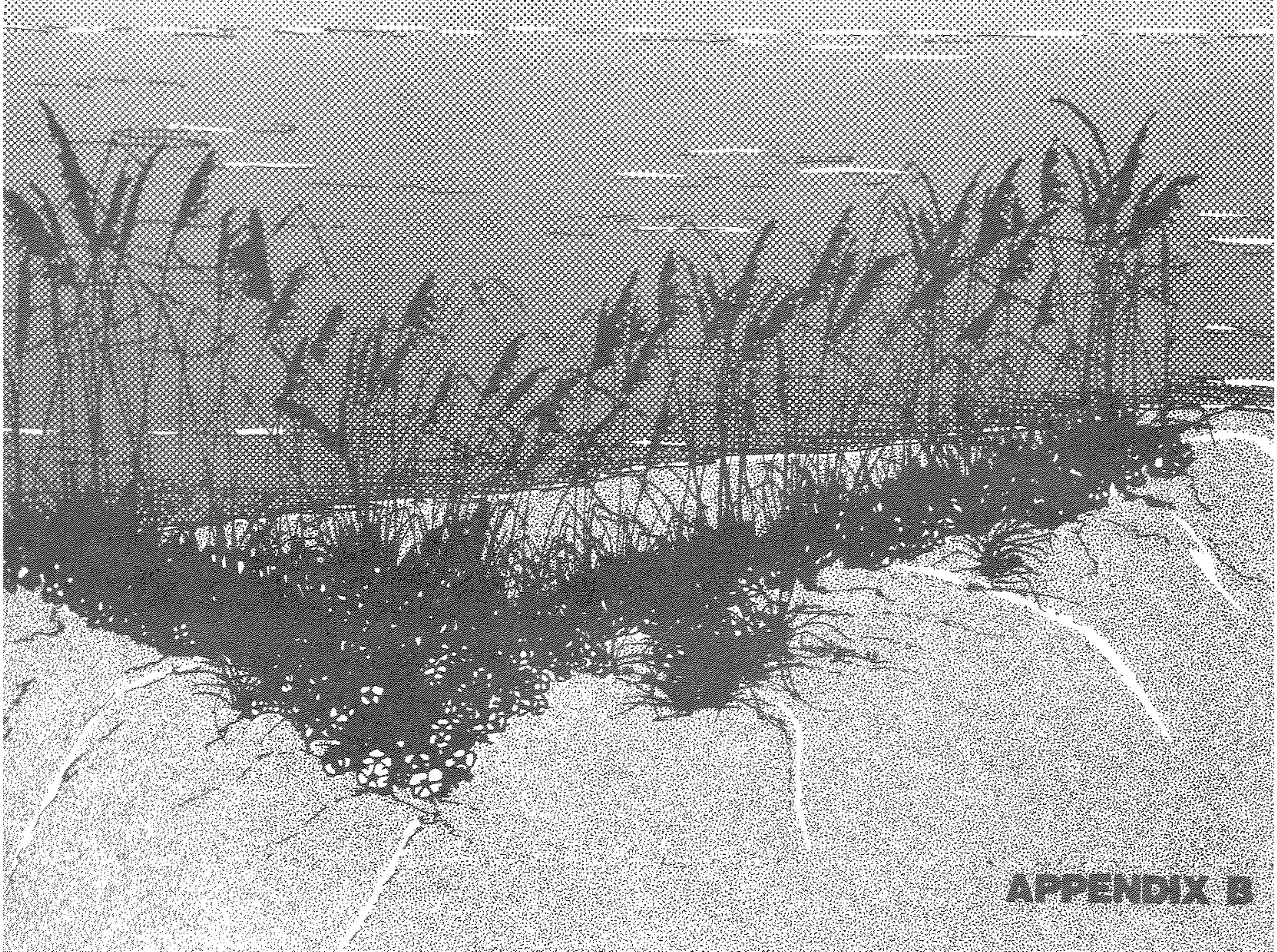
REPORT TO CONGRESS: COASTAL BARRIER RESOURCES SYSTEM

Coastal Barriers of the Great Lakes: Summary Report



APPENDIX B

U.S. Department of the Interior

REPORT TO CONGRESS: COASTAL BARRIER RESOURCES SYSTEM

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COASTAL BARRIERS OF THE GREAT LAKES: SUMMARY REPORT

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PREFACE

When the Coastal Barrier Resources Act was passed in 1982, Congress did not address the possibility of including barriers along coastlines other than the Atlantic Ocean and Gulf of Mexico. In 1983 the Coastal Barriers Study Group was directed by the Secretary of the Interior to identify and delineate the undeveloped coastal barriers along all U.S. coastlines. Other information concerning these barriers was also gathered. This appendix presents information about coastal barriers along the Great Lakes.

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INTRODUCTION

The five Great Lakes of North America constitute the greatest reservoir of freshwater on the surface of the earth (Figure 1). Lake Superior, with an area of 3,180 mi^2 (nearly half the area of New England), is the world's largest freshwater lake; Lake Huron ranks 4th in the world; Lake Michigan, 5th; Lake Erie, 11th; and Lake Ontario, 13th. Together the five lakes cover 95,200 mi^2. (Powers and Robertson 1966). They provide a continuous waterway into the heart of the continent that reaches nearly 1,990 mi from the mouth of the St. Lawrence River to Duluth, Minnesota, at the western tip of Lake Superior. The U.S. shoreline of the Great Lakes, including Lake St. Clair, stretches for a total length of nearly 4,000 mi and is the longest freshwater shoreline in the world.

The Great Lakes are obviously an inestimable natural resource for the United States and Canada. They supply vast amounts of water for public and industrial use and they serve as a transportation system which links many large inland cities to one another and to the Atlantic Ocean. Their falls and rapids generate huge supplies of hydroelectric power, and they offer a substantial food resource. Finally, they serve as an immense playground for people with opportunities for boating, swimming, fishing, or just relaxing.

Many reaches of the Great Lakes shoreline have been significantly transformed by the mining of iron ore and limestone, by the construction of hydroelectric power plants and harbor facilities, and by increasing industrial and urban land use. However, aesthetic aspects of the Great Lakes such as beaches, barriers, dunes, and wetlands continue to account for a significant tourist, fishing, and hunting industry in the region. Because of their isolation some areas, such as Lake Superior, northern Lake Michigan and Lake Huron, have experienced less development and thus continue to maintain their pristine qualities. Concern over the loss of critical fish and wildlife habitat in the Great Lakes and the coastal erosion associated with record high lake levels in recent years has encouraged several State and Federal regulatory agencies to examine the resources of the Great Lakes more closely (Raphael and Jaworski 1979). Among the resources being examined are the Great Lakes coastal barriers.

Coastal barriers in the Great Lakes are increasingly the focus of intense real estate speculation and development, causing conflict as natural values and public access are rapidly lost to lakeshore development. This development reflects a national trend; more than half of the major barriers and beaches in the United States are already fully committed to private housing and commercial enterprises on the marine shoreline (Clark 1976).

