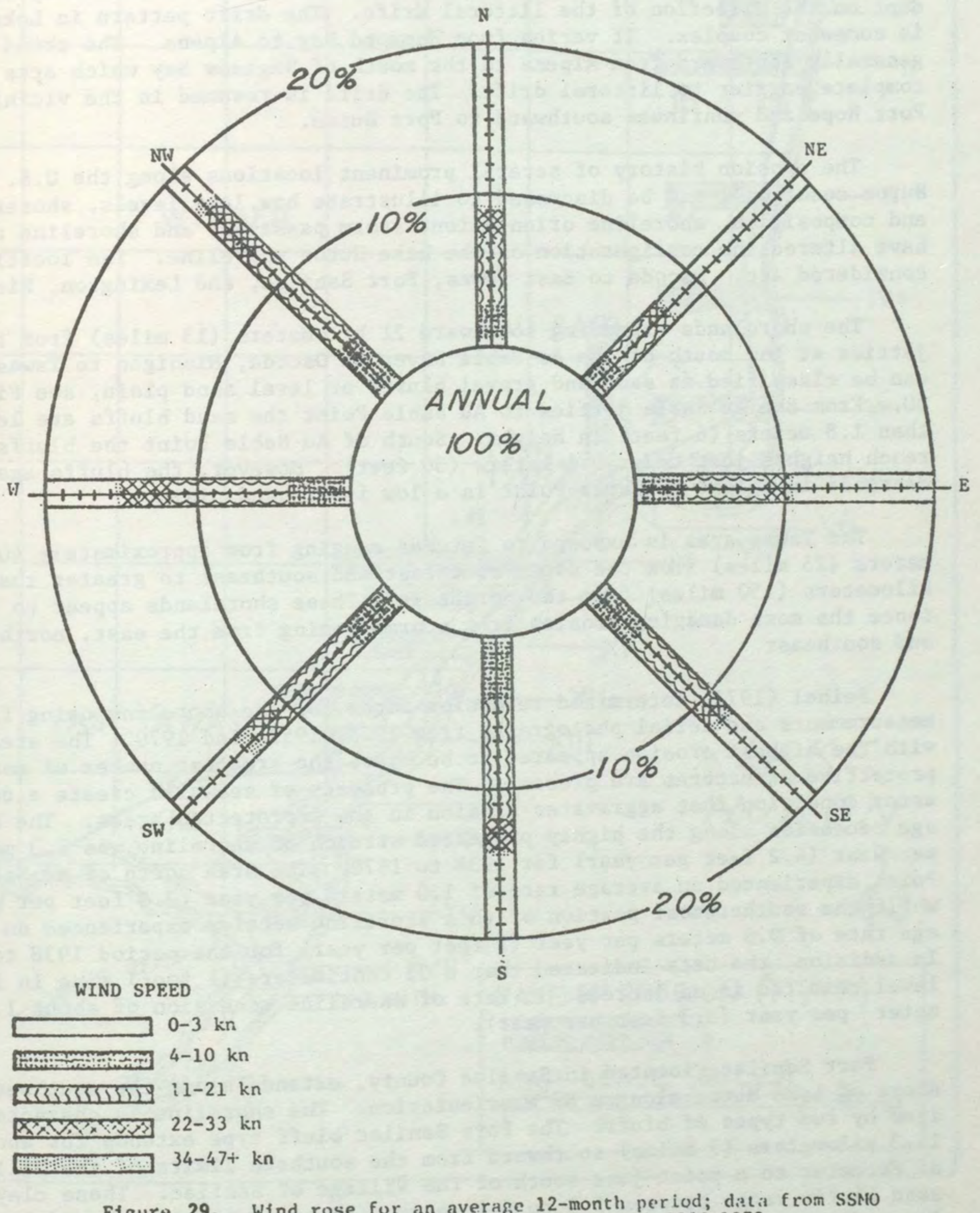


Figure 29. Wind rose for an average 12-month period; data from SSMO observations at Lake Huron Northwest 1960-1973

The ability of a beach to naturally rebuild itself is partially dependent on the direction of the littoral drift. The drift pattern in Lake Huron is somewhat complex. It varies from Hammond Bay to Alpena. The trend is generally southward from Alpena to the mouth of Saginaw Bay which acts as a complete barrier to littoral drift. The drift is resumed in the vicinity of Port Hope and continues southward to Port Huron.

The erosion history of several prominent locations along the U.S. Lake Huron coast will now be discussed to illustrate how lake levels, shoretype and composition, shoreline orientation, storm passages, and shoreline use have altered the configuration of the Lake Huron shoreline. The locations considered are: Oscoda to East Tawas, Port Sanilac, and Lexington, Michigan.

The shorelands extending southward 21 kilometers (13 miles) from the jetties at the mouth of the Au Sable River at Oscoda, Michigan to Tawas Point can be classified as sand and gravel bluffs or level sand plain, see Figure 30. From the Au Sable jetties to Au Sable Point the sand bluffs are less than 1.8 meters (6 feet) in height. South of Au Sable Point the bluffs reach heights just under 9.1 meters (30 feet). However, the bluffs again decrease in height as Tawas Point is a low level sand plain.

The Tawas area is exposed to fetches ranging from approximately 40 kilometers (25 miles) from the south-southeast and southeast to greater than 240 kilometers (150 miles) from the northeast. These shorelands appear to experience the most damaging erosion from storms coming from the east, northeast, and southeast.

Seibel (1972) determined recession rates for the shoreline using field measurements and aerial photographs from 1938, 1952, and 1970. The area with the highest erosion appeared to be where the greatest number of man-made protective structures are present. The presence of seawalls create a deep water condition that aggravates erosion in the unprotected areas. The average recession along the highly protected stretch of shoreline was 1.3 meters per year (4.2 feet per year) for 1938 to 1970. The area north of Au Sable Point experienced an average rate of 1.0 meters per year (3.3 feet per year) while the southernmost portion of this shoreline section experienced an average rate of 0.6 meters per year (2 feet per year) for the period 1938 to 1970. In addition, the data indicated that a 31 centimeters (1 foot) rise in lake level resulted in an increase in rate of shoreline recession of about 1.0 meter per year (3.3 feet per year).

Port Sanilac, located in Sanilac County, extends along the southwestern shore of Lake Huron along a N7°W orientation. The shoreline is characterized by two types of bluff. The Port Sanilac bluff type extends for about 11.3 kilometers (7 miles) southward from the southern limits of the Village of Forester to a point just south of the Village of Sanilac. These clay and sand bluffs range between 5.5 to 6.1 meters (18 to 20 feet) high and are fronted by gravel and cobble beaches up to 10.7 meters (35 feet) wide. The Lexington bluff type extends southward from 1.6 kilometers (1 mile) south of the Village of Port Sanilac to the Sanilac - St. Clair County line. These

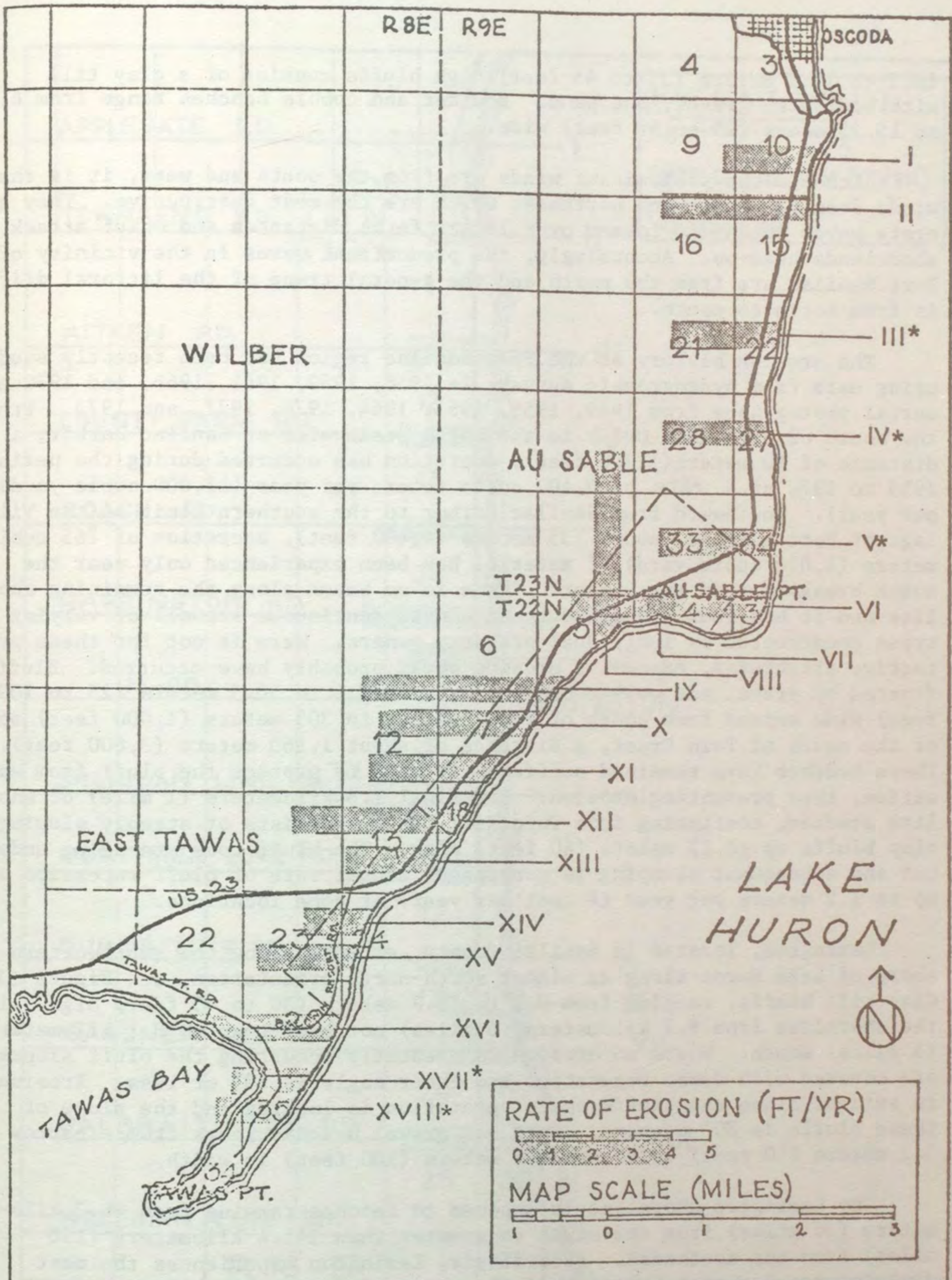


FIGURE 30. Study Area in the Vicinity of Tawas, Michigan.

SOURCE: Seibel, 1972.

10.7 to 13.7 meters (35 to 45 feet) high bluffs consist of a clay till with boulders, gravel, and sand. Boulder and cobble beaches range from 6.1 to 15.2 meters (20 to 50 feet) wide.

Although the predominant winds are from the south and west, it is the winds from the north and northeast which are the most destructive. They generate waves which are formed over larger fetch distances and which attack the shorelands head-on. Accordingly, the predominant waves in the vicinity of Port Sanilac are from the north and the general trend of the littoral drift is from north to south.

The erosion history of the Port Sanilac region has been recently studied using data from hydrographic surveys in 1936, 1950, 1961, 1966, and 1972 and aerial photographs from 1949, 1955, 1963, 1964, 1970, 1971, and 1973. From the mouth of the Liens Creek to the north breakwater at Sanilac Harbor, a distance of 40 meters(1,300 feet), accretion has occurred during the period 1955 to 1970 at a rate of 8,400 cubic meters per year (11,000 cubic yards per year). Southward from Sanilac Harbor to the southern limit of the Village of Port Sanilac, about 135 meters (4,400 feet), accretion of 765 cubic meters (1,000 cubic yard) of material has been experienced only near the south breakwater of the harbor. There is no beach along the remaining shoreline and it has been protected by an almost continuous seawall of varying types constructed by individual property owners. Were it not for these protective structures, extensive erosion would probably have occurred. Bluffs fronted by gravel and cobble beaches between 7.6 to 30.5 meters (25 to 100 feet) wide extend from south of Port Sanilac to 305 meters (1,000 feet) south of the mouth of Twin Creek, a distance of about 1,160 meters (3,800 feet). These beaches have remained sufficiently wide to protect the bluff from wave action, thus preventing erosion. The final 1.6 kilometers (1 mile) of shoreline studied, continuing from Twin Hill Creek, consists of steeply sloping clay bluffs up to 12 meters (40 feet) high. The bluff toes are being undercut and subsequent slumping is causing an annual rate of bluff recession of up to 1.2 meters per year (4 feet per year) at some locations.

Lexington, located in Sanilac County, extends along the southwestern shore of Lake Huron along an almost north-north orientation, see Figure 31. Clay till bluffs, ranging from 9.1 to 13.7 meters (30 to 45 feet) high, line the shoreline from 9.7 kilometers (6 miles) north of town to 8.1 kilometers (5 miles) south. Where no erosion is presently occurring the bluff slopes are covered with dense vegetation and their angle is 60° or less. Erosion is evident along the bluffs where vegetation is lacking and the slope of these bluffs is 80° or more. Sand and gravel beaches range from a narrow 3.1 meters (10 feet) to about 30.5 meters (100 feet) in width.

The Lexington shoreline is exposed to fetches ranging from 48.3 kilometers (30 miles) from the south to greater than 241.4 kilometers (150 miles) from the northeast. Accordingly, Lexington experiences the most damaging erosion when storm conditions arise from the northeast. Storms from the north, north-northeast, east-northeast, and east are not as damaging. Numerous groins have been constructed to protect the coast. They tend to retain sand on their updrift side and deprive the downdrift side of an adequate beach.

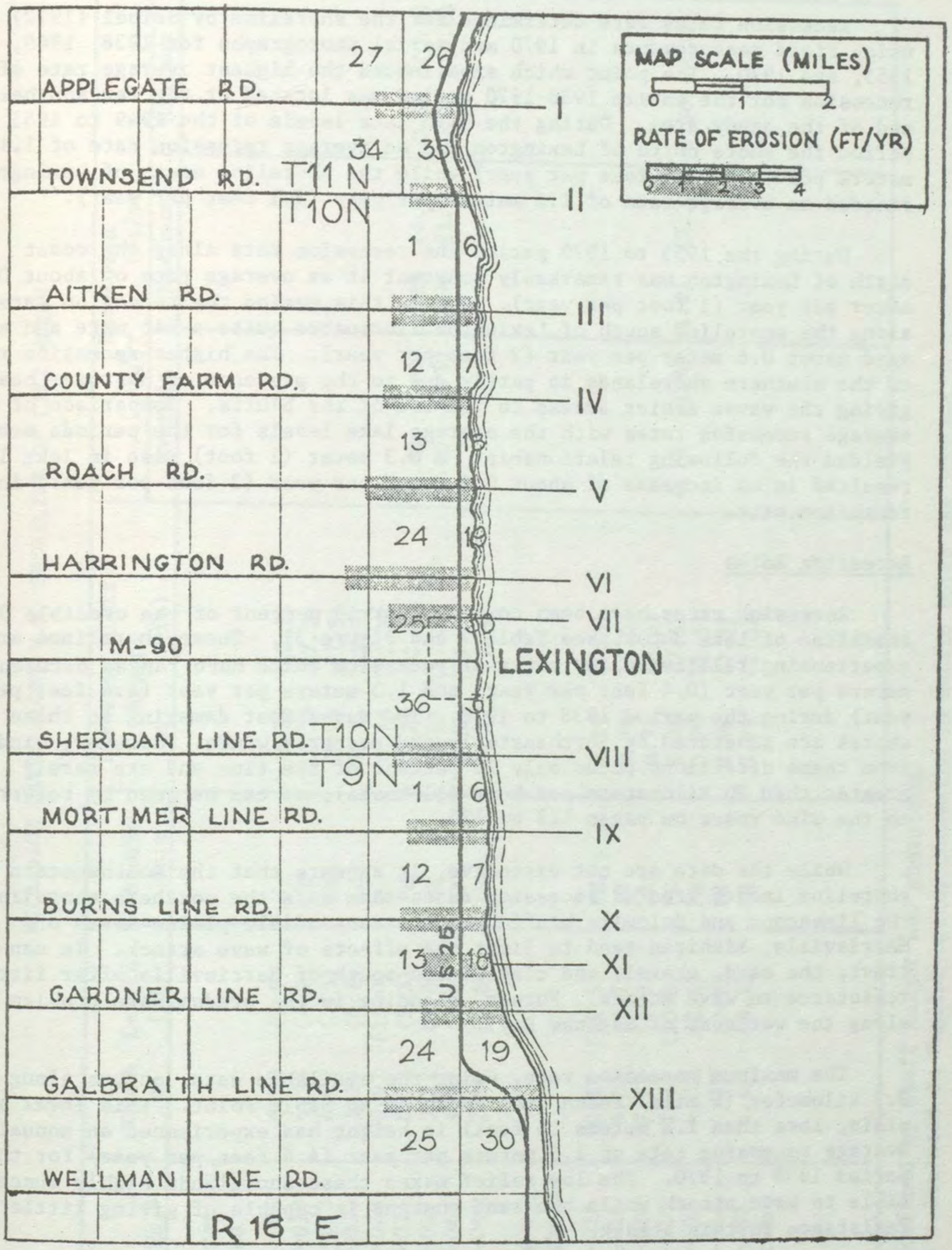


FIGURE 31. Study Area in the Vicinity of Lexington, Michigan.

SOURCE: Seibel, 1972.

Recession rates were determined for the shoreline by Seibel (1972) using field measurements in 1970 and aerial photographs for 1938, 1949, 1955, and 1970. The point which experienced the highest average rate of recession for the entire 1938-1970 period was located at the far southern end of the study area. During the high lake levels of the 1949 to 1955 period the shore north of Lexington had an average recession rate of 1.1 meters per year (3.6 feet per year) while the shoreline south of Lexington receded an average rate of 1.6 meters per year (5.1 feet per year).

During the 1955 to 1970 period the recession rate along the coast north of Lexington was remarkably constant at an average rate of about 0.3 meter per year (1 foot per year). During this period the recession rates along the shoreline south of Lexington fluctuated quite a bit more and averaged about 0.6 meter per year (2 feet per year). The higher recession rate of the southern shorelands is partly due to the presence of narrower beaches, giving the waves easier access to the toe of the bluffs. Comparison of the average recession rates with the average lake levels for the periods measured yielded the following relationship: a 0.3 meter (1 foot) rise in lake level resulted in an increase of about 0.6 meter per year (2 feet per year) in the recession rate.

Recession Rates

Recession rates have been compiled for 13 percent of the erodible U.S. shoreline of Lake Huron, see Table 7 and Figure 32. These shorelines are experiencing relatively low rates of recession which have ranged between 0.1 meters per year (0.4 feet per year) and 1.3 meters per year (4.4 feet per year) during the period 1938 to 1970. The waves most damaging to these shores are generated by northeasterly and easterly winds. However, winds from these directions occur only 18 percent of the time and are rarely greater than 20 kilometers per hour (11 knots), as can be seen by referring to the wind roses on pages 123 to 125.

While the data are not extensive, it appears that the southwestern shoreline incurs greater recession rates than does the northern shoreline. The limestone and dolomite bluffs and the nonerodible plains north of Harrisville, Michigan tend to limit the effects of wave attack. In contrast, the sand, gravel, and clay bluffs south of Harrisville offer little resistance to wave attack. Futher, flooding is the predominate problem along the wetlands of Saginaw Bay.

The maximum recession rate, using the available data, occurs along a 9.7 kilometer (6 mile) reach just north of Au Sable Point. This level sand plain, less than 1.8 meters (6 feet) in height has experienced an annual average recession rate of 1.3 meters per year (4.4 feet per year) for the period 1938 to 1970. The low relief makes these shorelands highly susceptible to wave attack while the sand content is capable of giving little resistance to this attack.

TABLE 7

RECESSION RATES ALONG U.S. SHORELINE OF LAKE HURON

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession Average m/yr	(ft/yr)	Maximum m/yr	(ft/yr)	Minimum m/yr	(ft/yr)
Cheboygan Co. Michigan											
51-001-005	6.28	(3.9)	W	0.76	(2.5)						
51-005-010	6.76	(4.2)	PE	2.29	(7.5)						
51-010-013	4.02	(2.5)	LBE	2.29	(7.5)						
51-013-014	1.29	(0.8)	LBE	0.76	(2.5)						
51-014-029	20.92	(13.0)	W	0.76	(2.5)						
51-029-036	8.53	(5.3)	PE	0.76	(2.5)	0.61	(2.0)	1.25	(4.1)	0.00	(0.0)
51-036-039	3.22	(2.0)	PE	5.33	(17.5)	0.15	(0.5)	0.30	(1.0)	0.00	(0.0)
51-039-042	4.18	(2.6)	LBE	5.33	(17.5)						
51-042-044	2.90	(1.8)	LBE	0.76	(2.5)						
Presque Isle Co. Michigan											
52-001-016	20.12	(12.5)	PE	2.29	(7.5)						
52-016-019	4.35	(2.7)	PE	0.76	(2.5)						
52-019-024	7.72	(4.8)	LBE	0.76	(2.5)						
52-024-037	17.38	(10.8)	PE	0.76	(2.5)	0.24	(0.8)	1.01	(3.3)	-0.06	(-0.2)
52-037-038	4.02	(2.5)	PN	0.76	(2.5)						
52-038-042	4.83	(3.0)	PN	2.29	(7.5)						
52-042-081 (6 reaches)	5.47	(3.4)	PN	0.76	(2.5)						

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 7--Continued

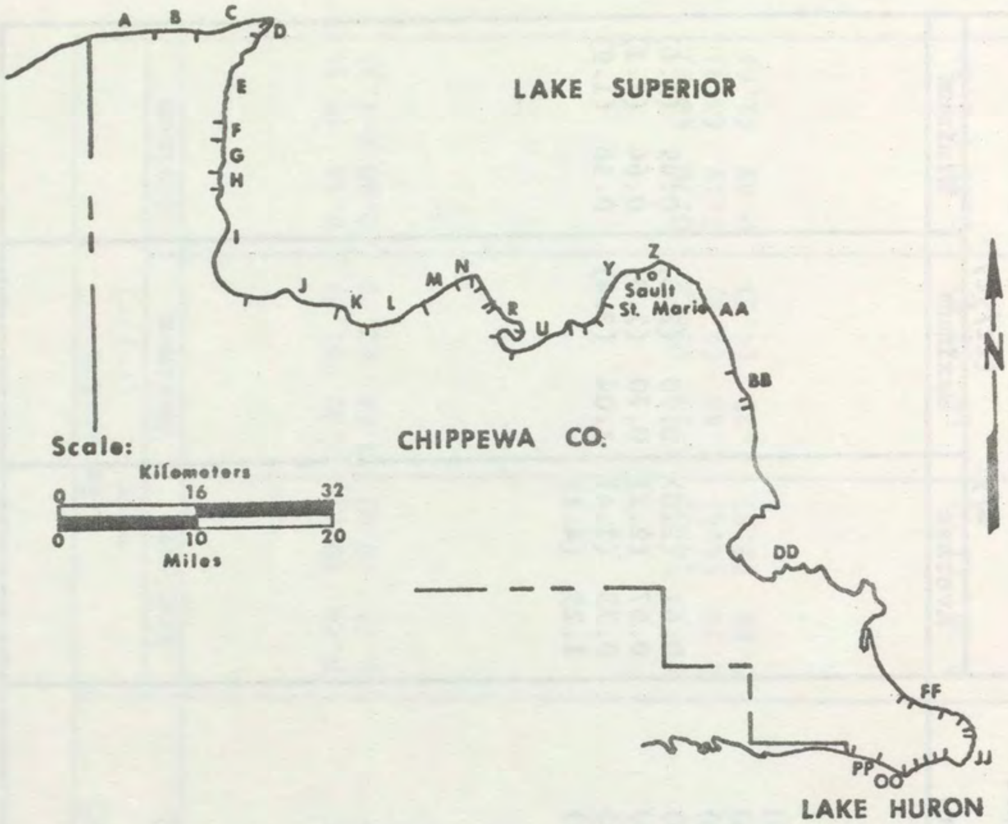
Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Alcona Co. Michigan											
54-001-006	8.21	(5.1)	PE	0.76	(2.5)	0.24	(0.8)	0.30	(1.0)	0.15	(0.5)
54-006-009	5.31	(3.3)	PE/W	0.76	(2.5)	0.12	(0.4)	0.64	(2.1)	-0.40	(-1.3)
54-009-016	9.33	(5.8)	PE	0.76	(2.5)						
54-016-018	2.25	(1.4)	PE	2.29	(7.5)						
54-018-023	6.92	(4.3)	PE	8.38	(27.5)						
54-023-028	9.98	(6.2)	PE	0.76	(2.5)						
Iosco Co. Michigan											
55-001-009	12.23	(7.6)	PE	0.76	(2.5)						
55-009-017	9.65	(6.0)	PE	0.76	(2.5)	1.22	(4.0)	1.55	(5.1)	0.70	(2.3)
55-017-019	2.90	(1.8)	LBE	2.29	(7.5)	1.34	(4.4)	1.46	(4.8)	1.19	(3.9)
55-019-026	9.65	(6.0)	PE	0.76	(2.5)	0.85	(2.8)	1.25	(4.1)	0.49	(1.6)
55-026-035	11.26	(7.0)	LBE	0.76	(2.5)						
55-035-043	11.26	(7.0)	PE	2.29	(7.5)						
Sanilac Co. Michigan											
60-001-009	12.23	(7.6)	HBE	11.43	(37.5)	0.30	(1.0)	1.16	(3.8)	-0.85	(-2.8)
60-009-011	4.51	(2.8)	HBE	5.33	(17.5)						
60-011-012	1.93	(1.2)	HBE	2.29	(7.5)						
60-012-016	4.83	(3.0)	LBN	2.29	(7.5)	0.21	(0.7)	0.37	(1.2)	0.00	(0.0)

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 7--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Sanilac Co. (continued)											
60-016-023	10.62	(6.6)	LBN	0.76	(2.5)						
60-023-024	2.09	(1.3)	LBN	8.38	(27.5)						
60-024-026	3.86	(2.4)	HBE	8.38	(27.5)						
60-026-028	3.38	(2.1)	HBE	11.43	(37.5)	0.61	(2.0)	0.70	(2.3)	0.49	(1.6)
60-028-030	2.74	(1.7)	HBE	5.33	(17.5)	0.67	(2.2)	0.70	(2.3)	0.64	(2.1)
60-030-037	12.71	(7.9)	HBE	8.38	(27.5)	0.73	(2.4)	1.04	(3.4)	0.58	(1.9)
60-037-039	3.86	(2.4)	HBE	3.81	(12.5)	1.25	(4.1)				

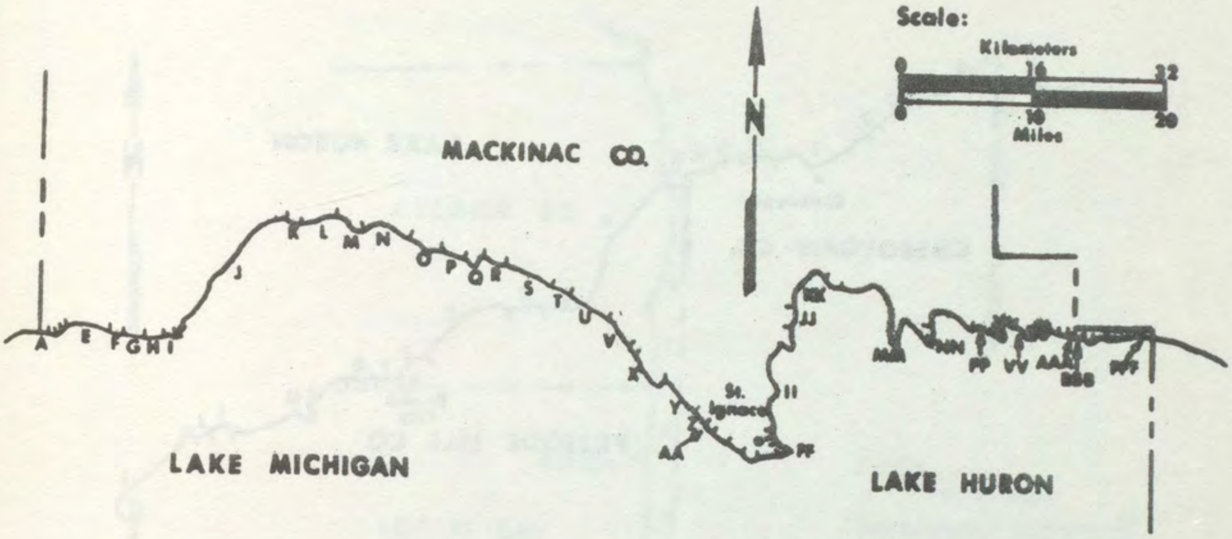
*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.



CHIPPEWA CO.

Code	Reach Number	Code	Reach Number
A	16-001-006	W	16-087-089
B	16-006-009	X	16-089-091
C	16-009-015	Y	16-091-093
D	16-015-018	Z	16-093-094
E	16-018-025	AA	16-094-106
F	16-025-026	BB	16-106-110
G	16-026-030	CC	16-110-110
H	16-030-032	DD	16-110-162
I	16-032-046	EE	16-162-164
J	16-046-056	FF	16-164-169
K	16-056-059	GG	16-169-171
L	16-059-066	HH	16-171-173
M	16-066-069	II	16-173-174
N	16-069-069	JJ	16-174-176
O	16-069-070	KK	16-176-177
P	16-070-072	LL	16-177-178
Q	16-072-073	MM	16-178-179
R	16-073-076	NN	16-179-181
S	16-076-079	OO	16-181-184
T	16-079-081	PP	16-184-188
U	16-081-086	QQ	16-188-189
V	16-086-087		

FIGURE 32. LAKE SUPERIOR AND LAKE HURON: Chippewa County Reach Locations.

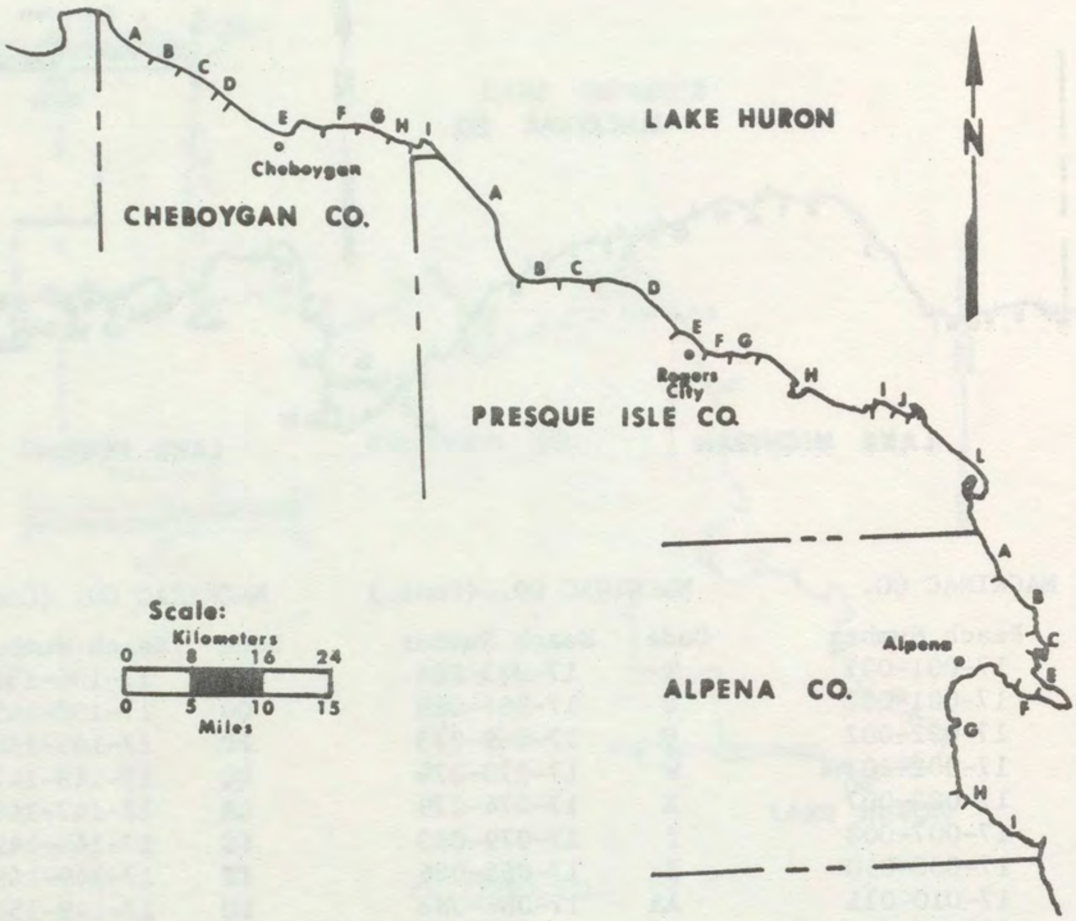


MACKINAC CO.	
Code	Reach Number
A	17-001-001
B	17-001-002
C	17-002-002
D	17-002-003
E	17-003-007
F	17-007-008
G	17-008-010
H	17-010-011
I	17-011-012
J	17-012-032
K	17-032-034
L	17-034-038
M	17-038-040
N	17-040-045
O	17-045-049
P	17-049-052
Q	17-052-056
R	17-056-057
S	17-057-063

MACKINAC CO. (Cont.)	
Code	Reach Number
T	17-063-064
U	17-064-069
V	17-069-073
W	17-073-074
X	17-074-079
Y	17-079-085
Z	17-085-086
AA	17-086-088
BB	17-088-090
CC	17-090-091
DD	17-091-091
EE	17-091-094
FF	17-094-095
GG	17-095-095
HH	17-095-097
II	17-097-110
JJ	17-110-111
KK	17-111-116
LL	17-116-122
MM	17-122-136

MACKINAC CO. (Cont.)	
Code	Reach Number
NN	17-136-138
OO	17-138-145
PP	17-145-148
QQ	17-148-147
RR	17-147-148
SS	17-148-149
TT	17-149-149
UU	17-149-151
VV	17-151-154
WW	17-154-154
XX	17-154-155
YY	17-155-155
ZZ	17-155-157
AAA	17-157-158
BBB	17-158-158
CCC	17-158-161
DDD	17-161-161
EEE	17-161-166
FFF	17-166-167

LAKE MICHIGAN AND LAKE HURON: Mackinac County Reach Locations.

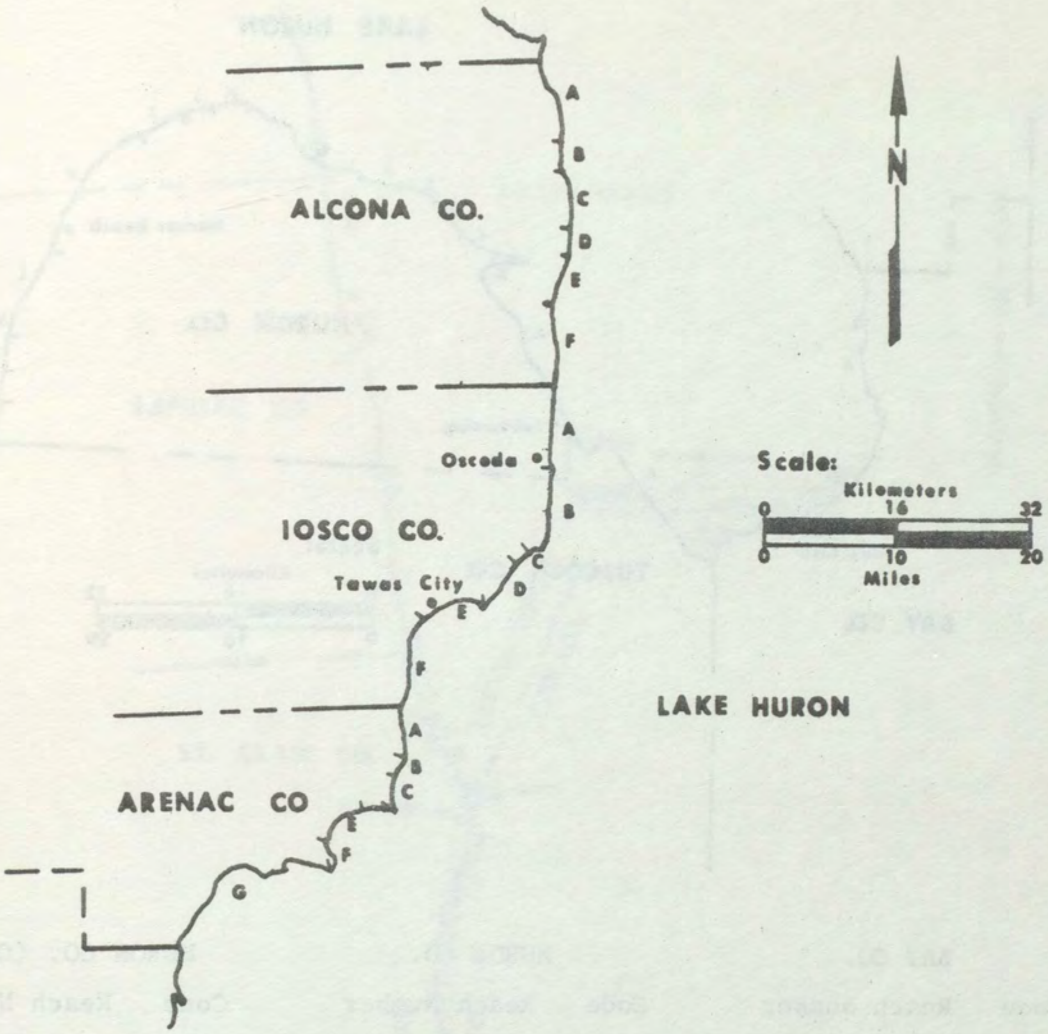


CHEBOYGAN CO.	
Code	Reach Number
A	51-001-005
B	51-005-010
C	51-010-013
D	51-013-014
E	51-014-029
F	51-029-036
G	51-036-039
H	51-039-042
I	51-042-044

PRESQUE ISLE CO.	
Code	Reach Number
A	52-001-016
B	52-016-019
C	52-019-024
D	52-024-037
E	52-037-038
F	52-038-042
G	52-042-044
H	52-044-055
I	52-055-061
J	52-061-064
K	52-064-064
L	52-064-081

ALPENA CO.	
Code	Reach Number
A	53-001-007
B	53-007-011
C	53-011-013
D	53-013-013
E	53-013-020
F	53-020-023
G	53-023-048
H	53-048-050
I	53-050-057

LAKE HURON: Cheboygan, Presque Isle, and Alpena County Reach Locations.

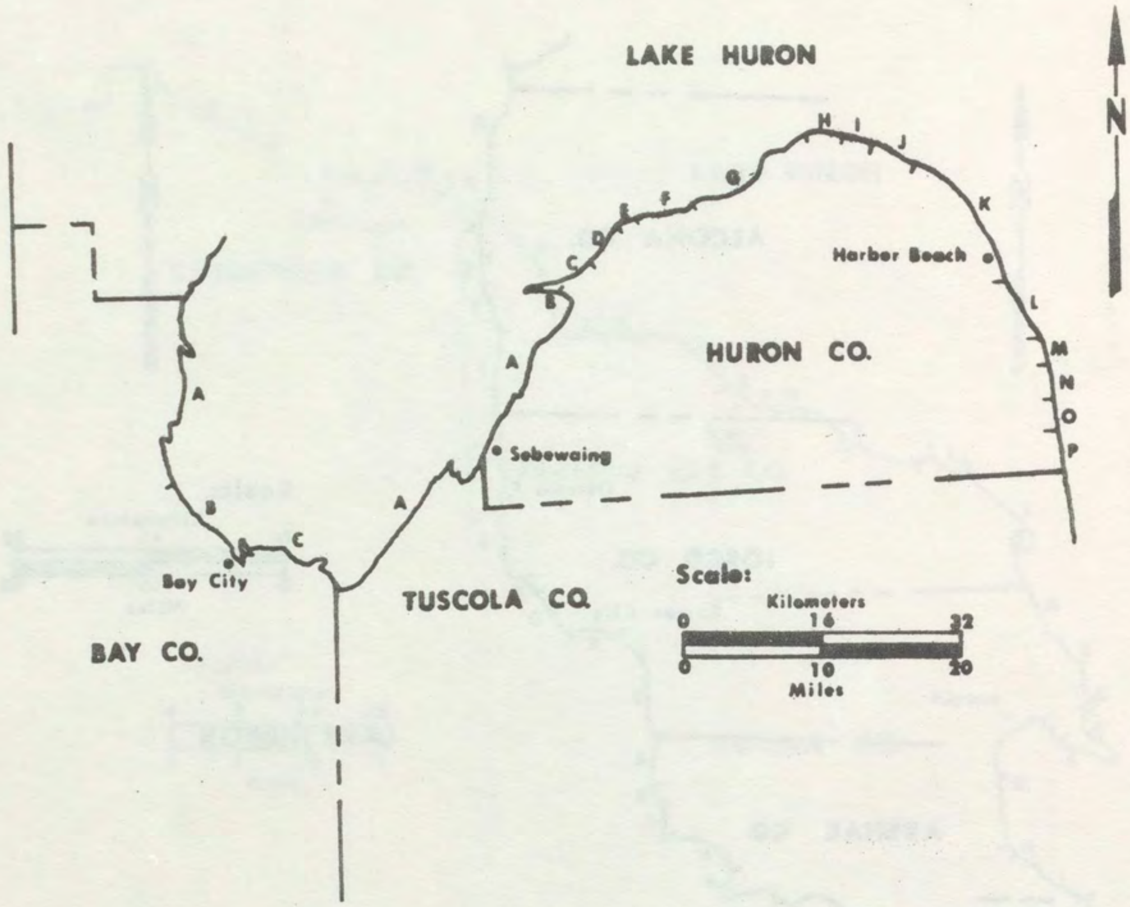


ALCONA CO.	
Code	Reach Number
A	54-001-006
B	54-006-009
C	54-009-016
D	54-016-018
E	54-018-023
F	54-023-028

IOSCO CO.	
Code	Reach Number
A	55-001-009
B	55-009-017
C	55-017-019
D	55-019-026
E	55-026-035
F	55-035-043

ARENAC CO.	
Code	Reach Number
A	56-001-004
B	56-004-007
C	56-007-012
D	56-012-015
E	56-015-018
F	56-018-023
G	56-023-043

LAKE HURON: Alcona, Iosco, and Arenac County Reach Locations.



BAY CO.

Code	Reach Number
A	57-001-020
B	57-020-028
C	57-028-041

TUSCOLA CO.