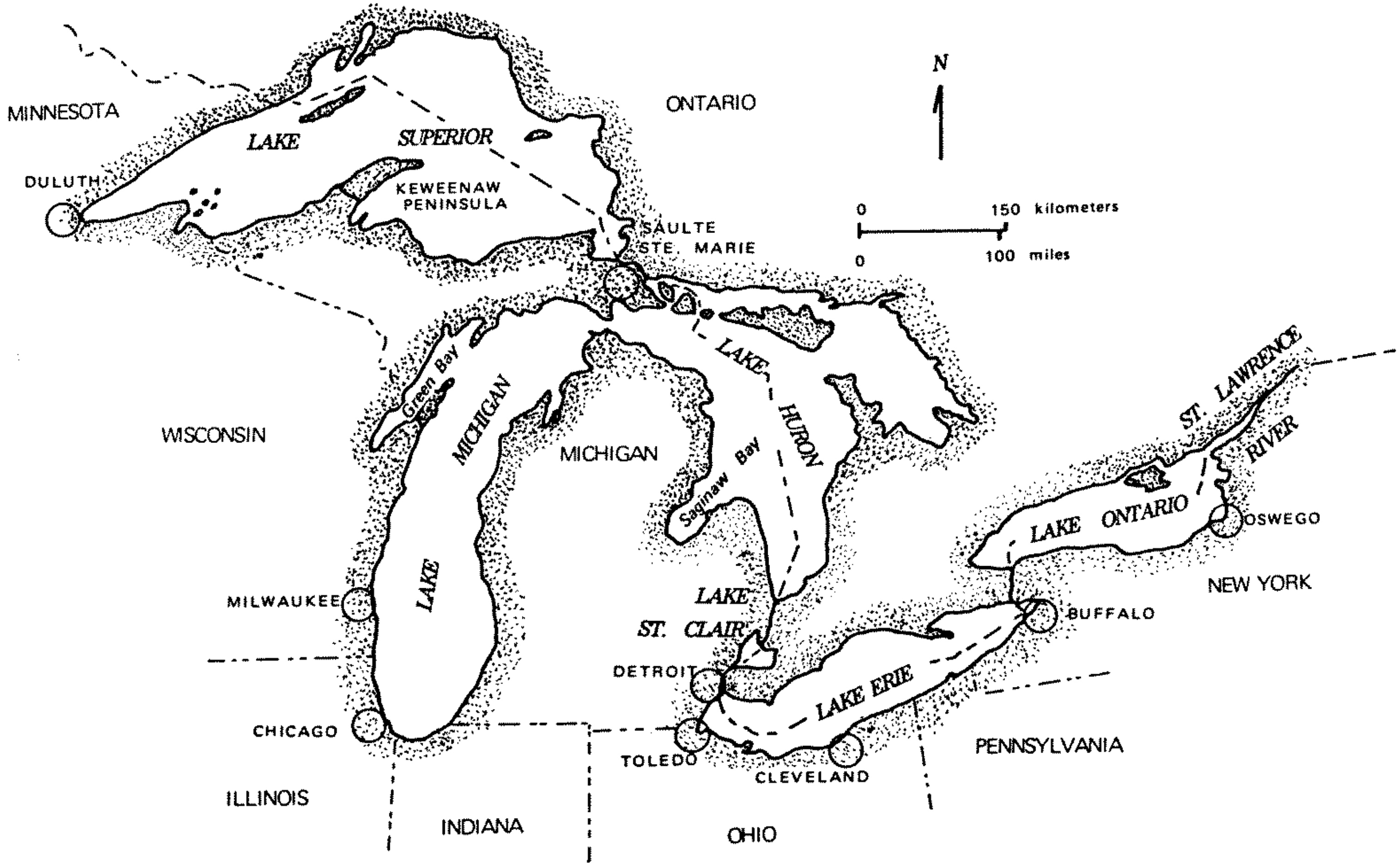


Figure 1. The Great Lakes and adjacent States and Provinces.

Barriers are temporary structures that constantly move and change shape. They cannot be held in place easily. Despite spending millions of dollars in public funds, most seawalls, groins, and beach restoration projects have been unsuccessful.

In this overview the physical characteristics of the Great Lakes barriers are discussed lake by lake. The ecological framework and interrelated ecosystems of each lake are then highlighted. The report concludes with a discussion of the policies of the Great Lakes States regarding conservation and of their regulatory programs for protecting coastal barrier resources.

In 1985 the Department of the Interior's Coastal Barriers Study Group identified 167 coastal barrier units along the Great Lakes' shoreline. Individual characteristics of particular barriers appear in appropriate sections throughout the report.

PHYSICAL CHARACTERISTICS OF COASTAL BARRIERS ALONG THE U.S. GREAT LAKES

Geologically and topographically the Great Lakes form a unique body of water. They represent one-fifth of the earth's surface-water water supply (Oghalai and Pomeroy, n.d.). Creation of the lakes began during the Pleistocene period, when continental glaciers moved into the Midwest, scouring and gouging the exposed bedrock as far south as the Ohio River. As the ice began to recede from its southern limit, some 18,000 to 20,000 years ago, the newly created Great Lakes were exposed.

The lakes occur as an interconnected group of deep troughs, geologically controlled by the bedrock configuration. Much of the western Lake Superior shoreline is dominated by ancient igneous and metamorphic rocks. Younger sedimentary rocks are exposed on the remainder of that lake and on the northern Lake Michigan and northern Lake Huron shorelines. The remaining Great Lake shoreline is most often characterized by glacial till and lake clays deposited during the Pleistocene ice age (Dorr and Eschman 1970). More recently the shoreline evolved to include several coastal depositional features such as barriers, sand dunes and deltas. Lake levels essentially stabilized about 3,000 years ago and the present-day coastal barriers were formed then.

The morphology of coastal barriers in the Great Lakes is in part related to the geological stability of the land as well as to changes in lake level. Since the melting of the Pleistocene ice, which began some 15,000 years ago in the Great Lakes Basin, isostatic adjustment or glacial rebound has continued. Farrand (1962) showed that uplift in the Great Lakes was most pronounced soon after deglaciation and gradually decreased until the present time. Studies (Bloom 1967; Flint 1971) reveal that uplift is most pronounced along an oblique line from the northwest shore of Lake Superior to Lake Huron and continues to the eastern shore of Lake Ontario. South of a hinge line from Milwaukee through Lake St. Clair and central Lake Erie, uplift is not evident. However, investigations in western Lake Erie suggest that subsidence is occurring. Shaffer (1951) summarized the rates of subsidence reported by several researchers and concluded that in coastal Lake Erie the shoreline is sinking at a rate of 6 to 24 inches/100 years. Broad, drowned embayments such as Maumee Bay and Sandusky Bay appear to confirm this view. Although somewhat anomalous with regard to the position of the hinge line, local subsidence is also occurring in western Lake Superior in the Duluth area.

Present-day coastal processes such as waves and longshore currents are significant in the development and maintenance of Great Lakes barriers. A unique aspect of the Great Lakes is the noncyclical changes in water levels over relatively short periods of time. It is not valid to attribute all coastal erosion to the level of the lakes; however, high lake levels do play a major role in accelerating erosion of coastal barriers (Hands 1984). Conversely, lower lake levels cause an increase in beach width, which provides protection to adjacent barriers.

WATER LEVELS

The Great Lakes have insignificant tidal variations, but are subject to seasonal and annual hydrologic changes in water level and to water level changes caused by wind setup, barometric variations, and seiches. Under present climatic conditions the water levels of all the Great Lakes, including Lake St. Clair, rise and fall periodically (Figure 2).

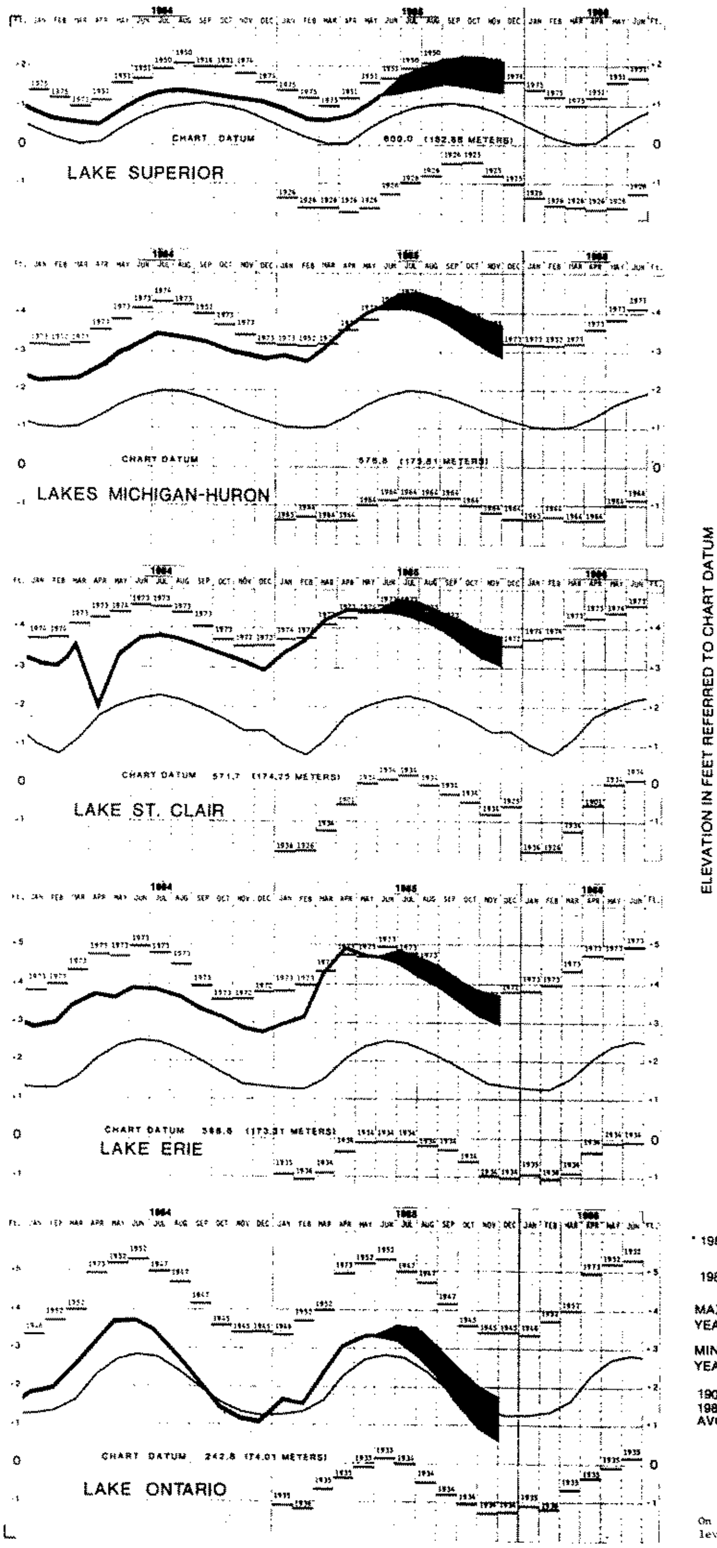
The water level of the Great Lakes depends on the balance between the total amount of water received by that lake and its discharge to the next lower lake. If the water received by the lake is greater than that discharged, its level rises. Conversely, if the water inflow is less than the discharge, the lake level drops.

Precipitation is the source of all natural water supplied to the Great Lakes. The low lake levels in the mid-1930's and 1960's were the result of persistent low precipitation for several years, while the high lake levels of the early 1970's were caused by above average precipitation for several successive years. Although noncyclical, water levels appear to range from a high-water period to a low-water period every 7 to 10 years. Normally, annual high-water levels occur in summer (June-August). Seasonal lows occur during the winter months.

During periods of low water coastal barriers are protected in two ways. As water levels drop, the beach zone is exposed, forming a wider buffer zone during high wave energy conditions. Also, in protected coastal reaches, such as Green Bay and Saginaw Bay, emergent wetland plants colonize the nearshore zone and disperse the incoming wave energy.

Temporary water level changes of short duration occur on all of the Great Lakes. Steep barometric gradients and onshore winds cause sudden rises in lake levels. These "wind tides" or seiches, drive water levels over low coastal barriers, which may flood and ultimately be breached. Barrier sediments are carried landward and deposited as overwash on the floor of adjacent lagoons. Such events more commonly occur in Green Bay, Saginaw Bay, Lake St. Clair, and Lake Erie.

Storm surge may occur from one of the following three causes (Seible 1972). First, water may be piled up at one end of the lake by a strong wind of constant direction. Second, rapid changes in barometric pressure may cause an increase or decrease in the mean water level. Finally, sudden changes in the quantities of water caused by ice jams may cause an increase or decrease in lake level. Existing high water levels coupled with rapid increases in the local water level due to storm surge increases the energy at the shoreline. Furthermore, storm surges decrease the effective beach width and waves may scour closer to the toe of barrier dunes.



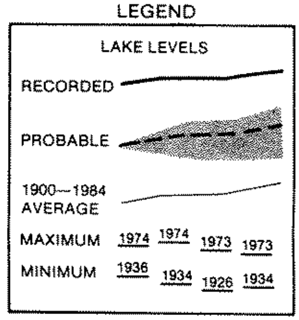
US Army Corps of Engineers
Detroit District

MONTHLY BULLETIN OF LAKE LEVELS FOR THE GREAT LAKES

MAY 1985

Recorded levels for the previous year and the current year to date and the probable levels for the next six months are shown in red. The shaded red area shows the probable range of levels (one standard deviation of the long-term average predictive error) over the next six months dependent upon weather variations.

These are compared with the 1900-1984 average and extreme levels which are shown in black.



Hydrographs are in feet above (+) or below (-) Chart Datum, the plane on each lake to which navigation chart depths and Federal navigation improvement depths are referred.

Chart Datum and all other elevations are in feet above mean water level at Father Point, Quebec (International Great Lakes Datum 1955). To convert feet to meters, multiply feet by 0.30480.

MAY MEAN LAKE LEVELS

	Superior	Mich.-Huron	St. Clair	Erie	Ontario
* 1985	601.05	580.80	576.12	573.29	246.13
1984	600.87	579.72	575.06	572.22	246.53
MAX. YEAR	601.53 1951	580.60 1973	576.06 1974	573.25 1973	247.95 1952
MIN. YEAR	598.30 1926	575.79 1964	571.64 1934	568.43 1934	242.67 1935
1900-1984 AVG.	600.41	578.42	573.73	570.98	245.48

*provisional

Correction to April 1985 Bulletin:
On the April Mean Lake Levels table, the provisional 1985 level of Lake Ontario should have read 245.86 not 575.86.