Code	Reach Number
A	58-001-024

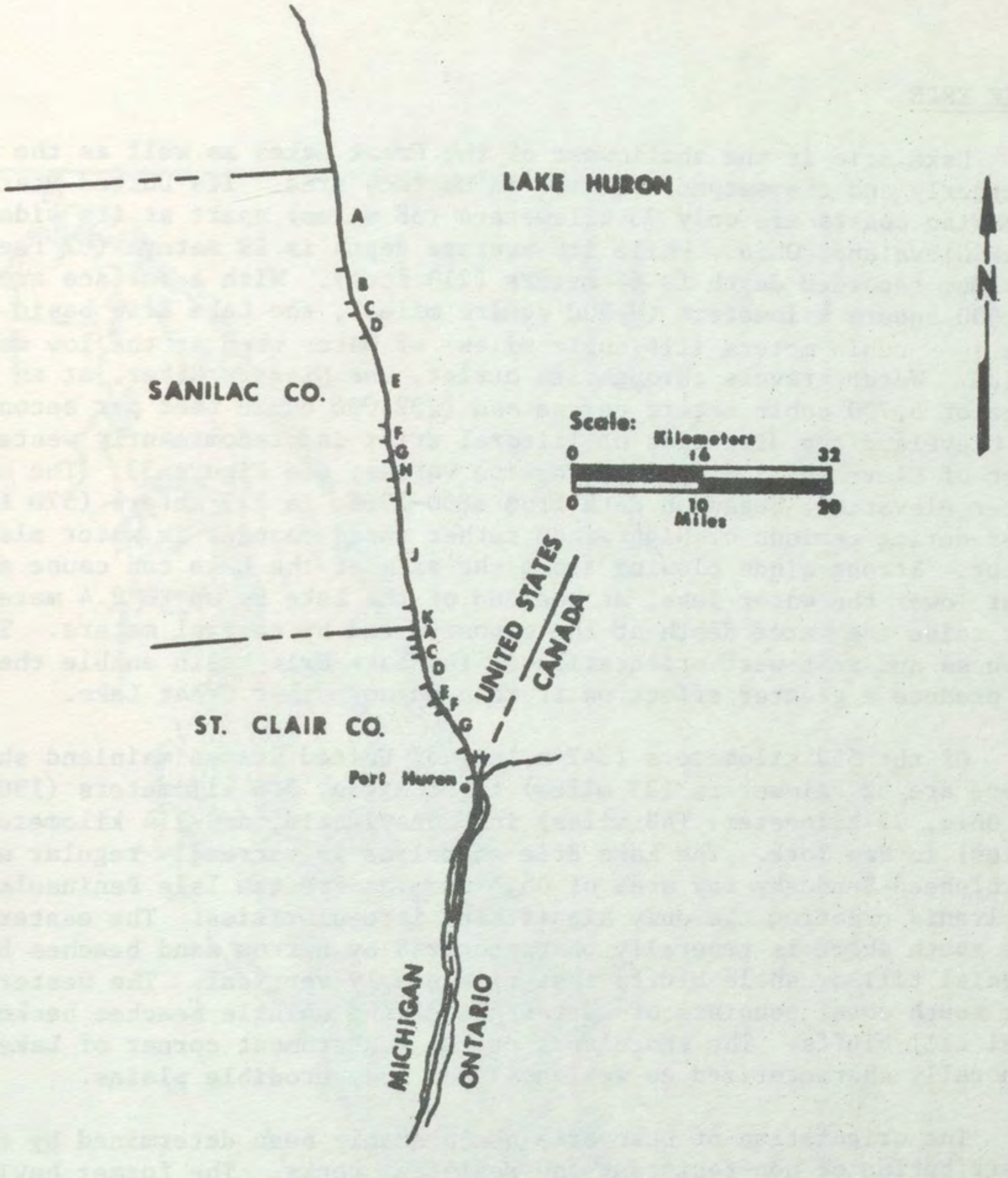
HURON CO.

Code	Reach Number
A	59-001-019
B	59-019-020
C	59-020-025
D	59-025-030
E	59-030-031
F	59-031-037
G	59-037-050
H	59-050-054

HURON CO. (Cont.)

Code	Reach Number
I	59-054-058
J	59-058-063
K	59-063-083
L	59-083-085
M	59-085-089
N	59-089-090
O	59-090-092
P	59-092-093

LAKE HURON: Bay, Tuscola, and Huron County Reach Locations.



SANILAC CO.	
Code	Reach Number
A	60-001-009
B	60-009-011
C	60-011-012
D	60-012-016
E	60-016-023
F	60-023-024
G	60-024-026
H	60-026-028
I	60-028-030
J	60-030-037
K	60-037-039

ST. CLAIR CO.	
Code	Reach Number
A	61-001-002
B	61-002-002
C	61-002-003
D	61-003-005
E	61-005-007
F	61-007-008
G	61-008-011
H	61-011-014

LAKE HURON: Sanilac and St. Clair County Reach Locations.

LAKE ERIE

Lake Erie is the shallowest of the Great Lakes as well as the most southerly and the second smallest in surface area. Its United States and Canadian coasts are only 93 kilometers (58 miles) apart at its widest point near Cleveland, Ohio. While its average depth is 19 meters (62 feet), the maximum recorded depth is 64 meters (210 feet). With a surface area of 26,000 square kilometers (9,900 square miles), the Lake Erie basin contains 5×10^{11} cubic meters (116 cubic miles) of water when at the low water datum. Water travels through its outlet, the Niagara River, at an average rate of 5,700 cubic meters per second (202,000 cubic feet per second). West of Cleveland the direction of littoral drift is predominantly westerly while east of Cleveland the drift direction varies; see Figure 33. The average water elevation, based on data from 1860-1968, is 175 meters (570 feet). However during periods of high winds rather rapid changes in water elevation can occur. Strong winds blowing along the axis of the Lake can cause seiches that lower the water level at one end of the Lake by up to 2.4 meters (8 feet) and raise the water depth at the opposite end by several meters. The shallowness and east-west orientation of the Lake Erie basin enable the seiches to produce a greater effect on it than on any other Great Lake.

Of the 550 kilometers (342 miles) of United States mainland shoreline, there are 53 kilometers (33 miles) in Michigan, 306 kilometers (190 miles) in Ohio, 77 kilometers (48 miles) in Pennsylvania, and 114 kilometers (71 miles) in New York. The Lake Erie shoreline is extremely regular with the Marblehead-Sandusky Bay area of Ohio and the Presque Isle Peninsula of Pennsylvania creating the only significant irregularities. The easterly half of the south shore is generally characterized by narrow sand beaches backed by glacial till or shale bluffs that rise nearly vertical. The westerly half of the south coast consists of narrow gravel and shingle beaches backed by glacial till bluffs. The shorelands of the westernmost corner of Lake Erie are generally characterized as wetlands and low, erodible plains.

The orientation of Lake Erie has probably been determined by the areal distribution of non-resistant and resistant rocks. The former having provided a relatively easy pathway for the south-westward advance of glacial ice. The western portion of the Lake basin lies along the axis of the Cincinatti Arch and is underlain by rock of Silurian and Devonian ages. These relatively resistant carbonate rocks form an arcuate pattern which is convex northward with the rocks dipping outward from the arc. The shallowness of this western basin may be due to the relatively high resistance of these carbonate rocks. The central and eastern portions of the Lake basin are located along the strike of a simple structure in which the beds are tilted to the south towards the Appalachain Geosyncline. These portions of the Lake basin were glacially excavated in soft Devonian shales and they are underlain by the more resistant Devonian limestones. The greater depths present in these sections are probably a consequence of the lower resistance of the shales and shaly sandstones to glacial scouring. Along the southern border of the Lake basin eastward from Cleveland, the northwestern edge of the Appalachian platform is present in the form of an escarpment composed mainly of Mississippian sandstones and shales.

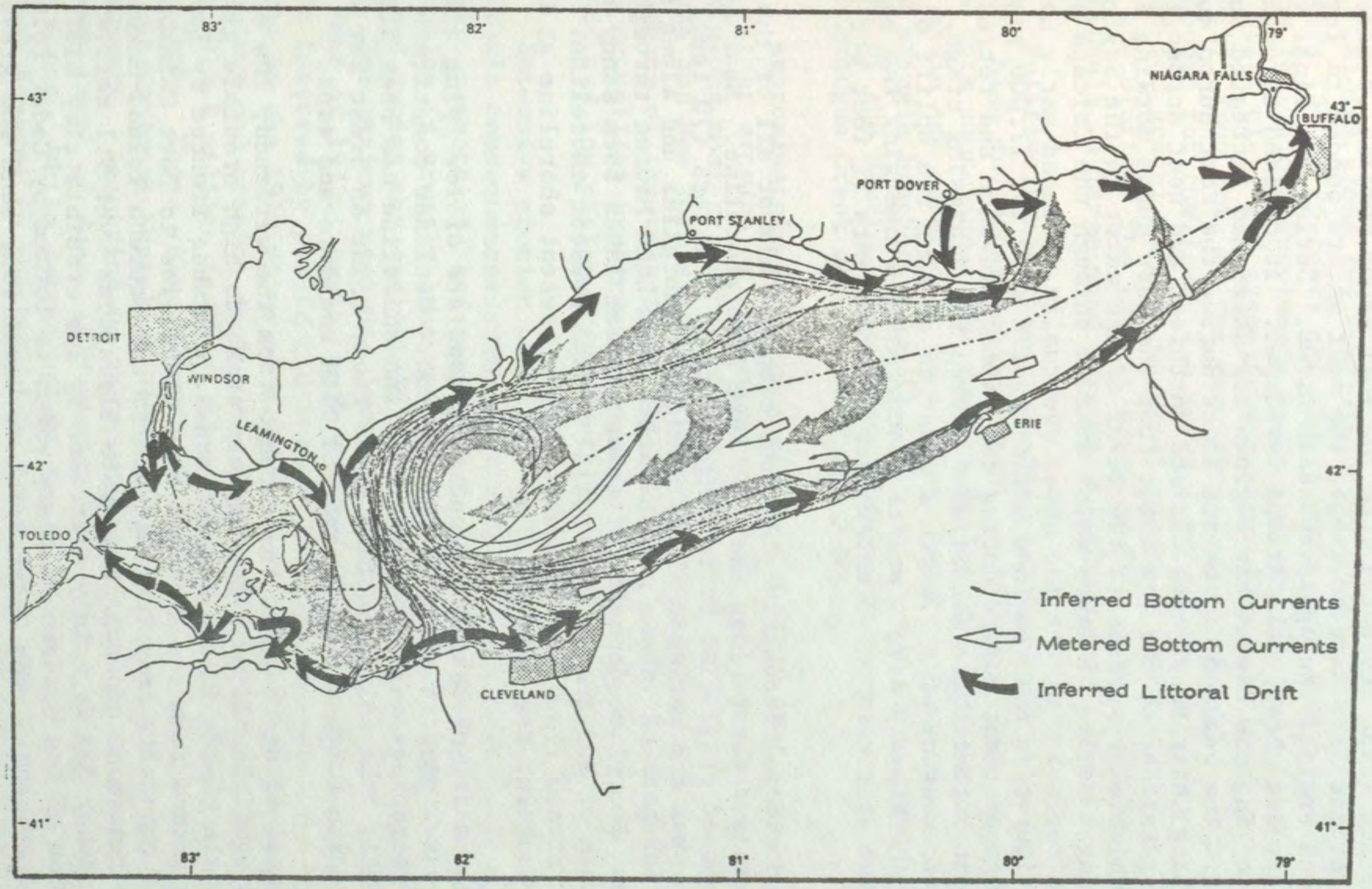


FIGURE 33. Generalized Map of Dominant Alongshore Drift and Bottom Currents in Lake Erie.

SOURCE: Sweeney, 1975

The glacial history which shaped the present shorelines is complex. The first glacial lake to form in what is now the Lake Erie basin was Lake Maumee. As the ice sheet retreated from the Fort Wayne moraine, a recessional moraine of the late Cary substage, the melt waters ponded to form Lake Maumee which drained through the Wabash River. During the final retreat of the Cary ice sheet, Lake Arkona developed. It drained through the lowlands south of Saginaw Bay as the Saginaw ice sheet had retreated sufficiently north. The advance of the ice front during the Port Huron substage created Lake Whittlesey which drained northwest and west across the Michigan thumb. Retreat of the ice sheet from the Port Huron moraine lowered the Lake Whittlesey surface to the level of the water in the Saginaw Bay area, forming a series of lakes which drained through the Chicago outlet. Continued recession of the ice sheet eventually produced early Lake Erie whose configuration has remained basically the same for 11,000 years. However, drainage patterns varied during the Valders advance and retreat until the present outlets were established during the Nipissing stage. Postglacial isostatic rebound of the earth's crust is causing the uplift of Lake Erie's outlet, the Niagara River, and is concurrently submerging the southwestern shoreline at a rate of .3 meters per hundred years (1 foot per hundred years).

Glacial and glacial lacustrine deposits comprise almost all of the surficial materials present along the U.S. Lake Erie shoreline. Near Ashtabula bluffs composed of glacial tills range up to 21.3 meters (70 feet) in height. The marshes and wetlands along Michigan's shoreline and along Maumee Bay lie in the lakebeds of former glacial lakes from Lake Maumee through early Lake Erie. Shoreline deposits of these glacial lakes form sandy ridges lying to the south of and generally parallel to the present shoreline. These beach ridges or strand lines are located near the present shoreline at Cleveland, Ohio and Dunkirk, New York.

The Michigan shore of Lake Erie generally consists of low-lying silt and clay materials which support extensive marshlands. Wetlands constitute 44 percent of the shorelands while 56 percent of the shoreline has been altered by artificial fill. The only exception is at Stony Point on Brest Bay where a brecciated dolomite forms a rocky shoreland with boulders and sand.

The shorelands along the Ohio coast range from the wetlands, low erodible bluffs and erodible plain in the western areas to high erodible glacial till and soft shale bluffs in the eastern areas. Marshes fronted by low barrier reaches extend from the Michigan-Ohio State line to Port Clinton. The relief rises gradually from Port Clinton to the Catawba Island-Marblehead peninsula where limestone and dolomite reach elevations over 9.1 meters (30 feet) high. Sandusky Bay is mainly encircled by low erodible clay bluffs with the exception of its eastern boundary which is formed by Cedar Point, a long, sand barrier beach. From Cedar Point to Vermilion, sand and gravel beaches are backed by bluffs of glacial till which range in height from 3.1 to 9.1 meters (10 to 30 feet). Alternating combinations of two general bluff types extend along the remaining Ohio shoreline from Vermilion to the Ohio-Pennsylvania State line. The first type consists primarily of glacial till topped by lacustrine deposits of sand or silt. The second bluff type is formed by relatively soft shale. Bluff heights along this stretch of Ohio coast range from 1.5 meters (5 feet) to over 18.3 meters (60 feet). Narrow sand and shingle beaches, up to 7.6 meters (25 feet), front many of the bluffs.

Bluffs along the Pennsylvania shoreline range in height from 15 to 23 meters (50 to 75 feet) and rise to 30 meters (100 feet) in several places. From the Ohio-Pennsylvania State line to Erie, the bluffs consist entirely of silt, clay, and granular material with shale bedrock present at water level. From Erie to the Pennsylvania-New York State line, shale frequently accounts for the lower 4.6 to 10.7 meters (15 to 35 feet) of the bluff. Sand and gravel beaches up to 45 meters (150 feet) wide extend along the toe of the bluffs. The largest beach on Lake Erie is formed by the Presque Isle Peninsula, a large sand spit which encloses Erie Harbor.

Relatively nonerodible bluffs, ranging from 12 to 15 meters (40 to 50 feet) high and occasionally rising to 30 meters (100 feet), extend along the New York shoreline. The lower portions of the bluffs are commonly composed of shale and covered by silt, clay, and granular material. Narrow gravel and shingle beaches, from 12 to 15 meters (40 to 50 feet) wide, extend along some of the bluffs. Wider sand beaches occur between Silver Creek and Cattaraugus Creek and in the town of Evans.

Approximately 98 percent of the U.S. Lake Erie shorelands are subjected to either erosion or flooding, see Table 8. Erosion is the predominant problem along most stretches of the Ohio coast while many sections of the Pennsylvania and New York shoreline are not subjected to critical erosion due to the presence of the relatively stable shale bluffs, see Figure 34. Flooding is the prevailing problem at the eastern and western ends of the Lake where wetlands and low plains predominate.

Extensive erosion and flooding along Lake Erie tend to create serious economic consequences since over half of the shoreline is devoted to industrial, commercial, and residential uses. The probability of erosion and flooding is greatly enhanced by high lake levels. Record high levels occurred during the early 1950's and the early through mid-1970's, see Figure 35. The maximum recorded level of 174.9 meters (573.5 feet) IGLD was reached in June of 1973. During both periods extensive erosion and flooding damages were incurred by public and private property owners. The following damages, based on the 1970 value of a dollar, to private and public property due to flooding and erosion during the 1950-1952 period are: $15.4 million in Michigan, $14.8 million in Ohio, $1 million in Pennsylvania, and $.2 million in New York. These values were derived for the Great Lakes Regional Inventory of the National Shoreline Study which was conducted by the U.S. Corps of Engineers. According to the Michigan Department of Natural Resources, the record level of June, 1973 caused $1.6 million damage in Monroe County, Michigan alone. While dollar values have not been estimated for much of the continual damages to the U.S. Lake Erie shorelands during the early to mid-1970's, there is widespread agreement that the problem is extremely critical.

TABLE 8

SHORETYPES ALONG THE U.S. SHORELINE OF LAKE ERIE*

SHORETYPES	MILES	KILOMETERS	PERCENTAGE
Artificial fill area	44.1	70.97	12.89
Erodible high bluff	144.1	231.89	42.14
Nonerodible high bluff	2.2	3.54	0.64
Erodible low bluff	76.4	122.95	22.34
Nonerodible low bluff	3.9	6.28	1.14
High dunes	0.0	0.00	0.00
Low dunes	8.1	13.04	2.37
Erodible low plain	11.7	18.83	3.42
Nonerodible low plain	1.3	2.09	0.38
Wetlands	46.4	74.67	13.57
Wetlands/Erodible low plain	3.8	6.12	1.11
Wetlands/Erodible low bluff	0.0	0.00	0.00
Total Shore Length	342.0	550.4	100.00

Source: Great Lakes Basin Commission, 1975.

*Sandusky Bay, Ohio was not included.

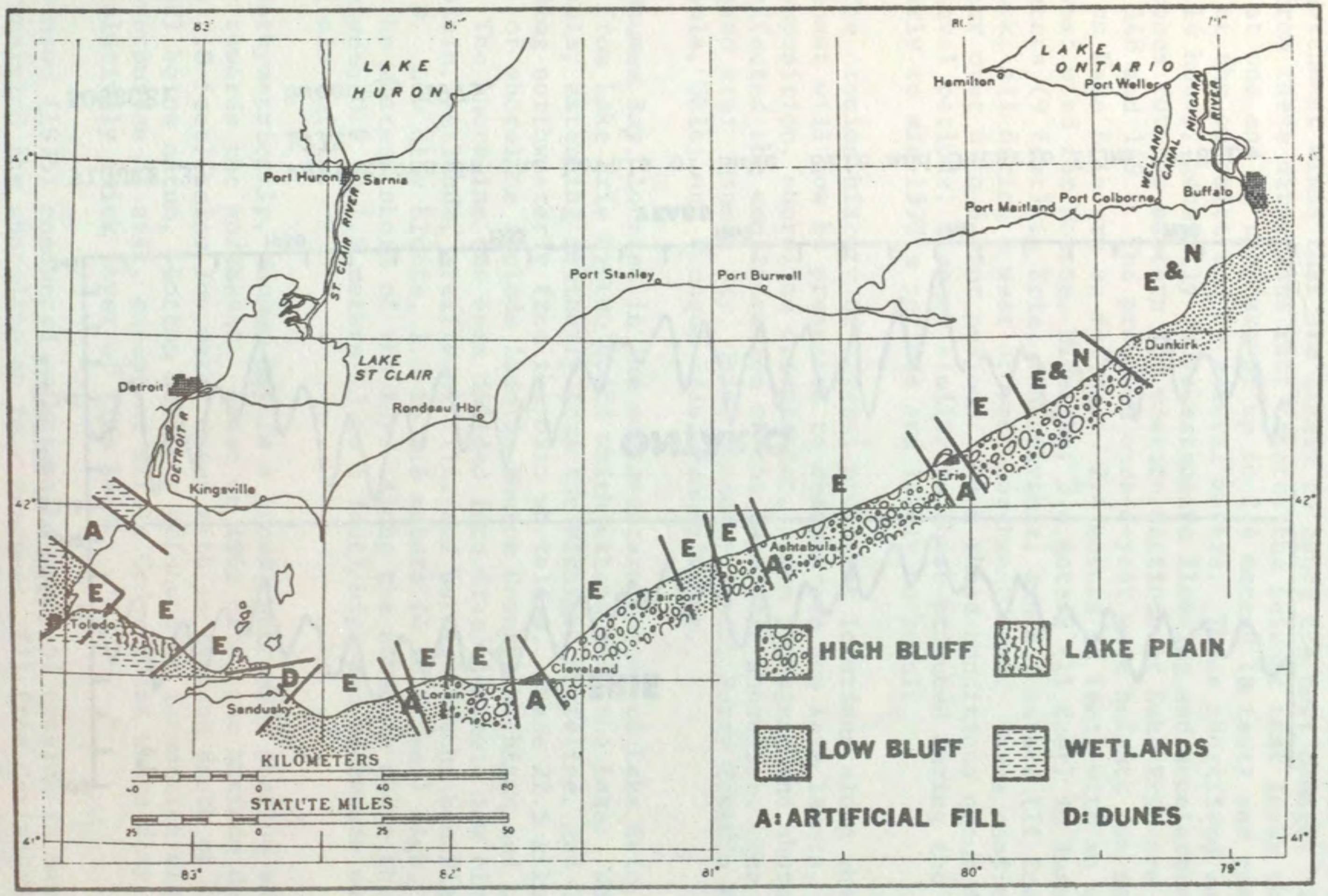


FIGURE 34. Shorelands Along Lake Erie.

SOURCE: Sweeney, 1975.

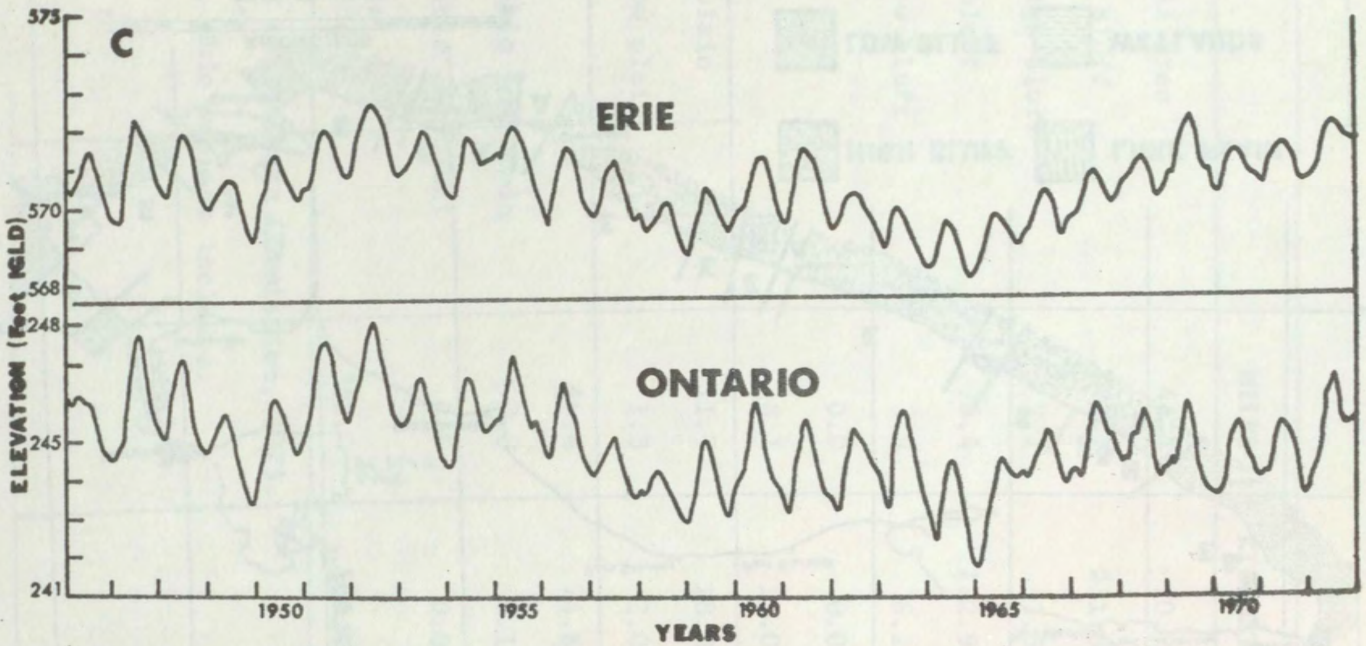


FIGURE 35. Variations in the Levels of Lake Erie and Ontario from 1948 to 1972.

SOURCE: Sweeney, 1975.

The intensity and direction of wind and the height of waves during a storm will largely determine the amount of damage that is created. While the prevailing winds come from the southwest, it is the west-north-west and east-northeast winds that are likely to cause the most damage. It is the wind from these directions that creates the seiches that lower the water level at one end of the Lake by up to 2.4 meters (8 feet) and raise the water depth at the opposite end by several meters. These shortlived conditions, up to 14 hours, generally cause extensive flooding and accelerate erosion. Wind roses for the eastern and western sections of Lake Erie are found on pages 148 and 149. The probable once-a-year wave heights for several locations on Lake Erie are as follows: 2.4 meters (8 feet) with an east or east-northwest wind for Monroe, Michigan; 3.4 meters (11 feet) in Huron, Ohio, 2.7 meters (9 feet) in Erie, Pennsylvania, and 3.4 meters (11 feet) in Buffalo, New York, all during a west or west-northwest wind. These conditions commonly occur over 6 to 8 hour periods. When these conditions occur during high lake level periods, damages similar to those produced during the 1951-1952 and early to mid-1970's periods are likely to result.

The erosion history of several prominent locations along the U.S. Lake Erie coast will now be presented to demonstrate how lake levels, shoretype and composition, shoreline orientation, storm passages, and shoreline use have affected the configuration of the Lake Erie shoreline. The locations discussed are: Maumee Bay, Ohio; Sandusky, Ohio; Perry Towship Park, Ohio; Ashtabula, Ohio; and Presque Isle, Pennsylvania.

Maumee Bay, located in the southwestern corner of Lake Erie, is separated from Lake Erie by two spits which extend into the Lake: Woodtick Peninsula, extending southerly from the Michigan shoreline, and Cedar Point, extending northwesterly from the Ohio shoreline. These 22.5 kilometers (14 miles) of shoreline include land in Monroe County, Michigan and Lucas County, Ohio. The shoreline has been divided into five classes: low clay bluff, clay plain, wetlands, artificial fill, and barrier beach; see Figure 38 and Table 9. Low clay bluffs, 1.2 to 1.8 meters (4 to 6 feet) high, predominate along the western shore of the Bay. Along the southern shore the bluff ranges between 0.9 to 1.5 meters (3 to 5 feet) high and decreases eastward, becoming clay plain.

Bathymetrically, Maumee Bay is a broad, extremely shallow shelf, sloping gently towards the northeast. Based on 1961 data, the maximum depth is 3.1 meters (10 feet) below low water datum with an average depth of 1.5 meters (5 feet) below datum. Bottom sediment offshore is lacustrine clay with a thin overburden of silt, except at Little Cedar Point where clay is overlain by a relatively thick layer of fine sand.

Benson (1975) conducted an extensive study of erosion in Maumee Bay which analyzed the shoreline as four reaches: (1) from Carland Beach to the Maumee River, (2) the Maumee River area, (3) the Maumee River to Norden Road, and (4) Norden Road to Cedar Point. Reccession rates were determined with the use of U.S. Lake Survey maps for 1877 and aerial photographs for 1940, 1957, 1958, and 1973. Due to the lack of development along Maumee Bay between 1877-1940, this period is assumed to give the best approximation of a natural recession rate. It also encompasses the high water level period

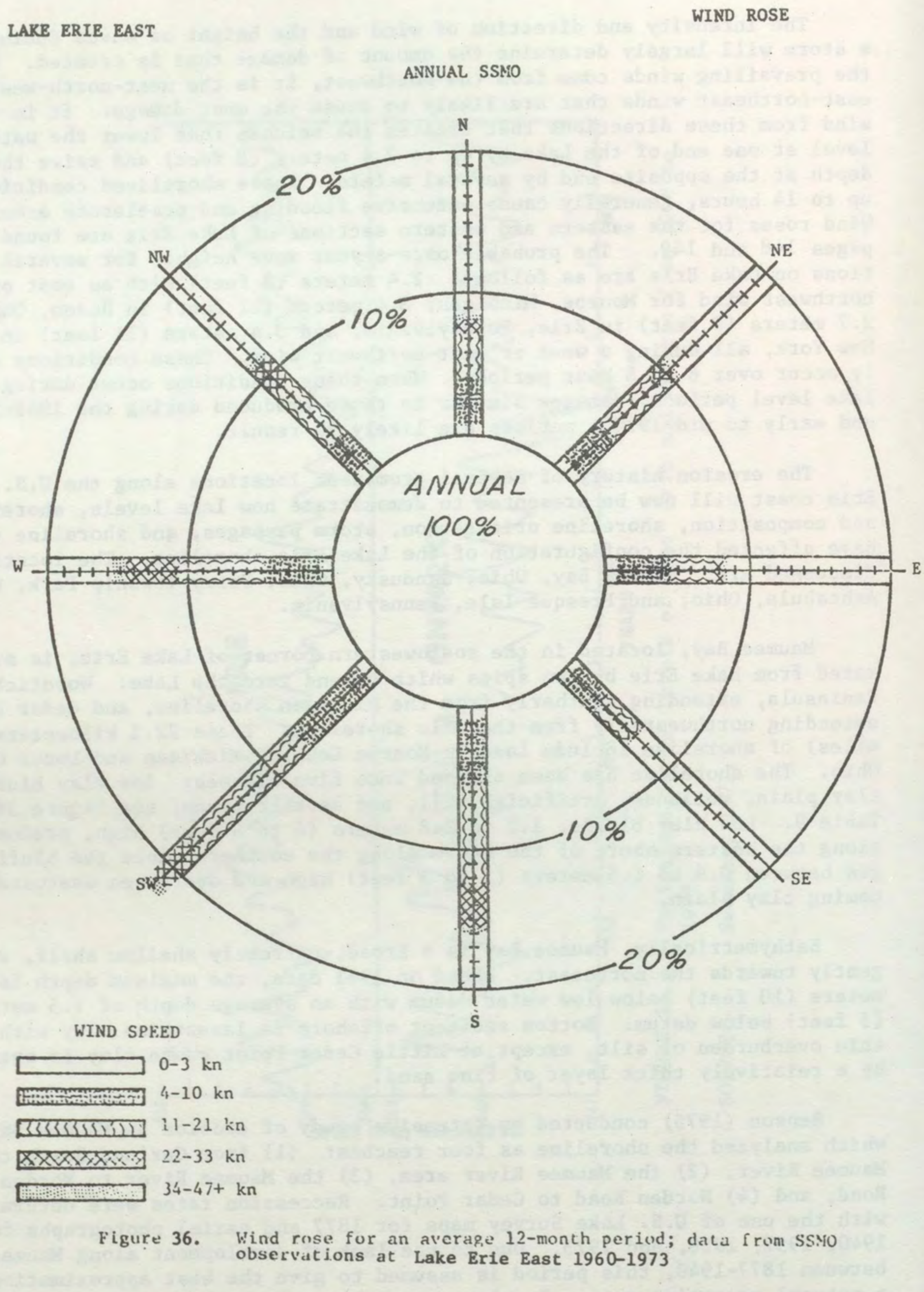


Figure 36. Wind rose for an average 12-month period; data from SSMO observations at Lake Erie East 1960-1973

ANNUAL SSMO

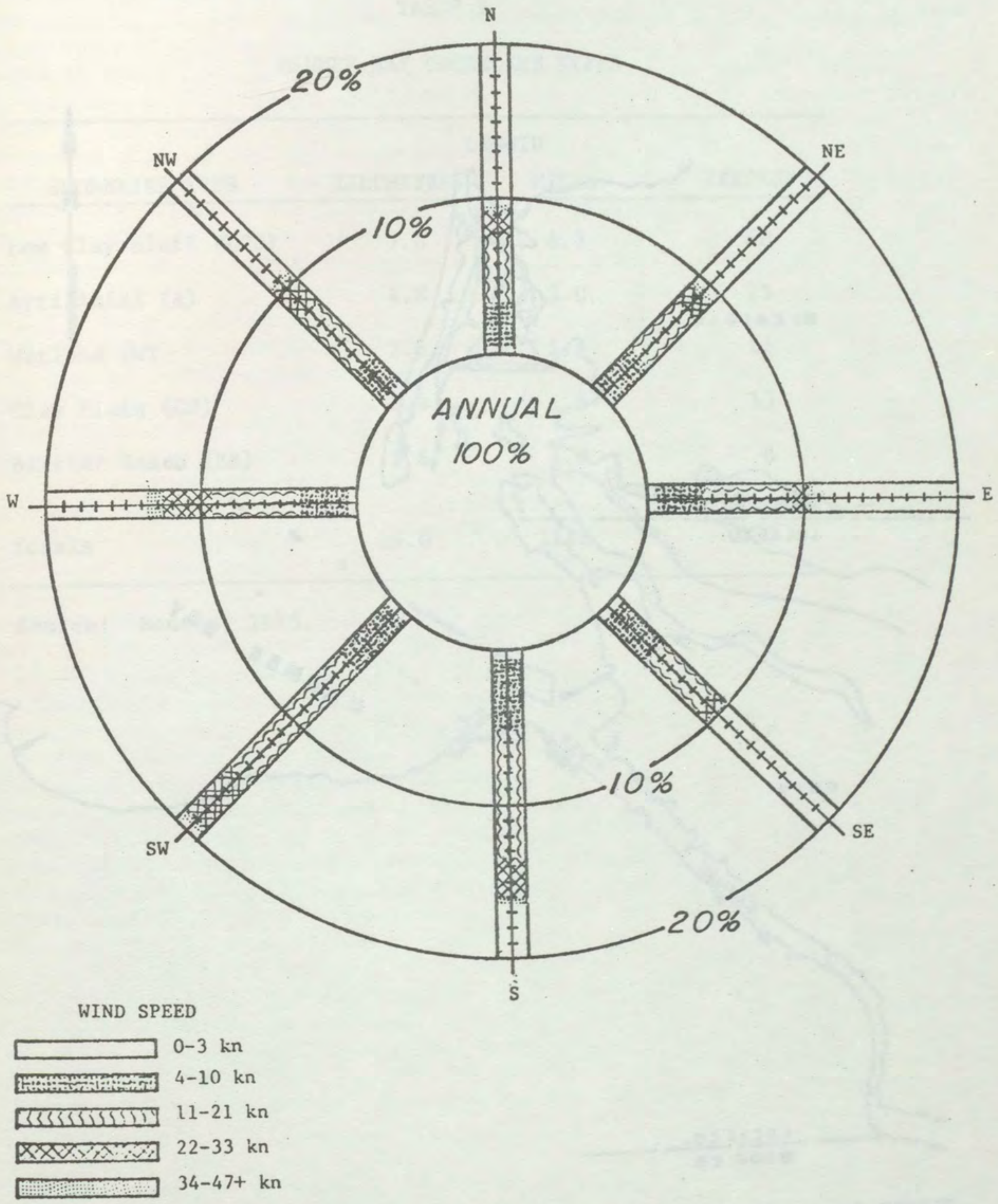


Figure 37. Wind rose for an average 12-month period; data from SSMO observations at Lake Erie West 1960-1973

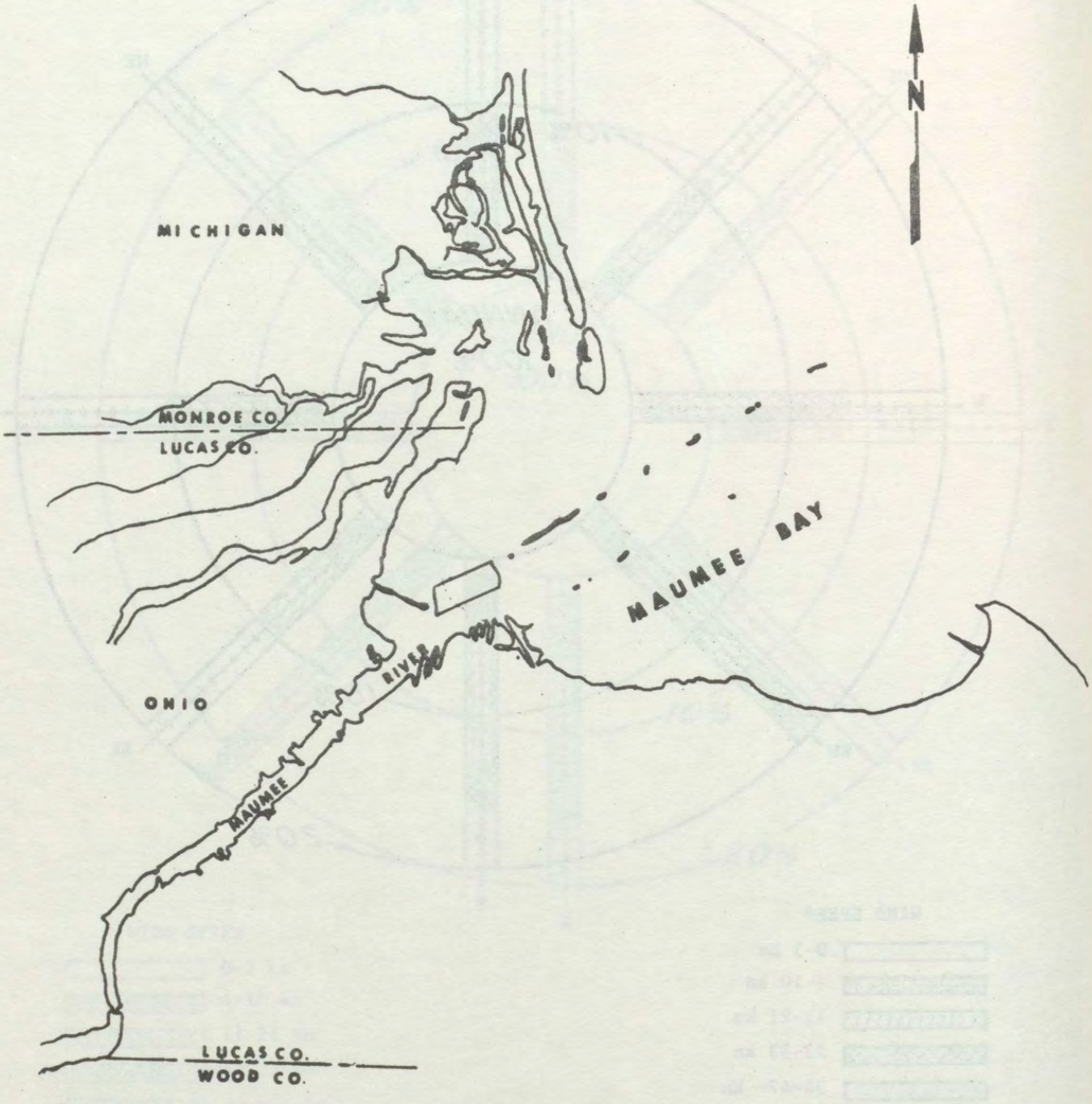


FIGURE 38. Shorelands Along Maumee Bay, Ohio.

SOURCE: Benson, 1975.

TABLE 9

MAUMEE BAY SHORELINE TYPES

SHORELINE TYPE	LENGTH KILOMETERS	MILES	PERCENT
Low Clay Bluff (LCB)	7.6	4.7	40
Artificial (A)	4.8	3.0	25
Wetland (W)	2.6	1.6	14
Clay Plain (CP)	2.4	1.5	13
Barrier Beach (BB)	1.6	1.0	8
Totals	19.0	11.8	100

Source: Benson, 1975.

of 1929-1930 and the low level period of 1934-1935. The following water levels were prevalent for the remaining periods of the study: 1940-1957, above average levels; 1957-1968, below average levels; 1968-1973, above average levels with a record high in 1973.

The shoreline from Carland Beach to the Maumee River (reach 1) experienced recession rates ranging from .3 meter per year to 3.1 meters per year (1.0 feet per year to 10.3 feet per year) with a weighted average of 1.5 meters per year (4.8 feet per year) during the 1877-1940 period. (The weighted average excluded shoreline which has been protected by man-made structures). The weighted average recession rate for 1877-1973 was 1.7 meters per year (5.6 feet per year). The reduction in the average recession rate over the 96-year period was due to the increased number of effective shore protection structures.

The Maumee River area (reach 2) experienced negligible recession rates during the study period as it is mainly composed of artificial fill.

From the Maumee River to Norden Road the shoreline (reach 3) experienced recession rates ranging from 0.7 meter per year to 3.6 meters per year (2.4 feet per year to 11.9 feet per year) with a weighted average of 2.3 meters per year (7.7 feet per year) during the 1877-1940 period. The weighted average recession rate for 1877-1973 was 2.1 meters per year (6.9 feet per year).

The shoreline from Norden Road to Cedar Point (reach 4) experienced recession rates ranging from accretion in the eastern portion to 4.6 meters per year (15.1 feet per year) in the western portion during the 1877-1940 period. The weighted average recession rate during the 1877-1973 period was 2.1 meters per year (6.9 feet per year).

Subaerial (above water) and subaqueous (under water) volumetric losses of shore materials due to erosion were calculated using the average recession rate, the average bluff height above low water datum, and the 1973 water depth below low water datum at a predetermined distance from shore. For each reach defined by Benson the average losses are as follows: Reach 1, 2.3 $m^3/m/yr$ (0.9 cu yds /ft/yr); Reach 2, less than 0.3 $m^3/m/yr$ (0.1 cu yds/ft/yr); Reach 3, 4.5 $m^3/m/yr$ (1.8 cu yds/ft/yr); and Reach 4, 3.3 $m^3/m/yr$ (1.7 cu yds/ft/yr). Erosion volumes for any specific area are a reflection of three factors: recession rates, shoreline physiography, and offshore slopes. The combination of thse factors in Maumee Bay has a net effect of limiting the amount of shore material that is actually contributed to the Bay; the average recession rate for the entire Bay was 1.5 meters per year (5.0 feet per year) while the amount of sediment contributed was only 3.0 $m^3/m/yr$ (1.3 cu yds/ft/yr).

During the last 100 years the Maumee Bay shoreline has undergone a change from an essentially rural, agricultural environment to a vastly more urban environment. This land use change has resulted in a marked reduction in recession rates and land lost due to the number of shore protection structures which have been erected. As of 1973, 65 percent of the Maumee Bay shoreline had been artificially protected. However, 25 percent of the present shoreline still has been classified as critical erosion areas. The present high lake levels have significantly accelerated the recession rates. Approximately 28,000 square meters (300,000 square feet) of shoreline is being lost yearly with an average annual damage cost of $60,000 (Benson 1975).