Figure 2. Present and historical Great Lakes water levels.

Not only does a surge increase the total energy at the shoreline, the increase and decrease in water level usually occurs in less than 60 minutes. Maresca (1975) determined that an increase in the water level significantly amplifies the total wave energy, especially if the storm waves are large (Figure 3). The greater the storm surge, the greater the increase in water level and the longer the duration at that height.

Ice jams frequently occur in connecting channels such as the St. Clair River. As ice accumulates jams form, causing a drop in the water level downstream. In April 1984 an ice dam blocked the St. Clair River, causing a 16-inch drop in the water level of Lake St. Clair (Figure 2). A slight drop was also recorded in Lake Erie.

Ice on barrier shorelines plays significant, but contrasting roles with regard to barrier protection. Freezing of the Great Lakes varies with latitude and local physical conditions (e.g., currents) but normally occurs from the shoreline out into the lake. As ice forms at the shoreline it acts as a buffer by absorbing wave impact, particularly during storm conditions, and thus protects adjacent coastal barriers. During ice breakup in spring, however, tabular ice blocks may be driven onshore by winds. As the ice moves shoreward it scrapes, gouges, and uproots nearshore wetland plants and scours beaches. Ice may be piled 10 ft or more in height and threaten dwellings sited on coastal barriers. During mild winters, such as in 1984-85, breakup occurs early. Strong onshore winds in March, 1985 caused considerable erosion and flooding on several exposed Great Lake reaches.

NEARSHORE PROCESSES

Waves on the Great Lakes are variable and depend in part on fetch and wind velocities and duration. Significant barrier erosion will occur during periods of high water levels and storm surges associated with low barometric pressure. As water levels rise, beaches, berms, and barrier faces are eroded (Figure 4). Barrier sediment is transported lakeward, accreting in the nearshore zone (Figure 4, profile C). Overwash and barrier breaching often occur during these periods. Following a storm, water levels decrease and waves transport sand from the nearshore zone to the beach. Although the beach profile may be reconstructed, the crest of the barrier may be displaced toward the land (Figure 4, profile D). Conversely, exposed beach deposits may be transported by the wind and contribute to the reconstruction of the barrier.

A significant factor in determining wave energy is wave height. In the Great Lakes, the energy delivered by a wave to a beach is conveniently described in terms of the ratio of wave height to wave length (i.e., wave steepness). Waves with a ratio greater than 0.03 build high berms while cutting back the beach and forming an offshore bar (Great Lakes Basin Commission 1975). In contrast, a less steep wave ratio deposits sediments onshore.

Table 1 represents probable once-a-year maximum wave energy in the offshore zone of selected localities. Lake Superior, with the greatest fetch, has the highest wave heights. Deep water wave heights are less in the lower Great

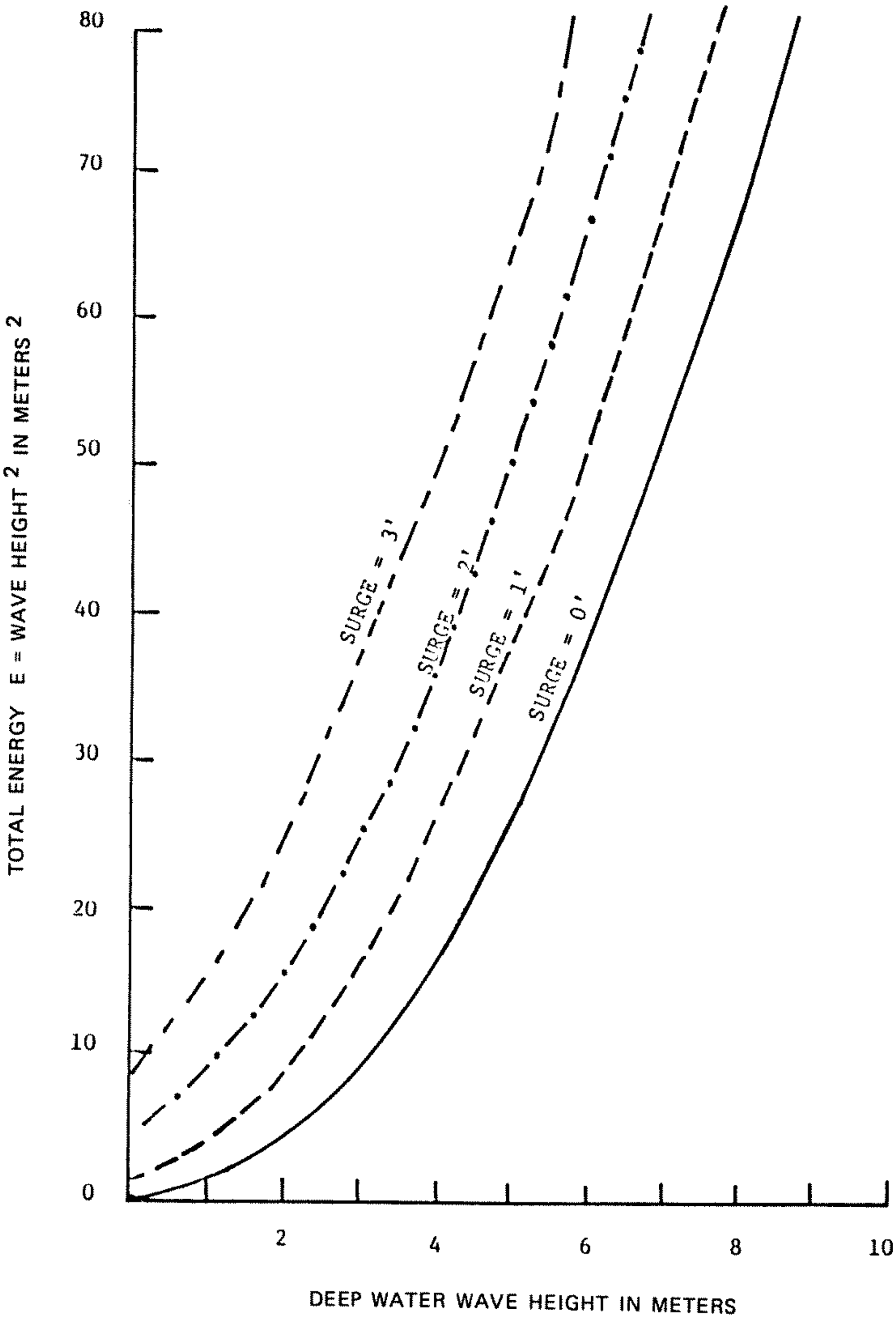


Figure 3. Increase in the total wave energy due to storm surges (Maresca 1975).

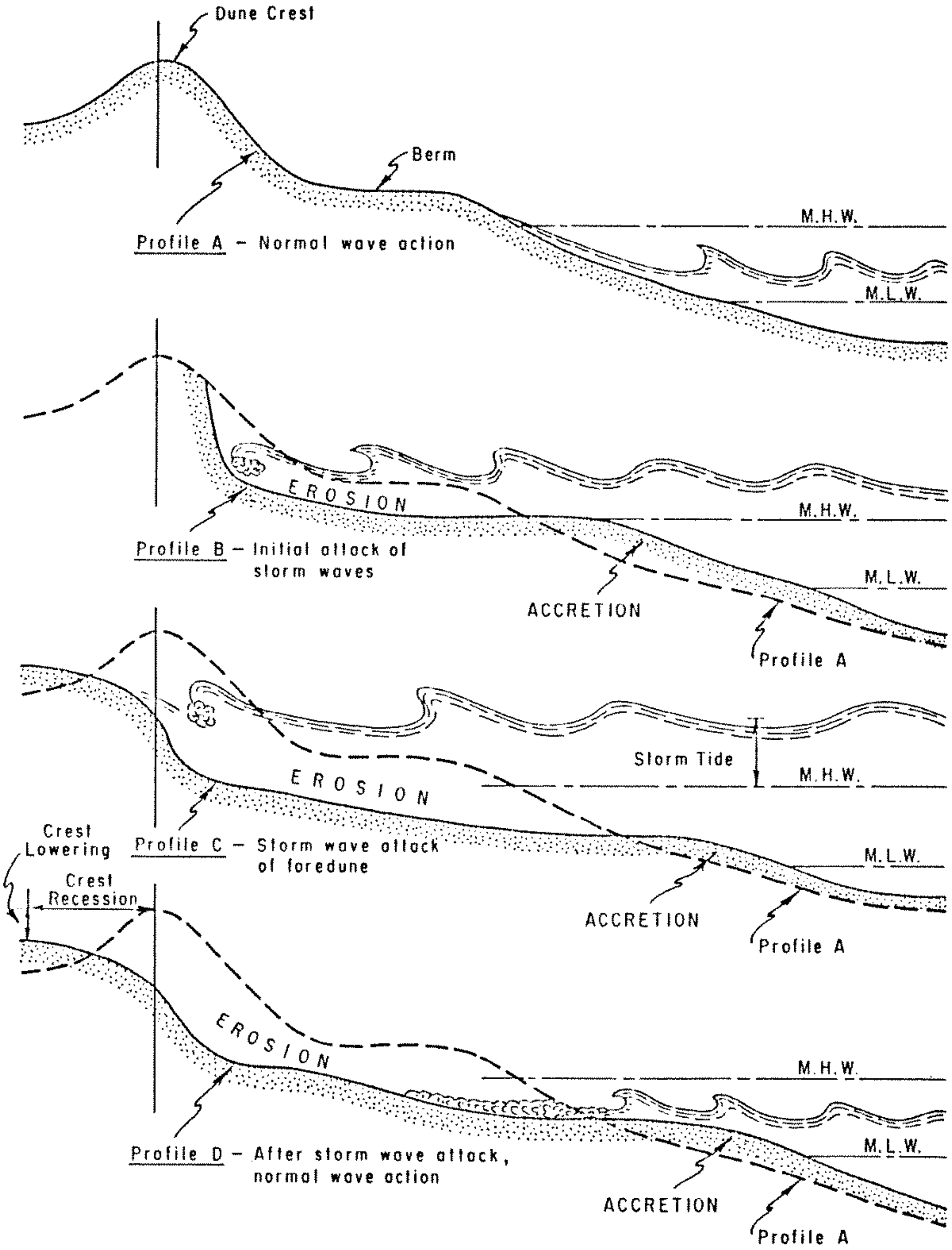


Figure 4. Impact of high water levels on Great Lakes beaches and coastal barriers (Great Lakes Basin Commission 1975).

Table 1. Probable once-a-year significant wave height values (Great Lakes Bas
Commission 1975).

Locality	Probable once-a-year maximum wave height (Ho) (ft)	Period range (seconds)	Probable directions of approach	Probab duratio (hours)
	Lake Superior			
Brule River	20	9-11	NE	6
Carver Bay	27	11-13	NE	6
Little Lake	22	10-12	NW	8
North Shore	15	7-9	E or NE	6
Grand Marais (Mich.)	25	11-13	NE	6
Eagle Harbor	29	13-15	N or NE	8
	Lake Michigan			
North Bay	9	4-5	NE or S	6
Milwaukee	13	5-6	E	5
Chicago	8.5	4-7	N	9
Muskegon	15	5-7	SW	10
Frankfort	17	4-7	SW or WSW	9
Kenosha	13	7-9	E	5
Manitowoc	11	7-8	E	5
Berrien County	11	7-8	W or NW	5
Indiana	12	7-8	N or E	6
	Lake Huron			
North Point	9	5-6	NE or SE	6
Harbor Beach	13	5-7	E	5
Port Huron	8	4-6	N	9
	Lake Erie			
Cleveland	9	5-6	W or WNW	6
Erie	9	5-6	W or WNW	6
Buffalo	11	6-7	W	8
Huron	11	6-7	W or WNW	6
Monroe	8	5-6	E or ENE	6
Reno Beach	5	4-5	E or ENE	6
	Lake Ontario			
Olcott	9	5-6	W or WNW	6
Oswego	11	6-7	W or WNW	8
Fair Haven State Park	11	6-7	E or ENE	6
Fort Niagara State Park	12	6-7	E or ENE	6

Lakes. Deep water wave energy can be determined from wave height (Seible 1972). As the height of waves increases there is an increase in wave energy. Because maximum wave heights occur in Lake Superior, wave energy is greatest in this lake. Wave energies in Lake Huron and Lake Erie are least; wave energies in Lake Michigan and Lake Ontario are in the middle range.

Longshore currents are generated by an oblique wave approach to the shoreline. These currents move parallel to the shore, and their velocities are determined primarily by the size of the waves and the angle of wave approach. Longshore currents may be locally altered by variables such as temperature differences, inflows from tributary streams, and abrupt changes in submarine topography. Figure 5 illustrates the net direction of longshore transport in the Great Lakes. In Lake Erie and Ontario, long shore transport is generally eastward, whereas in the upper Great Lakes, the direction is more variable.

Longshore current velocities and related sediment loads are not well known. Komar (1976) suggests net longshore drift in western Lake Michigan averages 41,850 yd^3/year. Bruno and Hiipakka (1973) determined a monthly drift rate of 1,300 to 77,160 yd^3/month at selected sites along eastern Lake Michigan and Lake Superior. Davis et al. (1973) suggests drift rates are variable along eastern Lake Michigan, but amount to 130,780 yd^3/year.

The composition and extent of coastal barriers reflect the sources of sediment. There are several sediment sources for barrier development and maintenance along the Great Lakes.

(1) Erodable high bluffs composed of glacial till. Eroding moraine deposits are most evident on Lake Michigan and Lake Huron.

(2) High dunes composed of well sorted sand abutting the lakes. The greatest dune assemblage is along eastern Lake Michigan. However, substantial dune deposits also occur on Lake Superior and contribute to longshore drift volumes there as well.

(3) Weathered bedrock in the coastal zone. Bedrock exposed at or near the lake surface is locally significant in the construction of gravel beaches and tombolos. Such morphologies are most prominent on coastal Lake Superior and northern Lake Michigan and Lake Huron.

(4) Fluvial sediments. Rivers eroding and draining glacial landscapes and emptying directly into the Great Lakes contribute to the longshore sediment supply throughout the Great Lakes Basin. Large drainage basins (e.g., Fox, Saginaw, and Maumee Rivers) drain glacial lake plains and transport a fine sediment fraction (silt and clay) to the coastal zone.