Sandusky Bay, located along the southern end of Lake Erie, is separated from the Lake by Bay Point and Cedar Point, see Figure 39. The Bay Point spit extends southward from the rockbound headlands of the Marblehead Peninsula into Sandusky Bay for a distance of 2,300 meters (7,500 feet). Cedar Point, at the eastern end of the Bay, terminates at the base of the nearly 1,800 meter (6,000 foot) long Cedar Point Jetty which protects the entrance to Sandusky Harbor. Moseley Channel, separating Bay Point and Cedar Point connects Sandusky Bay to Lake Erie. During normal water levels Moseley Channel is approximately 1.6 kilometers (1 mile) wide; however, during the low water levels of 1964 it was reduced to 0.5 kilometer (0.3 mile) in width. Depths of the Bay are seldom greater than 3 meters (10 feet) and the littoral drift varies.

Low clay bluffs, rising only to a height of 2.4 meters (8 feet) above low water datum, extend along much of the southern shore of Sandusky Bay. Marsh and wetland areas occur along the inner shore of the Bay and just southeast of the Cedar Point spit and the East Harbor beach. Beds of marl, exposed at storm water level, outcrop along the upper part of the southern shore of the Bay. All areas are highly susceptible to erosion and flooding.

Although the shallowness of the Bay somewhat restricts the wave heights the similarly low heights of the adjacent bluffs and their easily eroded components enable the waves to do extensive damage. In addition, severe northeasterly winds cause the water level to rise up to 1.5 meters (5 feet) above normal, thereby facilitating wave attack on shore. Storms from the northwest cause water to flow out of Sandusky Bay, lowering the water level and permitting waves to attack directly on some particularly weak lithologies which outcrop along the southern shore. However, the northeasterly storms, with their accompanying high water levels, are the most destructive.

The average recession rate for the Sandusky Bay shoreline during the 1820 to 1945 period ranged from 1.5 to 2.4 meters per year (5 to 8 feet per year). Most of the material eroded from the bluffs is so fine grained that it is carried offshore, and thus is not available as a beach building material. However, populated areas protected by groins and seawalls experience little retreat.

Contrastingly, accretion is occurring along the Bay Point and Cedar Point spits. The tip of Bay Point is accreting at an approximate rate of 3 meters per year (10 feet per year) at its southern end. Cedar is accreting at an approximate rate of 1.5 meters per year (5 feet per year) at its northeastern end. Accretion also is occurring in the Moseley Channel since material is able to travel through, over, and around the outer end of the Cedar Point jetty. If the Cedar Point jetty were not present, it is likely that the spits of Cedar Point and Bay Point would converge into a barrier beach and nearly block Sandusky Bay from Lake Erie.

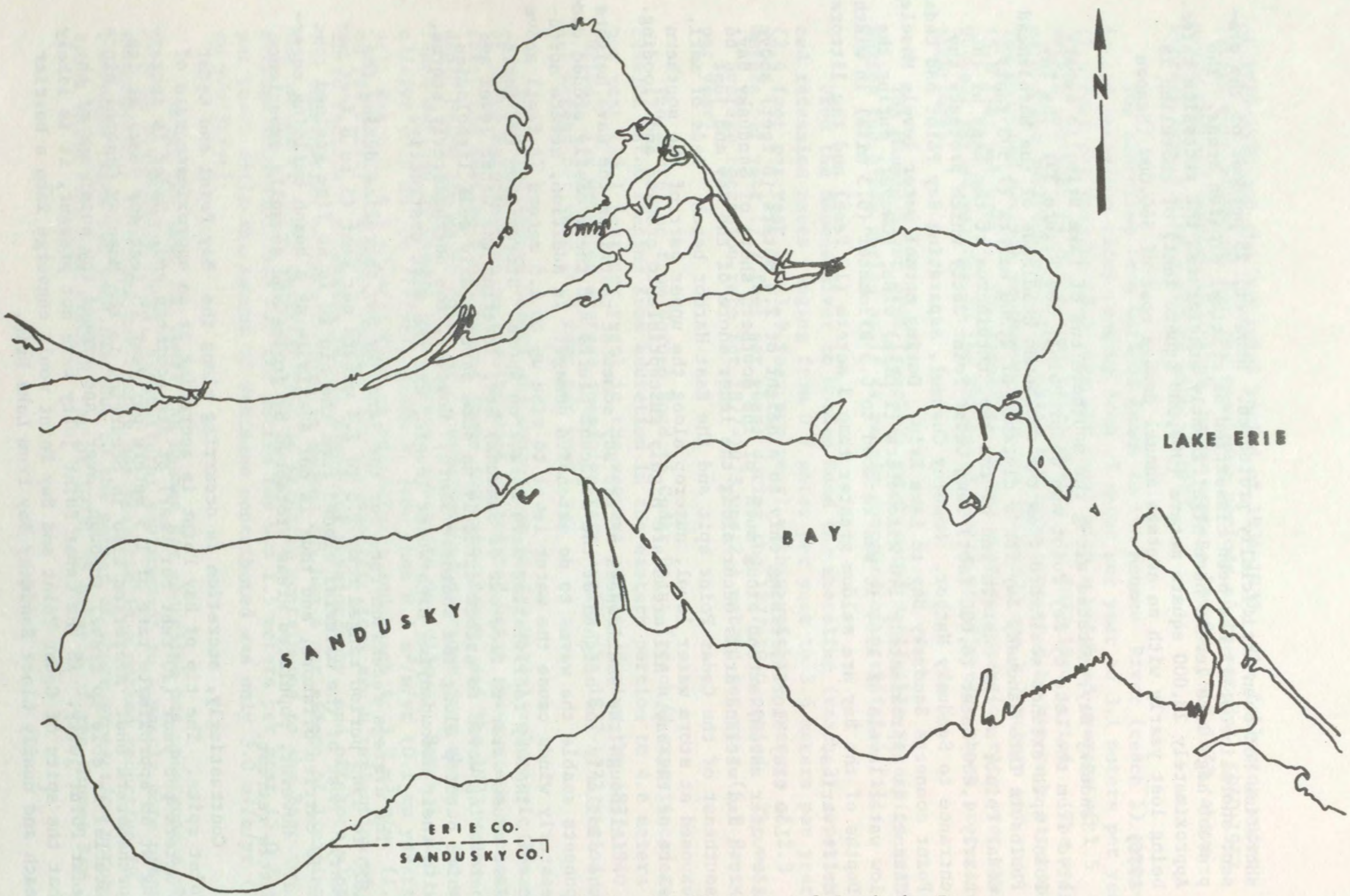


FIGURE 39. Shorelands in the Vicinity of Sandusky Bay.

Cedar Point is the largest sand deposit on the Ohio shore. The spit is nearly 10 kilometers (6 miles) long and several hundred meters wide. Erosion of the banks to the east have provided the source material. Since these bluffs are low in sand content, vast amounts of erosion must have occurred. The Cedar Point jetty extends far enough lakeward to be capable of interrupting the littoral drift and trapping the transported material on the updrift sides. The jetty has caused such a lakeward buildup of sand that the present shoreline is several hundred meters farther lakeward than in the late 1800's.

Perry Township Park extends along 260 meters (860 feet) of the Lake Erie shoreline in Lake County, Ohio. The coast is characterized by highly erodible bluffs which range in height from 9 to 12 meters (30 to 40 feet). The bluffs are composed of sand, lacustrine deposits, and glacial till. The prevailing littoral currents generally trend from west to east but occasionally reverse direction. Wind data from the U.S. Coast Guard at Fairport and Ashtabula indicate that winds from the southwest, west, and northwest account for approximately 52 percent of the total wind duration.

Based on U.S. Lake Survey data in 1876 and 1948, comparative profiles of the area between Fairport and just east of Perry Township Park revealed an average total loss of 50 meters (165 feet) or a bluff recession rate of 0.7 meter per year (2.3 feet per year). An analysis of 1957 and 1958 aerial photographs with a 1947 topographic survey indicated an average annual recession rate of 0.8 meter per year (2.8 feet per year). Profiles for the 12-year period demonstrated that the magnitude of sediment loss was greatest at the top portion of the bluff and decreased with distance downslope. It appears that as quickly as material was transported from the bluffs to the beach, wave action transported it lakeward and again left the bluff toe open to direct wave attack. These conditions infer that wave action is the primary cause of erosion.

The shoreline between the Lake-Ashtabula County line and the west breakwater of Ashtabula Harbor consists of bluffs ranging from 3 to 15 meters (10 to 50 feet) in height. The bluffs, composed of silt and clay with imbedded fragments of stone and shale, are easily erodible and quite susceptible to landslides. Land masses from 6 to 9 meters (20 to 30 feet) wide frequently slip as a unit down the slope. In addition, the high percentage of fine materials in these bluffs allows for little source material for beach buildup.

During average or above average lake levels, the predominatly west to east littoral drift fails to provide a supply of beach material which is sufficient to protect the shoreline. The present high lake levels also enable accelerated wave erosion at the toe of the bluffs. The situation is even more critical during storms from the northwest and northeast when waves reach heights over 3.4 meters (11 feet).

A 1966 Survey Report by the U.S. Army Corps of Engineers determined the annual recession rate for this area as 0.7 meter per year (2.4 feet per year). Subsequently, a study based on aerial photographs from 1960, 1968, and 1973, and a 1974 field reconnaissance derived a 0.8 meter per year (2.6 feet per year) recession rate. Near the Geneva Gaybrook Township line the top of the bluff presently coincides with the lakeward edge of the pavement of State Highway Route No. 531. Further recession of the bluff will destroy this section of the highway.

Presque Isle is an extensive compound sand spit, over 10 kilometers (6 miles) long, which has formed at Erie, Pennsylvania. It has a hookshaped configuration with the point recurved toward shore at the eastern end. The width at its neck is only several hundred meters wide while the width at the center exceeds 1.6 kilometers (1 mile). Presque Isle State Park, encompasing most of the peninsula, provides facilities for bathing, hiking, fishing, and picnicking.

The peninsula is composed of beach and dune sand deposits brought into the area by the littoral west to east current. The sand spit averages 2.1 to 2.4 meters (7 to 8 feet) high above low water datum. Currently four natural forces appear to be involved in the complex development of the spit: (1) the littoral current bearing beach material and deviating lakeward, (2) the conflicting current turning the spit inward to form a hook, (3) the northeasterly storm winds causing the formation of ridges, and (4) the effect of wind and vegetal cover on dunes and soil. Comparison of the present position of the peninsula with surveys of the shoreline in 1970 and 1834 reveals that the sand spit has migrated steadily more than a mile to the east during the last 176 years. The progressive eastward migration of the peninsula illustrates the effect of the predominant eastward littoral drift.

The natural supply of sand and gravel from updrift areas along the Pennsylvania and Ohio shoreline is inadequate to maintain the beaches along the neck of the peninsula. Recorded history of the peninsula shows growth at the distal end and recession of the lakeside beaches at the shoreward end. The most recent breach of the neck was closed in 1920-1922 by a stone seawall and hydraulic fill. Movement and losses of sand beach fill due to wave action and currents along the lakeward perimeter of the peninsula is the major erosion problem.

Wave heights up to 4 meters (13 feet) occur in the vicinity of Presque Isle. All waves in excess of 2.1 meters (7 feet) are from directions west to southwest through west to northwest. Temporary water level fluctuations of up to 0.7 meter (2.3 feet) from westerly storms are likely at least once a year. Storms from the north and northwest create an estimated wind setup of 0.3 meter (1 foot) above the stillwater level.

The peninsula is particularly susceptible to damage caused by storms from the west. On December 5, 1968, the wind peaked at 87 kilometers per hour (47 knots), producing large waves. Beaches along the neck of the peninsula were eroded and damages of $2 million were incurred. On December 30, 1971, 4.5 meter (15 foot) waves attacked the peninsula. Winds up to 88 kilometers per hour (55 miles per hour) significantly raised water levels. On January 25, 1972, winds blowing at 92 kilometers per hour (57 miles per hour) for a 4-hour period again produced large waves. In both cases the erosion damage was extensive. Average erosion rates for an unprotected area in the vicinity of Beach No. 6 are as follows: 43.4 m^3/m (17.3 cu yds/ft) for 1956-

1957, 52.4 m^3/m (20.9 cu yds/ft) for 1961-1962, 70.5 m^3/m (28.1 cu yds/ft) for 1966-1967, and 21.3 m^3/m (8.5 cu yds/ft) for 1969-1970 (U.S. Army, Corps of Engineers 1973).

Recession Rates

Recession rates have been determined for 93 percent of the erodible U.S. shoreline of Lake Erie, see Table 10 and Figure 40. The maximum recession rate occurs in Lucas County, Ohio where an average rate of 4.4 meters per year (14.5 feet per year) has been observed along a reach in the Woodtick Peninsula during the period of 1877-1973. Lucas County also is experiencing the greatest overall recession rate, averaging 2.2 meters per year (7.1 feet per year) for the period 1877-1973. Erie County, New York has incurred the lowest recession along the southern Lake Erie shoreline with an average rate of 0.2 meter per year (0.6 feet per year) for the period 1875-1974. The entire Ohio shoreline is experiencing much greater recession rates than those along Michigan, Pennsylvania, and New York.

The relative stability of the Erie County, New York shoreline is due to its orientation and the composition of the bluff material. The limited fetch length of this area would require a predominantly northwest storm, with strong winds for an extended period of time to create extensive erosion. Referring to the wind rose for eastern Lake Erie on page 148, it can be seen that only about 11.5 percent of the winds come from the northwest and only 3.5 percent of these entail winds of greater than 41 kilometers per hour (22 knots). In addition, the high shale content of the bluff material increases the ability of the shore to withstand the occasionally intense wave attack.

Lucas County, Ohio also has a relatively limited fetch length. Referring to the wind rose for western Lake Erie on page 149, it can be seen that approximately 10 percent of the winds come from the northeast and only about 3 percent of these have speeds greater than 41 kilometers per hour (22 knots). While these conditions are similar to those at Erie County, New York, the average recession rate is much higher. This is largely due to the differences in shoreform and shorematerial composition. Wetlands, barrier beaches, and low clay bluffs extend along the Lucas County shoreline. Their low relief makes these shorelands highly susceptible to even small wave heights while the clay and sand content is capable of giving little resistance to wave attack. Thus the shoreline of Lucas County is easily eroded, producing high average rates of recession.

TABLE 10

RECESSION RATES ALONG U.S. SHORELINE OF LAKE ERIE

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Monroe Co. Michigan											
64-008-011	5.15	(3.2)	W	0.76	(2.5)	0.30	(1.0)	0.61	(2.0)	0.15	(0.5)
64-011-019	13.20	(8.2)	A	2.29	(7.5)	0.55	(1.8)				
64-019-024	5.15	(3.2)	W	2.29	(7.5)	0.15	(0.5)				
64-024-032	9.33	(5.8)	A	0.76	(2.5)	0.70	(2.3)				
64-032-040	4.02	(2.5)	W	0.76	(2.5)	0.46	(1.5)				
Lucas Co. Ohio											
65-001-001	0.64	(0.4)	W	0.76	(2.5)	4.42	(14.5)	5.00	(16.4)	3.69	(12.1)
65-001-005	5.63	(3.5)	LBE	0.76	(2.5)	1.19	(3.9)	5.76	(18.9)	0.30	(1.0)
65-005-006	2.57	(1.6)	A	0.76	(2.5)	2.36	(7.6)	3.29	(10.8)	1.92	(6.3)
65-006-009	2.09	(1.3)	LBE	0.76	(2.5)	1.89	(6.2)	2.83	(9.3)	0.64	(2.1)
65-009-010	0.80	(0.5)	PE	0.76	(2.5)	2.19	(7.2)	2.74	(9.0)	2.01	(6.6)
65-010-011	5.31	(3.3)	W	0.76	(2.5)	2.77	(9.1)	4.27	(14.0)	1.58	(5.2)
65-011-017	6.92	(4.3)	PE/W	0.76	(2.5)	2.65	(8.7)	5.46	(17.9)	1.04	(3.4)
65-017-020	4.51	(2.8)	LBE	0.76	(2.5)	1.25	(4.1)	1.74	(5.7)	0.58	(1.9)
65-020-021	1.45	(0.9)	W	0.76	(2.5)	1.34	(4.4)				
65-021-025	4.18	(2.6)	PE/W	0.76	(2.5)	1.52	(5.0)	2.07	(6.8)	0.55	(1.8)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 10--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession Average m/yr	(ft/yr)	Maximum m/yr	(ft/yr)	Minimum m/yr	(ft/yr)
Ottawa Co. Ohio											
66-001-014	11.10	(6.9)	PE/W	0.76	(2.5)	1.65	(5.4)	2.19	(7.2)	0.09	(0.3)
66-014-016	1.77	(1.1)	LBE/A	0.76	(2.5)	0.55	(1.8)	1.43	(4.7)	0.24	(0.8)
66-016-018	1.93	(1.2)	W/PE	0.76	(2.5)	0.58	(1.9)	1.22	(4.0)	0.46	(1.5)
66-018-020	1.61	(1.0)	PE	0.76	(2.5)	0.15	(0.5)	0.21	(0.7)	0.09	(0.3)
66-020-022	1.77	(1.1)	W/PE	0.76	(2.5)						
66-022-029	4.35	(2.7)	LBE	0.76	(2.5)	0.24	(0.8)	0.46	(1.5)	0.06	(0.2)
66-029-031	1.77	(1.1)	LBN	0.76	(2.5)	0.21	(0.7)	0.30	(1.0)	0.06	(0.2)
66-031-032	0.80	(0.5)	LBE	0.76	(2.5)	0.21	(0.7)	0.34	(1.1)	0.15	(0.5)
66-032-035	5.15	(3.2)	HBN	0.76	(2.5)	0.12	(0.4)	0.27	(0.9)	0.03	(0.1)
66-035-036	0.48	(0.3)	LBN	0.76	(2.5)	0.40	(1.3)	0.49	(1.6)	0.18	(0.6)
66-036-037	2.41	(1.5)	LBE	0.76	(2.5)	0.15	(0.5)	0.21	(0.7)	0.03	(0.1)
66-037-039	7.08	(4.4)	LD/W	0.76	(2.5)	0.21	(0.7)	0.55	(1.8)	0.06	(0.2)
66-039-040	4.18	(2.6)	LBE	3.81	(12.5)	0.85	(2.8)	1.34	(4.4)	0.03	(0.1)
66-040-041	6.44	(4.0)	LBN	3.81	(12.5)	0.30	(1.0)	0.43	(1.4)	0.06	(0.2)
66-041-043	13.20	(8.2)	LBE	0.76	(2.5)	0.24	(0.8)	2.19	(7.2)	0.09	(0.3)
66-043-047	4.35	(2.7)	LD/W	0.76	(2.5)	0.43	(1.4)	1.86	(6.1)	0.09	(0.3)
66-047-049	1.61	(1.0)	LBE	0.76	(2.5)	2.62	(8.6)	3.69	(12.1)	0.46	(1.5)
66-049-051	1.61	(1.0)	W	0.76	(2.5)	0.49	(1.6)	0.64	(2.1)	0.27	(0.9)
66-051-057	5.15	(3.2)	LBE	0.76	(2.5)	1.28	(4.2)	4.14	(13.6)	0.18	(0.6)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 10--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum		Minimum	
Erie Co.,Ohio											
68-001-006 (8 reaches)	36.69	(22.8)									
68-006-009	10.46	(6.5)	LD	0.76	(2.5)	1.07	(3.5)				
68-009-010	1.29	(0.8)	W/PE	0.76	(2.5)	1.83	(6.0)				
68-010-011	5.79	(3.6)	LBE	2.29	(7.5)	0.45	(1.5)				
68-011-012	1.93	(1.2)	LBE	5.33	(17.5)	0.15	(0.5)				
68-012-013	7.72	(4.8)	HBE	8.38	(27.5)	0.30	(1.0)				
68-013-015	6.44	(4.0)	LBE	5.33	(17.5)	0.37	(1.2)				
Lorain Co. Ohio											
69-001-001	1.93	(1.2)	LBE	5.33	(17.5)	0.24	(0.8)	0.40	(1.3)	0.15	(0.5)
69-001-001	2.09	(1.3)	HBE	5.33	(17.5)	0.24	(0.8)	0.34	(1.1)	0.06	(0.2)
69-001-001	2.57	(1.6)	HBE	8.38	(27.5)	0.43	(1.4)	0.73	(2.4)	0.18	(0.6)
69-001-002	4.18	(2.6)	LBE	8.38	(27.5)	0.43	(1.4)	0.44	(3.1)	0.12	(0.4)
69-002-002	2.74	(1.7)	HBE	8.38	(27.5)	0.61	(2.0)	0.79	(2.6)	0.30	(1.0)
69-002-002	1.45	(0.9)	LBE	6.86	(22.5)	0.30	(1.0)	0.70	(2.3)	0.09	(0.3)
69-002-003	3.54	(2.2)	A	0.76	(2.5)	0.24	(0.8)	0.40	(1.3)	0.12	(0.4)
69-003-003	3.70	(2.3)	LBE	2.29	(7.5)	0.21	(0.7)	0.37	(1.2)	0.09	(0.3)
69-003-004	9.17	(5.7)	LBE	0.76	(2.5)	0.15	(0.5)	0.24	(0.8)	0.03	(0.1)
69-004-004	2.09	(1.3)	LBE	6.86	(22.5)	0.15	(0.5)	0.30	(1.0)	0.06	(0.2)
69-004-004	1.13	(0.7)	HBE	6.86	(22.5)						

***Reach defined by bluff height and shoreform.**
Values calculated in English units, converted to metric units and rounded.

TABLE 10--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession Average m/yr	(ft/yr)	Recession Maximum	Recession Minimum
Cuyahoga Co. Ohio									
70-001-002	9.33	(5.8)	HBE	11.43	(37.5)	0.18	(0.6)		
70-002-002	4.99	(3.1)	HBE	6.86	(22.5)	0.34	(1.1)		
70-002-003	6.76	(4.2)	HBN	11.43	(37.5)	0.18	(0.6)		
70-004-004	3.86	(2.4)	LBE	9.91	(32.5)	0.18	(0.6)		
70-004-005	7.72	(4.8)	LBE	5.33	(17.5)	0.21	(0.7)		
70-005-005	4.02	(2.5)	HBE	11.43	(37.5)	0.21	(0.7)		
Lake Co. Ohio									
71-001-002	4.99	(3.1)	HBE	11.43	(37.5)	0.67	(2.2)		
71-002-002	2.57	(1.6)	HBE	8.38	(27.5)	0.34	(1.1)		
71-002-002	1.61	(1.0)	LBE	9.91	(32.5)	0.52	(1.7)		
71-002-002	1.93	(1.2)	HBE	9.91	(32.5)	0.67	(2.2)		
71-002-003	4.35	(2.7)	HBE	3.81	(12.5)	0.52	(1.7)		
71-003-003	2.90	(1.8)	LBE/W	6.86	(22.5)	1.61	(5.3)		
71-003-003	2.41	(1.5)	HBE/W	6.86	(22.5)	0.24	(0.8)		
71-003-004	0.97	(0.6)	HBE/W	0.76	(2.5)	0.15	(0.5)		
71-004-004	1.77	(1.1)	LBN/LD	0.76	(2.5)	0.15	(0.5)		
71-004-004	1.45	(0.9)	LBN/LD	11.43	(37.5)	0.43	(1.4)		
71-004-004	2.57	(1.6)	HBE	11.43	(37.5)	0.70	(2.3)		
71-004-004	2.25	(1.4)	HBE	6.86	(22.5)	1.22	(4.0)		
71-004-005	11.91	(7.4)	HBE	12.95	(42.5)	0.43	(1.4)		

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 10--Continued

Reach No.*	Reach Length km (mi)	Shore-form	Average Bluff Height m (ft)	Recession m/yr (ft/yr) Average	Maximum	Minimum
71-005-005	2.41 (1.5)	HBE	5.33 (17.5)	0.24 (0.8)		
71-005-005	4.83 (3.0)	LBE	5.33 (17.5)	0.18 (0.6)		
Ashtabula Co. Ohio						
72-001-001	2.41 (1.5)	LBE	3.81 (12.5)	0.18 (0.6)		
72-001-001	0.97 (0.6)	LBE/W	3.81 (12.5)	0.15 (0.5)		
72-001-001	0.97 (0.6)	LBE	6.86 (22.5)	0.15 (0.5)		
72-001-001	3.22 (2.0)	HBE	6.86 (22.5)	0.15 (0.5)		
72-001-002	4.51 (2.8)	HBE	9.91 (32.5)	0.40 (1.3)		
72-002-002	4.35 (2.7)	HBE	12.95 (42.5)	0.27 (0.9)		
72-002-003	3.22 (2.0)	A	0.76 (2.5)	0.18 (0.6)		
72-003-003	2.74 (1.7)	HBE	12.95 (42.5)	0.49 (1.6)		
72-003-005	15.13 (9.4)	HBE	16.00 (52.5)	0.34 (1.1)		
72-005-005	4.35 (2.7)	A	6.86 (22.5)	0.24 (0.8)		
72-005-005	1.29 (0.8)	HBE	9.91 (32.5)	0.18 (0.6)		
Erie Co. Pennsylvania						
73-001-002	3.54 (2.2)	HBE	8.38 (27.5)	0.34 (1.1)		
73-002-003	2.25 (1.4)	HBE	17.53 (57.5)	0.43 (1.4)		
73-003-004	1.77 (1.1)	HBE	5.33 (17.5)	0.18 (0.6)		
73-004-004	6.44 (4.0)	HBE	20.57 (67.5)	0.21 (0.7)		
73-005-006	2.90 (1.8)	HBE	35.81 (117.5)	0.52 (1.7)		

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 10--Continued

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr Average	(ft/yr)	Maximum	Minimum
73-006-009	6.76	(4.2)	HBE	23.62	(77.5)	1.28	(4.2)		
73-009-010	3.38	(2.1)	HBE	20.57	(67.5)	0.27	(0.9)		
73-010-012	3.54	(2.2)	HBE	26.67	(87.5)	0.21	(0.7)		
73-012-013	4.51	(2.8)	HBE	29.72	(97.5)	0.49	(1.6)		
73-014-015	3.38	(2.1)	HBE	26.67	(87.5)	0.43	(1.3)		
73-018-020	2.41	(1.5)	HBE	17.53	(57.5)	0.06	(0.2)		
73-020-022	6.76	(4.2)	HBE	11.43	(37.5)	0.30	(1.0)		
73-022-022	2.41	(1.5)	HBE	20.57	(67.5)	0.49	(1.6)		
73-022-025	4.83	(3.0)	HBE	26.67	(87.5)	0.18	(0.6)		
73-025-025	1.77	(1.1)	HBE	32.77	(107.5)	0.21	(0.7)		
73-025-025	1.77	(1.1)	HBE	51.05	(167.5)	0.18	(0.6)		
73-025-026	1.29	(0.8)	HBE	26.67	(87.5)	0.27	(0.9)		
73-026-026	2.41	(1.5)	HBE	41.91	(137.5)	0.15	(0.5)		
73-026-027	3.22	(2.0)	HBE	14.48	(47.5)	0.37	(1.2)		
73-027-029	0.48	(0.3)	HBE	11.43	(37.5)	0.30	(1.0)		
Chautauqua Co New York									
74-001-002	3.06	(1.9)	HBE/HBN	11.43	(37.5)	0.18	(0.6)		
74-002-004	4.83	(3.0)	HBE/HBN	14.48	(47.5)	0.24	(0.8)		
74-004-007	7.56	(4.7)	HBE/HBN	8.38	(27.5)	0.18	(0.6)		
74-007-007	1.45	(0.9)	LBE	2.29	(7.5)	0.33	(1.1)		
74-007-008	2.90	(1.8)	HBE/HBN	11.43	(37.5)	0.24	(0.8)		
74-008-008	2.90	(1.8)	HBE/HBN	17.53	(57.5)	0.37	(1.2)		
74-008-010	3.38	(2.1)	HBE/HBN	11.43	(37.5)	0.27	(0.9)		

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 10--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum	Minimum
Chautauqua Co. (Continued)									
74-010-011	5.15	(3.2)	HBE/HBN	14.48	(47.5)	0.15	(0.5)		
74-011-012	1.45	(0.9)	HBE/HBN	23.62	(77.5)	0.27	(0.9)		
74-012-013	3.22	(2.0)	HBE/HBN	14.48	(47.5)	0.15	(0.5)		
74-013-015	4.51	(2.8)	LBE	2.29	(7.5)	0.15	(0.5)		
74-015-016	2.90	(1.8)	LBE/LBN	5.33	(17.5)	0.15	(0.5)		
74-016-016	2.41	(1.5)	LBE/LBN	2.29	(7.5)	0.15	(0.5)		
74-016-016	2.09	(1.3)	A	2.29	(7.5)	0.15	(0.5)		
74-016-017	1.93	(1.2)	LBE/LBN	2.29	(7.5)	0.61	(2.0)		
74-018-023	16.74	(10.4)	HBE/HBN LBE/LBN	6.86	(22.5)	0.21	(0.7)		
74-023-023	2.09	(1.3)	LBE	2.29	(7.5)	0.21	(0.7)		
Erie Co. New York									
75-001-003	2.90	(1.8)	LBE/LBN	3.81	(12.5)	0.15	(0.5)		
75-003-003	1.45	(0.9)	LBE/LBN	6.86	(22.5)	0.15	(0.5)		
75-003-003	1.13	(0.7)	LBE/LBN	3.81	(12.5)	0.15	(0.5)		
75-003-004	1.77	(1.1)	LBE/LBN	6.86	(22.5)	0.15	(0.5)		
75-004-005	2.90	(1.8)	LBE/LBN	3.81	(12.5)	0.15	(0.5)		
75-005-007	3.06	(1.9)	LBE	3.81	(12.5)	0.15	(0.5)		
75-007-007	2.41	(1.5)	LBE/LBN	3.81	(12.5)	0.15	(0.5)		
75-007-007	0.64	(0.4)	HBE/HBN	6.86	(22.5)	0.15	(0.5)		
75-007-009	4.83	(3.0)	LBE/LBN	6.86	(22.5)	0.15	(0.5)		
75-009-010	5.15	(3.2)	HBE/HBN	6.86	(22.5)	0.21	(0.7)		
75-010-011	3.06	(1.9)	HBE/HBN	9.91	(32.5)	0.15	(0.5)		
75-011-011	2.57	(1.6)	HBE/HBN	6.86	(22.5)	0.15	(0.5)		

*Reach defined by bluff height and shoreform.

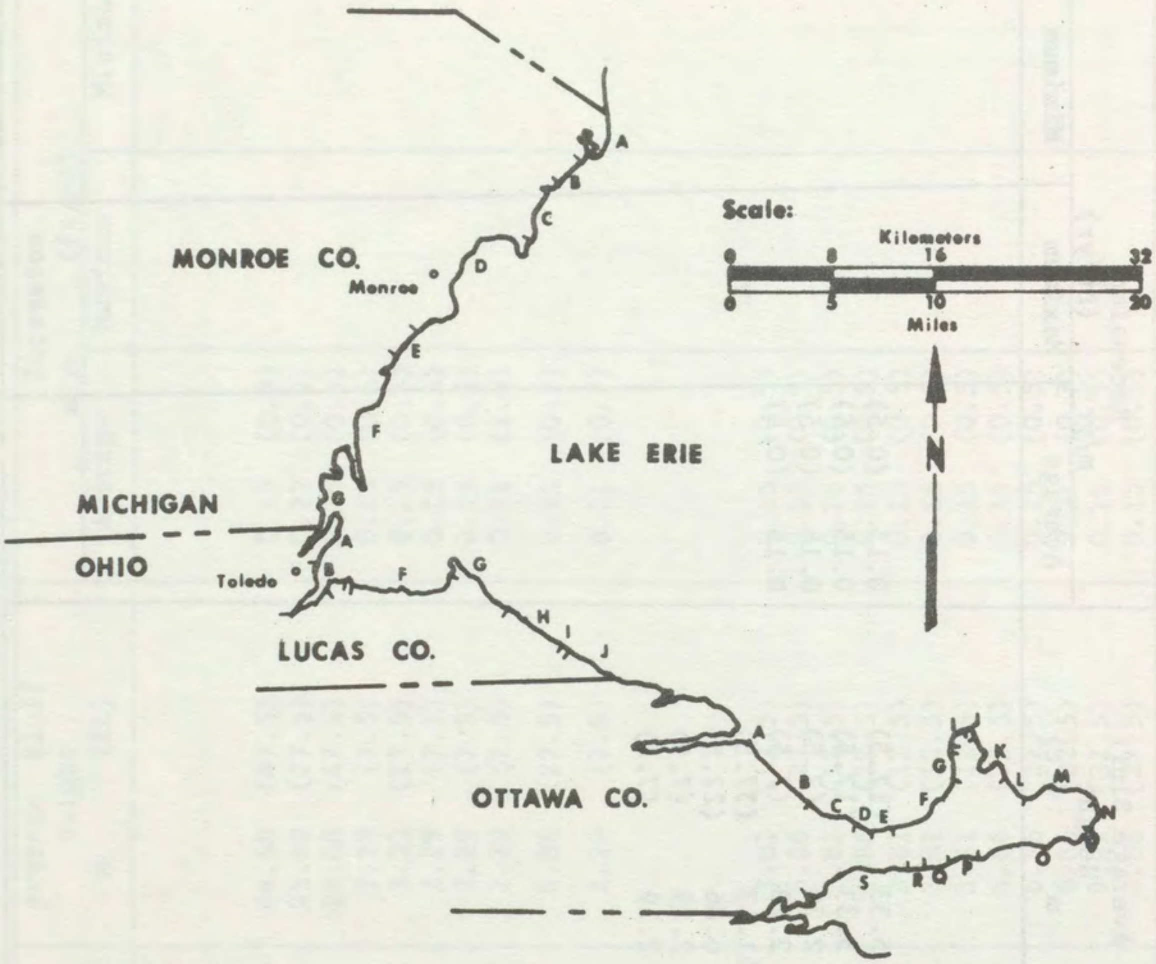
Values calculated in English units, converted to metric units and rounded.

TABLE 10--Continued

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Recession m/yr (ft/yr) Average		Maximum	Minimum
Erie Co. (Continued)									
75-011-013	3.38	(2.1)	LBE/LBN	5.33	(17.5)	0.15	(0.5)		
75-013-015	3.38	(2.1)	HBE/LBN	5.33	(17.5)	0.15	(0.5)		
75-015-015	2.41	(1.5)	LBN	2.29	(7.5)	0.15	(0.5)		
75-015-015	1.13	(0.7)	PN	2.29	(7.5)	0.15	(0.5)		
75-015-015	1.29	(0.8)	A	11.43	(37.5)				
75-015-016	1.93	(1.2)	A	6.86	(22.5)				
75-016-019	7.40	(4.0)	A	2.29	(7.5)				
75-019-024	3.38	(2.1)	A	2.29	(7.5)				

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.



MONROE CO.

Code	Reach Number
A	64-001-007
B	64-007-008
C	64-008-011
D	64-011-019
E	64-019-024
F	64-024-032
G	64-032-040

LUCAS CO.

Code	Reach Number
A	65-001-001
B	65-001-005
C	65-005-006
D	65-006-009
E	65-009-010

LUCAS CO. (Cont.)

Code	Reach Number
F	65-010-011
G	65-011-017
H	65-017-020
I	65-020-021
J	65-021-025

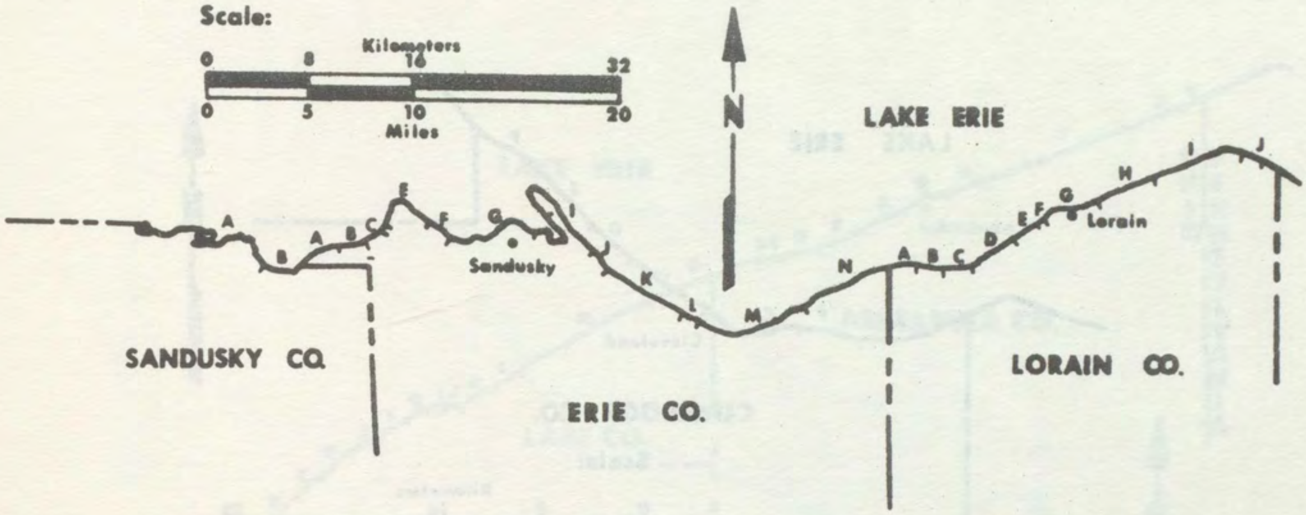
OTTAWA CO.

Code	Reach Number
A	66-001-014
B	66-014-016
C	66-016-018
D	66-018-020
E	66-020-022

OTTAWA CO. (Cont.)

Code	Reach Number
F	66-022-029
G	66-029-031
H	66-031-032
I	66-032-035
J	66-035-036
K	66-036-037
L	66-037-039
M	66-039-040
N	66-040-041
O	66-041-043
P	66-043-047
Q	66-047-049
R	66-049-051
S	66-051-057

FIGURE 40. LAKE ERIE: Ottawa, Lucas, and Monroe County Reach Locations.



SANDUSKY CO.

Code	Reach Number
A	67-001-008
B	67-008-010

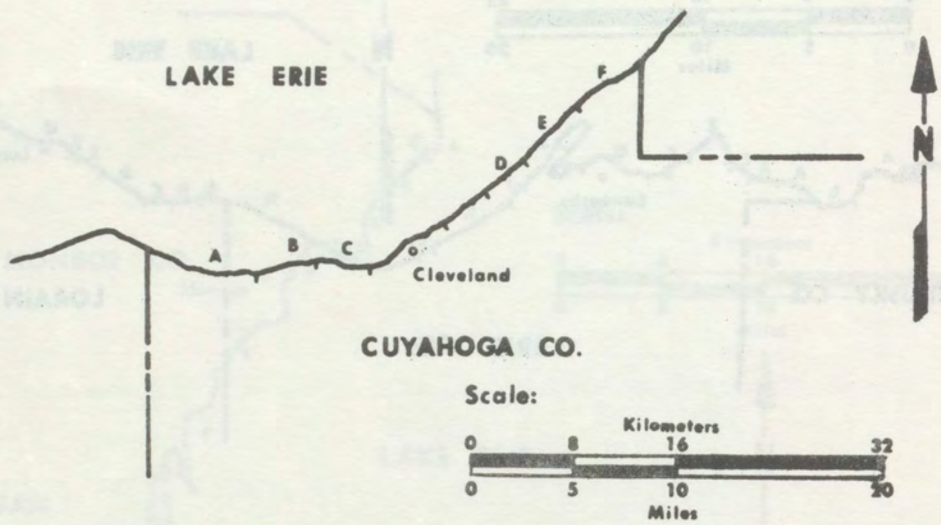
ERIE CO.

Code	Reach Number
A	68-001-001
B	68-001-002
C	68-002-003
D	68-003-003
E	68-003-004
F	68-004-005
G	68-005-006
H	68-006-006
I	68-006-009
J	68-009-010
K	68-010-011
L	68-011-012
M	68-012-013
N	68-013-015

LORAIN CO.

Code	Reach Number
A	69-001-001
B	69-001-001
C	69-001-001
D	69-001-002
E	69-002-002
F	69-002-002
G	69-002-003
H	69-003-003
I	69-003-004
J	69-004-004
K	69-004-004

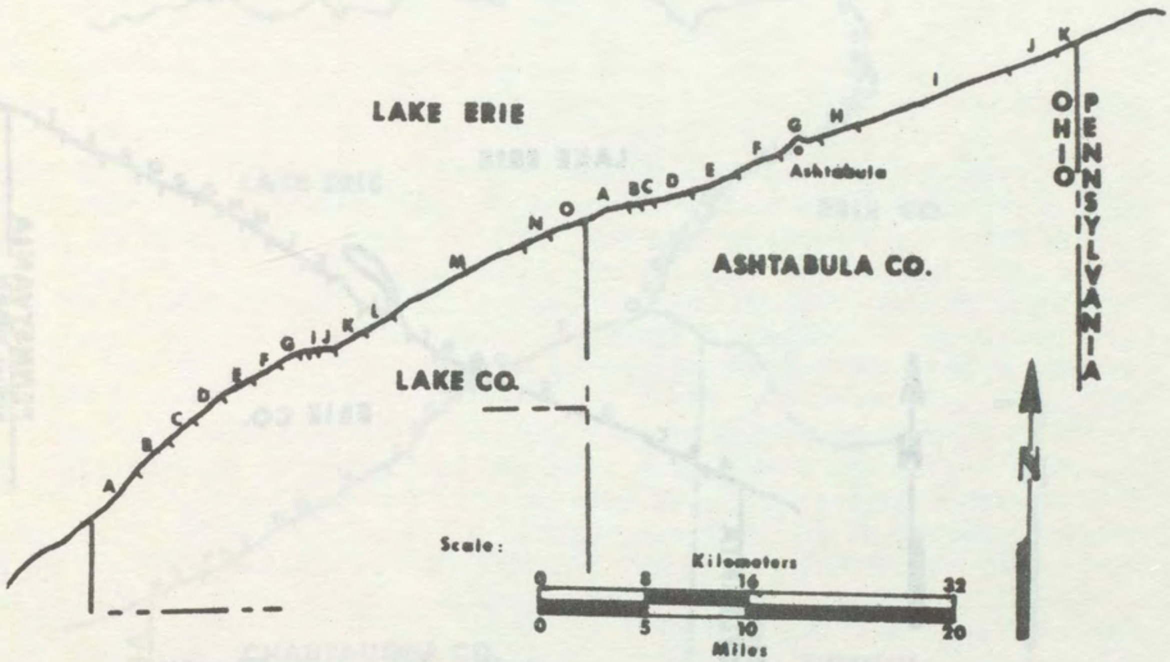
LAKE ERIE: Sandusky, Erie, and Lorain County Locations.