(5) Beach nourishment projects locally contribute sediment to several coastal zones. During the period 1974-82, 3,099,430 yd^3 of beach material was artificially deposited on Lake Michigan shorelines in Indiana and Michigan. Sediment for beach nourishment projects is derived from Great Lake bottoms as well as from inland sources (Jaworski et al. 1984).

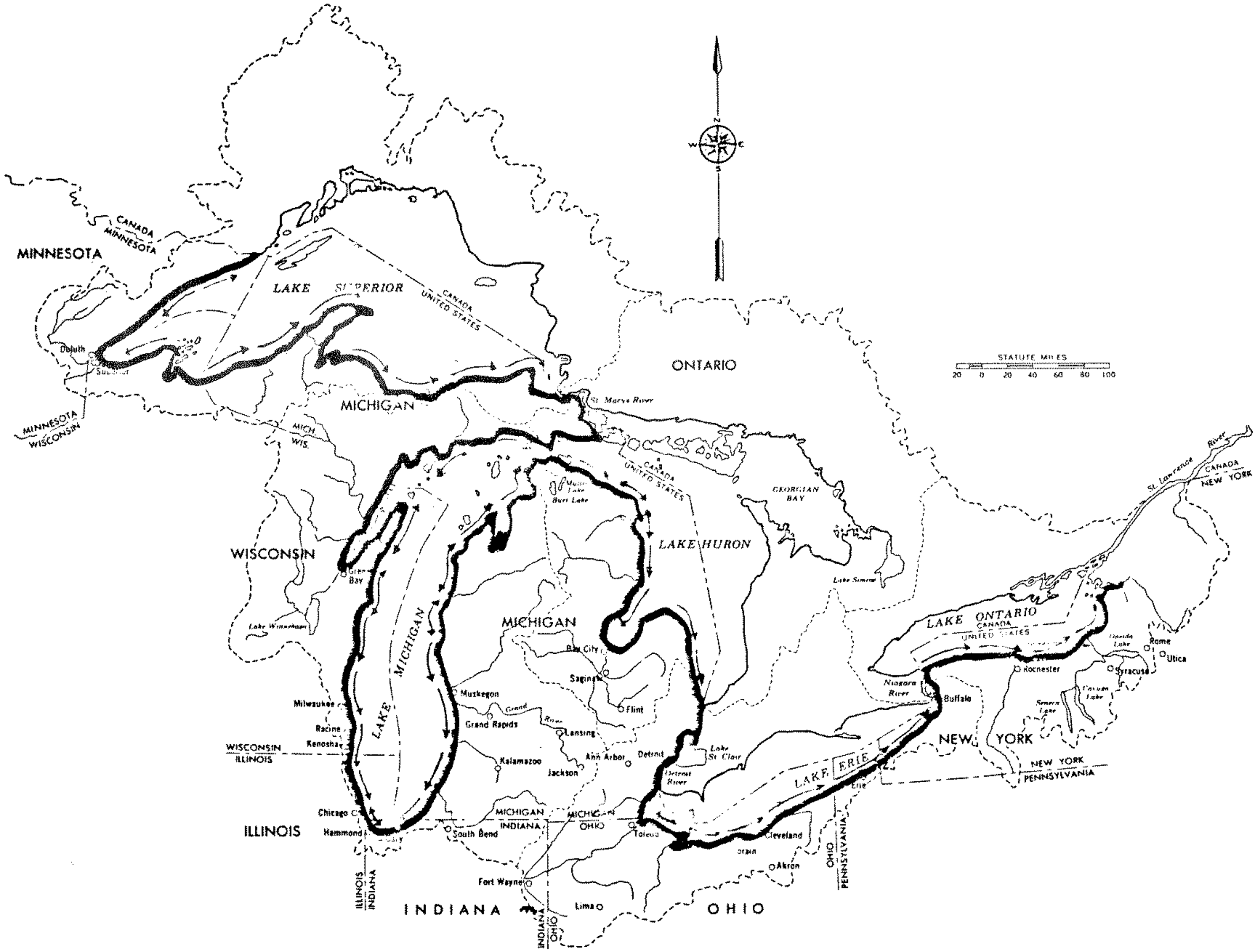


Figure 5. Net direction of longshore transport in the U.S. Great Lakes (Great Lakes Basin Commission 1975).

(6) Sand and gravel in the shallow nearshore zone. Perhaps the most volumetrically significant immediate source of sediment is longshore transport in the nearshore zone (Davis 1978). Although this sediment was originally provided by one of the sources noted above, longshore transport is the final distribution process of beach and barrier materials.

LAKE SUPERIOR BARRIERS

Lake Superior, the largest and northernmost Great Lake has the most rugged, uninhabited, and inaccessable shorelands of all the Great Lakes. The U.S. shoreline length is 913 mi. The lake is 1,332 ft deep and the mean water level is 602 ft above sea level. Although the discharge through the St. Marys River is regulated at Sault Ste. Marie, lake level oscillations do occur.

Because of the lack of development and the high scenic quality of the Lake Superior shoreline, almost all of the coastal zone is considered of prime recreational value (Great Lakes Basin Commission 1975). The lack of industrial development and the low population of the basin leaves the overall water quality of the lake excellent. A few problems exist in isolated areas, primarily as a result of mining activities.

The geology of the region plays a significant role in the character of the shoreline and the development and regional distribution of coastal barriers. The shoreline from the Keweenaw Peninsula west to the Ontario border is largely composed of Precambrian igneous and metamorphic rocks and is part of the Superior Upland. The topography is characterized by bedrock cliffs bordered by narrow gravel or sand beaches. Elevations are about 410 ft above lake level. East of the Keweenaw Peninsula the topography is more subdued and sedimentary rock outcrops are evident.

This ancient landscape was modified with the advance and eventual retreat of the glaciers. Coarse glacial outwash and numerous glacial features such as drumlins positioned at right angles to the Lake Superior shoreline were deposited by the ice. Also, vestiges of older and higher shorelines parallel the perimeter of the lake.

Coastal investigations of Lake Superior are not abundant. However, topographic maps and navigation charts suggest that the coastal barriers of Lake Superior have many diverse forms. Stretching north to south across the head of western Lake Superior are two parallel bay-head barriers. Minnesota Point-Wisconsin Point, near Duluth, is considered to be the longest freshwater barrier in the world. The barrier is about 10 mi long, 105 ft wide, and has a sediment volume of 22.5 million yd^3 (Loy 1963). Barrier sediments, which are 85% quartz, are derived from glacial till on the south shore of the lake. The barrier is approximately 5 ft above lake level and 30 ft thick, suggesting the deposit developed in relatively deep water. Although the barrier is exposed to a long fetch (300 mi), it is apparently stable.

Tilted older shorelines suggest that subsidence is occurring. Subsidence has drowned former river valleys and created Superior and St. Louis Bays (Martin

1965). Port Wing (Figure 6) also has multiple bay-mouth barriers which partly enclose a broad embayment created by the drowning of the lower Flag River Valley. Wetland plants dominate the aquatic habitat.