CUYAHOGA CO.

Code	Reach Number
A	70-001-002
B	70-002-002
C	70-002-003
D	70-004-004
E	70-004-005
F	70-005-005

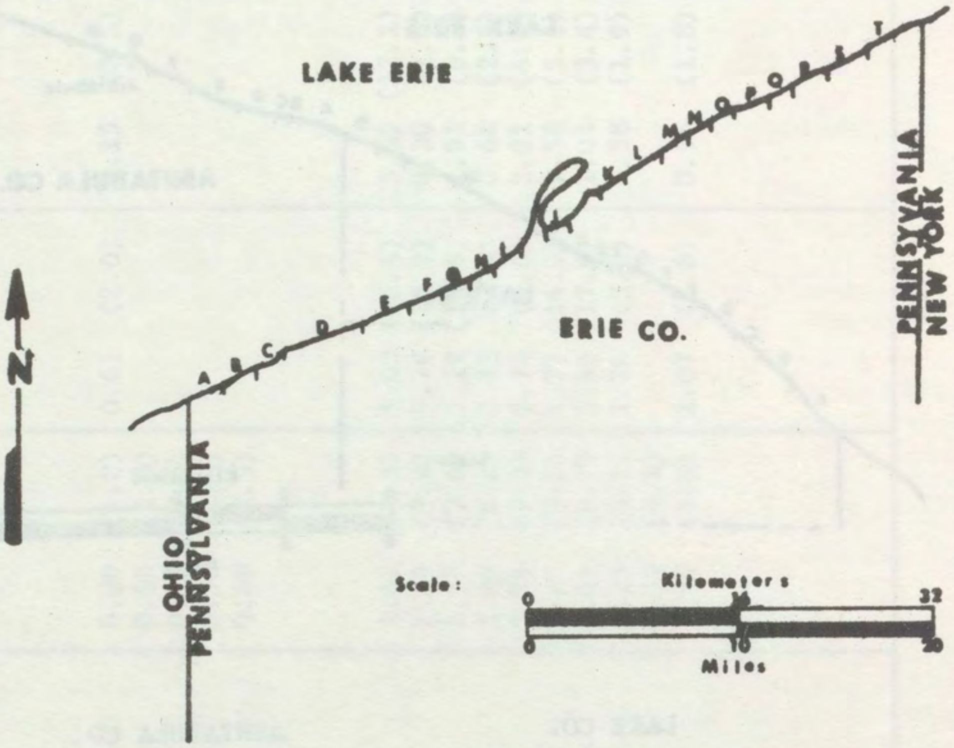
LAKE ERIE: Cuyahoga County Reach Locations.



LAKE CO.	
Code	Reach Number
A	71-001-002
B	71-002-002
C	71-002-002
D	71-002-002
E	71-002-003
F	71-003-003
G	71-003-003
H	71-003-004
I	71-004-004
J	71-004-004
K	71-004-004
L	71-004-004
M	71-004-005
N	71-005-005
O	71-005-005

ASHTABULA CO.	
Code	Reach Number
A	72-001-001
B	72-001-001
C	72-001-001
D	72-001-001
E	72-001-002
F	72-002-002
G	72-002-003
H	72-003-003
I	72-003-005
J	72-005-005
K	72-005-005

LAKE ERIE: Lake and Ashtabula County Reach Locations.



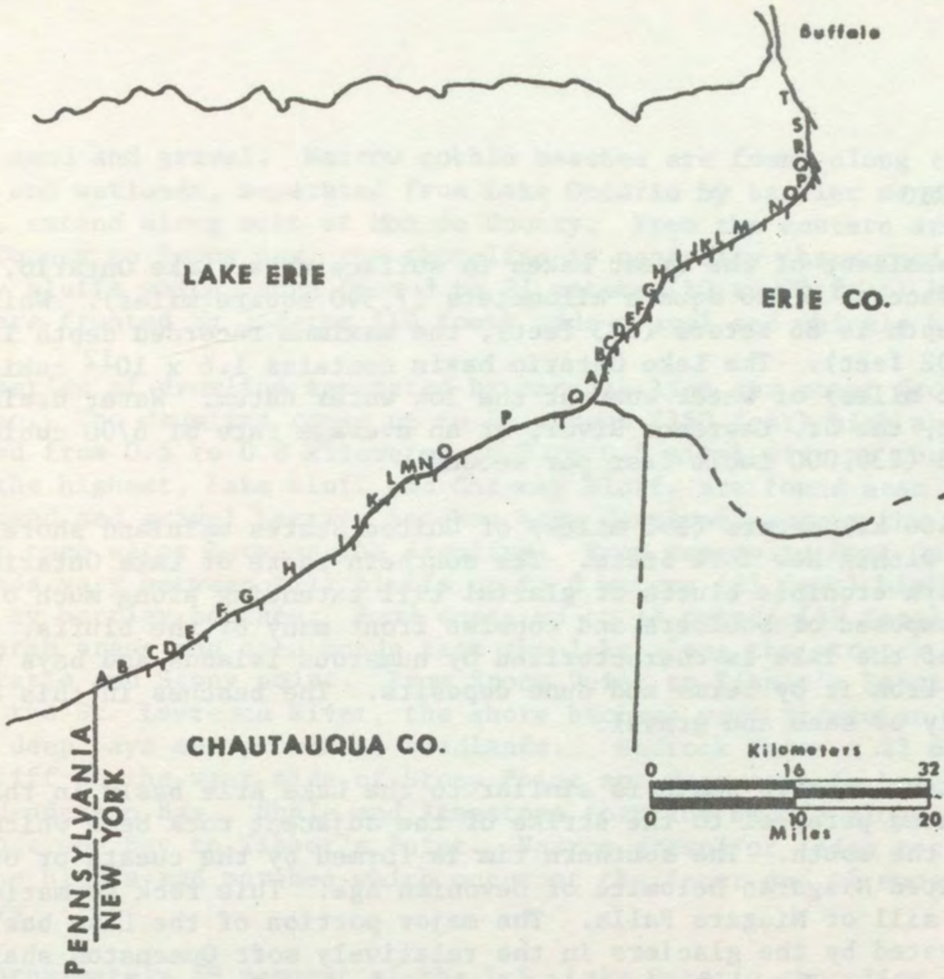
ERIE CO.

Code	Reach Number
A	73-001-002
B	73-002-003
C	73-003-004
D	73-004-004
E	73-005-006
F	73-006-009
G	73-009-010
H	73-010-012
I	73-012-013
J	73-014-015

ERIE CO. (Cont.)

Code	Reach Number
K	73-018-020
L	73-020-022
M	73-022-022
N	73-022-025
O	73-025-025
P	73-025-025
Q	73-025-026
R	73-026-026
S	73-026-027
T	73-027-029

LAKE ERIE: Erie County Reach Locations.



CHAUTAUQUA CO. N.Y.

Code	Reach Number
A	74-001-002
B	74-002-004
C	74-004-007
D	74-007-007
E	74-007-008
F	74-008-008
G	74-008-010
H	74-010-011
I	74-011-012
J	74-012-013
K	74-013-015
L	74-015-016
M	74-016-016
N	74-016-016
O	74-016-017
P	74-018-023
Q	74-023-023

ERIE CO. N.Y.

Code	Reach Number
A	75-001-003
B	75-003-003
C	75-003-003
D	75-003-004
E	75-004-005
F	75-005-007
G	75-007-007
H	75-007-007
I	75-007-009
J	75-009-010
K	75-010-011
L	75-011-011
M	75-011-013
N	75-013-015
O	75-015-015
P	75-015-015
Q	75-015-015
R	75-015-016
S	75-016-019
T	75-019-024

LAKE ERIE: Chautauqua and Erie County Reach Locations.

LAKE ONTARIO

The smallest of the Great Lakes in surface area, Lake Ontario, has a water surface of 19,000 square kilometers (7,340 square miles). While its average depth is 86 meters (283 feet), the maximum recorded depth is 245 meters (802 feet). The Lake Ontario basin contains 1.6 x 10^{12} cubic meters. (390 cubic miles) of water when at the low water datum. Water drains through its outlet, the St. Lawrence River, at an average rate of 6700 cubic meters per second (239,000 cubic feet per second).

The 466 kilometers (290 miles) of United States mainland shoreline lie entirely within New York State. The southern shore of Lake Ontario is quite regular with erodible bluffs of glacial till extending along much of it. Beaches composed of boulders and cobbles front many of the bluffs. The easterly end of the lake is characterized by numerous islands and bays which are separated from it by berms and dune deposits. The beaches in this area consist mostly of sand and gravel.

The Lake Ontario basin is similar to the Lake Erie basin in that it is also oriented parallel to the strike of the adjacent rock beds which dip gently to the south. The southern rim is formed by the cuesta or outcrop of the tilted Niagaran Dolomite of Devonian Age. This rock formation also forms the sill of Niagara Falls. The major portion of the Lake basin has been excavated by the glaciers in the relatively soft Queenston shale of Ordovician Age. The northern half of the lake bed is underlain by the more resistant Ordovician limestone. Accordingly, the deeper areas are located south of the center of the lake where the less resistant rocks form a relatively steep slope as they rise from the depths to the south shore.

Ice sheets covered the Lake Ontario basin during the Cary and Port Huron substages. During the later stages of Port Huron ice retreat, melt waters became impounded between the ice front and the Niagaran escarpment, forming several proglacial lakes. Lake Iroquois, dated a little over 12,000 years old, was the best developed of those proglacial lakes. Further ice retreat during the Two Creeks interval created approximately the present configuration of Lake Ontario. Concurrently, as ice receded from the St. Lawrence lowland, marine waters flooded the still depressed valley to produce the "St. Lawrence Sea". The advance of the ice sheet during the Valders did not extend to the St. Lawrence lowlands and consequently did not strongly affect the Lake Ontario basin. Uplift of the St. Lawrence lowlands and withdrawal of the marine waters occurred during the Nipissing time. The early effects of isostatic rebound of the earth's crust subsequent to the Valder's retreat is evidenced by the uplift. This isostatic rebound is still continuing; the St. Lawrence River is rising, relative to the southern end of the lake basin, at a rate of 0.3 meter per hundred years (1 foot per hundred years). Similarly the water level at Oswego, New York is rising about 0.16 meter per century (0.5 foot per century).

Erodible bluffs, ranging from 6 to 18 meters (20 to 60 feet) high, extend along the shore from the mouth of the Niagara River to the western boundary of Monroe County. They are generally composed of glacial deposits consisting of till and layered drift in the form of kames, eskers, and sheets of outwash sand and gravel. Narrow cobble beaches are found along the reach. Marshes and wetlands, separated from Lake Ontario by barrier sand and gravel beaches, extend along most of Monroe County. From the eastern areas of Monroe County to Sodus Bay, the shoreline is generally characterized by silt and clay bluffs which range from 3 to 21 meters (10 to 70 feet) high. The bluffs are fronted by 3-meter (10 foot) wide gravel and shingle beaches.

A series of drumlins separated by marshes line the coast from Sodus Bay to Oswego. The drumlins range up to 46 meters (150 feet) high above lake level and from 0.5 to 0.8 kilometer (0.3 to 0.5 mile) wide at their base. Two of the highest, Lake Bluff and Chimney Bluff, are found near Sodus Bay. Narrow sand and gravel barrier beaches have developed across the low marsh areas or open water between the drumlins. From Oswego to Port Ontario the shorelands vary between till bluffs up to 8 meters (25 feet) high and marshes fronted by barrier beaches. Sand dunes up to 14 meters (45 feet) high separate marsh areas and open ponds from the lake along the stretch between Port Ontario and Stony point. From Stony Point to Tibbet's Point at the head of the St. Lawrence River, the shore becomes very irregular and contains several deep bays and prominent headlands. Bedrock forms a 23 meter (75 foot) cliff on the west side of Stony Point and decreases in height gradually around Henderson Bay. Shale and limestone form low bluffs along the shore from Henderson Bay to Tibbet's Point. Narrow gravel or ledge rock beaches front the bluffs and marshes which occur at the inner end of some of the deep bays.

Approximately 59 percent of the U.S. Lake Ontario shoreline is susceptible to erosion or flooding, see Table 11. The entire coast from Niagara Falls to Henderson Bay consists of unconsolidated bluffs of glacial materials, barrier beaches and wetlands. During high lake levels the beaches are considerably depleted, enabling the waves to directly attack the nonresistant bluff toes. The remaining shorelands from Henderson Bay to Tibbit's Point are more resistant to erosion due to the presence of low bluffs of limestone and shale. Flooding is a major problem along the wetlands in the vicinity of Sodus Bay, see Figure 41.

Extensive erosion and flooding along the U.S. Lake Ontario shoreline cause serious economic consequences since 44 percent of the coast is devoted to residential use and 7 percent to industrial and commercial use. The potential for these conditions is greatly increased during periods of high lake levels. Record high levels occurred in the early 1950's, see Figure 42. Based on the 1970 value of the dollar, the damages resulting from flooding and erosion during the 1951 to 1952 period were $11.6 million. This value was derived for the Great Lakes Regional Inventory of the National Shoreline Study which was conducted by the U.S. Corps of Engineers. Critical erosion occurred at Selkirk Shores State Park during this period. Several hundred meters of concrete crib seawall were destroyed, causing subsequent loss of 12 meters (40 feet) of the bluff. During the high lake levels of the late 1960's to the mid-1970's, Lake Ontario has suffered relatively little damage as a consequence of lake regulation made possible by construction of the St. Lawrence Seaway. The effects of this regulation are to reduce the maximum monthly mean level by about 0.4 meters (1.3 feet) and raise the minimum mean

TABLE 11

SHORETYPES ALONG THE U.S. SHORELINE OF LAKE ONTARIO

SHORETYPES	MILES	KILOMETERS	PERCENTAGE
Artificial fill area	3.1	4.99	1.07
Erodible high bluff	33.6	54.07	11.60
Nonerodible high bluff	8.3	13.36	2.87
Erodible low bluff	91.2	146.77	31.49
Nonerodible low bluff	106.1	170.74	36.64
High dunes	0.0	0.00	0.00
Low dunes	0.0	0.00	0.00
Erodible low plain	12.0	19.31	4.14
Nonerodible low plain	0.0	0.00	0.00
Wetlands	35.3	56.81	12.19
Wetlands/Erodible low plain	0.0	0.00	0.00
Wetlands/Erodible low bluff	0.0	0.00	0.00
Total Shore Length	289.6	466.1	100.00

Source: Great Lakes Basin Commission, 1975.

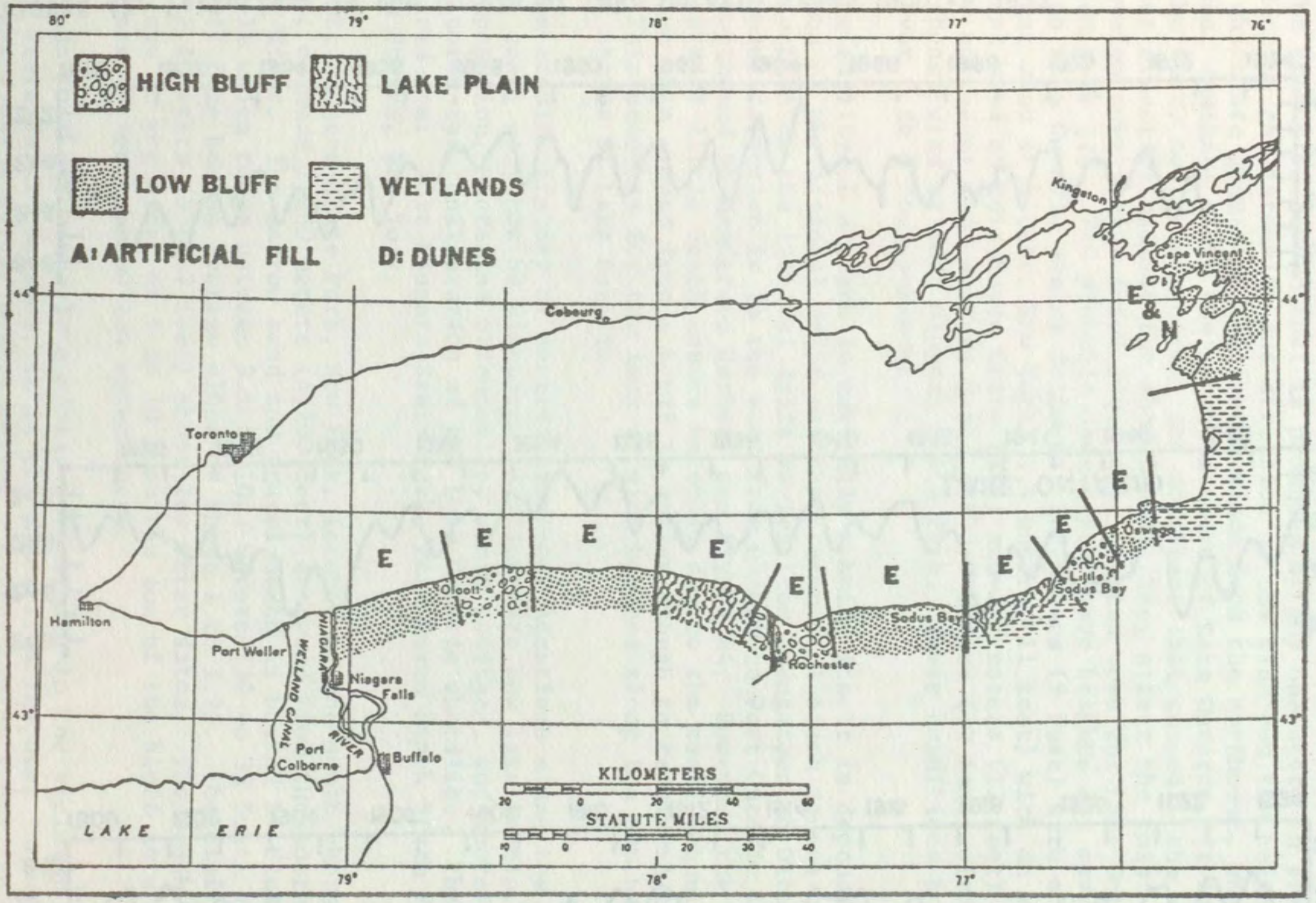


FIGURE 41. Shorelands Along Lake Ontario.

SOURCE: Sweeney, 1975.

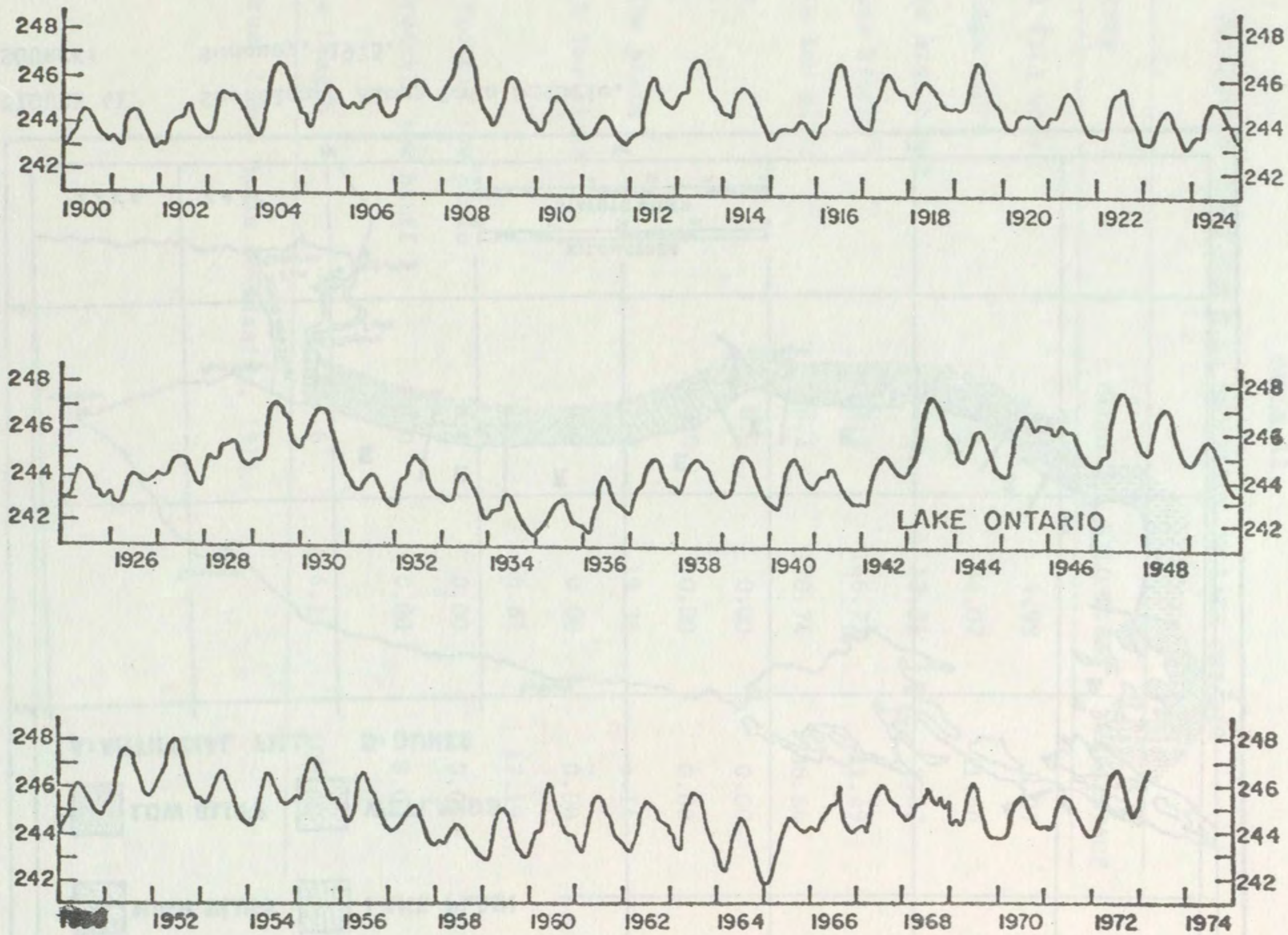


FIGURE 42. Variations in the Levels of Lake Ontario from 1900 to 1973.

SOURCE: Hegler, 1976.

level by about 0.1 meter (0.3 foot) from the respective levels without regulation. Consequently Lake Ontario will probably never again be exposed to the damaging high lake levels of the 1951-1952 period.

The amount of damage that is produced by any one storm is primarily dependent on the intensity and direction of the wind and the height of the waves which are generated. Although winds from the northwest, west, and southwest dominate along the southern shore of Lake Ontario, it is the winds from the west, northwest, north, and northeast that generate the waves that are most effective against the shorelands. They attack the coast directly and develop over longer fetch distances. A wind rose for Lake Ontario is found on page 178. The probable once-a-year wave heights for several locations on Lake Ontario are as follows: 2.7 meters (9 feet) with a west or northwest wind at Olcott, New York; 3.4 meters (11 feet) with an east or northeast wind at Fair Haven State Park; and 3.7 meters (12 feet) with an east or northeast wind at Ford Park; and 3.7 meters (12 feet) with an east or northeast wind at Fort Niagara State Park. These conditions commonly occur over 6 to 8 hour periods.

The ability of a beach to naturally rebuild itself is dependent on the direction of the littoral drift and the presence of beach source material. The direction of the littoral drift varies from Youngstown to Olcott. The predominant direction is to the east from Olcott to Port Ontario where it turns northward to Henderson Harbor, see Figure 44. However, the littoral drift carries little beach source material due to the small amount of material which when eroded from a bluff is coarse enough to remain in the beach zone. This accounts for the lack of wide beaches along the southern and eastern shores of Lake Ontario.

The erosion history of several prominent locations along the U.S. Lake Ontario coast will now be discussed to illustrate how lake levels, shoretype and composition, shoreline orientation, storm passages, and shoreline use have altered the configuration of the Lake Ontario shoreline. The locations considered are: Fort Niagara State Park, Fair Haven Beach State Park, and Selkirk Shores, New York.

Fort Niagara State Park, New York, located on the south shore of Lake Ontario, extends 1,280 meters (4,200 feet) eastward from the mouth of the Niagara River. The narrow sand and gravel beach is backed by bluffs of glacial till which range between 9.1 to 10.7 meters (30 to 35 feet) in height. The bluff face has an average slope of about 1 to 1.25. The bluff toe is 1.5 to 2.1 meters (5 to 7 feet) above low water datum. The beach has a uniform slope on the order of 1 to 10 from the toe of the bluff to a depth of 1.2 meters (4 feet) below low water datum.

Winds from the westerly quadrant predominate in the vicinity of Fort Niagara State Park. However, it is the winds from the west through north to northeast which affect the shoreline. Corresponding waves are generated over fetch distances of 57.9 kilometers (36 miles), 59.6 kilometers (37 miles) and 143.2 kilometers (89 miles), respectively. Consequently the storms from the northeast will cause the most erosion damage. The littoral drift trends from west to east but reverses during easterly storms.

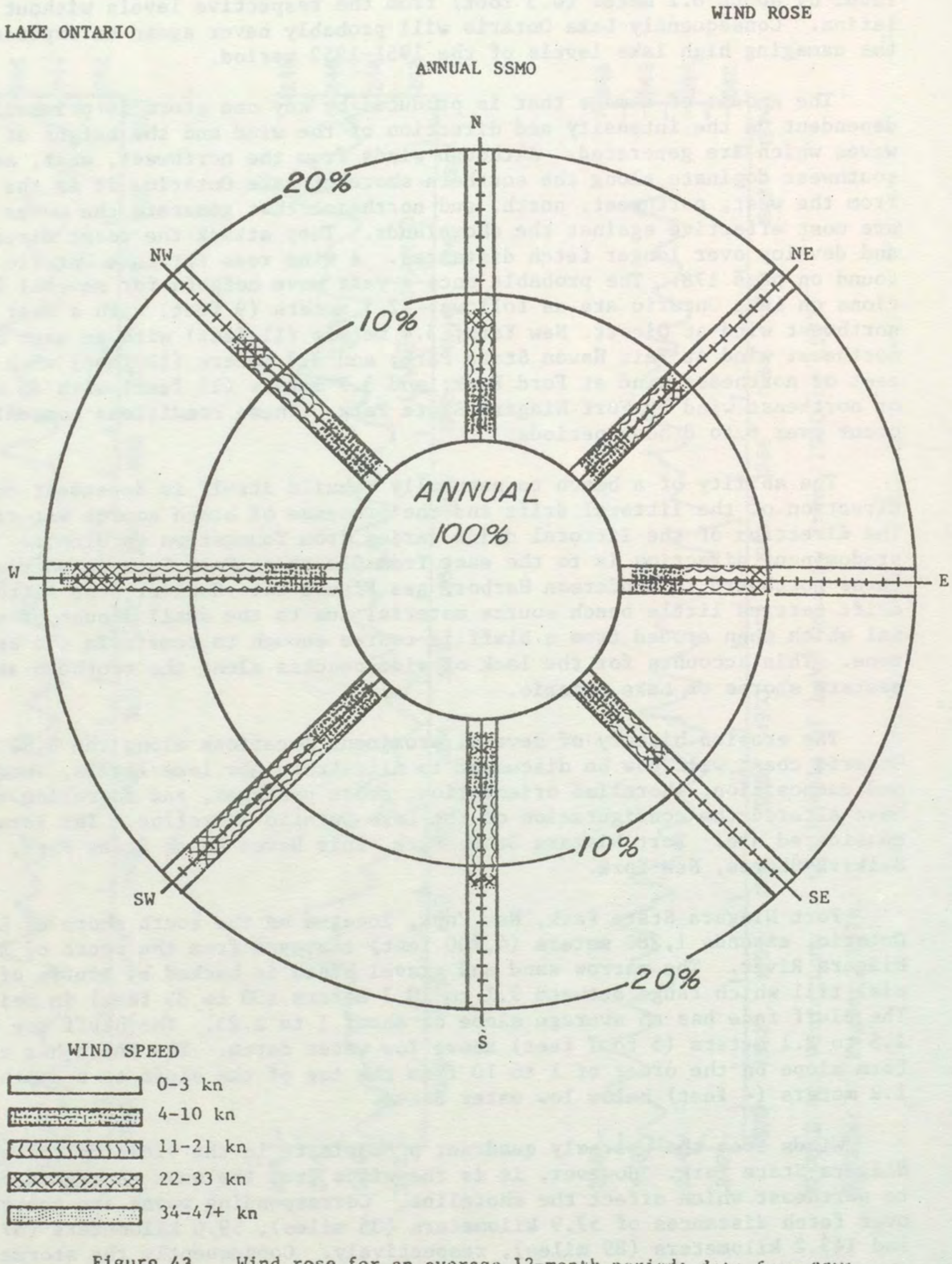


Figure 43. Wind rose for an average 12-month period; data from SSMO observations at Lake Ontario 1960-1972

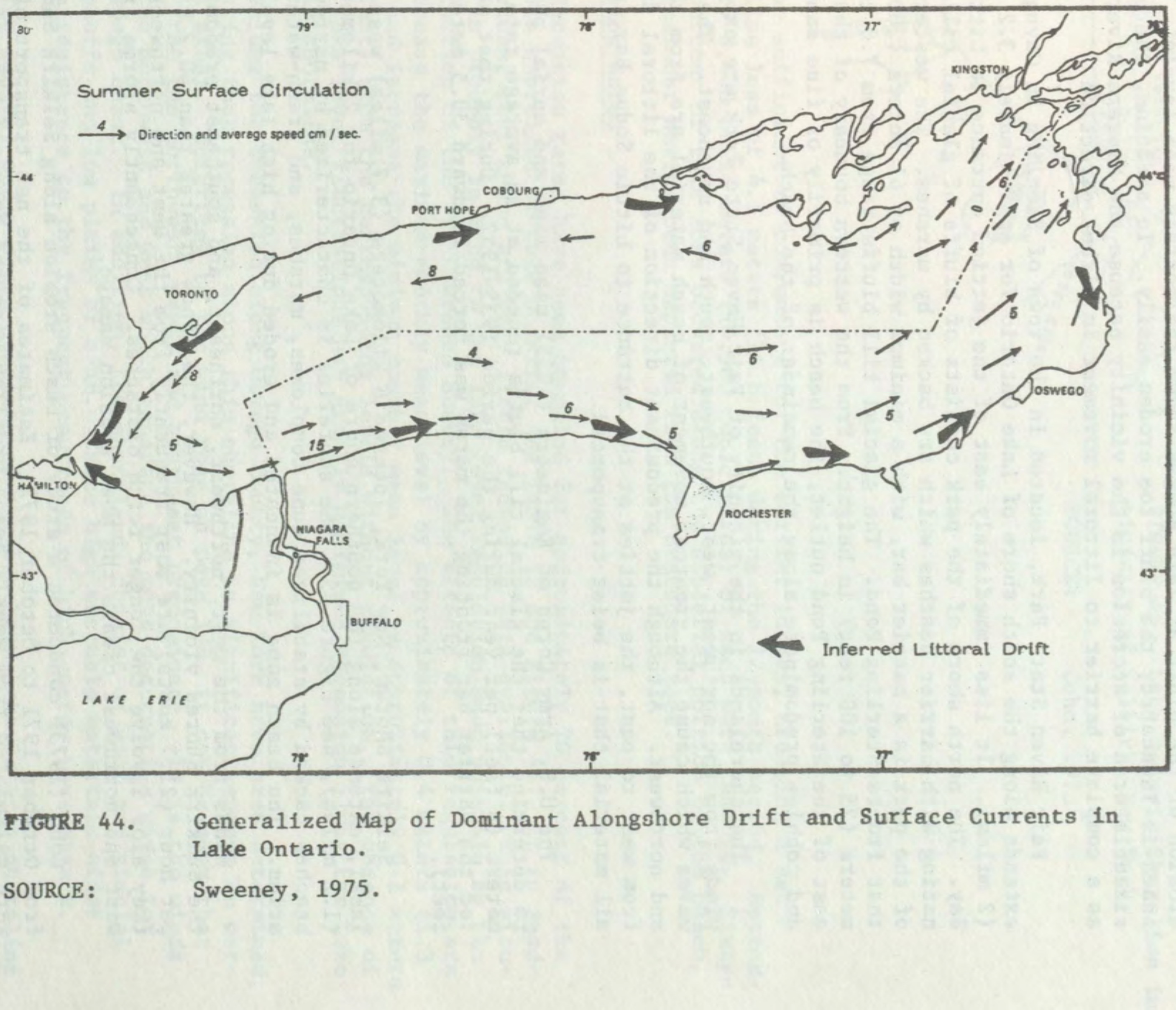


FIGURE 44. Generalized Map of Dominant Alongshore Drift and Surface Currents in Lake Ontario.

SOURCE: Sweeney, 1975.

A recent study by U.S. Army Corps of Engineers (1970) found that the existing beach height and width are inadequate to provide protection against erosion of the bluff at lake stages above the monthly mean levels. When the beach is inundated, the bluff toe erodes easily. In addition, there is no sizeable area of accretion in the vicinity because the Niagara River acts as a complete barrier to littoral movement in either direction.

Fair Haven State Park, located in the town of Sterling in Cayuga County, extends along the south shore of Lake Ontario for approximately 3.2 kilometers (2 miles). It lies immediately east of the jettied entrance to Little Sodus Bay. The north shore of the park consists of bluffs of glacial till alternating with barrier beaches which are backed by marshes. The western shore of the park is a barrier bar, with a minimum width of 61 meters (200 feet), that fronts Sterling Pond. The glacial till bluffs range from 7.6 to 30.5 meters (25 to 100 feet) in height. From the western boundary of the park to east of the Sterling Pond outlet, the beach is primarily of fine sand. Gravel and cobbles predominate along the remainder of the beach.

The shorelands in the vicinity of Fair Haven State Park are exposed to winds from the northwest, west, southwest, south and southeast. The storm waves which cause the greatest movement of beach material are from the west and northwest. Although the predominant direction of the littoral drift is from west to east, the jetties at the entrance to Little Sodus Bay intercept all material that is being transported.

The U.S. Army Corps of Engineers (1955) used maps and aerial photographs to determine that the glacial till bluffs receded at an average rate of 1.2 meters (4 feet) per year during the period 1935-1952. During that same period the barrier bar fronting the marsh was forced landward 30.5 meters (100 feet).

Selkirk Shores, New York, located 6 kilometers (3.7 miles) west of Pulaski, extends along the southern shore of Lake Ontario for 2 kilometers (1.2 miles), see Figure 45. The shoreline is characterized by narrow barrier beaches backed by stabilized dune complexes, marshes, and fresh-water estuaries. The beach zone is inundated and eroded during high lake levels.

Winds from the west, northwest, northeast, and southeast predominate in the Selkirk Shores vicinity. However, the winds greater than 40.2 kilometers per hour (21.7 knots) are most frequently from the west and northwest and they alos involve the longer fetch distances. Consequently storms from the west and northwest create the most erosion damage.

Cohn (1973) conducted a study of beach erosion along Selkirk Shores from October 1971 to October 1972. Estimates of the net transport of sand were calculated from weekly beach profiles measured from the base of the dune into water depths of 1.3 meters (4.1 feet). Loss of sand occurred during the spring and summer months when somewhat higher lake levels were coincident with winds from the northwest. Slightly lower lake levels and winds from the southeast during the late summer and early fall initiated accretion upon the beachface and in the extreme nearshore zone. However, the accretion

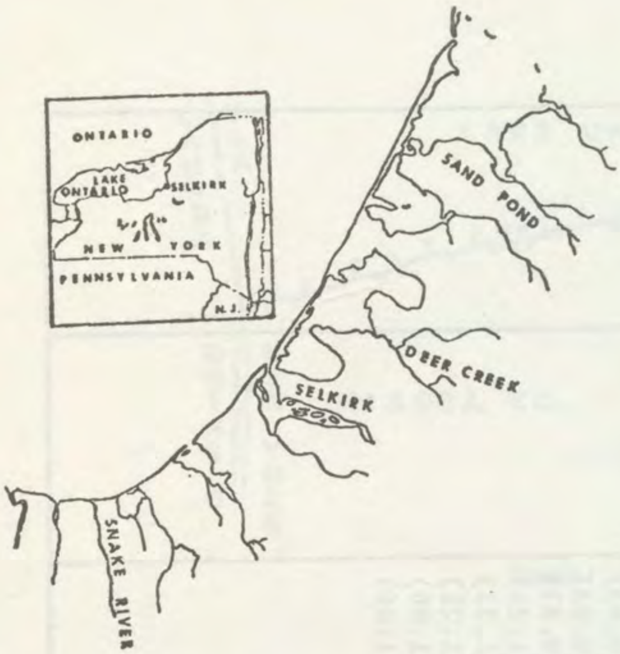


FIGURE 45. Lake Ontario Shoreline in the vicinity of Selkirk, New York.

SOURCE: Cohn, 1973

was not sufficient to compensate for the earlier losses, creating a net shoreline loss of 4.5 meters (14.8 feet) during the 12-month period. Approximately 8,400 cubic meters (10,980 cubic yards) of sand were removed. Sixty-five percent of this loss occurred along the subaerial portion of the beach, the remainder having been depleted from the nearshore zone.

Recession Rates

Recession rates have been compiled for approximately 20 percent of the erodible shoreline of Lake Ontario, see Table 12 and Figure 46. It is readily evident that there are very little recession data available. This situation is probably related to the lake level regulation made possible by the construction of the St. Lawrence Seaway. The effects of this regulation are to decrease the maximum monthly mean level by approximately 0.4 meters (1.3 feet) and increase the minimum monthly mean level by approximately 0.1 meters (0.3 feet) from the corresponding levels without regulation. The absence of large lake level fluctuations has greatly minimized recession along the Lake Ontario shoreline.

Values for recession along Oswego County, New York have been determined, indicating that recession along this shoreline is significant enough to warrant a study. Referring to the wind rose on page 178, it can be seen that winds from the northwest, west, and southwest predominate. It is the winds from the northwest and west which generate the most destructive waves for the Oswego coast. In addition, the shorelands consist of sand and glacial till bluffs and low plains of sand. These high unstable materials offer little resistance to the frequent occurrence of high energy wave attack.

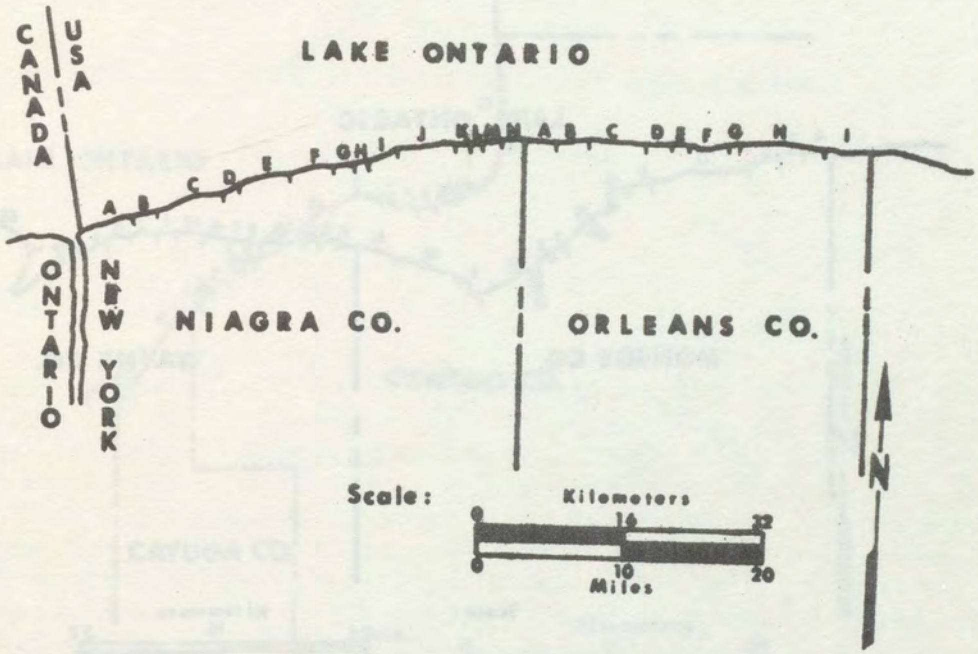
The central and western segments of the southern Lake Ontario shoreline are primarily affected by waves generated by winds from the north, northeast, and east. However, reference to the wind rose demonstrates that storms from these directions are fairly infrequent. Consequently, the low, easily erodible shoreforms along these areas are not subjected to the same frequency or intensity of storms that the eastern end of Lake Ontario experiences.

TABLE 12

RECESSION RATES ALONG U.S. SHORELINE OF LAKE ONTARIO

Reach No.*	Reach Length km	(mi)	Shore- form	Average Bluff Height m	(ft)	Recession Average m/yr	(ft/yr)	Maximum	Minimum
Oswego Co. New York									
81-001-001	1.61	(1.0)	LBE	3.81	(12.5)	0.25	(0.83)		
81-001-001	1.77	(1.1)	HBE	16.00	(52.5)	0.25	(0.83)		
81-001-002	1.29	(0.8)	PE/W	3.81	(12.5)	0.25	(0.83)		
81-002-003	4.02	(2.5)	LBE	3.81	(12.5)	0.25	(0.83)		
81-003-004	3.22	(2.0)	A	0.76	(2.5)	0.25	(0.83)		
81-004-005	1.77	(1.1)	LBE/LBN	0.76	(2.5)	0.25	(0.83)		
81-005-006	3.06	(1.9)	PE/W	0.76	(2.5)	0.25	(0.83)		
81-006-007	4.18	(2.6)	LBE	0.76	(2.5)	0.25	(0.83)		
81-007-008	4.83	(3.0)	LBE	3.81	(12.5)	0.25	(0.83)		
81-008-009	1.13	(0.7)	HBN	3.81	(12.5)	0.25	(0.83)		
81-009-010	5.95	(3.7)	LBE	3.81	(12.5)	0.37	(1.21)		
81-010-011	4.02	(2.5)	PE/W	0.76	(2.5)	0.37	(1.21)		
81-011-013	5.31	(3.3)	LBE	0.76	(2.5)	0.37	(1.21)		
81-013-013	1.61	(1.0)	A	12.95	(42.5)	0.57	(1.86)		
81-013-017	11.75	(7.3)	LD/W	12.95	(42.5)	0.57	(1.86)		

* Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.



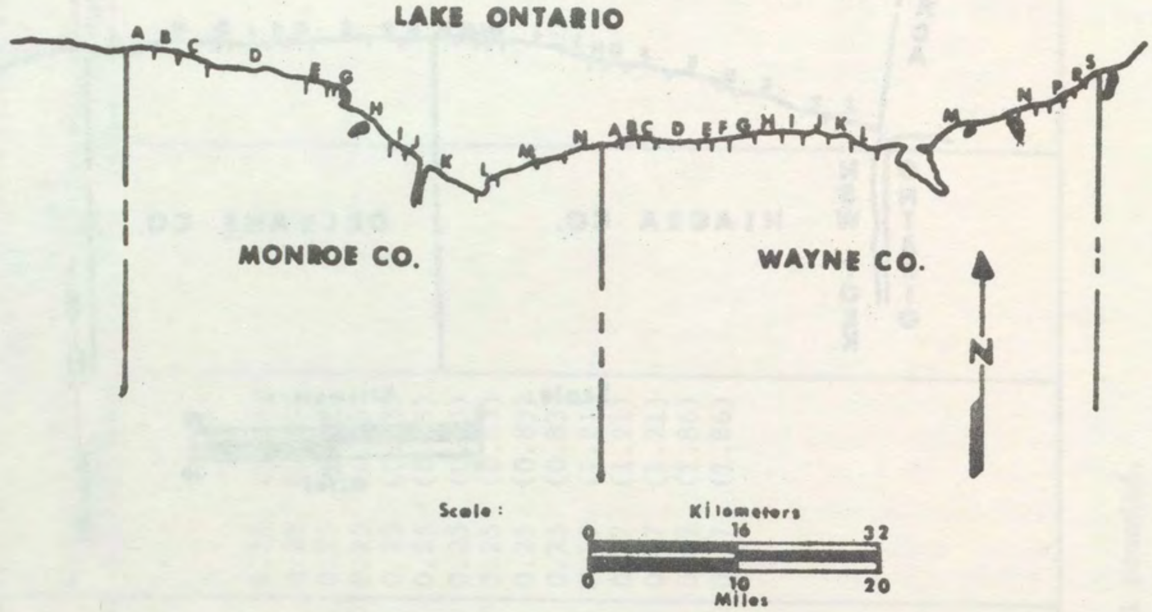
NIAGARA CO.

Code	Reach Number
A	76-007-009
B	76-009-010
C	76-010-012
D	76 012-013
E	76-013-013
F	76-013-017
G	76-017-018
H	76-018-019
I	76-019-019
J	76-019-020
K	76-020-020
L	76-020-021
M	76-021-023
N	76-023-023

ORLEANS CO.

Code	Reach Number
A	77-001-003
B	77-003-004
C	77-004-008
D	77-008-009
E	77-009-009
F	77-009-010
G	77-010-011
H	77-011-016
I	77-016-017

FIGURE 46. LAKE ONTARIO: **Niagara and Orleans County Reach Locations.**



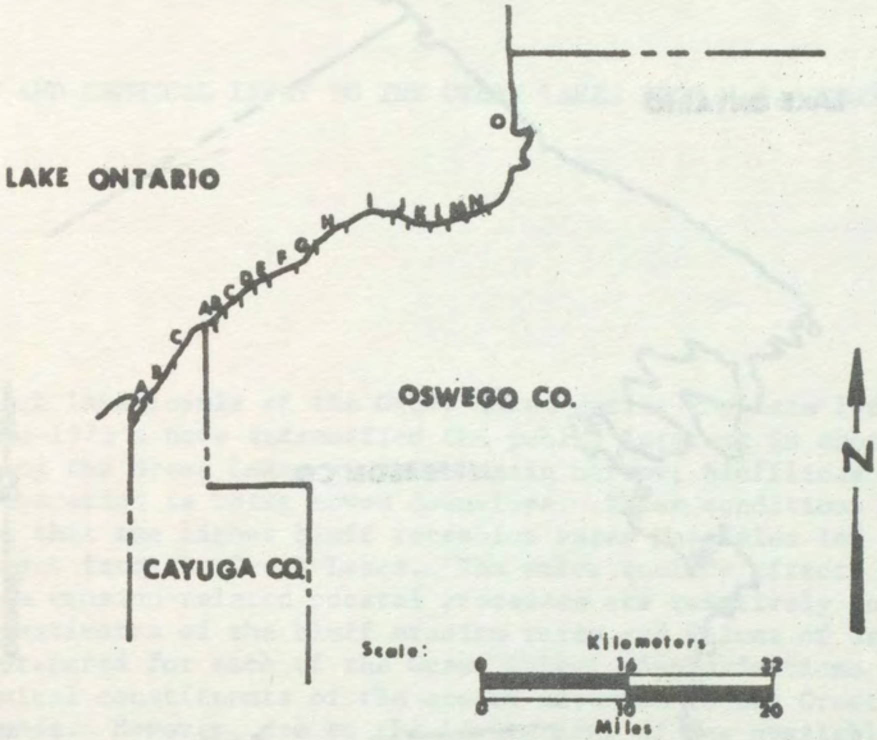
MONROE CO.

Code	Reach Number
A	78-001-001
B	78-001-002
C	78-002-002
D	78-002-006
E	78-006-008
F	78-008-009
G	78-008-008
H	78-008-011
I	78-011-011
J	78-011-012
K	78-012-014
L	78-014-015
M	78-015-019
N	78-019-019

WAYNE CO.

Code	Reach Number
A	79-001-001
B	79-001-002
C	79-002-002
D	79-002-005
E	79-005-005
F	79-005-006
G	79-006-008
H	79-008-008
I	79-008-008
J	79-008-008
K	79-008-009
L	79-009-009
M	79-009-015
N	79-015-015
O	79-015-016
P	79-016-016
Q	79-016-017
R	79-017-018
S	79-018-018

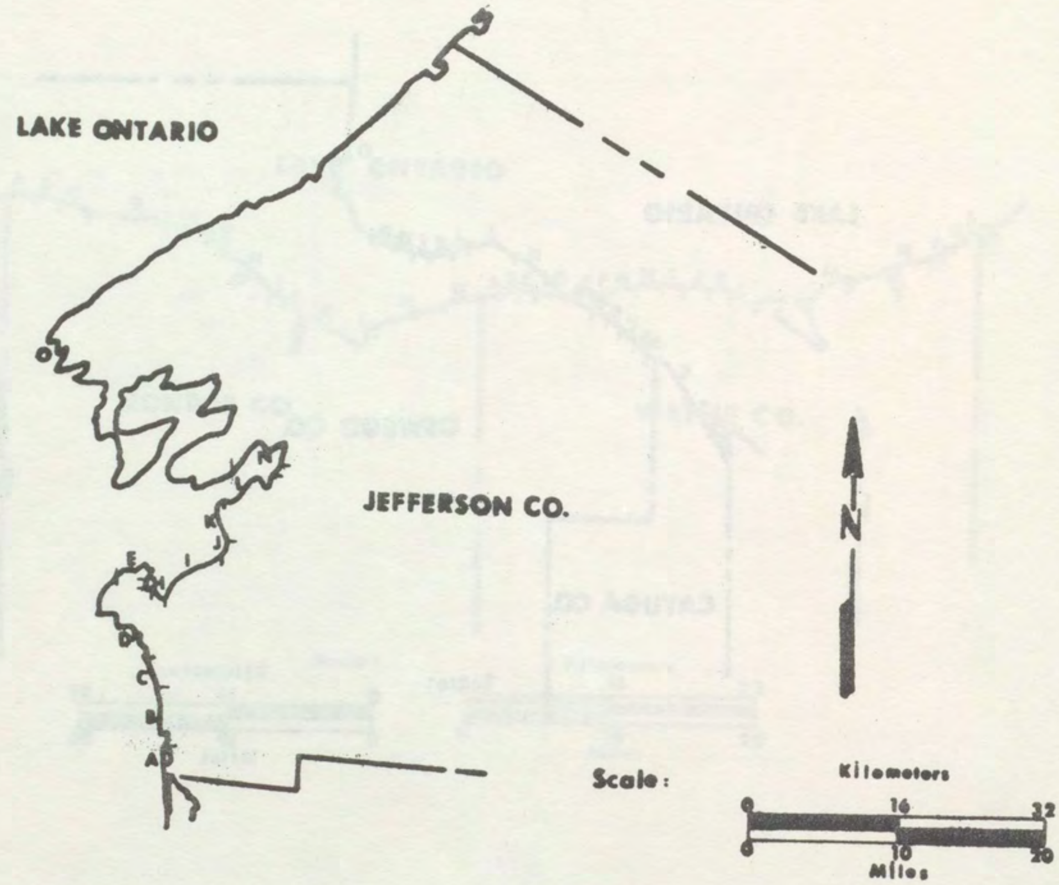
LAKE ONTARIO: Monroe and Wayne County Reach Locations.



CAYUGO CO.	
Code	Reach Number
A	80-001-002
B	80-002-003
C	80-003-006

OSWEGO CO.	
Code	Reach Number
A	81-001-001
B	81-001-001
C	81-001-002
D	81-002-003
E	81-003-004
F	81-004-005
G	81-005-006
H	81-006-007
I	81-007-008
J	81-008-009
K	81-009-010
L	81-010-011
M	81-011-013
N	81-013-013
O	81-013-017

LAKE ONTARIO: Cayugo and Oswego County Reach Locations.



JEFFERSON CO.

Code	Reach Number
A	82-001-004
B	82-004-005
C	82-005-007
D	82-007-010
E	82-010-010
F	82-010-011
G	82-011-011
H	82-011-012
I	82-012-012
J	82-012-014
K	82-014-015
L	82-015-016
M	82-016-019
N	82-019-031
O	82-031-037

LAKE ONTARIO: Jefferson County Reach Location

EROSION AND CHEMICAL INPUT TO THE GREAT LAKES FROM U.S. SHORELINE

The high lake levels of the Great Lakes during the late 1960's and early to mid-1970's have intensified the public interest in shoreline areas. Beaches along the Great Lakes are once again narrow; blufflines are retreating; and vegetation is being moved downslope. These conditions have led to speculation that the higher bluff recession rates have also led to greater sediment input into the Great Lakes. The water quality effects of sediment loading from erosion-related coastal processes are relatively unknown. In this study estimates of the bluff erosion rates and volume of eroded material have been prepared for each of the Great Lakes. Approximations of the input of the chemical constituents of the eroded material to the Great Lakes have also been made. However, due to the limitations of the available data, these values should be considered as only a first approximation.

EROSION RATES - LAKE SUPERIOR

Erosion rates (volumetric contribution) have been compiled for about 32 percent of the erodible U.S. shoreline of Lake Superior, see Table 13 and Figure 18 on page 59. Paralleling the trend of the recession rates, the highest erosion rates are found along the red clay bluffs in Douglas and Bayfield Counties, Wisconsin. The maximum rate occurs along a 1.6 kilometer (1 mile) stretch of shoreline in Bayfield County where the rate has averaged 138 cubic meters per year per meter (1,485 cubic feet per year per foot) during the period of 1938 to 1966. The clay bluffs along this stretch average 42.5 meters (139.5 feet) in height. The recession rate for this reach was 3.3 meters per year (10.8 feet per year) during the period 1938 to 1966. Thus, it is not surprising that the sediment contribution produced by that recession rate was quite high.

The erosion rates along the shores of Ontonagon, Keweenaw, and Marquette Counties were particularly low. The lack of appreciable recession along the rocky coasts of the Keweenaw Peninsula accounts for its low sediment contribution to Lake Superior. While recession is quite apparent along segments of the shorelines in Ontonagon and Marquette Counties, the low relief of the shoreforms reduces the volume of sediment which is contributed to the lake.

TABLE 13

EROSION RATES ALONG U.S. SHORELINE OF LAKE SUPERIOR

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m^3/yr/m (ft^3/yr/ft) Average		Maximum		Minimum	
Douglas Co. Wisconsin												
4-001-002	3.22	(2.0)	LD	2.29	(7.5)				0.77	(8.3)		
4-002-005	1.61	(1.0)	PE/W	2.29	(7.5)		0.91	(9.8)	1.47	(15.8)	0.21	(2.3)
4-005-012	9.01	(5.6)	HBE	14.49	(47.5)	EPA-76-14557-58	18.48	(204.3)	47.66	(513.0)		
4-012-015	4.18	(2.6)	HBE	17.53	(57.5)		15.50	(166.8)	25.64	(276.0)		
4-015-019	3.22	(3.2)	HBE	20.57	(67.5)	EPA-76-14355-56	37.00	(398.3)	57.69	(621.0)	18.81	(202.5)
4-019-022	2.90	(1.8)	HBE	17.53	(57.5)		31.52	(339.3)	63.04	(678.5)	16.57	(178.3)
4-022-023	1.61	(1.0)	HBE	14.49	(47.5)	EPA-76-14553-54	19.42	(209.0)	33.98	(365.8)	11.47	(123.5)
4-023-024	3.54	(2.2)	HBE	11.43	(37.5)		13.59	(146.3)	20.90	(225.0)	9.76	(105.0)
4-024-027	1.61	(1.0)	HBE	8.38	(27.5)		17.32	(187.0)	27.59	(297.0)	7.93	(85.3)
4-027-030	4.83	(3.0)	HBE	5.33	(17.5)	EPA-76-14551-52	13.83	(148.8)	19.18	(206.5)	6.02	(64.8)
Bayfield Co. Wisconsin												
5-001-008	9.17	(5.7)	LBE	5.33	(17.5)		7.48	(80.5)	16.26	(175.0)	1.63	(17.5)
5-008-009	0.80	(0.5)	HBE	5.33	(17.5)							
5-009-010	2.09	(1.3)	LBE/LBN	5.33	(17.5)		5.04	(54.3)	8.62	(92.8)	0.65	(7.0)
5-010-013	3.54	(2.2)	PE	0.76	(2.5)		3.70	(39.8)	11.08	(119.3)	1.25	(13.5)
5-013-015	2.09	(1.3)	HBE	23.62	(77.5)		25.20	(271.3)	34.56	(372.0)	12.24	(131.8)
5-015-017	2.57	(1.6)	HBE	29.72	(97.5)		55.26	(594.8)	95.11	(1023.8)	15.40	(165.8)
5-017-018	1.61	(1.0)	HBE	41.91	(137.5)		137.96	(1485.0)	160.95	(1732.5)	108.58	(1168.8)
5-018-020	0.80	(0.5)	HBN	41.91	(137.5)		39.49	(371.3)	53.65	(577.5)	20.44	(220.0)
5-020-021	1.61	(1.0)	HBE	17.53	(57.5)		9.08	(97.8)	23.50	(253.0)	1.61	(17.3)
5-021-023	2.90	(1.8)	PE	0.76	(2.5)		0.91	(9.8)	1.39	(15.0)	0.42	(4.5)
5-023-025	3.54	(2.2)	LBE	11.43	(37.5)		14.99	(161.3)	25.78	(277.5)	6.97	(75.0)
5-025-025	2.74	(1.7)	HBE	20.57	(67.5)							

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

Values calculated in English units, converted to metric units and rounded.

TABLE 13--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m³/yr/m (ft³/yr/ft) Average		Maximum		Minimum	
Bayfield Co. (continued)												
5-025-027	1.45	(0.9)	LBE	5.33	(17.5)		8.95	(96.3)	12.20	(131.3)	5.70	(61.3)
5-027-109 (42 reaches)		(64.0)										
Gogebic Co. Michigan												
08-001-002	2.74	(1.7)	HBN	23.62	(77.5)							
08-002-006	4.34	(2.7)	HBN	17.53	(57.5)							
08-006-007	1.45	(0.9)	LBN	5.33	(17.5)							
08-007-009	0.97	(0.6)	LBE	5.33	(17.5)		5.20	(56.0)	6.83	(73.5)	3.58	(38.5)
08-009-009	1.13	(0.7)	LBE	11.43	(37.5)		15.68	(168.8)	21.26	(228.8)	9.06	(97.5)
08-009-013	4.67	(2.9)	HBN	11.43	(37.5)		3.48	(37.5)	4.88	(52.5)	1.05	(11.3)
08-013-016	3.22	(2.0)	HBN	17.53	(57.5)							
08-016-018	1.93	(1.2)	HBN	11.43	(37.5)							
08-018-020	3.06	(1.9)	HBN	5.33	(17.5)							
08-020-020	0.48	(0.3)	HBE	5.33	(17.5)							
08-020-022	1.61	(1.0)	HBE	11.43	(37.5)							
08-022-024	4.50	(2.8)	HBE	23.62	(77.5)							
08-024-027	2.57	(1.6)	HBE	35.8	(117.5)		64.41	(693.3)	88.94	(975.3)	8.73	(94.0)
08-027-028	1.61	(1.0)	HBE	17.53	(57.5)		5.25	(57.5)	1.05	(109.3)	2.14	(23.0)
08-029-032	4.99	(3.1)	HBE	11.43	(37.5)							
08-032-036	2.57	(1.6)	HBE	23.62	(77.5)							
08-036-037	1.29	(0.8)	LBN	23.62	(77.5)							
08-037-038	4.02	(2.5)	LBN	11.43	(37.5)							
08-038-040	3.70	(2.3)	PN	11.43	(37.5)							

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 13--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m³/yr/m (ft³/yr/ft) Average		Maximum		Minimum	
Ontonagon Co. Michigan												
9-001-004	3.06	(1.9)	PN	11.43	(37.5)							
9-004-018	19.63	(12.2)	PN	5.33	(17.5)							
9-018-019	4.18	(2.6)	LPE	0.76	(2.5)		0.42	(4.5)	0.51	(5.5)	0.35	(3.8)
9-019-021	1.45	(0.9)	PN	0.76	(2.5)		0.42	(4.5)	0.63	(6.8)	0.23	(2.5)
9-021-022	0.97	(0.6)	W	0.76	(2.5)		0.19	(2.0)	0.35	(3.8)	0.00	(0.0)
9-022-026	5.15	(3.2)	PN	0.76	(2.5)		0.54	(5.8)	1.63	(17.5)		
9-026-040	17.54	(10.9)	LBE	0.76	(2.5)		0.51	(5.5)	1.65	(17.8)		
9-040-041	1.13	(0.7)	LBN	0.76	(2.5)		0.32	(3.4)	0.63	(6.8)	0.17	(1.8)
9-041-043	1.61	(1.0)	LBE	0.76	(2.5)		0.45	(4.8)	0.56	(6.0)	0.30	(3.2)
9-043-044	1.61	(1.0)	LBN	0.76	(2.5)		0.58	(6.2)	0.93	(10.0)	0.34	(4.2)
9-044-051	8.05	(5.0)	LBE	0.76	(2.5)		0.56	(6.0)	1.10	(11.8)		
9-051-051	0.48	(0.3)	LBN	0.76	(2.5)							
0-051-053	2.25	(1.4)	LBN	5.33	(17.5)		5.69	(61.2)	6.83	(73.5)	4.55	(49.0)
9-053-053	0.64	(0.4)	LBE	5.33	(17.5)		6.99	(75.2)	7.64	(82.2)	6.34	(68.2)
9-053-054	1.77	(1.1)	LBE	0.76	(2.5)		1.49	(16.0)	1.77	(19.0)	1.35	(14.5)
9-054-057	4.02	(2.5)	LBN	0.76	(2.5)							
9-057-059	2.74	(1.7)	LBE	0.76	(2.5)							
9-059-062	2.90	(1.8)	PN	0.76	(2.5)							
9-062-064	1.45	(0.9)	LBN	0.76	(2.5)							
9-064-064	1.13	(0.7)	PN	0.76	(2.5)							
9-064-067	3.54	(2.2)	LBE	0.76	(2.5)		0.14	(1.5)	0.30	(3.2)	0.07	(0.7)
9-067-069	4.18	(2.6)	LBE	5.33	(17.5)		4.88	(52.5)	8.75	(94.5)	2.28	(24.5)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

Values calculated in English units, converted to metric units and rounded.

TABLE 13--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m³/yr/m (ft³/yr/ft) Average		Maximum		Minimum	
Keweenaw Co. Michigan												
11-001-003	2.74	(1.7)	LBE	0.76	(2.5)		0.37	(4.0)	0.65	(7.0)	0.09	(1.0)
11-003-007	4.67	(2.9)	LBE	5.33	(17.5)		2.77	(29.8)	3.74	(40.3)	2.12	(22.8)
11-007-009	2.74	(1.7)	LBE	0.76	(2.5)							
11-009-015	6.44	(4.0)	LBN	5.33	(17.5)		0.65	(7.0)	1.95	(21.0)		
11-015-015	1.61	(1.0)	LBN	11.43	(37.5)							
11-015-016	1.61	(1.0)	LD	11.43	(37.5)		8.36	(90.0)	13.24	(142.5)	3.14	(33.8)
11-016-019	3.06	(1.9)	LD	28.19	(92.5)							
11-019-021	1.61	(1.0)	LD	11.43	(37.5)							
11-021-022	2.41	(1.5)	LD	0.76	(2.5)		0.63	(6.8)	0.77	(8.3)	0.49	(5.3)
11-022-023	1.77	(1.1)	LD	2.29	(7.5)		2.33	(25.1)	2.33	(25.1)	2.33	(25.1)
11-023-027	6.76	(4.2)	LD	25.15	(82.5)		6.13	(66.0)	10.73	(115.5)	1.53	(16.5)
11-027-028	2.57	(1.6)	LBN	0.76	(2.5)		0.16	(1.7)	0.16	(1.7)	0.16	(1.7)
11-028-029	2.09	(1.3)	LBN	5.33	(17.5)							
11-029-029	0.32	(0.2)	LBE	5.33	(17.5)							
11-029-033	3.38	(2.1)	LBE	3.81	(12.5)							
11-033-033	5.63	(3.5)	LBN	3.81	(12.5)							
11-033-035	3.86	(2.4)	LBN	5.33	(17.5)							
11-035-036	4.51	(2.8)	LBN	28.19	(92.5)							
11-036-039	5.63	(3.5)	LBN	5.33	(17.5)							
11-039-043	8.05	(5.0)	LBN	8.38	(27.5)							
11-043-011 (18 reaches)	75.46	(46.9)										

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 13--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum		Minimum	
Marquette Co. Michigan												
13-001-057 (29 reaches)	78.52	(48.8)										
13-057-057	0.80	(0.5)	LD	9.91	(32.5)		0.60	(6.5)	1.51	(16.2)		
13-057-057	1.13	(0.7)	HBN	9.91	(32.5)		0.00	(0.0)	2.12	(22.8)		
13-057-058	2.90	(1.8)	LD	0.76	(2.5)							
13-058-058	0.48	(0.3)	LBN	0.76	(2.5)							
13-058-058	1.77	(1.1)	LBN	28.19	(92.5)							
13-058-059	1.93	(1.2)	LBN	0.76	(2.5)							
13-059-062	2.73	(1.7)	LD	0.76	(2.5)							
13-062-064	1.29	(0.8)	LBN	0.76	(2.5)							
13-064-069	4.83	(3.0)	LBN	2.29	(7.5)							
13-069-069	1.29	(0.8)	LD	2.29	(7.5)							
13-069-076	7.56	(4.7)	LD	0.76	(2.5)		0.70	(7.5)	1.51	(16.2)		
13-076-079	7.08	(4.4)	LD	5.33	(17.5)		1.46	(16.3)	2.36	(26.25)	0.00	(0.0)
13-079-082	5.95	(3.7)	LD	0.76	(2.5)							
Luce Co. Michigan												
15-001-002	2.41	(1.5)	PE	3.81	(12.5)		2.21	(23.8)	2.68	(28.8)	1.86	(20.0)
15-002-019	22.37	(13.9)	PE	2.29	(7.5)		0.56	(6.0)	1.12	(12.0)	0.00	(0.0)
15-019-020	2.09	(1.3)	HBE	2.29	(7.5)							
15-020-021	1.45	(0.9)	LBE	2.29	(7.5)							
15-021-025	5.95	(3.7)	LBE	5.33	(17.5)							
15-025-027	1.45	(0.9)	PE	5.33	(17.5)							
15-027-030	4.51	(2.8)	PE	6.86	(22.5)							
15-030-034	4.18	(2.6)	HBE	14.48	(47.5)		11.04	(118.8)	22.95	(247.0)	3.53	(38.0)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 13--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m³/yr/m (ft³/yr/ft) Average		Maximum		Minimum	
Luce Co. (continued)												
15-034-039	7.56	(4.7)	LBE	2.29	(7.5)							
Chippewa Co. Michigan												
16-001-009 (2 reaches)	14.80	(9.2)		0.76	(2.5)							
16-009-015	9.01	(5.6)	LBE	2.29	(7.5)	EPA-76-14407-10	3.28	(35.3)	6.21	(66.8)	0.21	(2.3)
16-015-025 (2 reaches)	12.07	(7.5)		2.29	(7.5)							
16-025-026	2.25	(1.4)	LBE	0.76	(2.5)	EPA-76-14399-406	0.68	(7.3)	0.86	(9.3)	0.40	(4.3)
16-026-031 (2 reaches)	6.92	(4.3)	LBN									
16-031-046	18.97	(11.8)	LBN	0.76	(2.5)		0.74	(8.0)	1.12	(12.0)	0.33	(3.5)
16-046-179 (28 reaches)	130.23	(80.9)				EPA-76-14397-98 (reach 16-046-056)						
16-179-181	3.70	(2.3)	LBE	2.29	(7.5)		0.21	(2.25)	1.04	(11.2)		
16-181-184	3.54	(2.2)	PN	2.29	(7.5)		1.04	(11.2)	2.28	(24.7)	0.28	(3.0)
16-184-188	8.05	(5.0)	LBE	2.29	(7.5)		1.18	(12.7)	2.17	(23.3)		
16-188-189	1.93	(1.2)	LBN	2.29	(7.5)							

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

EROSION RATES - LAKE MICHIGAN

Erosion rates (volumetric contribution) have been determined for about 50 percent of the erodible shoreline of Lake Michigan, see Table 14 and Figure 25 on page 103. Corresponding with the recession rates, the higher erosion rates generally occur along the eastern coast of Lake Michigan. Referring to Figure 19 on page 73 it can be seen that the presence of a large number of shoreforms with low relief have minimized the volume of sediment contributed to Lake Michigan from the western shorelands.

The maximum erosion rates occur in Leelanaw County, Michigan where an average erosion rate of 77.9 cubic meters per year per meter (838.5 cubic feet per year per foot) has been experienced along a 2.9 meter (1.8 mile) reach during the 1938 to 1974 period. This reach consists of bluffs of unconsolidated material which reach heights of greater than 76.2 meters (250 feet). In addition, the average recession rate for this stretch of shoreline during the 1938 to 1974 period was only 0.8 meters per year (2.6 feet per year), see Table 5 on page 84. Consequently, even a relatively low recession rate for such high bluffs will produce a large volumetric contribution of sediment to the lake.

TABLE 14

EROSION RATES ALONG SHORELINE OF LAKE MICHIGAN

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m³/yr/m (ft³/yr/ft) Average		Maximum		Minimum	
Kewaunee Co. Wisconsin												
38-001-004	4.18	(2.6)	LBE	2.29	(2.5)							
38-004-007	3.22	(2.0)	LBE	2.28	(7.5)							
38-007-010	3.86	(2.4)	PE	2.28	(7.5)							
38-010-014	2.90	(1.8)	HBE	11.43	(37.5)		1.75	(18.8)	1.75	(18.8)	1.75	(18.8)
38-014-015	2.41	(1.5)	LBE	5.33	(17.5)							
38-015-018	3.54	(2.2)	LBE	5.33	(17.5)							
38-018-023	5.79	(3.6)	HBE	11.43	(37.5)		1.39	(15.0)	2.09	(22.5)	1.05	(11.3)
38-023-025	4.99	(3.1)	HBE	11.43	(37.5)		2.79	(30.0)	3.84	(41.3)	2.09	(22.5)
38-025-034	11.26	(7.0)	HBE	17.53	(57.5)		4.27	(46.0)	9.09	(97.8)	2.14	(23.0)
38-034-037	2.57	(1.6)	HBE	5.33	(17.5)							
38-037-037	0.97	(0.6)	LBE	11.43	(37.5)		7.66	(82.5)	7.66	(82.5)	7.66	(82.5)
Manitowoc Co. Wisconsin												
40-001-007	8.85	(5.5)	LBE	5.33	(17.5)		3.25	(35.0)	4.55	(49.0)	0.65	(7.0)
40-007-007	0.97	(0.6)	LBE	2.29	(7.5)							
40-007-018	12.87	(8.0)	LD	2.29	(7.5)							
40-018-018	0.80	(0.5)	PE	2.29	(7.5)							
40-018-019	0.80	(0.5)	PE	2.29	(7.5)							
40-019-022	4.67	(2.9)	LBE	0.76	(2.5)							
40-022-026	4.83	(3.0)	LBE	5.33	(17.5)							
40-026-027	2.41	(1.5)	A	5.33	(17.5)							
40-027-027	0.97	(0.6)	HBE	5.33	(17.5)							
40-027-030	4.02	(2.5)	HBE	17.53	(57.5)		8.55	(92.0)	10.68	(115.0)	5.87	(63.2)
40-030-037	9.01	(5.6)	HBE	11.43	(37.5)		0.70	(7.5)	1.04	(11.2)	0.70	(7.5)
40-037-043	8.85	(5.5)	HBE	14.48	(47.5)		5.74	(61.8)	8.83	(95.0)	1.77	(19.0)

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m^3/yr/m Average	(ft^3/yr/ft)	Maximum		Minimum	
Sheboygan Co. Wisconsin												
41-001-005	7.24	(4.5)	HBE	14.48	(47.5)		5.30	(57.0)	7.06	(76.0)	3.98	(42.8)
41-005-006	1.93	(1.2)	HBE	11.43	(37.5)		4.53	(48.8)	5.89	(63.4)	3.48	(37.5)
41-006-009	2.41	(1.5)	HBE	14.48	(47.5)							
41-009-012	4.34	(2.7)	HBE	11.43	(37.5)		0.00	(0.0)	0.00	(0.0)	0.00	(0.0)
41-012-013	1.45	(0.9)	A	0.76	(2.5)							
41-013-014	1.45	(0.9)	PE	0.76	(2.5)							
41-014-014	1.45	(0.9)	HBE	9.91	(32.5)		3.02	(32.5)	3.02	(32.5)	3.02	(32.5)
41-014-015	1.45	(0.9)	LBE	9.91	(32.5)							
41-015-022	8.21	(5.1)	LBE	2.29	(7.5)							
41-022-023	1.61	(1.0)	LD	0.76	(2.5)							
41-023-030	12.87	(8.0)	PE	0.76	(2.5)		0.05	(0.5)	0.12	(1.25)		
Ozaukee Co. Wisconsin												
42-001-004	4.99	(3.1)	PE	0.76	(2.5)		0.02	(0.2)	0.02	(0.2)	0.02	(0.2)
42-004-008	6.28	(3.9)	LBE	2.29	(7.5)		0.07	(0.8)	0.07	(0.8)	0.00	(0.1)
42-008-015	7.88	(4.9)	HBE	23.62	(77.5)		9.36	(100.8)	9.36	(100.8)	9.36	(100.8)
42-015-015	2.41	(1.5)	A	0.76	(2.5)							
42-015-020	5.63	(3.5)	HBE	29.72	(97.5)		15.40	(165.8)	15.40	(165.8)	15.40	(165.8)
42-020-027	10.94	(6.8)	HBE	35.81	(117.5)		33.84	(364.2)	37.12	(399.5)	32.75	(352.5)
42-027-031	6.60	(4.1)	HBE	29.72	(97.5)							
Milwaukee Co. Wisconsin												
43-001-006	7.24	(4.5)	HBE	29.72	(99.5)		3.62	(39.0)	4.53	(48.8)	0.91	(9.8)
43-006-007	2.74	(1.7)	HBE	35.81	(117.5)		19.65	(211.5)	20.74	(223.2)	18.56	(199.8)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum		Minimum	
Milwaukee Co. (continued)												
43-007-014	5.63	(3.5)	HBE	32.77	(107.5)		19.97	(215.0)	30.96	(333.2)	12.99	(139.8)
43-014-014	0.80	(0.5)	A	0.76	(2.5)							
43-014-015	2.41	(1.5)	PE	0.76	(2.5)							
43-015-021	9.65	(6.0)	A	0.76	(2.5)							
43-021-023	3.06	(1.9)	HBE	11.43	(37.5)		5.57	(60.0)	5.93	(63.8)	5.22	(56.2)
43-023-024	0.80	(0.5)	A	0.76	(2.5)							
43-024-029	8.85	(5.5)	HBE	29.72	(97.5)		7.25	(78.0)	10.87	(117.0)	2.71	(29.2)
43-029-030	1.77	(1.1)	HBE	26.67	(87.5)		5.69	(61.2)	5.69	(61.2)	5.69	(61.2)
43-030-031	0.80	(0.5)	A	0.76	(2.5)		0.39	(4.2)	0.39	(4.2)	0.39	(4.2)
43-031-034	3.86	(2.4)	HBE	26.67	(87.5)		21.14	(227.5)	22.76	(245.0)	20.33	(218.8)
43-034-034	1.45	(0.9)	A	0.76	(2.5)		0.51	(5.5)	0.51	(5.5)	0.51	(5.5)
Racine Co. Wisconsin												
44-001-006	5.95	(3.7)	HBE	14.48	(47.5)	EPA-76-14527-32	10.15	(109.2)	15.45	(166.3)	5.17	(55.6)
44-006-011	9.81	(6.1)	HBE	8.38	(27.5)	EPA-76-14533-34						
44-011-013	3.22	(2.0)	A	0.76	(2.5)							
44-013-017	5.47	(3.4)	HBE	11.43	(37.5)	EPA-76-14535-40						
44-017-017	1.77	(1.1)	HBE	8.38	(27.5)							
Kenosha Co. Wisconsin												
45-001-005	6.44	(4.0)	HBE	8.38	(27.5)		7.92	(85.2)	9.71	(104.5)	6.13	(66.0)
45-005-006	3.22	(2.0)	A	0.76	(2.5)		0.05	(0.5)	0.05	(0.5)	0.05	(0.5)
45-006-009	2.41	(1.5)	LBE	0.76	(2.5)							

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum		Minimum	
Kenosha Co. (continued)												
45-009-010	2.25	(1.4)	A	2.29	(7.5)		2.93	(31.5)	2.93	(31.5)	2.93	(31.5)
45-010-012	4.83	(3.0)	LBE	2.29	(7.5)							
45-012-014	4.02	(2.5)	PE	0.76	(2.5)		1.95	(21.0)	1.95	(21.0)	0.95	(21.0)
Lake Co. Illinois												
46-001-010	17.70	(11.0)	PE	0.76	(2.5)							
46-010-012	1.61	(1.0)	HBE	2.29	(7.5)							
46-012-013	2.25	(1.4)	HBE	5.33	(17.5)							
46-013-029	25.70	(16.0)	HBE	20.57	(67.5)		10.03	(108.0)	15.68	(168.8)	4.39	(47.2)
Porter Co. Indiana												
49-001-003	4.67	(2.9)	LD	5.33	(17.5)							
49-003-007	5.63	(3.5)	A	5.33	(17.5)							
49-007-009	4.18	(2.6)	HD	20.57	(67.5)							
49-009-011	2.90	(1.8)	PE/HD	20.57	(67.5)							
49-011-014	5.79	(3.6)	HD	20.57	(67.5)							
49-014-019	4.83	(3.0)	LD	5.33	(17.5)		4.39	(47.3)	6.35	(68.3)	3.42	(36.9)
49-019-021	4.02	(2.5)	HD	20.57	(67.5)		19.44	(209.2)	25.08	(270.0)	14.42	(155.2)
La Porte Co. Indiana												
50-001-002	2.32	(1.2)	HD	20.57	(67.5)							
50-002-004	2.57	(1.6)	HD	0.76	(2.5)							

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion Average $m^3/yr/m$	($ft^3/yr/ft$)	Maximum $m^3/yr/m$	($ft^3/yr/ft$)	Minimum $m^3/yr/m$	($ft^3/yr/ft$)
La Porte Co. (continued)												
50-004-004	1.13	(0.7)	A	2.29	(7.5)							
50-004-006	4.02	(2.5)	LD	2.29	(7.5)							
50-006-008	1.61	(1.0)	LD	8.38	(27.5)		5.62	(60.5)	5.62	(60.5)	5.62	(60.5)
Berrien Co. Michigan												
021-001-002	3.38	(2.1)	LD	5.33	(17.5)		3.90	(42.0)	6.50	(70.0)	0.00	(0.0)
021-002-007	6.76	(4.2)	LD	8.38	(27.5)		5.88	(63.3)	11.75	(126.5)	3.07	(33.3)
021-007-013	6.60	(4.1)	LD	11.43	(37.5)		2.79	(30.0)	5.23	(56.3)	1.05	(11.3)
021-013-015	2.09	(1.3)	LD	8.38	(27.5)		4.60	(49.5)	6.64	(71.5)	1.27	(13.7)
021-015-019	3.38	(2.1)	HBE	11.43	(37.5)							
021-019-020	1.45	(0.9)	HBE	16.00	(52.5)							
021-020-020	0.64	(0.4)	HD	23.62	(77.5)							
021-020-032	14.97	(9.3)	HD	11.43	(37.5)		6.97	(75.0)	11.15	(120.0)	4.53	(48.8)
021-032-033	1.45	(0.9)	HD	9.91	(32.5)		5.44	(58.5)	7.25	(78.0)	3.92	(42.2)
021-033-036	2.09	(1.3)	HBE	9.91	(32.5)		9.36	(100.8)	14.20	(152.8)	4.83	(52.0)
021-036-039	4.83	(3.0)	HBE	17.53	(57.5)		18.16	(195.5)	28.85	(310.5)	4.80	(51.7)
021-039-043	5.15	(3.2)	LBE	0.76	(2.5)		0.95	(10.2)	0.95	(10.2)	0.95	(10.2)
021-043-050	9.98	(6.2)	HBE	23.62	(77.5)		8.64	(93.0)	18.00	(193.7)	0.00	(0.0)
021-050-051	1.93	(1.2)	HD	23.62	(77.5)							
021-051-055	6.12	(3.8)	HD	11.43	(37.5)		2.09	(22.5)	3.13	(33.7)	1.05	(11.25)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m³/yr/m (ft³/yr/ft) Average		Maximum		Minimum	
Allegan Co. Michigan												
23-001-001	0.80	(0.5)	HBE	23.62	(77.5)							
23-001-008	8.69	(5.4)	HBE	23.62	(77.5)		24.48	(263.5)	38.88	(418.5)	11.52	(124.0)
23-008-012	17.06	(10.6)	HBE	17.53	(57.5)		16.03	(172.5)	28.85	(310.5)	6.95	(74.8)
23-012-015	4.83	(3.0)	HD	5.33	(17.5)		6.50	(70.0)	13.82	(148.7)	2.28	(24.5)
23-015-020	9.98	(6.2)	HD	23.62	(77.5)		29.53	(317.8)	40.32	(434.0)	19.44	(209.2)
Van Buren Co. Michigan												
22-001-010	10.46	(6.5)	HD	23.62	(77.5)		12.24	(131.8)	18.72	(201.5)	3.61	(38.8)
22-010-010	1.45	(0.9)	HBE	11.43	(37.5)							
22-010-017	10.14	(6.3)	HBE	11.43	(37.5)		9.06	(97.5)	26.82	(288.7)	0.00	(0.0)
Ottawa Co. Michigan												
24-001-002	3.54	(2.2)	HD	17.53	(57.5)		14.96	(161.0)	25.10	(270.2)	5.34	(57.5)
24-002-009	10.30	(6.4)	HBE	17.53	(57.5)		6.94	(74.7)	25.10	(270.2)	0.00	(0.0)
24-009-019	13.04	(8.1)	HD	17.53	(57.5)		12.82	(138.0)	22.44	(241.5)	2.66	(28.7)
24-019-021	9.17	(5.7)	HD	23.62	(77.5)		15.79	(170.0)	30.96	(333.3)	2.88	(31.0)
24-021-028	6.92	(4.3)	HD	22.10	(72.5)		6.06	(65.2)	16.17	(174.0)	0.00	(0.0)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum		Minimum	
Oceana Co. Michigan												
26-001-001	1.13	(0.7)	HD	23.62	(77.5)		15.12	(162.7)	20.16	(217.0)	5.76	(62.0)
26-001-008	8.69	(5.4)	HBE	23.62	(77.5)		12.24	(131.7)	30.19	(325.0)		
26-008-014	11.10	(6.9)	HD	11.43	(37.5)		10.45	(112.5)	26.76	(288.0)		
26-014-020	6.92	(4.3)	HD	5.33	(17.5)		3.18	(35.0)	6.83	(73.5)	1.79	(19.3)
26-020-027	8.53	(5.3)	HD	11.43	(37.5)		5.05	(54.4)	16.37	(176.2)		
26-027-032	8.05	(5.0)	HD	14.48	(47.5)		3.98	(42.8)	4.88	(52.5)	2.20	(23.7)
Muskegon Co. Michigan												
25-001-004	4.83	(3.0)	HD	26.67	(87.5)		8.08	(87.0)	23.58	(253.8)		
25-004-006	4.02	(2.5)	HD	12.95	(42.5)	EPA-76-14449-53	10.66	(114.8)	16.18	(174.2)		
25-006-009	3.70	(2.3)	HD	26.67	(87.5)							
25-009-013	3.54	(2.2)	HD	12.95	(42.5)		3.95	(42.5)	10.27	(110.5)		
25-013-013	2.41	(1.5)	HD	23.62	(77.5)		8.64	(93.0)	18.00	(193.8)		
25-013-020	8.05	(5.0)	LBE	5.33	(17.5)	EPA-76-14454-60	1.78	(19.2)	3.73	(40.2)		
25-020-021	1.45	(0.9)	LBE	11.43	(37.5)		5.93	(63.8)	13.24	(142.5)		
25-021-024	4.18	(2.6)	HD	11.43	(37.5)		12.87	(138.5)	20.21	(217.5)	7.65	(82.5)
25-024-025	1.93	(1.2)	HD	5.33	(17.5)		1.30	(14.0)	2.93	(31.5)	0.33	(3.5)
25-025-029	4.83	(3.0)	HBE	23.62	(77.5)	EPA-76-14461-67	12.24	(131.8)	36.00	(387.5)		
25-029-033	5.95	(3.7)	HD	23.62	(77.5)		15.84	(170.5)	39.60	(426.2)	0.72	(7.8)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ (ft^3/yr/ft) Average		Maximum		Minimum	
Mason Co. Michigan												
27-001-003	4.35	(2.7)	HD	14.48	(47.5)		2.65	(28.5)	8.83	(95.0)		
27-003-009	7.89	(4.9)	HBE	14.48	(47.5)		6.18	(66.5)	15.44	(166.2)		
27-009-009	0.64	(0.4)	LD	14.48	(47.5)		2.20	(23.7)	5.74	(61.8)		
27-009-011	4.18	(2.6)	LD	3.81	(12.5)		2.32	(25.0)	4.88	(52.5)	0.23	(2.5)
27-011-022	17.38	(10.8)	LD	5.33	(17.5)		4.07	(43.8)	7.80	(84.0)	0.00	(0.0)
27-022-033	14.16	(8.8)	HBE	17.53	(57.5)		14.43	(155.3)	44.87	(483.0)		
Manistee Co. Michigan												
28-001-005	6.60	(4.1)	HBE	17.53	(57.5)	EPA-76-14434-39	6.41	(69.0)	8.55	(92.0)	2.14	(23.0)
28-005-008	3.54	(2.2)	LBE	0.76	(2.5)		0.17	(1.8)	0.46	(5.0)	0.00	(0.0)
28-008-012	5.47	(3.4)	HBE	17.53	(57.5)		8.55	(92.0)	22.44	(241.5)		
28-012-013	2.90	(1.8)	LBE	5.33	(17.5)		6.35	(68.3)	7.80	(84.0)	5.20	(56.0)
28-013-016	3.70	(2.3)	HBE	17.53	(57.5)		11.75	(126.5)	21.91	(235.8)	6.95	(74.8)
28-016-016	0.64	(0.4)	LBE	17.53	(57.5)		8.02	(86.3)	8.55	(92.0)	6.95	(74.8)
28-016-018	3.54	(2.2)	LBE	5.33	(17.5)		3.42	(36.8)	3.90	(42.0)	2.93	(31.5)
28-018-022	4.67	(2.9)	HBE	35.81	(117.5)		15.28	(164.5)	32.75	(352.5)		
28-022-024	4.51	(2.8)	LBE	5.33	(17.5)	EPA-76-14440-43	1.95	(21.0)	3.42	(36.8)	0.82	(8.8)
28-024-026	3.70	(2.3)	LBE	35.81	(117.5)		10.92	(117.5)	31.77	(340.8)		
28-026-028	2.25	(1.4)	LBE	5.33	(17.5)		2.60	(28.0)	4.23	(45.5)	0.33	(3.5)
28-028-029	1.45	(0.9)	HBE	5.33	(17.5)	EPA-76-14444-48	1.95	(21.0)	3.25	(35.0)	0.33	(3.5)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum		Minimum	
Benzie Co. Michigan												
29-001-002	3.22	(2.0)	HBE	35.81	(117.5)		14.20	(152.8)	39.30	(423.0)	0.00	(0.0)
29-002-003	0.97	(0.6)	HBE	5.33	(17.5)		0.65	(7.0)	1.30	(14.0)	0.33	(3.5)
29-003-004	3.54	(2.2)	LBE	5.33	(17.5)		0.49	(5.3)	1.14	(12.3)	0.00	(0.0)
29-004-007	5.15	(3.2)	HBE	35.81	(117.5)		19.65	(211.5)	40.39	(434.8)		
29-007-007	0.97	(0.6)	LBE	35.81	(117.5)							
29-007-010	1.93	(1.2)	LBE	5.33	(17.5)							
29-010-013	5.95	(3.7)	HD	35.81	(117.5)		16.37	(176.3)	41.46	(446.5)		
29-013-018	6.60	(4.1)	LD	5.33	(17.5)		3.25	(35.0)	8.78	(94.5)		
29-018-023	7.56	(4.7)	HD	5.33	(17.5)		2.12	(22.8)	3.58	(38.5)	1.46	(15.7)
29-023-026	3.54	(2.2)	HD	0.76	(2.5)		0.26	(2.8)	1.12	(12.0)		
29-026-027	1.61	(1.0)	HD	5.33	(17.5)		5.53	(59.5)	8.45	(91.0)	1.63	(17.5)
29-027-028	1.93	(1.2)	LBE	98.30	(322.5)		23.97	(258.0)	47.94	(516.0)	3.00	(32.3)
Leelanau Co. Michigan												
30-001-002	3.22	(2.0)	HBE	98.30	(322.5)		77.90	(838.5)	188.76	(2031.8)	11.98	(129.0)
30-002-003	0.97	(0.6)	HBE	5.33	(17.5)		2.43	(26.2)	3.58	(38.5)	1.63	(17.5)
30-003-004	0.64	(0.4)	LD	5.33	(17.5)		3.73	(40.2)	7.64	(82.2)	3.08	(33.2)
30-004-005	2.57	(1.6)	LD	15.24	(50.0)		9.29	(100.0)	16.26	(175.0)	2.79	(30.0)
30-005-006	0.97	(0.6)	LD	5.33	(17.5)							
30-006-009	5.31	(3.3)	HD	100.58	(330.0)							
30-009-010	2.41	(1.5)	HD	15.24	(50.0)							
30-010-011	2.90	(1.8)	HD	5.33	(17.5)							
30-011-011	0.32	(0.2)	HBE	5.33	(17.5)							
30-011-014	5.15	(3.2)	HBE	0.76	(2.5)							