Farther east are the bedrock outcrops of the Apostle Islands, which create more complex longshore currents. Consequently, a diversity of barrier forms has been deposited. There are small spits tied to some of the islands, many of which trend southwestward. Tombolos, such as those on York Island, commonly link islands less than 1.3 mi apart. These depositional features are usually less than 3,300 ft in width and are curvilinear in form. There are also spits which converge, enclosing lagoons on Stockton Island. On Madeline Island, the largest of the Apostle archipelago, the head of Big Bay is barred by a bay-mouth barrier. This is also the case on the southwestern side of this island. At Bark Bay a long narrow recurved spit has been deposited, trending to the northwest and partly enclosing Chequamegon Bay. In the mid-1800's this barrier was breached by storms, and permanent inlets developed. The bay landward of the point is in excess of 30 ft deep in many localities, suggesting a drowned origin. From Chequamegon Bay, east to the Keweenaw Peninsula, the Superior Upland abuts against the shoreline and barriers are less numerous and less extensive. Barrier development is confined to small bays usually less than 0.4 mi in length. The barriers stand about 6.5 ft above lake level and are often capped with dune hummocks poorly stabilized with dune grasses.

East of the Keweenaw Peninsula the shoreline is underlain by southerly dipping Cambrian sandstones (Hamblin 1958). Exposures occasionally occur at the shoreline but become less common further eastward. The longshore currents are to the east and carry a significant sediment load. At Little Lake about 77,000 yd^3/year of sediment is being transported from west to east in the nearshore zone (Kureth 1978).

Additionally, 116,400 yd^3/year of material derived from bluffs and upcurrent beaches may be added for a total drift volume of 193,400 yd^3/year. These high volumes may account for the numerous and lengthy barriers. From Keweenaw Bay to Marquette, numerous small embayments are cut off from Lake Superior by bay-mouth barriers (e.g., Snake Head Lake). The embayments are, in most cases, abruptly terminated by higher land on their landward side.

From Munising east to the St. Marys River the barriers are dune-ridge features adjacent to higher and older glacial deposits or shorelines. The ridge crests stand up to 23 ft above Lake Superior. Occasionally linear tracts of wetland vegetation occur in the swales.

LAKE MICHIGAN BARRIERS

Lake Michigan is the only Great Lake situated entirely within the United States. Its total shoreline length is 1,354 mi. It is different from the other four Great Lakes in that it extends from north to south. Lake Michigan contains numerous embayments but has the least number of islands and island groups in the Great Lakes.

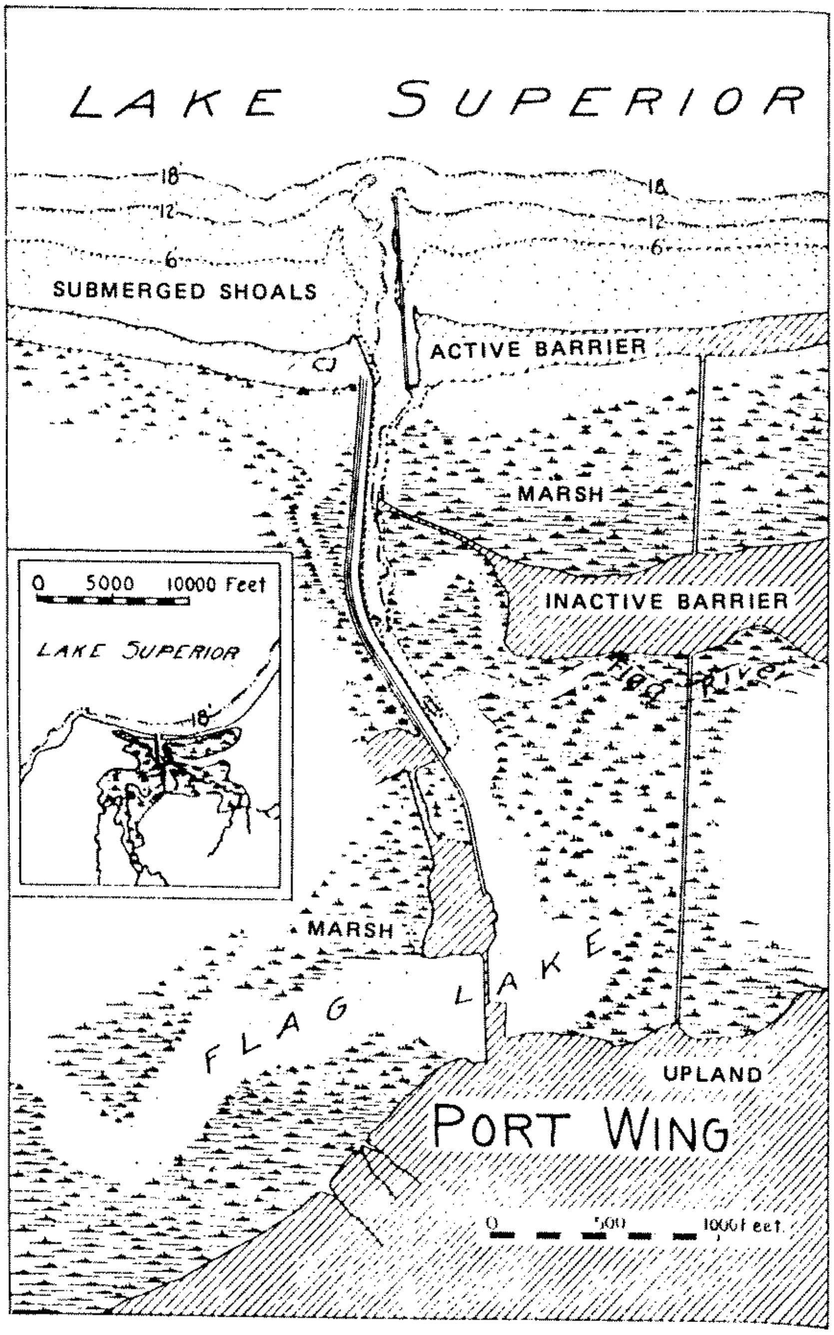


Figure 6. Multiple bay-mouth barriers at Port Wing, Minnesota (Martin 1965).

With the recession of the glaciers, the basin of present-day Lake Michigan was exposed. Between 16,000 and 13,500 years B.P. several premodern lakes occupied the basin, which drained southward through the Chicago area. In time, the ice retreated sufficiently to expose the Straits of Mackinaw and the lake began to discharge eastward into Lake Huron. The Lake Michigan shoreline, in part, reflects the glacial activity of the past. Most of the Michigan and Wisconsin shoreline is characterized by knobby recessional moraines and stranded beaches located well above the present lake level. Spectacular parabolic dunes were deposited from Indiana northward along the Michigan shoreline to Traverse Bay. Bedrock and ancient lake plains are exposed in the northern portion of the basin. The Green Bay area and the north shore of Lake Michigan are the most significant areas of coastal barrier development.

For the purpose of this overview, coastal barriers on the Lake Michigan shoreline may be divided into three morphological settings which generally conform to three geographical areas: the linear shoreline of Lake Michigan south of Green Bay and Traverse Bay; the Northern Lake Michigan area exclusive of Green Bay; and the Green Bay-Big Bay de Noc area.

The lower two-thirds of Lake Michigan, especially the Indiana and Michigan shoreline, is highlighted by enormous sand dunes interspersed with glacial deposits. Coastal barriers make up a small part of the lower Lake Michigan coastline. The lack of barrier development is primarily caused by the relatively high wave energies and the abrupt moraine bluff morphology of much of the shoreline (Hands 1970; Buckler and Winters 1983).