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	Reach Length (mi)	Shore-form	Average Bluff Height m	Average Bluff Height (ft)	Soil Analysis	Erosion Average m³/yr/m	Erosion Average (ft³/yr/ft)	Erosion Maximum m³/yr/m	Erosion Maximum (ft³/yr/ft)	Erosion Minimum m³/yr/m	Erosion Minimum (ft³/yr/ft)
Leelanau Co. (continued)												
30-014-016	2.90	(1.8)	HBE	76.20	(250.0)		37.16	(400.0)	85.93	(925.0)	6.97	(75.0)
30-016-019	2.74	(1.7)	HBE	21.34	(70.0)		13.66	(47.0)	28.61	(308.0)	1.95	(21.0)
30-019-019	1.93	(1.2)	HBE	5.33	(17.5)		1.47	(15.8)	1.47	(15.8)	0.65	(7.0)
30-019-021	1.77	(1.1)	HBE	88.39	(290.0)		13.47	(145.0)	37.72	(406.0)		
30-021-021	0.64	(0.4)	PE	88.39	(290.0)							
30-021-027	8.37	(5.2)	PE	0.76	(2.5)							
30-027-033	8.85	(5.5)	HBE	27.43	(90.0)		2.51	(27.0)	7.53	(81.0)		
30-033-034	2.90	(1.8)	PE	67.82	(222.5)		24.80	(267.0)	51.67	(556.2)	12.40	(133.5)
30-034-037	4.18	(2.6)	LBE	5.33	(17.5)		0.82	(8.8)	1.78	(19.2)	0.00	(0.0)
30-037-041	2.74	(1.7)	HBE	29.72	(97.5)		8.16	(87.8)	11.78	(126.8)	0.91	(9.8)
30-041-043	4.02	(2.5)	PE	5.33	(17.5)		2.28	(24.5)	2.93	(31.5)	1.13	(12.2)
30-043-045	2.90	(1.8)	PE	9.91	(32.5)		2.71	(29.2)	3.62	(39.0)	1.51	(16.3)
30-045-045	1.13	(0.7)	HBE	9.91	(32.5)		8.75	(94.2)	13.29	(143.0)	8.75	(94.2)
30-045-049	6.76	(4.2)	HBE	67.82	(222.5)		12.40	(133.5)	51.17	(556.3)	0.00	(0.0)
30-049-054	2.74	(1.7)	HBE	25.15	(82.5)		10.73	(115.5)	26.83	(288.8)	1.53	(16.5)
30-054-056	2.90	(1.8)	PE	5.33	(17.5)		2.28	(24.5)	3.58	(38.5)	0.00	(0.0)
30-056-057	3.22	(2.0)	PE	15.25	(50.0)		7.43	(80.0)	10.68	(115.0)	3.72	(40.0)
30-057-058	2.74	(1.7)	PE	5.33	(17.5)							
30-058-063	8.05	(5.0)	PE	0.76	(2.5)		0.42	(4.5)	0.60	(6.5)	0.14	(1.5)
30-063-067	6.44	(4.0)	PE	2.29	(7.5)							
30-067-068	2.74	(1.7)	PE	5.33	(17.5)		2.77	(29.8)	4.52	(49.0	0.65	(7.0)
30-068-069	2.74	(1.7)	PE	0.76	(2.5)							
30-069-070	2.74	(1.7)	PE	5.33	(17.5)							
30-070-072	1.45	(0.9)	LBE	5.33	(17.5)							
30-072-074	4.51	(2.8)	LBE	0.76	(2.5)							
30-074-078	5.47	(3.4)	LBE	5.33	(17.5)							

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum		Minimum	
Leelanau Co. (continued)												
30-078-078	0.97	(0.6)	PE	5.33	(17.5)							
30-078-079	3.06	(1.9)	PE	2.29	(7.5)							
30-079-080	2.41	(1.5)	PE	5.33	(17.5)							
30-080-086	6.12	(3.8)	LBE	5.33	(17.5)							
30-086-089	2.09	(1.3)	PE	0.76	(2.5)		0.07	(.75)	0.21	(2.3)		
30-089-090	3.22	(2.0)	PE	2.29	(7.5)							
30-090-091	2.57	(1.6)	PE	0.76	(2.5)							
30-091-091	1.77	(1.1)	PE	33.53	(110.0)							
30-091-092	1.45	(0.9)	PE	29.72	(97.5)							
30-092-094	2.74	(1.7)	PE	6.86	(22.5)							
30-094-095	2.09	(1.3)	PE	0.76	(2.5)							
30-095-097	3.70	(2.3)	LBE	5.33	(17.5)		2.28	(24.5)	5.04	(54.2)	0.33	(3.5)
30-097-102	9.33	(5.8)	LBE	77.72	(255.0)		21.32	(229.5)	40.27	(433.5)	0.00	(0.0)
30-102-103	3.54	(2.2)	LBE	33.53	(110.0)		8.18	(88.0)	19.42	(209.0)	0.00	(0.0)
30-103-104	1.29	(0.8)	LBE	5.33	(17.5)							
30-104-105	1.61	(1.0)	LBE	2.29	(7.5)							
Grand Traverse Co., Michigan												
31-001-004	4.02	(2.5)	PE	0.76	(2.5)		0.18	(1.9)	0.33	(3.5)		
31-004-009	6.60	(4.1)	LBE	48.77	(160.0)							
31-009-013	4.67	(2.9)	LBE	5.33	(17.5)							
31-013-015	3.06	(1.9)	LBE	2.29	(7.5)							
31-015-017	3.38	(2.1)	LBE	0.76	(2.5)		0.45	(4.8)	0.46	(5.0)	0.00	(0.0)
31-017-020	2.41	(1.5)	LBE	5.33	(17.5)							
31-020-021	1.93	(1.2)	LBE	2.29	(7.5)							

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ $(ft^3/yr/ft)$ Average		Maximum		Minimum	
Grand Traverse Co. (continued)												
31-021-024	3.22	(2.0)	LBE	5.33	(17.5)							
31-024-025	1.77	(1.1)	LBE	2.29	(7.5)							
31-025-025	1.13	(0.7)	LBE	5.33	(17.5)							
31-025-029	5.47	(3.4)	PE	5.33	(17.5)		0.17	(1.8)	0.650	(7.0)		
31-029-029	3.38	(2.1)	PE	0.76	(2.5)		0.29	(3.1)	0.390	(4.2)	0.093	(1.0)
31-029-029	0.48	(0.3)	PE	29.72	(97.5)							
31-029-033	4.35	(2.7)	HBE	29.72	(97.5)							
31-033-033	2.74	(1.7)	PE	0.76	(2.5)							
31-033-033	1.29	(0.8)	PE	5.33	(17.5)							
31-033-034	1.13	(0.7)	LBE	5.33	(17.5)							
31-034-035	1.93	(1.2)	LBE	39.62	(130.0)							
31-035-036	1.13	(0.7)	LBE	9.14	(30.0)							
31-036-039	5.15	(3.2)	LBE	5.33	(17.5)		0.98	(10.5)	4.39	(47.2)		
31-039-040	2.41	(1.5)	HBE	23.62	(77.5)							
31-040-050	11.10	(6.9)	LBE	5.33	(17.5)							
31-050-056	10.78	(6.7)	PE	0.76	(2.5)							
31-056-058	2.90	(1.8)	LBE	0.76	(2.5)							
31-058-059	1.45	(0.9)	LBE	17.53	(57.5)							
31-059-061	2.09	(1.3)	PE	0.76	(2.5)							
31-061-063	1.29	(0.8)	PE	16.00	(52.5)		2.93	(31.5)	6.34	(68.2)	0.483	(5.2)
31-063-063	1.29	(0.8)	PE	0.76	(2.5)							

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m³/yr/m (ft³/yr/ft) Average		Maximum		Minimum	
Antrim Co. Michigan												
32-001-004	3.70	(2.3)	PE	3.05	(10.0)		1.77	(19.0)	2.32	(25.0)	0.28	(3.0)
32-004-011	9.33	(5.8)	PE	1.52	(5.0)		0.33	(3.5)	0.79	(8.5)	0.00	(0.0)
32-011-027	28.00	(17.4)	PE	0.76	(2.5)		0.22	(2.4)	0.48	(5.4)		
Charlevoix Co., Michigan												
33-001-004	4.02	(2.5)	PE	5.33	(17.5)		0.65	(7.0)	2.60	(28.0)		
33-004-008	6.60	(4.1)	PE	0.76	(2.5)							
33-008-010	2.25	(1.4)	PE	5.33	(17.5)							
33-010-012	3.38	(2.1)	PN	5.33	(17.5)		1.95	(21.0)	6.34	(68.2)	0.17	(1.8)
33-012-013	1.77	(1.1)	PN	0.76	(2.5)							
33-013-014	0.80	(0.5)	PE	0.76	(2.5)							
33-014-017	4.02	(2.5)	PE	5.33	(17.5)							
33-017-017	0.80	(0.5)	PE	0.76	(2.5)							
33-017-025	9.50	(5.9)	PN	0.76	(2.5)							
33-025-026	3.54	(2.2)	LBN	5.33	(17.5)							
Emmet Co. Michigan												
34-001-005	1.61	(1.0)	LBN	21.34	(70.0)							
34-005-012	11.59	(7.2)	LBN	2.29	(7.5)							
34-012-014	3.70	(2.3)	HD	2.29	(7.5)							
34-014-017	1.93	(1.2)	W	2.29	(7.5)							
34-017-022	10.30	(6.4)	HBE	2.29	(7.5)							
34-022-025	3.70	(2.3)	HBE	67.82	(222.5)							

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m³/yr/m Average	(ft³/yr/ft) Average	m³/yr/m Maximum	(ft³/yr/ft) Maximum	m³/yr/m Minimum	(ft³/yr/ft) Minimum
Emmet Co. (continued)												
34-025-028	4.83	(3.0)	HBE	82.30	(270.0)							
34-028-030	2.09	(1.3)	HBE	21.34	(70.0)		1.95	(21.0)	2.60	(28.0)	1.30	(14.0)
34-030-036	8.53	(5.3)	HBE	28.96	(95.0)							
34-036-039	1.93	(1.2)	HBE	7.62	(25.0)							
34-039-042	5.95	(3.7)	HBE	21.34	(70.0)							
34-042-044	2.57	(1.6)	HBE	7.62	(25.0)							
34-044-047	3.54	(2.2)	HBE	13.72	(45.0)							
34-047-048	0.97	(0.6)	HBE	13.72	(45.0)							
34-048-055	6.44	(4.0)	HD	6.86	(22.5)		1.25	(13.5)	2.30	(24.7)	0.63	(6.8)
34-055-058	3.22	(2.0)	HD	0.76	(2.5)		0.45	(4.8)	0.65	(7.0)	0.07	(0.7)
34-058-063	17.22	(10.7)	W	0.76	(2.5)							
34-063-062	2.90	(1.8)	PE	0.76	(2.5)							
34-062-066	2.74	(1.7)	PE	2.29	(7.5)							
34-066-066	2.90	(1.8)	W	5.33	(17.5)							
34-066-067	1.77	(1.1)	W	2.29	(7.5)							
34-067-068	0.97	(0.6)	PE	2.29	(7.5)							
34-068-073	2.41	(1.5)	PE	0.76	(2.5)							
34-073-075	3.38	(2.1)	W	2.29	(7.5)							
34-075-076	1.93	(1.2)	PE	2.29	(7.5)							
34-076-081	5.15	(3.2)	W	1.52	(5.0)							
34-081-082	1.77	(1.1)	HD	1.52	(5.0)							
34-082-085	4.99	(3.1)	HBE	2.29	(7.5)		0.15	(1.6)	0.362	(3.9)	0.000	(0.0)

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion Average $m^3/yr/m$	($ft^3/yr/ft$)	Maximum $m^3/yr/m$	($ft^3/yr/ft$)	Minimum $m^3/yr/m$	($ft^3/yr/ft$)
Schoolcraft Co., Michigan												
18-001-003	5.31	(3.3)	PN	0.76	(2.5)							
18-003-004	0.64	(0.4)	PN	6.86	(22.5)							
18-004-004	1.29	(0.8)	W	6.86	(22.5)							
18-004-005	0.80	(0.5)	PN	6.86	(22.5)	EPA-76-14486-88						
18-005-006	1.29	(0.8)	PN	11.43	(37.5)							
18-006-008	1.13	(0.7)	PN	0.76	(2.5)							
18-008-009	1.93	(1.2)	W	0.76	(2.5)							
18-009-009	0.48	(0.3)	PN	0.76	(2.5)							
18-009-011	2.25	(1.4)	W	0.76	(2.5)							
18-011-011	0.64	(0.4)	W	6.86	(22.5)							
18-011-012	2.25	(1.4)	PN	6.86	(22.5)		4.18	(45.0)	5.02	(54.0)	2.30	(24.8)
18-012-013	1.77	(1.1)	HBE	0.76	(2.5)		0.28	(3.0)	0.31	(3.3)	0.22	(2.4)
18-013-013	0.16	(0.1)	PN	0.76	(2.5)							
18-013-014	1.29	(0.8)	PN	2.29	(7.5)		0.42	(4.5)	0.42	(4.5)	0.42	(4.5)
18-014-016	1.13	(0.7)	HBE	0.76	(2.5)		0.05	(0.5)	0.07	(0.7)	0.00	(0.0)
18-016-023	5.63	(3.5)	PN	0.76	(2.5)		0.19	(2.0)	0.35	(3.8)	0.00	(0.0)
18-023-026	3.54	(2.2)	LD	0.76	(2.5)	EPA-76-14481-85						
18-026-027	1.45	(0.9)	PN	0.76	(2.5)							
18-027-028	2.90	(1.8)	PE	0.76	(2.5)							
18-028-028	0.64	(0.4)	LD	0.76	(2.5)							
18-028-029	1.61	(1.0)	PE	0.76	(2.5)							
18-029-031	3.22	(2.0)	LD	0.76	(2.5)	EPA-76-14474-80						
18-031-035	7.72	(4.8)	PN	0.76	(2.5)	EPA-76-14472-73						
18-035-036	1.61	(1.0)	LD	0.76	(2.5)							
18-036-038	1.61	(1.0)	PE	0.76	(2.5)							
18-038-045	2.57	(6.1)	LD	3.81	(12.5)	EPA-76-14469-71						
18-045-048	4.02	(2.5)	PN	2.29	(7.5)							

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum		Minimum	
Schoolcraft Co. (continued)												
18-048-051	7.24	(4.5)	PN	0.76	(2.5)							
18-051-053	2.09	(1.3)	PN	3.81	(12.5)							
18-053-053	0.81	(0.5)	PN	0.76	(2.5)							
Delta Co. Michigan												
19-001-001	1.45	(0.9)	PN	0.76	(2.5)							
19-001-003	1.77	(1.1)	PN	2.29	(7.5)							
19-003-004	3.70	(2.3)	LBE	2.29	(7.5)		0.76	(8.2)	0.98	(10.5)	0.48	(5.2)
19-004-014	6.28	(3.9)	PE	2.29	(7.5)		0.42	(4.5)	0.63	(6.8)	0.14	(1.5)
19-014-017	10.14	(6.3)	PE	0.76	(2.5)							
19-017-019	2.41	(1.5)	PE	2.29	(7.5)		0.98	(10.5)	1.04	(11.2)	0.84	(9.0)
19-019-021	3.22	(2.2)	LD	0.76	(2.5)							
19-021-027	10.30	(6.4)	W	0.76	(2.5)							
19-027-027	2.57	(1.6)	PE	0.76	(2.5)							
19-027-028	1.61	(1.0)	A	0.76	(2.5)		0.23	(2.5)	0.28	(3.0)	0.19	(2.0)
19-028-028	1.29	(0.8)	W	0.76	(2.5)							
19-028-029	1.93	(1.2)	LBE	0.76	(2.5)							
19-029-030	0.97	(0.6)	PE	0.76	(2.5)							
19-030-030	0.97	(0.6)	W	5.33	(17.5)							
19-030-033	2.41	(1.5)	W	5.33	(17.5)		1.63	(17.5)	1.95	(21.0)	1.30	(14.0)
19-033-037	2.09	(1.3)	HBE	11.43	(37.5)							
19-037-038	2.41	(1.5)	PEW	11.43	(37.5)							
19-038-047	18.51	(11.5)	W	0.76	(2.5)		0.33	(3.5)	0.46	(5.0)	0.20	(2.2)
19-047-175 (54 reaches)	236.56	(147.0)										

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 14--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum		Minimum	
Menominee Co. Michigan												
20-045-048	4.99	(3.1)	PE	0.76	(2.5)							
20-043-045	1.77	(1.1)	LBE	0.76	(2.5)							
20-041-043	2.90	(1.8)	PE	0.76	(2.5)							
20-040-041	1.61	(1.0)	PN	0.76	(2.5)							
20-036-040	4.67	(2.9)	PE	0.76	(2.5)							
20-034-036	2.74	(1.7)	PN	0.76	(2.5)							
20-032-034	1.93	(1.2)	PE	0.76	(2.5)							
20-031-032	1.61	(1.0)	LBE	2.29	(7.5)							
20-030-031	1.77	(1.1)	LBE	0.76	(2.5)							
20-023-030	9.66	(6.0)	PE	0.76	(2.5)		0.19	(2.0)	0.32	(3.5)	0.05	(0.5)
20-022-023	2.25	(1.4)	PN	2.29	(7.5)							
20-020-022	3.22	(2.0)	PE	0.76	(2.5)							
20-018-020	1.77	(1.1)	PN	0.76	(2.5)							
20-016-018	4.35	(2.7)	PE	0.76	(2.5)		0.12	(1.3)	0.12	(1.3)	0.12	(1.3)
20-014-016	4.02	(2.5)	LBE	0.76	(2.5)		0.28	(3.0)	0.45	(4.8)	0.12	(1.3)
20-005-014	12.55	(7.8)	PE	0.76	(2.5)		0.17	(1.8)	0.31	(3.3)	0.07	(0.8)
20-005-005	2.09	(1.3)	A	0.76	(2.5)		0.63	(6.8)	1.10	(11.8)	0.33	(3.5)
20-001-005	4.83	(3.0)	PE	0.76	(2.5)							

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

EROSION RATES - LAKE HURON

Erosion rates (volumetric contribution) have been determined for about 13 percent of the erodible U.S. shoreline of Lake Huron, see Table 15 and Figure 32 on page 134. Reflecting the trend of the recession rates, the erosion rates are relatively low for the entire western shoreline of Lake Huron. As previously discussed, this shoreline is generally not subjected to strong enough winds for the extended periods of time necessary to create serious recession. Consequently, the amount of sediment contributed to the lake from these shorelands is comparatively low.

Although the data are not extensive, the maximum erosion appears to occur along a 12.2 meter (7.6 mile) reach in northern Sanilac County, Michigan. The clay and sand bluffs, averaging 11.4 meters (37.5 feet) high, have experienced an average annual erosion rate of 3.5 cubic meters per year per meter (37.5 feet per year per foot) during the period 1938 to 1970. This reach has been subjected to a recession rate of only 0.3 meters per year (1.0 feet per year) during the period 1938 to 1970. Thus, the moderate amount of sediment input is attributable to the height of the bluffs.

TABLE 15

EROSION RATES ALONG U.S. SHORELINE OF LAKE HURON

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum		Minimum	
Cheboygan Co., Michigan												
51-001-005	6.28	(3.9)	W	0.76	(2.5)							
51-005-010	6.76	(4.2)	PE	2.29	(7.5)							
51-010-013	4.02	(2.5)	LBE	2.29	(7.5)							
51-013-014	1.29	(0.8)	LBE	0.76	(2.5)							
51-014-029	20.92	(13.0)	W	0.76	(2.5)							
51-029-036	8.53	(5.3)	PE	0.76	(2.5)		0.47	(5.0)	0.94	(10.2)	0.00	(0.0)
51-036-039	3.22	(2.0)	PE	5.33	(17.5)		0.82	(8.8)	1.63	(17.5)	0.00	(0.0)
51-039-042	4.18	(2.6)	LBE	5.33	(17.5)							
51-042-044	2.90	(1.8)	LBE	0.76	(2.5)							
Presque Isle Co., Michigan												
52-001-016	20.12	(12.5)	PE	2.29	(7.5)							
52-016-019	4.35	(2.7)	PE	0.76	(2.5)							
52-019-024	7.72	(4.8)	LBE	0.76	(2.5)							
52-024-037	17.38	(10.8)	PE	0.76	(2.5)		0.20	(2.1)	0.96	(8.2)		
52-037-028	4.02	(2.5)	PN	0.76	(2.5)							
52-038-042	4.83	(3.0)	PN	2.29	(7.5)							
52-042-081 (7 reaches)	5.47	(3.4)	PN	0.76	(2.5)							

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 15--Continued

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m³/yr/m (ft³/yr/ft) Average		Maximum		Minimum	
Alcona Co. Michigan												
54-001-006	8.21	(5.1)	PE	0.76	(2.5)	EPA-76-14395-96	0.19	(2.0)	0.23	(2.5)	0.11	(1.2)
54-006-009	5.31	(3.3)	PE/W	0.76	(2.5)	EPA-76-14391-94	0.09	(1.0)	0.48	(5.2)		
54-009-016	9.33	(5.8)	PE	0.76	(2.5)							
54-016-018	2.25	(1.4)	PE	2.29	(7.5)							
54-018-023	6.92	(4.3)	PE	8.38	(27.5)							
54-023-028	9.98	(6.2)	PE	0.76	(2.5)	EPA-76-14388-90						
Iosco Co. Michigan												
55-001-009	12.23	(7.6)	PE	0.76	(2.5)							
55-009-017	9.65	(6.0)	PE	0.76	(2.5)		0.93	(10.0)	1.19	(12.8)	0.54	(5.8)
55-017-019	2.90	(1.8)	LBE	2.29	(7.5)		3.07	(33.0)	3.35	(36.0)	2.77	(29.3)
55-019-026	9.65	(6.0)	PE	0.76	(2.5)		0.65	(7.0)	0.96	(10.3)	0.37	(4.0)
55-026-035	11.26	(7.0)	LBE	0.76	(2.5)							
55-035-043	11.26	(7.0)	PE	2.29	(7.5)							
Sanilac Co. Michigan												
60-001-009	12.23	(7.6)	HBE	11.43	(37.5)		3.48	(37.5)	13.24	(142.5)		
60-009-011	4.51	(2.8)	HBE	5.33	(17.5)							
60-011-012	1.93	(1.2)	HBE	2.29	(7.5)							
60-012-016	4.83	(3.0)	LBN	2.29	(7.5)		0.49	(5.25)	0.84	(9.0)	0.00	(0.0)

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 15--Continued

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m^3/yr/m (ft^3/yr/ft) Average	Maximum	Minimum
Sanilac Co. (continued)									
60-016-023	10.62	(6.6)	LBN	0.76	(2.5)				
60-023-024	2.09	(1.3)	LBN	8.38	(27.5)				
60-024-026	3.86	(2.4)	HBE	8.38	(27.5)				
60-026-028	3.38	(2.1)	HBE	11.43	(37.5)		6.97 (75.0)	8.02 (86.3)	5.57 (60.0)
60-028-030	2.74	(1.7)	HBE	5.33	(17.5)		3.58 (38.5)	3.74 (40.3)	3.41 (36.8)
60-030-037	12.71	(7.9)	HBE	8.38	(27.5)		6.13 (66.0)	8.69 (93.5)	4.86 (52.3)
60-037-039	3.86	(2.4)	HBE	3.81	(12.5)		4.77 (51.3)		

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

EROSION RATES - LAKE ERIE

Erosion rates (volumetric contribution) have been determined for approximately 93 percent of the erodible U.S. shoreline of Lake Erie, see Table 16 and Figure 40 on page 166. The maximum erosion rates occur in Erie County, Pennsylvania where an average erosion rate of 30.2 cubic meters per year per meter (325.5 cubic feet per year per foot) has been observed during the period 1877-1973 along one reach characterized by high erodible bluffs. High erosion rates have been experienced along the Lake Erie shoreline from Ashtabula County, Ohio through sections of Chautauqua County, New York. This stretch of coast has been subject to relatively low recession rates during the period, see Table 10 on page 158. However, the bluffs are so high that even a small recession rate will yield a large volumetric contribution.

The minimum erosion rates occur from Monroe County, Michigan through Erie County, Ohio, see Table 16. This section of the Lake Erie coast has been subjected to relatively high recession rates and includes Lucas County which experienced the highest average recession rate for the 1877-1973 period. However, the low relief of the shoreforms and the presence of scattered non-erodible areas minimized the volume of sediment contributed to Lake Erie. Consequently, areas experiencing high recession rates may ultimately produce a limited volume of sediment which is deposited in the lake.

TABLE 16

EROSION RATES ALONG U.S. SHORELINE OF LAKE ERIE

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum		Minimum	
Monroe Co. Michigan												
64-008-011	5.15	(3.2)	W	0.76	(2.5)		0.23	(2.5)	0.47	(5.0)	0.111	(1.2)
64-011-019	13.20	(8.2)	A	2.29	(7.5)		1.25	(13.5)				
64-019-024	5.15	(3.2)	W	2.29	(7.5)		0.35	(3.8)				
64-024-032	9.33	(5.8)	A	0.76	(2.5)		0.54	(5.8)				
64-032-040	4.02	(2.5)	W	0.76	(2.5)		0.34	(3.7)				
Lucas Co. Ohio												
65-001-001	0.64	(0.4)	W	0.76	(2.5)		2.83	(30.3)	3.81	(41.0)	3.35	(36.0)
65-001-005	5.63	(3.5)	LBE	0.76	(2.5)		0.91	(9.8)	4.39	(47.2)	0.23	(2.5)
65-005-006	2.57	(1.6)	A	0.76	(2.5)		1.77	(19.0)	2.51	(27.0)	1.46	(15.7)
65-006-009	2.09	(1.3)	LBE	0.76	(2.5)		1.44	(15.5)	2.16	(23.2)	0.48	(5.2)
65-009-010	0.80	(0.5)	PE	0.76	(2.5)		1.67	(18.0)	2.09	(22.5)	1.53	(16.5)
65-010-011	5.31	(3.3)	W	0.76	(2.5)		2.11	(22.7)	3.25	(35.0)	1.21	(13.0)
65-011-017	6.92	(4.3)	PE/W	0.76	(2.5)		2.02	(21.7)	4.15	(44.7)	0.79	(8.5)
65-017-020	4.51	(2.8)	LBE	0.76	(2.5)		0.95	(10.2)	1.32	(14.2)	0.45	(4.8)
65-020-021	1.45	(0.9)	W	0.76	(2.5)		1.02	(11.0)				
65-021-025	4.18	(2.6)	PE/W	0.76	(2.5)		1.16	(12.5)	1.58	(17.0)	0.42	(4.5)
Ottawa Co. Ohio												
66-001-014	11.10	(6.9)	PE/W	0.76	(2.5)		1.25	(13.5)	1.67	(18.0)	0.07	(0.7)
66-014-016	1.77	(1.1)	LBE/A	0.76	(2.5)		0.42	(4.5)	1.09	(11.7)	0.20	(2.2)
66-016-018	1.93	(1.2)	W/PE	0.76	(2.5)		0.45	(4.8)	0.93	(10.0)	0.35	(3.8)
66-018-020	1.61	(1.0)	PE	0.76	(2.5)		0.11	(1.2)	0.16	(1.7)	0.07	(0.7)

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 16--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m³/yr/m (ft³/yr/ft) Average		Maximum		Minimum	
Ottawa Co. (continued)												
66-020-022	1.77	(1.1)	W/PE	0.76	(2.5)							
66-022-029	4.35	(2.7)	LBE	0.76	(2.5)		0.18	(1.9)	0.35	(3.8)	0.05	(0.5)
66-029-031	1.77	(1.1)	LBN	0.76	(2.5)		0.17	(1.8)	0.23	(2.5)	0.05	(0.5)
66-031-032	0.80	(0.5)	LBE	0.76	(2.5)		0.16	(1.7)	0.25	(2.7)	0.12	(1.2)
66-032-035	5.15	(3.2)	HBN	0.76	(2.5)		0.09	(1.0)	0.20	(2.2)	0.02	(0.2)
66-035-036	0.48	(0.3)	LBN	0.76	(2.5)		0.30	(3.2)	0.37	(4.0)	0.14	(1.5)
66-036-037	2.41	(1.5)	LBE	0.76	(2.5)		0.11	(1.2)	0.16	(1.7)	0.10	(0.2)
66-037-039	7.08	(4.4)	LD/W	0.76	(2.5)		0.16	(1.7)	0.42	(4.5)	0.05	(0.5)
66-039-040	4.18	(2.6)	LBE	3.81	(12.5)		3.25	(35.0)	5.11	(55.0)	0.12	(1.3)
66-040-041	6.44	(4.0)	LBN	3.81	(12.5)		1.16	(12.5)	1.63	(17.5)	0.23	(2.5)
66-041-043	13.20	(8.2)	LBE	0.76	(2.5)		0.19	(2.0)	1.67	(18.0)	0.07	(0.8)
66-043-047	4.35	(2.7)	LD/W	0.76	(2.5)		0.33	(3.5)	1.41	(15.2)	0.07	(0.8)
66-047-049	1.61	(1.0)	LBE	0.76	(2.5)		2.00	(21.5)	2.82	(30.3)	0.35	(3.8)
66-049-051	1.61	(1.0)	W	0.76	(2.5)		0.37	(4.0)	0.48	(5.2)	0.21	(2.3)
66-051-057	5.15	(3.2)	LBE	0.76	(2.5)		0.98	(10.5)	3.16	(34.0)	0.14	(1.5)
Erie Co., Ohio												
68-001-006 (8 reaches)	36.69	(22.8)										
68-006-009	10.46	(6.5)	LD	0.76	(2.5)		0.82	(8.8)				
68-009-010	1.29	(0.8)	W/PE	0.76	(2.5)		1.39	(15.0)				
68-010-011	5.79	(3.6)	LBE	2.29	(7.5)		1.05	(11.3)				
68-011-012	1.93	(1.2)	LBE	5.33	(17.5)		0.82	(8.8)				
68-012-013	7.72	(4.8)	HBE	8.36	(27.5)		2.56	(27.5)				
68-013-015	6.44	(4.0)	LBE	5.33	(17.5)		1.95	(21.0)				

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 16--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum		Minimum	
Lorain Co. Michigan												
69-001-001	1.93	(1.2)	LBE	5.33	(17.5)		1.30	(14.0)	2.12	(22.8)	0.82	(8.8)
69-001-001	2.09	(1.3)	HBE	5.33	(17.5)		1.30	(14.0)	1.78	(19.2)	0.33	(3.5)
69-001-001	2.57	(1.6)	HBE	8.38	(27.5)		3.58	(38.5)	6.13	(66.0)	1.53	(16.5)
69-001-002	4.18	(2.6)	LBE	8.38	(27.5)		3.58	(38.5)	7.92	(85.2)	1.02	(11.0)
69-002-002	2.74	(1.7)	HBE	8.38	(27.5)		5.11	(55.0)	6.64	(71.5)	2.56	(27.5)
69-002-002	1.45	(0.9)	LBE	6.86	(22.5)		2.09	(22.5)	4.81	(51.8)	0.63	(6.8)
69-002-003	3.54	(2.2)	A	0.76	(2.5)		0.19	(2.0)	0.30	(3.2)	0.09	(1.0)
69-003-003	3.70	(2.3)	LBE	2.29	(7.5)		0.49	(5.3)	0.84	(9.0)	0.21	(2.3)
69-003-004	9.17	(5.7)	LBE	0.76	(2.5)		0.11	(1.2)	0.19	(2.0)	0.02	(0.2)
69-004-004	2.09	(1.3)	LBE	6.86	(22.5)		1.04	(11.2)	2.09	(22.5)	0.42	(4.5)
69-004-004	1.13	(0.7)	HBE	6.86	(22.5)		1.04	(11.2)	2.09	(22.5)	0.63	(6.8)
Cuyahoga Co. Ohio												
70-001-002	9.33	(5.8)	HBE	11.43	(37.5)		2.04	(22.0)				
70-002-002	4.99	(3.1)	HBE	6.86	(22.5)		2.30	(24.8)				
70-002-003	6.76	(4.2)	HBN	11.43	(37.5)		2.09	(22.5)				
70-004-004	3.86	(2.4)	LBE	9.91	(32.5)		1.81	(19.5)				
70-004-005	7.72	(4.8)	LBE	5.33	(17.5)		1.14	(12.3)				
70-005-005	4.02	(2.5)	HBE	11.43	(37.5)		2.43	(26.2)				

*Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

TABLE 16--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m^3/yr/m (ft^3/yr/ft) Average		Maximum	Minimum
Lake Co. Ohio										
71-001-002	4.99	(3.1)	HBE	11.43	(37.5)		7.66	(82.5)		
71-002-002	2.57	(1.6)	HBE	8.38	(27.5)		2.82	(30.3)		
71-002-002	1.61	(1.0)	LBE	9.91	(32.5)		5.13	(55.2)		
71-002-002	1.93	(1.2)	HBE	9.91	(32.5)		6.64	(71.5)		
71-002-003	4.35	(2.7)	HBE	3.81	(12.5)		1.98	(21.3)		
71-003-003	2.90	(1.8)	LBE/W	6.86	(22.5)		11.08	(119.3)		
71-003-003	2.41	(1.5)	HBE/W	6.86	(22.5)		1.67	(18.0)		
71-003-004	0.97	(0.6)	HBE/W	0.76	(2.5)		0.11	(1.2)		
71-004-004	1.77	(1.1)	LBN/LD	0.76	(2.5)		0.11	(1.2)		
71-004-004	1.45	(0.9)	LBN/LD	11.43	(37.5)		4.88	(52.5)		
71-004-004	2.57	(1.6)	HBE	11.43	(37.5)		8.01	(86.2)		
71-004-004	2.25	(1.4)	HBE	6.86	(22.5)		8.36	(90.0)		
71-004-005	11.91	(7.4)	HBE	12.95	(42.5)		5.53	(59.5)		
71-005-005	2.41	(1.5)	HBE	5.33	(17.5)		1.30	(14.0)		
71-005-005	4.83	(3.0)	LBE	5.33	(17.5)		0.99	(10.6)		
Ashtabula Co. Ohio										
72-001-001	2.41	(1.5)	LBE	3.81	(12.5)		0.70	(7.5)		
72-001-001	0.97	(0.6)	LBE/W	3.81	(12.5)		0.58	(6.2)		
72-001-001	0.97	(0.6)	LBE	6.86	(22.5)		1.04	(11.2)		
72-001-001	3.22	(2.0)	HBE	6.86	(22.5)		1.04	(11.2)		
72-001-002	4.51	(2.8)	HBE	9.91	(32.5)		3.92	(42.2)		
72-002-002	4.35	(2.7)	HBE	12.95	(42.5)		3.55	(38.2)		
72-002-003	3.22	(2.0)	A	0.76	(2.5)		0.15	(1.6)		

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 16--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum	Minimum
Ashtabula Co. (continued)										
72-003-003	2.74	(1.7)	HBE	12.95	(42.5)		6.32	(68.0)		
72-003-005	15.13	(9.4)	HBE	16.00	(52.5)		5.37	(57.8)		
72-005-005	4.35	(2.7)	A	6.86	(22.5)		1.67	(18.0)		
72-005-005	1.29	(0.8)	HBE	9.91	(32.5)		1.81	(19.5)		
Erie Co. Pennsylvania										
73-001-002	3.54	(2.2)	HBE	8.38	(27.5)		2.81	(30.2)		
73-002-003	2.25	(1.4)	HBE	17.53	(57.5)		7.48	(80.5)		
73-003-004	1.77	(1.1)	HBE	5.33	(17.5)		0.98	(10.5)		
73-004-004	6.44	(4.0)	HBE	20.57	(67.5)		4.39	(47.3)		
73-005-006	2.90	(1.8)	HBE	35.81	(117.5)		18.56	(199.8)		
73-006-009	6.76	(4.2)	HBE	23.62	(77.5)		30.24	(325.5)		
73-009-010	3.38	(2.1)	HBE	20.57	(67.5)		5.65	(60.8)		
73-010-012	3.54	(2.2)	HBE	26.67	(87.5)		5.69	(61.2)		
73-012-013	4.51	(2.8)	HBE	29.73	(97.5)		14.49	(156.0)		
73-014-015	3.38	(2.1)	HBE	26.67	(87.5)		10.57	(113.8)		
73-018-020	2.41	(1.5)	HBE	17.53	(57.5)		1.07	(11.5)		
73-020-022	6.76	(4.2)	HBE	11.43	(37.5)		3.48	(37.5)		
73-022-022	2.41	(1.5)	HBE	20.57	(67.5)		10.03	(108.0)		
73-022-025	4.83	(3.0)	HBE	26.67	(87.5)		4.88	(52.5)		
73-025-025	1.77	(1.1)	HBE	32.77	(107.5)		6.99	(75.2)		
73-025-025	1.77	(1.1)	HBE	51.05	(167.5)		9.34	(100.5)		
73-025-026	1.29	(0.8)	HBE	26.67	(87.5)		7.32	(78.8)		
73-026-026	2.41	(1.5)	HBE	41.91	(137.5)		6.39	(68.8)		
73-026-027	3.22	(2.0)	HBE	14.48	(47.5)		5.30	(57.0)		

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 16--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average		Maximum	Minimum
Erie Co. (continued)										
73-027-029	0.48	(0.3)	HBE	11.43	(37.5)		3.48	(37.5)		
Chautauqua Co. New York										
74-001-002	3.06	(1.9)	HBE/HBN	11.43	(37.5)		2.09	(22.5)		
74-002-004	4.83	(3.0)	HBE/HBN	14.48	(47.5)		3.53	(38.0)		
74-004-002	7.56	(4.7)	HBE/HBN	8.38	(27.5)		1.53	(16.5)		
74-007-007	1.45	(0.9)	LBE	2.29	(7.5)		0.78	(8.4)		
74-007-008	2.90	(1.8)	HBE/HBN	11.43	(37.5)		2.79	(30.0)		
74-008-008	2.90	(1.8)	HBE/HBN	17.53	(57.5)		6.41	(69.0)		
74-008-010	3.38	(2.1)	HBE/HBN	11.43	(37.5)		3.14	(33.8)		
74-010-011	5.15	(3.2)	HBE/HBN	14.48	(47.5)		2.68	(23.8)		
74-011-012	1.45	(0.9)	HBE/HBN	23.62	(77.5)		6.48	(69.8)		
74-012-013	3.22	(2.0)	HBE/HBN	14.48	(47.5)		2.21	(23.8)		
74-013-015	4.51	(2.8)	LBE	2.29	(7.5)		0.35	(3.8)		
74-015-016	2.90	(1.8)	LBE/LBN	5.33	(17.5)		0.82	(8.8)		
74-016-016	2.41	(1.5)	LBE/LBN	2.29	(7.5)		0.35	(3.8)		
74-016-016	2.09	(1.3)	A	2.29	(7.5)		0.35	(3.8)		
74-016-017	1.93	(1.2)	LBE/LBN	2.29	(7.5)		1.39	(15.0)		
74-018-023	16.74	(10.4)	HBE/HBN LBE/LBN	6.86	(22.5)		1.47	(15.8)		
74-023-023	2.09	(1.3)	LBE	2.29	(7.5)		0.48	(5.2)		

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

TABLE 16--Continued

Reach No.*	Reach Length km	(mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion m³/yr/m (ft³/yr/ft) Average	Maximum	Minimum
Erie Co. New York									
75-001-003	2.90	(1.8)	LBE/LBN	3.81	(12.5)		0.58 (6.2)		
75-003-003	1.45	(0.9)	LBE/LBN	6.86	(22.5)		1.04 (11.2)		
75-003-003	1.13	(0.7)	LBE/LBN	3.81	(12.5)		0.58 (6.2)		
75-003-004	1.77	(1.1)	LBE/LBN	6.86	(22.5)		1.04 (11.2)		
75-004-005	2.90	(1.8)	LBE/LBN	3.81	(12.5)		0.58 (6.2)		
75-005-007	3.06	(1.9)	LBE	3.81	(12.5)		0.58 (6.2)		
75-007-007	2.41	(1.5)	LBE/LBN	3.81	(12.5)		0.58 (6.2)		
75-007-007	0.64	(0.4)	HBE/HBN	6.86	(22.5)		1.04 (11.2)		
75-007-009	4.83	(3.0)	LBE/LBN	6.86	(22.5)		1.04 (11.2)		
75-009-010	5.15	(3.2)	HBE/HBN	6.86	(22.5)		1.47 (15.8)		
75-010-011	3.06	(1.9)	HBE/HBN	9.91	(32.5)		1.50 (16.2)		
75-011-011	2.57	(1.6)	HBE/HBN	6.86	(22.5)		1.04 (11.2)		
75-011-013	3.38	(2.1)	LBE/LBN	5.33	(17.5)		0.82 (8.8)		
75-013-015	3.38	(2.1)	HBE/LBN	5.33	(17.5)		0.82 (8.8)		
75-015-015	2.41	(1.5)	LBN	2.29	(7.5)		0.35 (3.8)		
75-015-015	1.13	(0.7)	PN	2.29	(7.5)		0.35 (3.8)		
75-015-015	1.29	(0.8)	A	11.43	(37.5)				
75-015-016	1.93	(1.2)	A	6.86	(22.5)				
75-016-019	7.40	(4.0)	A	2.29	(7.5)				
75-019-024	3.38	(2.1)	A	2.29	(7.5)				

*Reach defined by bluff height and shoreform.

Values calculated in English units, converted to metric units and rounded.

EROSION RATES - LAKE ONTARIO

Erosion rates (volumetric contribution) have been compiled for about 20 percent of the erodible U.S. shoreline of Lake Ontario (see Table 17 and Figure 46 on page 183). It is readily apparent that there are very little erosion data available. As previously discussed, this situation is probably related to the lake level regulation made possible by the construction of the St. Lawrence Seaway. The effects of this regulation are to reduce the maximum monthly mean level by about 0.4 meters (1.3 feet) and raise the minimum mean level by about 0.1 meters (0.3 feet) from the respective levels without regulation. The absence of large lake level fluctuations has significantly decreased recession along the Lake Ontario shoreline. The combined effect of minimized recession rates and the predominately low shoreform has produced limited amounts of sediment input to Lake Ontario.

Values for erosion along Oswego County, New York have been determined by demonstrating that this segment of shoreline is contributing moderate amounts of sediment to Lake Ontario. Average erosion rates ranged from 0.2 cubic meters per year per meter (2.1 cubic feet per year per foot) to 7.3 cubic meters per year per meter (79.1 cubic feet per year per foot) during the period 1938 to 1974. The maximum rate occurs along a reach of shoreline consisting of barrier beaches and dunes which average 12.9 meters (42.5 feet) high. These are backed by marshes and wetlands. The high relief and non-resistant character of the shoreforms would account for the larger sediment input.

TABLE 17

EROSION RATES ALONG U.S. SHORELINE OF LAKE ONTARIO

Reach No.*	Reach km	Length (mi)	Shore-form	Average Bluff Height m	(ft)	Soil Analysis	Erosion $m^3/yr/m$ ($ft^3/yr/ft$) Average	Maximum	Minimum
Oswego Co. New York									
81-001-001	1.61	(1.0)	LBE	3.81	(12.5)		1.40 (15.1)		
81-001-001	1.77	(1.1)	HBE	16.00	(52.5)		4.05 (43.6)		
81-001-002	1.29	(0.8)	PE/W	3.81	(12.5)		0.97 (10.4)		
81-002-003	4.02	(2.5)	LBE	3.81	(12.5)	EPA-76-14523-26	0.97 (10.4)		
81-003-004	3.22	(2.0)	A	0.76	(2.5)		0.20 (2.1)		
81-004-005	1.77	(1.1)	LBE/LBN	0.76	(2.5)		0.20 (2.1)		
81-005-006	3.06	(1.9)	PE/W	0.76	(2.5)		0.20 (2.1)		
81-006-007	4.18	(2.6)	LBE	0.76	(2.5)		0.20 (2.1)		
81-007-008	4.83	(3.0)	LBE	3.81	(12.5)		0.97 (10.4)		
81-008-009	1.13	(0.7)	HBN	3.81	(12.5)		0.97 (10.4)		
81-009-010	5.95	(3.7)	LBE	3.81	(12.5)	EPA-76-14518-22	0.97 (10.4)		
81-010-011	4.02	(2.5)	PE/W	0.76	(2.5)		0.30 (3.0)		
81-011-013	5.31	(3.3)	LBE	0.76	(2.5)		0.30 (3.0)		
81-013-013	1.61	(1.0)	A	12.95	(42.5)		7.35 (79.1)		
81-013-017	11.75	(7.3)	LD/W	12.95	(42.5)	EPA-76-14510-17	7.35 (79.1)		

* Reach defined by bluff height and shoreform.
Values calculated in English units, converted to metric units and rounded.

Inputs of the Chemical Constituents of Eroded Bluff Material

In an unpolluted system, the lithology of the source terrain generally controls the composition of the chemical loads in both surface and subsurface water (Upchurch, 1972). However, definite correlations cannot be formed in the Great Lakes due to the pollutant effects of man. Both natural and cultural or anthropogenic loads must be considered when approximating the total chemical loads to the Great Lakes. Recent studies by Kemp et al. (1976) and Bahnick and Roubal (1976) have attempted to examine the chemical effects of sediment input, resulting from bluff recession, on Great Lakes waters. While no definitive results have been obtained, several trends are apparent.

Kemp et al. (1976) compared the chemical composition of six cores from the bottom of Lake Erie with sediment samples from twelve shoreline bluff locations along the Ontario coast. Sediment cores were taken from locations near the zone of maximum postglacial sediment thickness in each of the three basins, the Western, Central, and Eastern. Fine grained glacial tills or clays were collected from each bluff site.

The fine grained sediments of the cores Kemp studied exhibited similar physical characteristics. These sediments consisted of clay minerals, quartz, feldspars, carbonates, and organic matter. Distinct suites of anthropogenic particles were present in each core with those from the Central basin containing the largest concentrations. In contrast, the chemical composition of the sediments varied at each location. Consequently the chemical composition was normalized to a baseline aluminum concentration to account for surface enrichments or depletions of carbonates and organic matter in the sediments. A sediment enrichment factor (SEF) was derived for each element, relating the excess, depletion, or uniformity of the elemental concentration to the normalized baseline values. Groupings were formed on the basis of the concentration profiles and the SEF values. Silicon, aluminum, potassium, sodium, and magnesium were the most abundant elements in the sediment of the cores and were indicative of the major mineralogical species. Their concentrations were uniform in each core, reflecting the unchanging terrigenous input from the land cover of the Lake Erie drainage basin. Surface enrichment of mercury, lead, zinc, cadmium, copper, organic carbon, nitrogen, and phosphorus were observed in each core as a consequence of the increasing anthropogenic loading of these elements since 1850. The concentrations of manganese, iron, and sulfur were related to the sediment Eh values (oxidation potential) and the mobilization of these elements in the pore or interstitial waters.

Comparison of the core sediments and the bluff sediments substantiated the anthropogenic origin of the heavy metals (Kings, 1976). Concentrations of lead, copper and cadmium in the lower portions of the cores matched those of the bluffs which are the primary source materials. This suggests that the higher concentrations of these metals in the upper portions of the cores are of anthropogenic origin.

Erosion of the shoreline bluffs is considered by Kemp et al. (1976) as the major source of the natural fine grained sediment. They estimate that bluff erosion contributes 26 million metric tons (28.6 million tons) of silt and clay-sized particles to the lake each year. Sixty percent of this input is attributed to bluff recession between Erieau and Long Point on the Ontario shore. River inputs, contributing only 4.1 million metric tons (4.5 million tons) of suspended materials to the lake each year, are ranked as a secondary source of sediment.

According to Kemp, approximately 30 million metric tons (33.0 million tons) of fine grained sediment is deposited on the lake bed each year. Of this, 8 million metric tons (8.8 million tons) accumulate in the Central basin and 15 million metric tons (16.5 million tons) in the Eastern basin. Natural and anthropogenic inputs of mercury, lead, zinc, cadmium, copper, organic carbon, nitrogen, and phosphorus parallel the sedimentation rates, with the greatest inputs to the Eastern and Western basins. About 60 percent of the total heavy metal and nutrient loading to the sediments is deposited in the Eastern basin. This suggests that the anthropogenic materials are also transported the long distance from the major source areas of Detroit, Toledo, and Cleveland to the lake bottom in the Eastern basin (Kemp, 1976).

The extensive erosion of glacial-lacustrine red clay deposits located along the northern Wisconsin shoreline of Lake Superior may be affecting the local water quality. Eroded red clay causes considerable turbidity problems along the southwestern coast of Lake Superior. Red clay bluffs line this shoreline for approximately 170 kilometers (150 miles). A major portion of the eroded material disperses into the Lake Superior water as fine particles, forming suspensions of lengthy stability.

Bahnick and Roubal (1976) conducted a study along the coast of Douglas County, Wisconsin to evaluate the chemical effects of the red clay erosion on the southwestern portion of Lake Superior. The solubilization and sorptive properties of the clay minerals in the soils, river particulates and sediments were analyzed. Samples of clay bearing material were obtained from the shoreline and tributary clay bluffs, suspended particulate matter in the Nemadji River and sediments from the bottom of the Nemadji River and Lake Superior. These samples were analyzed for dissolved solids, dissolved oxygen, total Kjeldahl nitrogen, nitrate, total soluable phosphate, inorganic soluable phosphate, alkalinity, silica, sodium, potassium, magnesium, calcium, iron, manganese, zinc, copper, lead, nickel, chromium, selenium, arsenic, mercury, chloride, phenolics, chlorinated hydrocarbons, and PCB's.

Leaching and exchange experiments were conducted by Bahnick and Roubal on the soil samples from the shoreline and tributary bluffs and on sediment samples from the Nemadji River and Lake Superior bottoms. The results indicated small increases in the concentration of most of the metals that naturally occur in Lake Superior water. Concentrations of copper, cadmium, chromium, iron, manganese, magnesium, and sodium were slightly higher. While the sediment samples did not exhibit the large initial solubilization of solids which occurred in the soil samples, they did demonstrate a steady dissolution with time. Under similar conditions, the sediments produced smaller alkalinity releases than did the soil samples. The orthophosphate release was greater for the sediment samples than for the soil samples and occurred over a longer period of time. The experiments by Bahnick and Roubal indicated an absence of clay effects on the ammonia and organic nitrogen levels in Lake Superior water. The sediment samples also appeared to release less sodium, potassium, and calcium than did the soil samples. Although both the sediment and soil samples showed progressive releases of silica, the amounts released by the sediment samples were greater.

The chemical characteristics of the interstitial waters in near-shoreline and river sediments which contain clay minerals may also affect sediment leaching. Core samples thought to be representative of red clay bearing river or lake bottom were obtained by Bahnick and Roubal. However, attempts to obtain core samples consisting of significant quantities of deposited clay from the shallower areas of the lake were unsuccessful as the sediment was primarily composed of sand and gravel. This suggests that the majority of the clay-sized particles which enter Lake Superior due to erosion are transported to the deeper regions of the lake. Chemical analyses were conducted on the interstitial water, the water overlying the sediment, and the sediment itself. The potential inputs from the interstitial water for the following parameters were found to be insignificant when compared to those resulting from the shoreline and river erosion of soils: orthophosphate, silica, sodium, potassium, calcium, and magnesium (Bahnick and Roubal, 1976).

Approximations of the input of the chemical constituents of the eroded shoreline material to the Great Lakes have been derived in this study for about 58 percent of the erodible U.S. Great Lakes shoreline. Chemical analyses of soil samples, taken from along the Great Lakes shores for a different project, were provided by the U.S. EPA and served as the basis for these input estimates. The U.S. EPA analyses were used in conjunction with the recession rate (when available) of the reach from which a representative soil sample was taken, and the specific gravity of the soil sample to determine the total input of each chemical constituent from that particular reach. These values were then classed according to shoreform-material category. An inventory of similar reaches along each Great Lake for each shoreform-material category was compiled. The total average annual input of the chemical constituents of the eroded material for each shoreform-material category was derived using the weighted average recession rate and the weighted average bluff height for a shoreform category and the specific gravity and chemical analysis of the representative soil sample for that category. The approximations obtained in this study for the inputs of each chemical component of the eroded shore material from along the U.S. shoreline to each Great Lake will now be presented.

Lake Superior

The following sources of data were utilized to determine the average input per year of each chemical constituent of eroded U.S. shoreline material to Lake Superior: the U.S. EPA soil sample analyses, the composition of the bluff material, and average recession rates and bluff heights of reaches consisting of similar shoreform and material composition. The specific gravity of the soil samples provided by the U.S. EPA for Lake Superior ranged between 1.79 to 2.84 g/cc. Data pertaining to the inputs for the chemical constituents are presented in Table 18 on page 230. This table includes the following: shoreform-material categories (HBE, glacial till); the identification numbers of the representative U.S. EPA soil sample which conformed to the relevant shoreform-material category; a listing of reaches along Lake Superior which are similar in shoreform and material; an average total volume of the material eroded from the similar reaches which was derived from an average recession rate, an average bluff height and an average reach length, and the average annual input of each constituent of the eroded material. The detailed procedure used to calculate the chemical inputs may be found in the methodology chapter on page 19. A summary of the average annual inputs of these components in the eroded sediment deposited in Lake Superior is presented in Table 19 on page 232. The information that was required for these input approximations were available for only 18 percent of the erodible U.S. Lake Superior shoreline.

TABLE 18

LAKE SUPERIOR: CONJECTURED INPUT OF THE CHEMICAL CONSTITUENTS OF THE ERODED MATERIAL FOR REACHES OF SIMILAR SHOREFORM AND MATERIAL DERIVED FROM REACH DATA

Shoreform Material	Representative EPA Sample No. State State No.	Similar Reaches	Total Ave. Mat'l. Eroded From Similar Reaches* m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material** (10^3kg/year)
HBE Clay	EPA-76-14554, 56 and 58 Douglas Co. WI D-2-2, D-3-2, and D-4-2	4-005-027 (7 reaches) 5-008-009	626,500 (22,124,750	P-716.7, N-434.9, CA-58,478.1, MG-8703.3, FE-65,047.5, MN-1060.5, AL-38,442.0, B-272.0, CU-78.2, PB-35.8, ZN-118.9, TI-1185.8, OC-2524.8
HBE Glatial till	EPA-76-14528,31 Racine Co., WI R-1-2, R-2-2	5-013-018 (3 reaches) 5-020-021; 5-025-025 8-020-028 (5 reaches) 8-029-036 (2 reaches)	981,400 (34,657,650)	P-779.8, N-793.3, CA-163,493.6, MG-95,998.7, FE-49,209.4, MN-1,140.2, AL-22,238.4, CU-43.0, PB-59.2, ZN-150.6, TI-650.7, OC-12,235.1
LBE Clay	EPA-76-14552 Douglas Co., WI D-1-2	4-027-030; 5-001-008 5-009-010; 8-006-009 (3 reaches)	184,850 (6,528,400)	P-212.0, N-242.1, CA-12,112.6, MG-2,255.7, FE-21,448.9, MN-291.3, AL-11,658.3, BA-130.9, CU-23.2, PB-10.4, ZN-37.1, TI-267.6, OC-1,312.3
LBE Glacial till	EPA-76-14503 St. Louis Co., MN Sample 3-104"-198"	3-001-026 (4 reaches) 5-023-025; and 5-025-027	435,750 (15,387,950)	P-4,055.8, N-1,247.9, CA-11,933.6, MG-7,019.8, NA-413.4, FE-19,499.4, MN-382.2, AL-8,813.7, BA-803.4, CU-405.6, PB-93.6, ZN-55.4, V-132.6, TI-600.6, OC-312.0

* Values calculated in English units, converted to metric units and rounded to nearest 50.
**Organic Carbon is referred to as OC.

TABLE 18--Continued

Shoreform Material	Representative EPA Sample No. State State No.	Similar Reaches	Total Ave. Mat'l. Eroded From Similar Reaches* m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material** (10^3kg/year)
LBE Sand	EPA-76-14405,10 Chippewa Co., MI 033-3-7 033-4-4	9-026-040;9-041-043 9-044-051; 9-053-054 (2 reaches); 9-057-059 9-064-067; 16-009-015 and 16-025-026	58,850 (2,078,450)	P-15.2, N-10.1, CA-69.6, MG-50.0, FE-109.5, AL-112.2, TI-9.1, OC-160.1
PE Sand	EPA-76-144394 Alcona, Co., MI 001-4-1	3-026-036; 4-002-005 5-010-013; and 5-021-023	85,800 (3,029,275)	P-11.7, N-6.3, CA-2,923.9, MG-723.1, NA-28.4, FE-708.0, MN-9.5, AL-141.2, V-3.7, ZN-23.6, TI-27.5, OC-67.8

* Values calculated in English units, converted to metric units and rounded to nearest 50.

**Organic Carbon is referred to as OC.

TABLE 19

TOTAL AVERAGE INPUT OF THE CHEMICAL CONSTITUENTS FOR LAKE SUPERIOR DERIVED FROM 18 PERCENT OF THE EXAMINED ERODIBLE U.S. SHORELINE*

Chemical Constituent	Input Per Year (10^3 kg)**
Phosphorus	5,800
Nitrogen	2,750
Calcium	249,000
Magnesium	114,750
Sodium	450
Iron	149,000
Manganese	2,900
Aluminum	81,400
Boron	250
Barium	950
Copper	550
Lead	200
Zinc	400
Vanadium	150
Titanium	2,750
Organic Carbon	16,600

* U.S. Lake Superior Erodible Shoreline as defined by the Great Lakes Basin Commission (1975) = 784.0 km, 487.2 mi.

**Values rounded to the nearest 50,000 kg.

Lake Michigan

The average annual input of each chemical component of the eroded shoreline material to Lake Michigan was derived from the following sources of data: the U.S. EPA soil sample analyses, the composition of the bluff material, and average recession rates and bluff heights of reaches comprised of similar shoreform and material composition. The specific gravity of the soil samples supplied by the U.S. EPA for Lake Michigan ranged between 1.56 to 2.97 g/cc. Data relevant to the inputs for chemical constituents are documented in Table 20 on page 234. The following parameters are included in this table: shoreform-material categories (HBE, glacial till); the indentification numbers of the representative U.S. EPA soil sample which corresponded to the appropriate shoreform-material category; a listing of reaches along Lake Michigan which are similar in shoreform and material to the relevant category; an average total volume of the sediment eroded from the similar reaches which was determined from an average recession rate, an average bluff height, and an average reach length; and the average input per year of each component of the eroded material. The manner in which these chemical inputs were calculated is described in the methodology chapter on page 19. The average inputs per year of the chemical constituents in the eroded material deposited in Lake Michigan are summarized in Table 21 on page 239. The information that was necessary for these input approximations were available for only 56 percent of the erodible Lake Michigan shoreline.

TABLE 20

LAKE MICHIGAN: CONJECTURED INPUT OF THE CHEMICAL CONSTITUENTS OF THE ERODED MATERIAL FOR REACHES OF SIMILAR SHOREFORM AND MATERIAL DERIVED FROM REACH DATA

Shoreform Material	Representative EPA Sample No. State State No.	Similar Reaches	Total Ave. Mat'l. Eroded From Similar Reaches * m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material** (10^3kg/year)
HBE Glatial till	EPA-76-14528-31 Racine Co., WI R-1-3, R-2-3	43-001-006 (3 reaches) 43-021-023;43-024-030 (2 reaches); 43-031-034;44-001-011 (2 reaches); 44-013-017 (2 reaches) 45-001-005;46-010-029 (3 reaches); 47-001-009 (3 reaches) 21-033-039 (2 reaches) 21-043-050; 22-010-17 (2 reaches) 23-001-001;26-001-008 27-003-009;30-049-054 31-004-009;31-029-033 31-034-035;31-039-040 31-058-059;34-017-048 (10 reaches)	3,118,050 (110,112,650)	P-1,941.9, N-2,387.0, CA-1.4 x 10^6, MG-288,861.5, FE-148,072.4, MN-3,430.8, AL-66,915.1, CU-129.4, PB-178.0, ZN-453.1, TI-1,958.1, OC-36,815.7
HBE Sand	EPA-76-14464-67 Muskegon Co., MI 121-6-1 121-8-1	21-015-020(2 reaches) 23-001-012(2 reaches) 24-002-009;25-025-029 30-091-092(2 reaches) 31-061-063	599,950 (21,182,850)	P-74.0, CA-3,300.5, MG-1,500.0, FE-4,800.0, MN-46.0, AL-480.0, TI-110.3

* Values calculated in English units, converted to metric units and rounded to nearest 50.
**Organic Carbon is referred to as OC.

TABLE 20--Continued

Shoreform Material	Representative EPA Sample No. State State No.	Similar Reaches	Total Ave. Mat'l. Eroded From Similar Reaches* m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material** (10^3kg/year)
HBE Sand till	EPA-76-14448 Manistee Co., MI 101-6-1	27-022-033;28-008-012 28-013-016;28-018-022 28-028-029;29-001-003 (2 reaches); 29-004-007;30-001-003 30-014-021(5 reaches) 30-027-034(2 reaches) 30-037-041;30-045-049 (2 reaches); 30-097-103(2 reaches) 31-029-029	1,733,950 (61,233,150)	P-220.0, N-120.0, CA-27,000.0, MG-16,000.0, FE-5,600.0, MN-80.0, AL-2,200.0, TI-140.0, OC-5,100.0
HD Sand	EPA-76-14452 Muskegon Co., MI 121-2-1	21-020-033(3 reaches) 21-050-055(2 reaches) 22-001-010;23-012-020 (2 reaches); 24-001-002;24-009-028 (3 reaches); 25-001-013(4 reaches) 25-021-024;25-024-025 25-029-033;26-001-001 26-008-032(4 reaches) 27-001-003;29-018-027 (3 reaches); 34-012-014;34-048-055	1,711,200 (60,429,600)	P-210.0, N-750.0, CA-7,100.0, MG-4,400.0, FE-16,000.0, MN-190.0, AL-2,600.0, TI-1,000.0, OC-2,300.0

* Values calculated in English units, converted to metric units and rounded to nearest 50.
**Organic Carbon is referred to as OC.

TABLE 20--Continued

Shoreform Material	Representative EPA Sample No. State State No.	Similar Reaches	Total Ave. Mat'l. Eroded From Similar Reaches * m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material** $(10^3 kg/year)$
LBE Glacial till	EPA-76-14503 Sample 3 108"-109"	31-009-015(2 reaches) 31-017-025(5 reaches) 31-033-034;31-035-039 (2 reaches); 31-040-050	22,050 (778,400)	P-20.5, N-6.3, CA-603.6, MG-958.7, NA-20.9, FE-986.3, MN-19.3, AL-445.8, BA-4.1, CU-2.0, PB-0.47, ZN-2.8, V-6.7, TI-30.4, OC-15.8
LBE Sand	EPA-76-14459-60 Muskegon Co., MI 121-4-2,3	40-019-022;40-022-026 25-013-021(2 reaches) 30-011-014(2 reaches) 30-104,105;31-015-017 31-056-058;34-082-085	88,050 (3,109,350)	P-16.0, N-23.5, CA-6,300.3, MG-2,400.0, FE-510.0, MN-10.0, AL-170.0, TI-171.0, OC-118.0
LBE Sand till	EPA-76-14442-43 Manistee Co., MI 101-4-1,2	28-005-008;28-012-013 28-016-018(2 reaches) 28-022-028(3 reaches) 29-003-004;29-007-010 (2 reaches); 30-034-037;30-070-078 (3 reaches); 30-080-086;30-095-097 30-103-104	153,650 (5,425,300)	P-35.2, N-10.0, CA-9,391.0, MG-3,599.9, FE-2,076.0, AL-234.9, ZN-2.2, TI-80.0, OC-695.6

* Values calculated in English units, converted to metric units and rounded to nearest 50.
**Organic Carbon is referred to as OC.

TABLE 20--Continued

Shoreform Material	Representative EPA Sample No. State State No.	Similar Reaches	Total Ave. Mat'l. Eroded From Similar Reaches* m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material** (10^3kg/year)
LD Sand	EPA-76-14471 Schoolcraft Co., MI 153-1-3	40-007-018;21-001-015 (3 reaches); 27-009-022(3 reaches) 30-003-005(2 reaches) 34-081-082;18-023-026 18-029-031;18-038-045	261,900 (9,249,600)	No recession data available for calculation.
PE Sand	EPA-76-14394 Alcona Co., MI 001-4-1	40-018-019;46-001-010 30-021-027;30-041-045 (2 reaches); 30-054-070(8 reaches) 30-086-091(3 reaches) 30-092-095(2 reaches) 31-001-004;31-050-056 31-059-061;31-063-063 32-001-027(3 reaches) 33-001-010(3 reaches) 33-013-017(3 reaches) 34-067-073(2 reaches) 34-075-076;18-031-035 18-004-005	120,950 (4,270,900)	P-16.5, N-8.91, CA-7,633.7, MG-1,021.0, NA-40.0, FE-998.7, MN-13.3, AL-199.0, V-5.09, ZN-33.4, TI-38.8, OC-95.4

* Values calculated in English units, converted to metric units and rounded to nearest 50.
**Organic Carbon is referred to as OC.

TABLE 20--Continued

Shoreform Material	Representative EPA Sample No. State State No.	Similar Reaches	Total Ave. Mat'l. Eroded From Similar Reaches* m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material** (10^3kg/year)
PE Sand till	EPA-76-14396 Alcona Co., MI 001-5-2	30-078-080(3 reaches) 31-025-029(2 reaches) 34-062-066(2 reaches)	9,900 (350,050)	P-14.63, N-4.39, CA-229.71, MG-122.66, NA-0.58, FE-51.45, MN-0.78, AL-22.38, ZN-0.29, TI-4.05, OC-143.87
W Sand	EPA-76-14394 Alcona Co., MI 001-4-1	34-014-017;34-058-063 34-066-067(2 reaches) 34-073-075;34-076-081	6,350 (245,000)	P-0.87, N-0.47, CA-402.10, MG-53.79, NA-2.11, FE-52.61, MN-0.70, AL-104.89, V-0.27, ZN-1.76, TI-2.04, OC-5.03

* Values calculated in English units, converted to metric units and rounded to nearest 50.

**Organic Carbon is referred to as OC.

TABLE 21

TOTAL AVERAGE INPUT OF THE CHEMICAL CONSTITUENTS FOR LAKE MICHIGAN DERIVED FROM 56 PERCENT OF THE EXAMINED ERODIBLE SHORELINE*

Chemical Constituent	Input Per Year (10^3 kg)**
Phosphorus	2,550
Nitrogen	3,300
Calcium	1,461,950
Sodium	50
Magnesium	318,900
Iron	179,150
Manganese	3,800
Aluminum	9,900
Copper	150
Lead	200
Zinc	500
Titanium	3,550
Organic Carbon	45,300

* U.S. Lake Michigan Erodible Shoreline as defined by the Great Lakes Basin Commission (1975) = 1,688.9 km, 1,049.5 mi.

**Values rounded to the nearest 50,000 kg.

Lake Huron

The following sources of data were utilized to estimate the average input per year of each chemical constituent of eroded shoreline sediment to Lake Huron: the U.S. EPA soil sample analyses, the composition of the bluff material, and average recession rates and bluff heights of reaches consisting of similar shoreform and material composition. The specific gravity of the soil samples provided by U.S. EPA for Lake Huron ranged between 1.56 to 2.97 g/cc. Data pertinent to the chemical constituents are presented in Table 22 on page 241. This table contains the following information: shoreform-material categories (HBE, glacial till); the identification numbers and the chemical analyses of the representative U.S. EPA soil sample which conformed to the relevant shoreform-material category; a listing of reaches along Lake Huron which are similar in shoreform and material to each category; an average total volume of the material eroded from the similar reaches which was calculated from an average recession rate, an average bluff height, and an average reach length; and the average annual contribution of each constituent of the eroded material to Lake Huron. The detailed procedure used to derive the chemical inputs may be found in the methodology chapter on page 19. A summary of the average annual inputs of the components of the eroded material released into Lake Huron is presented in Table 23 on page 243. The information that was required for these input approximations were available for 74 percent of the erodible U.S. Lake Huron shoreline.

TABLE 22

LAKE HURON: CONJECTURED INPUT OF THE CHEMICAL CONSTITUENTS OF THE ERODED MATERIAL FOR REACHES OF SIMILAR SHOREFORM AND MATERIAL DERIVED FROM REACH DATA

Shoreform Material	Representative EPA Sample No. State State No.	Similar Reaches	Total Ave. Mat'l. Eroded From Similar Reaches* m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material** (10^3kg/year)
PE Sand	EPA-76-14394 Alcona Co,, MI 001-4-1	51-005-010;51-029-036 (2 reaches); 52-001-019(2 reaches) 52-024-037;53-007-013 (4 reaches); 53-048-050;54-001-006 54-009-016;54-018-028 (2 reaches); 55-001-015;55-019-025 55-035-043;56-001-014 (5 reaches); 57-019-029;59-056-059 59-063-090(2 reaches) 61-002-005(2 reaches) 61-008-016(2 reaches)	453,182 (6,085,150)	P-23.6, N-12.7, CA-10,876.3, MG-1,454.7, NA-571.0, FE-1,422.9, MN-19.0, AL-283.7, V-7.2, ZN-47.6, TI-55.3, OC-135.9
W Sand	EPA-76-14394 Alcona Co., MI 001-4-1	51-001-005;51-014-029 54-006-009;56-018-043 (2 reaches); 57-001-019;57-029-041 58-009-024;59-001-017	18,900 (666,850	P-2.6, N-1.4, CA-1,191.4, MG-159.4, NA-6.3, FE-155.9, MN-2.1, AL-31.1, V-0.8, ZN-5.2, TI-6.1, OC-14.9

* Values calculated in English units, converted to metric units and rounded to the nearest 50.
**Organic Carbon is referred to as OC.

TABLE 22--Continued

Shoreform Material	Representative EPA Sample No. State State No.	Similar Reaches	Total Ave. Mat'l. Eroded From Similar Reaches* m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material** (10^3kg/year)
HBE Clay	No sample available for this shoreform and material	59-090-093(3 reaches) 60-001-009		
HBE Glacial till	EPA-76-14438,39 Manistee Co., MI 101-2-1,2	60-009-012(2 reaches) 60-024-039(5 reaches) 60-001-002(2 reaches)	497,850 (6,774,750)	P-112.0, N-11.4, CA-26,907.5, MG-12,570.1, FE-3,442.5, MN-104.3, AL-2,528.9, PB-8.9, TI-120.2, OC-497.8
LBE Sand	EPA-76-14459-60 Muskegon Co., MI 121-4-2,3	51-039-044(2 reaches) 52-019-024;55-017-019 55-026-035;59-017-030	103,800 (3,665,100)	P-1.9, N-2.9, CA-7,828.2 MG-2,931.9, FE-628.9, MN-12.6, AL-215.5, TI-21.2, OC-146.6
LBE Sand till	EPA-76-14442-3 Manistee Co., MI 101-4-1,2	51-010-024(2 reaches) 60-012-024(3 reaches)	258,550 (3,232,150)	P-209.4, N-5.9, CA-5,584.8, MG-2,140.8, FE-1,234.6, AL-139.8, PB-1.3, TI-48.1, OC-413.7
LD Sand	No sample available for this shoreform and material	59-030-050(3 reaches)		

* Values calculated in English units, converted to metric units and rounded to the nearest 50.

**Organic Carbon is referred to as OC.

TABLE 23

TOTAL AVERAGE INPUT OF THE CHEMICAL CONSTITUENTS FOR LAKE HURON DERIVED FROM 74 PERCENT OF THE EXAMINED ERODIBLE U.S. SHORELINE*

Chemical Constituent	Input Per Year (10^3 kg) **
Phosphorus	350
Nitrogen	50
Calcium	52,400
Sodium	600
Magnesium	17,800
Iron	6,900
Aluminum	3,200
Vanadium	0
Lead	0
Zinc	50
Titanium	250
Manganese	0
Organic Carbon	1,200

* U.S. Lake Huron Erodible Shoreline as defined by the Great Lakes Basin Commission (1975) = 739.6 km, 459.6 mi.

**Values rounded to the nearest 50,000 kg.

Lake Erie

Data were taken from Sediment Load Measurements Along the U.S. Shore of Lake Erie by C. H. Carter to derive the average annual input of each chemical constituent of the eroded U.S. shoreline material to Lake Erie. The compilation of this data was somewhat similar to the methodology utilized for the data pertaining to the U.S. EPA soil sample analyses. An effort was made to keep Carter's data intact, and thereby not manipulate his results in any unreasonable way. The entire U.S. shoreline along Lake Erie was covered in Carter's study. While his major emphasis was on the volume of sediment contributed to Lake Erie, he also presented annual recession rates for many reaches along the coast and chemical analyses for 20 soil samples taken from various sites along the shore. This study utilized his soil sample analyses and the annual recession rates to approximate the average annual input of the chemical components of the eroded sediment to Lake Erie; these values are presented in Table 24 on page 246.

Carter identified the 20 soil sample locations by a letter/number code, i.e., P1 denotes the first sample location in Pennsylvania. Table 24 indicates Carter's code number, the state, county, and city, the appropriate reach number, the shoreform and the material composition for each of his soil samples. His values for the total average volume of material eroded during the 1930's to 1970's in each county along the Lake Erie shoreline were also included.

The average annual inputs of the chemical components of the eroded material were calculated on a county basis. These values were derived from the total volume of material eroded along the shoreline of a county and the chemical analysis of the representative soil sample obtained along its shore. Carter's sampling sites and the respective material compositions correlated with the predominant material compositions of the individual counties. The exceptions were Monroe and Wayne Counties, Michigan and Sandusky Bay and Loraine County, Ohio where no representative soil samples were available for the erodible shoreline. No samples were taken along Sandusky Bay, and there were apparent discrepancies in the shoretype and material composition at the other locations. For example, the soil samples obtained along the shore of Loraine County, Ohio consisted of shale while glaciolacustrine clay and till are the dominant shore materials of the county.

Carter's chemical analyses were presented in two forms: 1) weight percent and 2) micrograms per gram. The values expressed in weight percents were multiplied by the average weight per year of the eroded material to yield approximations for the weight of a chemical component in the eroded sediment of the respective county. The average weight per year of the eroded material (kilograms per year) was obtained by converting the recession rate from cubic yards per year to cubic meters per year and multiplying it by the specific gravity of 1.9 gm/cc. The values expressed in micrograms per gram were utilized in a procedure similar to that used for the other Great Lakes.

Reviewing the calculation: average weight per year (kg/yr)* content by chemical component (μg/g)*(10^{-6} g/μg) = average kilograms per year.

A summary of the average annual inputs of the chemical constituents of the material eroded from the U.S. shoreline which is deposited in Lake Erie is presented in Table 25 on page 251. The information that was necessary for these input approximations were available for 85 percent of the erodible U.S. Lake Erie shoreline.

TABLE 24

INPUT OF THE CHEMICAL CONSTITUENTS OF THE ERODED MATERIAL FOR LAKE ERIE

DERIVED FROM C. H. CARTER'S LAKE ERIE STUDY

Carter's ID No.	Location: State County Approx. Reach	Shoreform Material*	Total Vol. of Material Eroded in County 1930-1970** m^3 (ft^3)	Input of the Chemical Constituents of the Eroded Material*** (10^3kg/year)		
	Ohio Lucas and Ottawa Co.					
011	Maumee Bay, Ohio 65-006-009	LBE L	17,550 (620,000)	SI-9340 TI-360 NA-140 OC-160 CU-0.77 CD-0.0099 P-18.7	AL-2400 CA-210 K-1090 MN-17.7 ZN-3.6 HG-0.0016 CR-3.5	FE-1490 MG-350 S-10 NI-2.0 AS-0.08 PB-1.9
010 08	Sand Beach, Ohio 66-001-014 Marblehead, Ohio 66-039-040	LD Dune Sand LBE Till	36,200 (1,278,000)	SI-17480 TI-570 NA-910 OC-110 CU- CD-0.53 P-39.7	AL-4150 CA-4020 K-1470 MN-44.6 ZN-5.1 HG-0.0006 CR-7.2	FE-2440 MG-1130 S-20 NI-3.3 AS-0.2079 PB-3.8

*L-Glaciolacustrine Clay.

**Values calculated in English units, converted to metric units and rounded to nearest 50.

***Values derived from Carter (1975) and decimal places expanded to indicate the relative quantities; organic carbon is referred to as OC.

TABLE 24--Continued

Carter's ID No.	Location: State County Approx. Reach	Shoreform Material*	Total Vol. of Material Eroded in County 1930-1970** m^3 (ft^3)	Input of the Chemical Constituents of the Eroded Material*** (10^3kg/year)
	Erie Co., Ohio			
07	Huron, Ohio 68-010-011	LBE L	14,450 (590,900)	SI-6530 AL-1920 FE-1150 TI-160 CA-1210 MG-600 NA- K-650 S- OC-40 MN-15.6 NI-1.5 CU-0.80 ZN-2.4 AS-0.1490 CD- HG-0.0001 PB-1.6 P-13.9 CR-2.3
06	Vermillion, Ohio 69-013-015	LBE Till	16,750 (591,550)	SI-8370 AL-2000 FE-1270 TI-220.0 CA-880 MG-530 NA- K-780 S-140 OC-170 MN-14.6 NI-4.9 CU-0.92 ZN-5.2 AS-0.15 CD-0.0159 HG-0.0008 PB-2.3 P-15.9 CR-2.6
	Cuyahoga Co., OH			
04 B	Bay Village, OH 70-001-002	HBE L	7,600 (267,750)	SI-3700 AL-1000 FE-620 TI-80 CA-540 MG-230 NA- K-370 S-90 OC-70 MN-7.0 NI-1.2 CU-0.0504 Z-1.2 AS- CD- HG-0.0004 PB-1.0 P-6.6 CR-1.4

*L-Glaciolacustrine Clay.

**Values calculated in English units, converted to metric units and rounded to nearest 50.

***Values derived from Carter (1975) and decimal places expanded to indicate the relative quantities; organic carbon is referred to as OC.

TABLE 24--Continued

Carter's ID No.	Location: State County Approx. Reach	Shoreform Material*	Total Vol. of Material Eroded in County 1930-1970** m^3 (ft^3)	Input of the Chemical Constituents of the Eroded Material*** (10^3kg/year)
04 A 03	Bay Village, OH 70-001-002 Bratenahl, OH 70-004-004	HBE Till HBE Till	22,300 (787,350)	SI-11360 AL-2810 FE-1950 TI-300 CA-470 MG-630 NA-280 K-1060 S-280 OC-170 MN-20.0 NI-3.0 CU-1.0 ZN-3.9 AS-0.29 CD-0.0530 HG-0.0009 PB-2.3 P-17.8 CR-3.7
	Lake Co., OH			
02 A	Madison, OH 71-005-005	HBE	94,350 (3,331,700)	SI-45500 AL-11310 FE-8300 TI-1720 CA-4530 MG-2490 NA-1250 K-4450 S-990 OC-730 MN-116.5 NI-13.8 CU- ZN-22.2 AS-1.2 CD-2.0 HG-0.0052 PB- P-68.1 CR-16.8
02 B	Madison, OH 71-005-005	HBE Till	203,100 (7,171,950)	SI-103030 AL-30830 FE-170.0 TI-4010 CA-10460 MG-4900 NA-1660 K-12430 S-4090 OC-1430 MN-181.0 NI-16.6 CU- ZN-45.1 AS-2.9 CD-1.4 HG-0.0087 PB- P-143.1 CR-44.4

*L-Glaciolacustrine Clay.

**Values calculated in English units, converted to metric units and rounded to nearest 50.

***Values derived from Carter (1975) and decimal places expanded to indicate the relative quantities; organic carbon is referred to as OC.

TABLE 24--Continued

Carter's ID No.	Location: State County Approx. Reach	Shoreform Material*	Total Vol. of Material Eroded in County 1930-1970** m^3 (ft^3)	Input of the Chemical Constituents of the Eroded Material*** (10^3kg/year)		
	Ashtabula Co., OH					
01	Ashtabula, OH	HBE	169,600	SI-90130	AL-27520	FE-15760
	72-003-003	Till	(5,989,200)	TI-3350	CA-6190	MG-4160
				NA-1390	K-9860	S-3480
				OC-1060	MN-147.3	NI-31.9
				CU-9.7	ZN-33.5	AS-3.3
				CD-3.6	HG-0.0100	PB-
				P-120.2	CR-42.9	
	Pennsylvania					
	Erie Co.					
P2	Girard, PA	HBE	201,700	SI-110950	AL-24760	FE-18680
	73-004-004	Till	(7,123,300)	TI-2320	CA-8340	MG-4200
P1	Northeast, PA	HBE		NA-2700	K-8010	S-4560
	73-026-027	Till		OC-840	MN-162.9	NI-30.1
				CU-10.7	ZN-50.4	AS-3.5
				CD-0.38	HG-0.0035	PB-18.4
				P-123.8	CR-25.9	

*L-Glaciolacustrine Clay.

**Values calculated in English Units, converted to metric units and rounded to nearest 50.

***Values derived from Carter (1975) and decimal places expanded to indicate the relative quantities; organic carbon is referred to as OC.

TABLE 24--Continued

Carter's ID No.	Location: State County Approx. Reach	Shoreform Material*	Total Vol. of Material Eroded in County 1930-1970** m^3 (ft^3)	Input of the Chemical Constituents of the Eroded Material*** (10^3kg/year)		
	New York					
	Chautauqua Co.					
NY 2B	Barcelona, NY	HBE	38,800	SI-21210	AL-4670	FE-3340
	74-007-008	Till	(1,370,500)	TI-450	CA-2150	MG-790
NY 1B	Sliver Creek, NY	HBE		NA-440	K-1430	S-690
	74-018-023	Till		OC-250	MN-34.3	NI-7.4
				CU-4.6	ZN-10.6	AS-0.49
				CD-0.0881	HG-0.0016	PB-3.2
				P-23.2	CR-5.74	

*L-Glaciolacustrine Clay.

**Values calculated in English units, converted to metric units and rounded to nearest 50.

***Values derived from Carter (1975) and decimal places expanded to indicate the relative quantities; organic carbon is referred to as OC.

TABLE 25

TOTAL AVERAGE INPUT OF THE CHEMICAL CONSTITUENTS FOR LAKE ERIE DERIVED FROM 85 PERCENT OF THE EXAMINED ERODIBLE U.S. SHORELINE*

Chemical Constituent	Input Per Year (10^3 kg)**
Phosphorus	600
Calcium	40,000
Sodium	8,750
Magnesium	20,000
Iron	73,150
Manganese	750
Aluminum	113,350
Lead	50
Zinc	200
Titanium	13,550
Organic Carbon	5,050
Silicon	427,600
Potassium	41,650
Sulfur	14,350
Nickel	100
Arsenic***	12
Cadmium***	8
Mercury***	0
Chromium	150
Copper***	29

* U.S. Lake Erie Erodible Shoreline as defined by the Great Lakes Basin Commission (1975) = 538.5 km, 334.6 mi.

** Values rounded to the nearest 50,000 kg.

***Values are recorded as close to the original as rounding might give incorrect impression.

Lake Ontario

The average annual input of each chemical component of the eroded U.S. shoreline material to Lake Ontario was derived from the following sources of data: the U.S. EPA soil sample analyses, the composition of the bluff material, and average recession rates and bluff heights of reaches comprised of similar shoreform and material composition. The specific gravity of the soil samples supplied by the U.S. EPA for Lake Ontario range from 1.95 to 2.84 g/cc. Data relevant to the inputs for chemical constituents are documented in Table 26 on page 253. The following parameters are included in this table: shoreform-material categories (HBE, glacial till); the identification numbers of the representative U.S. EPA soil samples which corresponded to the appropriate shoreform-material category; a listing of reaches along Lake Ontario which are similar in shoreform and material to the relevant category; an average total volume of the sediment eroded from the similar reaches which was determined from an average recession rate, an average bluff height, and an average reach length; and the input per year of each component of the eroded material. The manner in which these chemical inputs were calculated is described in the methodology chapter on page 19 . The average inputs per year of the chemical constituents in the eroded material deposited in Lake Ontario are summarized in Table 27 on page 254. The information that was necessary for these input approximations were available for only 40 percent of the erodible U.S. Lake Ontario shoreline.

TABLE 26

LAKE ONTARIO: CONJECTURED INPUT OF THE CHEMICAL CONSTITUENTS OF THE ERODED MATERIAL

FOR REACHES OF SIMILAR SHOREFORM AND MATERIAL DERIVED FROM REACH DATA

Shoreform Material	Representative EPA Sample No. State State No.	Similar Reaches	Total Ave. Mat'l. Eroded From Similar Reaches* m^3/yr (ft^3/yr)	Input of the Chemical Constituents of the Eroded Material** (10^3kg/year)
HBE Glacial till	EPA-76-14525 Oswego Co., NY Profile 4-67" C	76-007-009;76-017-018 76-001-002;80-002-003 and 81-001-001	45,650 (161,150)	P-62.8, N-10.9, CA-4,603.5, MG-1,159.2, FE-1,885.0, MN-46.8, AL-555.2, CU-1.5, ZN-1.5, TI-56.3
LBE Glacial till	EPA-76-14525 Oswego Co., NY Profile 4-67" C	76-009-023(5 reaches) 78-001-001;80-003-006 81-001-001;81-002-003 81-004-005;81-006-008 (2 reaches); 81-009-010 and 81-011-013	48,600 (1,715,500)	P-66.9, N-11.6, CA-4,900.5, MG-1,234.0, FE-2,006.6, MN-49.8, AL-591.1, CU-1.6, ZN-1.6, TI-50.1
PE Glatial till	EPA-76-14524 Oswego Co., NY Profile 4-37" B	81-001-002;81-005-006 and 81-010-011	2,600 (92,050)	P-3.5, N-1.2, CA-212.4, MG-57.0, FE-102.1, MN-2.6, AL-30.9, CU-30.9, ZN-0.07, TI-1.2, OC-13.3
LD Sand	EPA-76-14516,60 Oswego Co., NY Profile 2-42" II C Profile 1-11"	81-013-017	86,300 (3,046,900)	P-41.8, N-14.0, CA-132.5, MG-366.2, FE-1,921.8, MN-109.3, AL-673.2, CU-5.3, TI-11.8

* Values calculated in English units, converted to metric units and rounded to nearest 50.
**Organic Carbon referred to as OC.

TABLE 27

TOTAL AVERAGE INPUT OF THE CHEMICAL CONSTITUENTS FOR LAKE ONTARIO DERIVED FROM 40 PERCENT OF THE EXAMINED ERODIBLE U.S. SHORELINE*

Chemical Constituent	Input Per Year (10^3 kg)**
Phosphorus	150
Nitrogen	50
Calcium	9,850
Magnesium	2,800
Iron	5,900
Manganese	200
Aluminum	1,350
Copper	0
Zinc	0
Titanium	100
Organic Carbon	0

* U.S. Lake Ontario Erodible Shoreline as defined by the Great Lakes Basin Commission (1975) = 277.0 km, 172.1 mi.

**Values rounded to nearest 50,000 kg.

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APPENDIX A

COUNTY IDENTIFICATION NUMBERS

County	Number
Minnesota	
Cook County	1
Lake County	2
St. Louis County	3
Wisconsin	
Douglas County	4
Bayfield County	5
Ashland County	6
Iron County	7
Michigan	
Gogebic County	8
Ontonagon County	9
Houghton County	10
Keweenaw County	11
Baraga County	12
Marquette County	13
Alger County	14
Luce County	15
Chippewa County	16
Mackinac County	17
Schoolcraft County	18
Delta County	19
Menominee County	20
Berrien County	21
Van Buren County	22
Allegan County	23
Ottawa County	24
Muskegon County	25
Oceana County	26
Mason County	27
Manistee County	28
Benzie County	29
Leelanau County	30
Grand Traverse County	31

APPENDIX A--continued

County	Number
Michigan (contd)	
Antrim County	32
Charlevoix County	33
Emmet County	34
Wisconsin	
Marinette County	35
Oconto County	36
Brown County	37
Kewaunee County	38
Door County	39
Manitowoc County	40
Sheboygan County	41
Ozaukee County	42
Milwaukee County	43
Racine County	44
Kenosha County	45
Illinois	
Lake County	46
Cook County	47
Indiana	
Lake County	48
Porter County	49
La Porte County	50
Michigan	
Cheboygan County	51
Presque Isle County	52
Alpena County	53
Alcona County	54
Iosco County	55
Arenac County	56
Bay County	57
Tuscola County	58
Huron County	59
Sanilac County	60
St. Clair County	61
Macomb County	62
Wayne County	63
Monroe County	64

APPENDIX A--continued

County	Number
Ohio	
Lucas County	65
Ottawa County	66
Sandusky County	67
Erie County	68
Lorain County	69
Cuyahoga County	70
Lake County	71
Ashtabula County	72
Pennsylvania	
Erie County	73
New York	
Chautauqua County	74
Erie County	75
Niagara County	76
Orleans County	77
Monroe County	78
Wayne County	79
Cayuga County	80
Oswego County	81
Jefferson County	82

APPENDIX B

REACHES ALONG THE U.S. SHORELINE OF THE GREAT LAKES FOR WHICH DATA WAS NOT AVAILABLE

Reach No. *	Shoreform	Average Bluff Height m	(ft)
	LAKE SUPERIOR		
Cook Co., Minnesota			
(158.51 km. 98.5 mi)			
1-001-002	HBN	34.29	(112.5)
1-002-007	HBN	5.33	(17.5)
1-007-010	HBN	0.76	(2.5)
1-010-012	HBN	11.43	(37.5)
1-012-014	HBN	19.05	(62.5)
1-014-017	HBN	5.33	(17.5)
1-017-019	HBN	0.76	(2.5)
1-019-022	LBN	0.76	(2.5)
1-022-034	LBN	3.81	(12.5)
1-034-036	LBN	0.76	(2.5)
1-036-047	LBN	5.33	(17.5)
1-047-051	LBN	0.76	(2.5)
1-051-055	LBN	3.81	(12.5)
1-055-064	LBN	5.33	(17.5)
1-064-066	LBN	0.76	(2.5)
1-066-077	HBN	14.48	(47.5)
1-077-86	HBN	9.91	(32.5)
1-086-091	HBN	11.43	(37.5)
1-091-093	HBN	14.48	(47.5)
1-093-096	HBN	9.91	(32.5)
1-096-101	HBN	14.48	(47.5)
1-101-103	HBN	9.91	(32.5)
1-103-105	HBN	14.48	(47.5)
1-105-108	HBN	9.91	(32.5)
1-108-114	HBN	14.48	(47.5)
1-114-116	HBN	9.91	(32.5)
Lake Co., Minnesota			
(96.23 km, 59.8 mi)			
2-001-003	HBN	14.48	(47.5)
2-003-004	HBN	43.43	(142.5)

* Reach defined by shoreform and bluff height.

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE SUPERIOR--continued		
Lake Co., Minnesota continued			
2-004-008	HBN	29.72	(97.5)
2-008-009	HBN	9.91	(32.5)
2-009-017	HBN	14.48	(47.5)
2-017-019	HBN	9.91	(32.5)
2-019-020	HBN	49.53	(162.5)
2-020-021	HBN	14.48	(47.5)
2-021-023	HBN	9.91	(32.5)
2-023-029	HBN	14.48	(47.5)
2-009-042	HBN	12.95	(42.5)
2-042-049	HBN	9.91	(32.5)
2-049-051	HBN	14.48	(47.5)
2-051-053	HBN	9.91	(32.5)
2-053-055	HBN	14.48	(47.5)
2-055-058	HBN	9.91	(32.5)
2-058-059	HBN	8.38	(27.5)
2-059-061	HBN	14.48	(47.5)
2-061-063	HBN	8.38	(27.5)
2-063-066	HBN	9.91	(32.5)
2-066-072	HBN	6.86	(22.5)
St. Louis Co. Minnesota (34.76 km, 21.6 mi)			
3-001-003	LBN	6.86	(22.5)
3-003-005	LBN	14.48	(47.5)
3-005-019	LBN	8.38	(27.5)
3-019-026	LBE	8.38	(27.5)
3-026-036	PE	2.29	(7.5)
Bayfield Co., Wisconsin (102.98 km, 64.0 mi)			
5-027-034	LBE	0.76	(2.5)
5-034-036	HBN	14.48	(47.5)
5-036-037	LBE	8.38	(27.5)
5-037-038	PE/W	0.76	(2.5)
5-038-039	HBN	8.38	(27.5)

* Reach defined by shoreform and bluff height.

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE SUPERIOR--continued		
Bayfield Co., Wisc. continued			
5-039-041	LBE	8.38	(27.5)
5-041-043	HBN	23.62	(77.5)
5-043-044	HBE	11.43	(37.5)
5-044-047	HBE/HBN	5.33	(17.5)
5-047-049	LBE	5.33	(17.5)
5-049-050	PE/W	5.33	(17.5)
5-050-052	LBE	5.33	(17.5)
5-052-053	HBN	9.91	(32.5)
5-053-055	PE	8.38	(27.5)
5-055-056	LBE	8.38	(27.5)
5-056-058	HBE/HBN	11.43	(37.5)
5-058-058	HBE/HBN	14.48	(47.5)
5-058-061	LBE	14.48	(47.5)
5-061-062	PE/W	0.76	(2.5)
5-062-063	HBE/HBN	17.73	(57.5)
5-063-065	HBE/HBN	12.86	(42.5)
5-065-067	PE/W	6.86	(22.5)
5-067-069	HBE/HBN	16.00	(52.5)
5-069-070	PE/W	3.81	(12.5)
5-070-074	HBN	19.05	(62.5)
5-074-075	LBE	8.38	(27.5)
5-075-077	LBE	12.86	(42.5)
5-077-080	HBN/HBE	14.48	(47.5)
5-080-083	PE/W	0.76	(2.5)
5-083-085	HBN	16.00	(52.5)
5-085-087	LBE	0.76	(2.5)
5-087-089	PEW	0.76	(2.5)
5-089-091	LBE/LBN	5.33	(17.5)
5-091-093	HBE/HBN	14.48	(47.5)
5-093-096	HBN	14.48	(47.5)
5-096-097	HBN	8.38	(27.5)
5-097-100	LBE	8.38	(27.5)
5-100-101	LBE	5.33	(17.5)
5-101-101	HBE/HBN	5.33	(17.5)
5-101-102	LBE	2.29	(7.5)
5-102-105	PE/W	0.76	(2.5)
5-105-109	LBE	0.76	(2.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE SUPERIOR--continued		
Ashland Co., Wisconsin (54.23 km, 33.7 mi)			
6-001-002	LBE	0.76	(2.5)
6-002-006	A	0.76	(2.5)
6-006-007	A	5.33	(17.5)
6-007-010	LBE	5.33	(17.5)
6-010-012	LBE	2.29	(7.5)
6-012-019	PE	0.76	(2.5)
6-019-023	LD	0.76	(2.5)
6-023-026	LD	2.29	(7.5)
6-026-029	LBE/W	0.76	(2.5)
6-029-033	LBE/W	2.29	(7.5)
6-033-033	LBE	0.76	(2.5)
6-033-036	HBE	14.48	(47.5)
6-036-037	HBE	20.57	(67.5)
Iron Co., Wisconsin (5.47 km, 3.7 mi)			
7-001-006	HBE	17.53	(57.5)
7-006-010	HBE	35.81	(117.5)
Houghton Co., Michigan (89.15 km, 55.4 mi)			
10-001-002	LBE	5.33	(17.5)
10-002-004	LBE	17.53	(57.5)
10-004-005	LBE	23.62	(77.5)
10-005-006	LBE	16.00	(52.5)
10-006-013	LBE	0.76	(2.5)
10-013-015	HBN	23.62	(77.5)
10-015-016	LBE	23.62	(77.5)
10-016-018	LBE	0.76	(2.5)
10-018-022	LBE	2.29	(7.5)
10-022-024	HBN	48.01	(157.5)
10-024-026	HBN	25.15	(82.5)
10-026-029	HBN	0.76	(2.5)
10-029-030	LBE	2.29	(7.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE SUPERIOR--continued		
Houghton Co., Mich. continued			
10-030-037	LBE	5.33	(17.5)
10-038-040	LD	0.76	(2.5)
10-040-043	LBN	0.76	(2.5)
10-043-044	LD	11.43	(37.5)
10-044-047	LD	0.76	(2.5)
10-047-048	HBN	0.76	(2.5)
10-048-051	HBN	17.53	(57.5)
10-051-054	LD	2.29	(7.5)
10-054-059	HBN	2.29	(7.5)
10-059-061	HBN	16.00	(52.5)
10-061-064	LD	16.00	(52.5)
10-064-065	LBN	0.76	(2.5)
10-065-067	LBN	0.76	(2.5)
10-067-068	LBN	22.10	(72.5)
Keweenaw Co., Michigan (75.46 km, 46.9 mi)			
11-043-047	HBN	5.33	(17.5)
11-047-048	HBN	0.76	(2.5)
11-048-052	HBN	5.33	(17.5)
11-052-052	HBN	0.76	(2.5)
11-052-052	HBN	5.33	(17.5)
11-052-055	HBN	8.38	(27.5)
11-055-063	HBN	8.38	(27.5)
11-063-065	HBN	0.76	(2.5)
11-065-071	HBN	5.33	(17.5)
11-071-072	HBN	2.29	(7.5)
11-072-076	HBN	29.72	(97.5)
11-076-077	LBE	29.72	(97.5)
11-077-094	LBE	0.76	(2.5)
11-094-094	LBN	0.76	(2.5)
11-094-103	LBN	2.29	(7.5)

* Reach defined by shoreform and bluff height.

Reach No.*	Shoreform	Average Bluff Height m	(ft)
LAKE SUPERIOR--continued			
Keweenaw Co., Mich., cont.			
11-103-105	LBN	5.33	(17.5)
11-105-105	LD	5.33	(17.5)
11-105-111	LD	0.76	(2.5)
Baraga Co., Michigan (122.30 km, 76.0 mi)			
12-001-004	LBN	12.95	(42.5)
12-004-005	LBE	12.95	(42.5)
12-005-006	LBE	5.33	(17.5)
12-006-008	LBE	19.05	(62.5)
12-008-011	LBE	12.95	(42.5)
12-011-021	LBE	0.76	(2.5)
12-021-029	LBE	29.72	(97.5)
12-029-032	LBE	0.76	(2.5)
12-032-035	LBE	12.95	(42.5)
12-035-037	LD	12.95	(42.5)
12-037-038	LD	0.76	(2.5)
12-038-041	LBE	31.24	(102.5)
12-041-044	LBE	17.53	(57.5)
12-044-051	LBE	5.33	(17.5)
12-051-055	LBE	0.76	(2.5)
12-055-057	LBN	0.76	(2.5)
12-057-061	LBN	11.43	(37.5)
12-061-067	LBE	11.43	(37.5)
12-067-072	LBE	5.33	(17.5)
12-072-071	LBE	0.76	(2.5)
12-072-074	LBE	5.33	(17.5)
12-074-075	LBE	25.15	(82.5)
12-075-076	LBE	5.33	(17.5)
12-076-080	LBE	0.76	(2.5)
12-080-082	LBE	11.43	(37.5)
12-082-084	LD	0.76	(2.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE SUPERIOR--continued		
Marquette Co., Michigan			
(119.73 km, 74.4 mi)			
13-001-003	LBN	0.76	(2.5)
13-003-008	LBN	5.33	(17.5)
13-008-010	LBN	10.82	(35.5)
13-010-014	LD	0.76	(2.5)
13-014-015	LD	23.62	(77.5)
13-015-017	LD	0.76	(2.5)
13-017-018	LD	29.72	(97.5)
13-018-020	LD	0.76	(2.5)
13-020-021	HBN	17.53	(57.5)
13-021-023	HBN	29.72	(97.5)
13-023-025	LBE	0.76	(2.5)
13-025-026	LBE	5.33	(17.5)
13-026-026	LBN	5.33	(17.5)
13-026-030	LBE	0.76	(2.5)
13-030-034	LBN	0.76	(2.5)
13-034-035	LBN	2.29	(7.5)
13-035-036	LBN	5.33	(17.5)
13-036-037	LBN	10.88	(35.7)
13-037-041	LBE	5.33	(17.5)
13-041-041	LBE	8.38	(27.5)
13-041-043	HBN	29.72	(97.5)
13-043-043	LD	3.81	(12.5)
13-043-047	HBN	19.05	(62.5)
13-047-049	LD	2.29	(7.5)
13-049-050	LBE	0.76	(2.5)
13-050-052	LBE	2.29	(7.5)
13-052-052	HBN	2.29	(7.5)
13-052-052	LBN	26.67	(87.5)
13-052-057	LD	9.91	(32.5)
Alger Co., Michigan (136.95 km, 85.1 mi)			
14-001-009	HBN	0.76	(2.5)
14-009-012	HBN	17.53	(57.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
		LAKE SUPERIOR--continued	
Alger Co., Michigan continued			
14-012-012	HBN	29.72	(97.5)
14-012-014	HBN	11.43	(37.5)
14-014-015	LBE	0.76	(2.5)
14-015-020	LBE	3.81	(12.5)
14-020-023	LD	5.33	(17.5)
14-023-025	LBN	5.33	(17.5)
14-025-028	HBN	5.33	(17.5)
14-028-031	HBN	11.43	(37.5)
14-031-034	HBN	5.33	(17.5)
14-034-035	HBN	0.76	(2.5)
14-035-039	LBN	0.76	(2.5)
14-039-040	LBN	2.29	(7.5)
14-040-041	LBN	5.33	(17.5)
14-041-045	LBN	0.76	(2.5)
14-045-046	LBE	5.33	(17.5)
14-046-049	LBE	0.76	(2.5)
14-049-051	HBN	48.01	(157.5)
14-051-053	HBN	60.20	(197.5)
14-053-054	HBN	11.43	(37.5)
14-054-055	HBN	5.33	(17.5)
14-055-057	HBN	31.24	(102.5)
14-057-059	HBN	5.33	(17.5)
14-059-067	HBN	31.24	(102.5)
14-067-069	HBN	22.10	(72.5)
14-069-074	HBN	11.43	(37.5)
14-074-079	HBN	5.33	(17.5)
14-079-087	HBN	0.76	(2.5)
14-087-090	HBN	2.29	(7.5)
14-090-094	HD	31.24	(102.5)
14-094-096	LD	0.76	(2.5)
14-096-100	PE	0.76	(2.5)
14-100-101	PE	5.33	(17.5)
14-101-101	HBE	5.33	(17.5)
14-101-102	HBE	14.48	(47.5)
14-101-103	HBE	9.91	(32.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE SUPERIOR--continued		
Chippewa Co., Michigan			
(163.96 km, 101.9 mi)			
16-001-006	PE	0.76	(2.5)
16-006-009	LBE	0.76	(2.5)
16-015-018	PE	0.76	(2.5)
16-018-025	LBE	2.29	(7.5)
16-026-030	LBN	2.29	(7.5)
16-030-031	LBN	8.38	(27.5)
16-046-056	PE	0.76	(2.5)
16-046-059	LBN	2.29	(7.5)
16-059-066	LBE	2.29	(7.5)
16-066-069	LBE	8.38	(27.5)
16-069-069	LBE	3.81	(12.5)
16-069-070	LBE	0.76	(2.5)
16-070-072	LBE	2.29	(7.5)
16-072-073	LBE	5.33	(17.5)
16-073-076	LBE	0.76	(2.5)
16-076-079	PE	0.76	(2.5)
16-079-081	PE	2.29	(7.5)
16-081-086	LBE	2.29	(7.5)
16-086-087	HBE	0.76	(2.5)
16-087-089	HBE	8.38	(27.5)
16-089-091	HBE	0.76	(2.5)
16-091-093	LBE	2.29	(7.5)
16-093-094	A	0.76	(2.5)
16-094-106	PE	0.76	(2.5)
16-106-110	W	0.76	(2.5)
16-110-110	W	3.81	(12.5)
16-110-162	W	0.76	(2.5)
16-162-164	W	3.81	(12.5)
16-164-169	W	0.76	(2.5)
16-169-171	LBE	3.81	(12.5)
16-171-173	LBE	6.86	(22.5)
16-173-174	LBN	3.81	(12.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No. *	Shoreform	Average Bluff Height m	(ft)
	LAKE SUPERIOR--continued		
Chippewa Co., Mich., continued			
16-174-176	LBN	2.29	(7.5)
16-176-177	LBN	0.76	(2.5)
16-177-178	LBN	2.29	(7.5)
16-178-179	LBN	0.76	(2.5)
	LAKE MICHIGAN		
Oconto Co., Wisconsin (45.70 km, 28.4 mi)			
36-001-003	W	0.76	(2.5)
36-003-011	PE/W	0.76	(2.5)
36-011-014	W	0.76	(2.5)
36-014-016	W/PE	0.76	(2.5)
36-016-020	W	0.76	(2.5)
36-020-024	W/PE	0.76	(2.5)
36-024-025	W	0.76	(2.5)
36-025-033	W/PE	0.76	(2.5)
Brown Co., Wisconsin (57.77 km, 35.9 mi)			
37-001-017	W/PE	0.76	(2.5)
37-017-019	A	0.76	(2.5)
37-019-023	W/PE	0.76	(2.5)
37-023-024	W/PE	5.33	(17.5)
37-024-024	PN	5.33	(17.5)
37-024-028	PN	0.76	(2.5)
37-028-029	W/PE	0.76	(2.5)
37-029-931	W/HBE	0.76	(2.5)
37-031-031	W/HBE	11.43	(37.5)
37-031-033	PE	0.76	(2.5)
37-033-034	HBN	0.76	(2.5)
37-034-038	HBN	17.53	(57.5)
37-038-038	LBE	0.76	(2.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
LAKE MICHIGAN--continued			
Door Co., Wisconsin (230.13 km, 143.0 mi)			
39-001-004	PN/HBN	0.76	(2.5)
39-004-006	PN/HBN	2.29	(7.5)
39-006-011	HBN	23.62	(77.5)
39-011-013	LBN	9.91	(32.5)
39-013-015	HBN	17.53	(57.5)
39-015-019	HBN	11.43	(37.5)
39-019-019	LBN	5.33	(17.5)
39-019-022	LBN	11.43	(37.5)
39-022-035	PE	0.76	(2.5)
39-035-035	PE	11.43	(37.5)
39-035-036	LBN	2.29	(7.5)
39-036-036	PN	2.29	(7.5)
39-036-037	PN	0.76	(2.5)
39-037-038	HBN	5.33	(17.5)
39-038-041	PE	5.33	(17.5)
39-041-044	PE	0.76	(2.5)
39-044-045	LBN	2.29	(7.5)
39-045-046	A	2.29	(7.5)
39-046-049	PN	2.29	(7.5)
39-049-054	PN	0.76	(2.5)
39-054-057	PN	5.33	(17.5)
39-057-061	PN	0.76	(2.5)
39-061-063	PN	2.29	(7.5)
39-063-065	PN	0.76	(2.5)
39-065-066	PE	2.29	(7.5)
39-066-068	HBN	23.62	(77.5)
39-068-070	PE	0.76	(2.5)
39-070-072	PN/LBN	5.33	(17.5)
39-072-072	PE	2.29	(7.5)
39-072-073	HBN	5.33	(17.5)
39-073-075	PE	2.29	(7.5)
39-075-077	HBN	23.62	(77.5)
39-077-079	PE	2.29	(7.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE MICHIGAN--continued		
Door Co., Wisconsin continued			
39-079-081	PE	32.78	(107.5)
39-081-083	HBN	32.78	(107.5)
39-083-084	HBN	9.91	(32.5)
39-084-085	PE	23.62	(77.5)
39-085-086	PE	2.29	(7.5)
39-086-086	PN/LBN	2.29	(7.5)
39-086-088	PN/LBN	11.43	(37.5)
39-088-090	HBN	11.43	(37.5)
39-090-090	HBN	32.78	(107.5)
39-090-092	PE	5.33	(17.5)
39-092-093	HBN	11.43	(37.5)
39-093-094	HBN	23.62	(77.5)
39-094-096	PN	11.43	(37.5)
39-096-096	HBN	11.43	(37.5)
39-096-097	PN	11.43	(37.5)
39-097-099	HBN	11.43	(37.5)
39-099-100	LBN	5.33	(17.5)
39-100-101	PN	5.33	(17.5)
39-101-102	PN	0.76	(2.5)
39-102-103	PN	5.33	(17.5)
39-103-110	PN	2.29	(7.5)
39-110-114	PN	0.76	(2.5)
39-114-119	PN	2.29	(7.5)
39-119-120	PN	5.33	(17.5)
39-120-124	PN	0.76	(2.5)
39-124-132	PN	2.29	(7.5)
39-132-137	PN	0.76	(2.5)
39-137-139	PN	2.29	(7.5)
39-139-141	LBN	2.29	(7.5)
39-141-143	PN	2.29	(7.5)
39-143-147	LD	2.29	(7.5)
39-147-149	PE	2.29	(7.5)
39-149-151	PN	5.33	(17.5)
39-151-151	LD	5.33	(17.5)

*Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE MICHIGAN--continued		
Door Co., Wisconsin continued			
39-151-154	PE	5.33	(17.5)
39-154-158	LBN	2.29	(7.5)
39-158-159	PE	2.29	(7.5)
39-159-162	LD	2.29	(7.5)
39-162-164	PE	2.29	(7.5)
39-164-177	PE	0.76	(2.5)
39-177-179	LBE	0.76	(2.5)
39-179-180	LBE	5.33	(17.5)
Cook Co., Illinois (63.24 km, 39.3 mi)			
47-001-005	HBE	20.57	(67.5)
47-005-007	HBE	9.91	(32.5)
47-007-009	PE	8.38	(27.5)
47-009-019	A	0.76	(2.5)
47-019-023	A	2.29	(7.5)
47-023-043	A	0.76	(2.5)
Lake Co., Indiana (37.50 km, 23.3 mi)			
48-001-019	A	0.76	(2.5)
48-009-021	A	5.33	(17.5)
48-021-025	LD	5.33	(17.5)
Mackinac Co., Michigan (95.27 km, 59.2 mi)			
17-001-001	PN	0.76	(2.5)
17-001-002	PE	0.76	(2.5)
17-002-002	PN	0.76	(2.5)
17-002-003	PE	0.76	(2.5)
17-003-007	PE	3.81	(12.5)
17-007-008	PE	3.81	(12.5)
17-008-010	PN	3.81	(12.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE MICHIGAN--continued		
Mackinac Co., Mich. continued			
17-010-011	PE	3.81	(12.5)
17-011-012	PN	3.81	(12.5)
17-012-032	PE	3.81	(12.5)
17-032-034	PN	No	USGS
17-034-038	PE		
17-038-040	LD		
17-040-045	PE		
17-045-049	PN		
17-049-052	PN	0.76	(2.5)
17-052-056	W	0.76	(2.5)
17-056-057	HBE	0.76	(2.5)
17-057-063	HBE	35.81	(117.5)
17-063-064	HBE	9.91	(32.5)
17-064-069	HD	9.91	(32.5)
17-069-073	HD	6.86	(22.5)
17-073-074	LBE	0.76	(2.5)
17-074-079	LBE	2.29	(7.5)
17-079-085	LBE	0.76	(2.5)
17-085-086	LBE	2.29	(7.5)
17-086-088	PN	0.76	(2.5)
17-088-090	PN	3.81	(12.5)
17-090-091	PN	2.29	(7.5)
17-091-091	PN	0.76	(2.5)
17-091-094	PN	2.29	(7.5)
17-094-095	LBE	2.29	(7.5)
17-095-095	LBE	5.33	(17.5)
17-095-097	LBE	0.76	(2.5)
17-097-110	PE	0.76	(2.5)
17-110-111	PE	2.29	(7.5)
17-111-116	PE	0.76	(2.5)
17-116-122	PE	2.29	(7.5)

* Reach defined by shoreform and bluff height.

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE MICHIGAN--continued		
Mackinac Co., Michigan continued			
17-122-136	PE	0.76	(2.5)
17-136-138	LBE	0.76	(2.5)
17-138-145	LBE	0.76	(2.5)
17-145-148	LBE	2.29	(7.5)
17-148-147	LBN	2.29	(7.5)
17-147-148	LBN	0.76	(2.5)
17-148-149	W	2.29	(7.5)
17-149-199	W	0.76	(2.5)
17-149-151	LBN	0.76	(2.5)
17-151-154	LBN	2.29	(7.5)
17-154-154	LBN	0.76	(2.5)
17-154-155	LBN	9.91	(32.5)
17-155-155	LBN	2.29	(7.5)
17-155-157	LBN	0.76	(2.5)
17-157-158	LBN	2.29	(7.5)
17-158-158	LBN	0.76	(2.5)
17-158-161	PE	0.76	(2.5)
17-161-161	LBN	2.29	(7.5)
17-161 166	LBN	0.76	(2.5)
17-166-167	LBN	2.29	(7.5)
Delta Co., Michigan (236.56 km, 147.0 mi)			
19-047-058	W	5.33	(17.5)
19-058-061	W	0.76	(2.5)
19-061-062	W	5.33	(17.5)
19-062-063	PE	5.33	(17.5)
19-063-063	LBE	5.33	(17.5)
19-063-064	LBN	5.33	(17.5)
19-064-067	PN	5.33	(17.5)
19-067-070	PN	0.76	(2.5)
19-070-071	PN	5.33	(17.5)
19-071-074	PN	0.76	(2.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE MICHIGAN--continued		
Delta Co., Michigan continued			
19-074-075	PE	0.76	(2.5)
19-075-080	PN	0.76	(2.5)
19-080-081	PE	0.76	(2.5)
19-081-082	W	0.76	(2.5)
19-082-086	PN	0.76	(2.5)
19-086-087	PE	0.76	(2.5)
19-087-097	W	0.76	(2.5)
19-097-098	PE	0.76	(2.5)
19-098-100	W	0.76	(2.5)
19-100-101	PE	0.76	(2.5)
19-101-102	A	0.76	(2.5)
19-102-102	PE	0.76	(2.5)
19-102-104	PN	0.76	(2.5)
19-104-105	W	0.76	(2.5)
19-105-109	PN	0.76	(2.5)
19-109-114	W	0.76	(2.5)
19-114-116	W	5.33	(17.5)
19-116-118	W	0.76	(2.5)
19-118-119	HBN	9.91	(32.5)
19-119-120	HBE	9.91	(32.5)
19-120-122	PN	11.43	(37.5)
19-122-122	LBN	5.33	(17.5)
19-122-124	W	0.76	(2.5)
19-124-126	PN	2.29	(7.5)
19-126-127	W	0.76	(2.5)
19-127-129	PN	14.48	(47.5)
19-129-130	HBE	14.48	(47.5)
19-130-131	PN	2.29	(7.5)
19-131-135	HBN	6.68	(22.5)
19-135-136	LBE	6.68	(22.5)
19-136-136	LBE	20.57	(67.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE MICHIGAN--continued		
Delta Co., Michigan continued			
19-136-138	HBN	20.57	(67.5)
19-138-137	HBN	6.86	(22.5)
19-139-142	PE	2.29	(7.5)
19-142-145	HBN	19.05	(62.5)
19-145-146	PE	2.29	(7.5)
19-146-155	PN	2.29	(7.5)
19-155-159	PN	5.33	(17.5)
19-159-164	PN	2.29	(7.5)
19-164-165	LD	2.29	(7.5)
19-165-167	PN	2.29	(7.5)
19-167-170	PN	0.76	(2.5)
19-170-171	LD	0.76	(2.5)
19-171-175	PN	0.76	(2.5)
Marinette Co., Wisconsin (32.51 km, 20.2 mi)			
35-001-004	PE/W	0.76	(2.5)
35-004-005	PE/W	2.29	(7.5)
35-005-008	W/LBE	2.29	(7.5)
35-008-011	W/LBE	0.76	(2.5)
35-011-018	W/PE	0.76	(2.5)
	LAKE HURON		
Presque Isle Co., Michigan (5.47 km, 3.4 mi)			
52-042-044	PN	2.29	(7.5)
52-044-055	PN	5.33	(17.5)
52-055-061	PN	0.76	(2.5)
52-061-064	PN	2.29	(7.5)
52-064-064	LBE	0.76	(2.5)
52-064-081	PN	0.76	(2.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE HURON--continued		
Alpena Co., Michigan			
(105.94 km, 65.9 mi)			
53-001-007	PN	0.76	(2.5)
53-007-011	PE	0.76	(2.5)
53-011-013	PE	2.29	(7.5)
53-013-013	W	2.29	(7.5)
53-013-020	W	0.76	(2.5)
53-020-023	W	2.29	(7.5)
53-023-048	W	0.76	(2.5)
53-048-050	PE	0.76	(2.5)
53-050-057	W	0.76	(2.5)
Arenac Co., Michigan			
(70.97 km, 44.1 mi)			
56-001-004	PE	2.29	(7.5)
56-004-007	PE	0.76	(2.5)
56-007-012	PE	3.81	(12.5)
56-012-015	PE	2.29	(7.5)
56-015-018	W	0.76	(2.5)
56-018-023	PE	0.76	(2.5)
56-023-043	W	0.76	(2.5)
Bay Co., Michigan			
(75.80 km, 47.1 mi)			
57-001-020	W	0.76	(2.5)
57-020-028	PE	0.76	(2.5)
57-028-041	W	0.76	(2.5)
Tuscola Co., Michigan			
(32.35 km, 20.1 mi)			
58-001-024	W	0.76	(2.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE HURON--continued		
Huron Co., Michigan			
(119.09 km, 74.0 mi)			
59-001-019	W	0.76	(2.5)
59-019-020	LBE	0.76	(2.5)
59-020-025	LBE	2.29	(7.5)
59-025-030	LBE	0.76	(2.5)
59-030-031	LD	6.86	(22.5)
59-031-037	LD	2.29	(7.5)
59-037-050	LD	0.76	(2.5)
59-050-054	LBN	0.76	(2.5)
59-045-058	PE	0.76	(2.5)
59-058-063	LBN	0.76	(2.5)
59-063-083	PE	0.76	(2.5)
59-083-085	LBN	2.29	(7.5)
59-085-089	PE	0.76	(2.5)
59-089-090	HBN	0.76	(2.5)
59-090-092	HBN	6.86	(22.5)
59-092-093	HBN	11.43	(37.5)
St. Clair, Co., Michigan			
(10.24 km, 6.4 mi)			
61-001-002	HBE	3.81	(12.5)
61-002-002	HBE	5.33	(17.5)
61-002-003	PE	5.33	(17.5)
61-003-005	PE	3.81	(12.5)
61-005-007	LBE	3.81	(12.5)
61-007-008	LBE	2.29	(7.5)
61-008-011	LBE/PE	2.29	(7.5)
61-011-014	LBE/PE	0.76	(2.5)
Monroe, Co. Michigan	LAKE ERIE		
64-001-007	W	0.76	(2.5)
64-007-008	A	0.76	(2.5)

*Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE ERIE		
Sandusky Co., Ohio			
(14.72 km, 9.2 mi)			
67-001-008	W/PE	0.76	(2.5)
67-008-010	LBE	2.29	(7.5)
Erie Co., Ohio			
(36.69 km, 22.8 mi)			
68-001-001	LBE	2.29	(7.5)
68-001-002	WPE	2.29	(7.5)
68-002-003	WPE	0.76	(2.5)
68-003-003	W	0.76	(2.5)
68-003-004	LBE	0.76	(2.5)
68-004-005	W	0.76	(2.5)
68-005-006	LBE	0.76	(2.5)
68-006-006	WPE	0.76	(2.5)
	LAKE ONTARIO		
Niagara Co., New York			
(56.64 km, 35.2 mi)			
76-007-009	HBE	3.81	(12.5)
76-009-010	LBE	9.91	(32.5)
76-010-012	LBE	6.86	(22.5)
76-012-013	HBE	6.86	(22.5)
76-013-013	LBE	0.76	(2.5)
76-013-017	LBE	3.81	(12.5)
76-017-018	HBE	12.95	(42.5)
76-018-019	HBE	6.86	(22.5)
76-019-019	LBE	6.86	(22.5)
76-019-020	HBE/HBN	6.86	(22.5)
76-020-020	LBE	3.81	(12.5)
76-020-021	HBE	3.81	(12.5)
76-021-023	LBE	3.81	(12.5)
76-023-023	LBE/PE	0.76	(2.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE ONTARIO--continued		
Orleans Co., New York			
(40.39 km, 25.1 mi)			
77-001-003	LBE	0.76	(2.5)
77-003-004	LBE	3.81	(12.5)
77-004-008	LBE	0.76	(2.5)
77-008-009	LBE	3.81	(12.5)
77-009-009	HBE	0.76	(2.5)
77-009-010	LBE	0.76	(2.5)
77-010-011	HBE	9.91	(32.5)
77-011-016	LBE	0.76	(2.5)
77-016-017	LBE/PE	3.81	(12.5)
Monroe Co., New York			
(59.54 km, 37.0 mi)			
78-001-001	LBE/HBE	6.86	(22.5)
78-001-002	LBE	9.91	(32.5)
78-002-002	LBE	0.76	(2.5)
78-002-006	PE/W	0.76	(2.5)
78-006-008	LBE	0.76	(2.5)
78-008-009	W	0.76	(2.5)
78-008-008	LBE	0.76	(2.5)
78-008-011	PE/W	0.76	(2.5)
78-011-011	HBE	14.48	(47.5)
78-011-012	LBE/PE	5.33	(17.5)
78-012-014	HBE	9.91	(32.5)
78-014-015	PE	2.29	(7.5)
78-015-019	HBE	11.43	(37.5)
78-019-019	HBE	14.48	(47.5)
Wayne Co., New York			
(60.50 km, 37.6 mi)			
79-001-001	HBE	11.43	(37.5)
79-001-002	LBE	5.33	(17.5)
79-002-002	HBE	9.91	(32.5)

* Reach defined by shoreform and bluff height.

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE ONTARIO--continued		
Wayne Co., New York continued			
79-002-005	LBE	3.81	(12.5)
79-005-005	HBE	9.91	(32.5)
79-005-006	LBE	3.81	(12.5)
79-006-008	LBE	2.29	(7.5)
79-008-008	HBE	25.15	(82.5)
79-008-008	LBE	3.81	(12.5)
79-008-008	HBE	16.00	(52.5)
79-008-009	LBE/PE	3.81	(12.5)
79-009-009	HBE	16.00	(52.5)
79-009-015	LBE/PE	3.81	(12.5)
79-015-015	HBE/PE	19.05	(62.5)
79-015-016	PE/W	0.76	(2.5)
79-016-016	LBE	19.05	(62.5)
79-016-017	PE/W	0.76	(2.5)
79-017-018	HBE	19.05	(62.5)
79-018-018	LBE	0.76	(2.5)
Cayuga Co., New York (12.87 km, 8.0 mi)			
80-001-002	LBE	0.76	(2.5)
80-002-003	HBE	16.00	(52.5)
80-003-006	LBE	5.33	(17.5)
Jefferson Co., New York (172.16 km, 107.0 mi)			
82-001-004	LD/W	3.81	(12.5)
82-004-005	LD/W	0.76	(2.5)
82-005-007	LBE/LBN	0.76	(2.5)
82-007-010	HBE/HBN	16.00	(52.5)
82-010-010	LBE/LBN	0.76	(2.5)
82-010-011	HBE/HBN	16.00	(52.5)
82-011-011	LBE/LBN	0.76	(2.5)
82-011-012	HBE/HBN	22.10	(72.5)

* Reach defined by shoreform and bluff height.

APPENDIX B--continued

Reach No.*	Shoreform	Average Bluff Height m	(ft)
	LAKE ONTARIO--continued		
Jefferson Co., New York continued			
82-012-012	LBE/LBN	0.76	(2.5)
82-012-014	LBE/LBN	3.81	(12.5)
82-014-015	LBE/LBN	0.76	(2.5)
82-015-016	LBE/LBN	6.86	(22.5)
82-016-019	LBE/LBN	3.81	(12.5)
82-019-031	LBE/LBN	0.76	(2.5)
82-031-037	LBN	0.76	(2.5)

* Reach defined by shoreform and bluff height.