A unique aspect of the Michigan shoreline is that embayments forming rather deep lakes occur along this coastal zone. The lakes formed as bays along the shoreline after lake levels reached their present position or were drowned river valleys that were excavated during lower lake level and subsequently inundated when Lake Michigan reached its present level. In either case, one may speculate that the existing barriers were formed as bay-mouth bars or accretionary spits (Figure 7). These barriers have a relatively narrow beach zone.

In most instances, the barriers are approximately 13-20 ft above lake level and are well vegetated. At the southern end of the lake, the barriers are capped with parabolic dunes, which are stabilized by woody vegetation. Overwash deposits are minor features on these barriers, suggesting that landward barrier migration is not an active process on this shoreline. Barrier stability may be related to sea walls or groins constructed at several sites and the abundance of sand in the longshore transport system.

The lagoons, landward of the barriers, are abruptly terminated by glacial uplands or river and coastal terraces. Where wetlands occur they contain submerged or floating aquatic plants or emergent plants such as cattails (*Typha* spp.), sedges (*Carex* spp.), and shrubs (ash, *Fraxinus* spp., and dogwood, *Cornus* spp.).

The northern Lake Michigan area encompasses the coastal zone from Traverse Bay northward and then westward to Schoolcraft County, Michigan. The barriers in

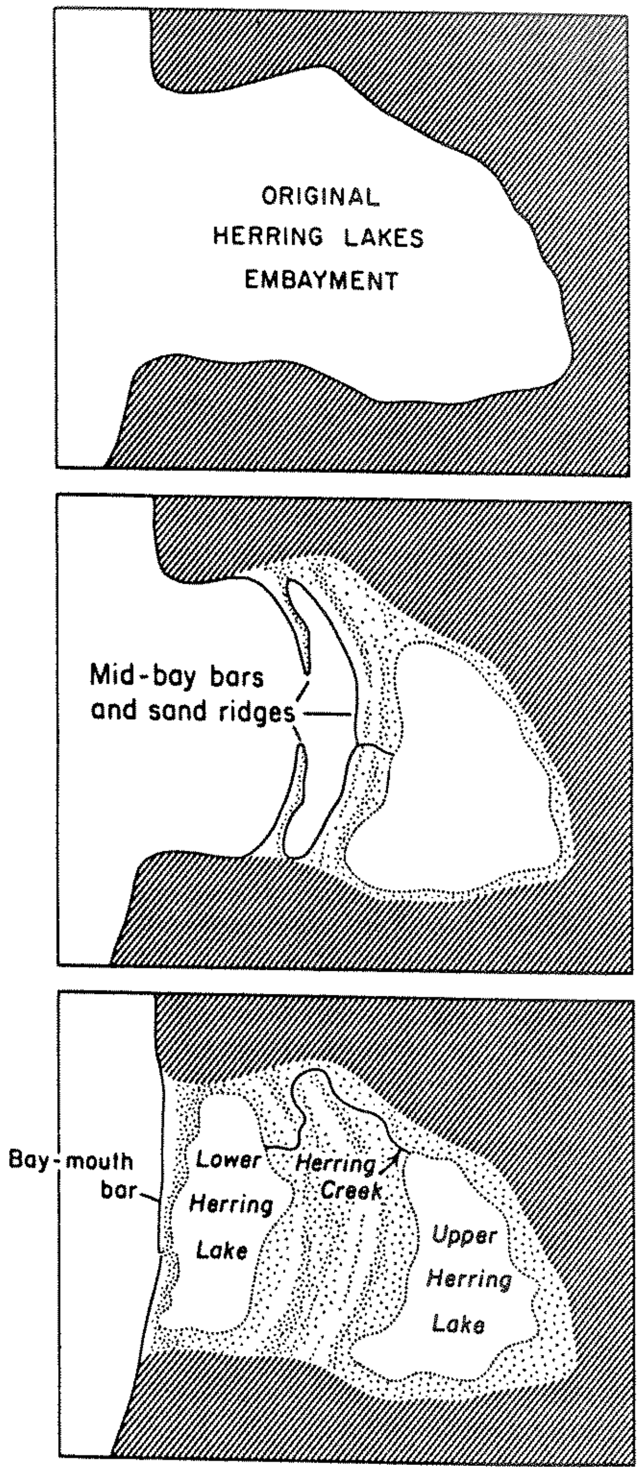


Figure 7. Typical barrier development along the eastern Lake Michigan shoreline (Dorr and Eschman 1970).

this area are either long, straight depositional features or extensive curved features paralleling the shoreline. In both instances they commonly exceed 1.2 mi in length and 0.4 mi in width, and are adjacent to extensive wetlands on their landward sides, which are vegetated by acid-tolerant swamp plants. Most of these barriers are characterized by sand or fine-gravel beaches and may be classified as parallel dune-ridge complexes. The dune-ridges are continuous along the shoreline and well vegetated. In swales between ridges, linear ponds and poorly drained wetlands commonly occur. Overwash deposits and mobile sand sheets are conspicuously absent from these barriers.

Locally barriers of the north shore of Lake Michigan are referred to as "corrugated plains," which aptly describes the appearance of the ridges and the swales on topographic maps and on aerial photographs. The surface is uniformly furrowed by 5 to 10 ridges, typically spaced at 165-245 ft intervals. The corrugated plains occupy a level between the present lake and older and higher shore features and typically exhibit a total relief of less than 33 ft.

Although the stratigraphy of these barriers has not been investigated in detail, they appear to be prograding features, deposited when Lake Michigan reached its present level. They are unique because they represent extensive coastal deposition, which, with the exception of deltas, is not common in the Great Lakes Basin.

Green Bay-Big Bay de Noc is partly separated by the main Lake Michigan Basin by the Door and Garden Island Peninsulas. The prominent peninsulas are exposed beds of the Niagara dolomite which encircle Michigan's lower peninsula and in this area dip steeply to the west-southwest. The longshore current in the bay is counterclockwise (Bertrand et al. 1976). In spite of its semi-isolation from Lake Michigan, the bay does experience seiche movements. Scott et al. (1957) observed that the normal range in water level is 1 ft or much less, but in November 18-19, 1957, the East River had an oscillation of 4.4 ft in 17 hours. Similar abrupt water level changes were noted by others here and in the Fox River in the city of Green Bay (Schrufnagel 1966).

Barrier islands in the Green Bay-Big Bay de Noc are localized sand deposits oblique to the shoreline. In Big Bay de Noc, Portage Point is a simple spit, projecting northeastwardly into the bay. It is poorly vegetated and just above lake level. The regular landward boundary of these barriers suggests washovers occasionally occur. The washover areas are vegetated with marsh plants. Figure 8 illustrates the uniqueness of the Green Bay barriers. The barriers are skewed to the south and are composed of a single low sand ridge some 2.5 mi long. Similar barrier spits occur farther north and are anchored along the western shore of the bay. These elongated depositional features are less than 3.3 ft above the level of the bay and are poorly vegetated.

LAKE HURON BARRIERS

Lake Huron, the second largest of the Great Lakes, is separated from Lake Michigan by the Straits of Mackinac. Lake Huron's U.S. shoreline, a total mainland length of 565 mi, is entirely within the State of Michigan. Other

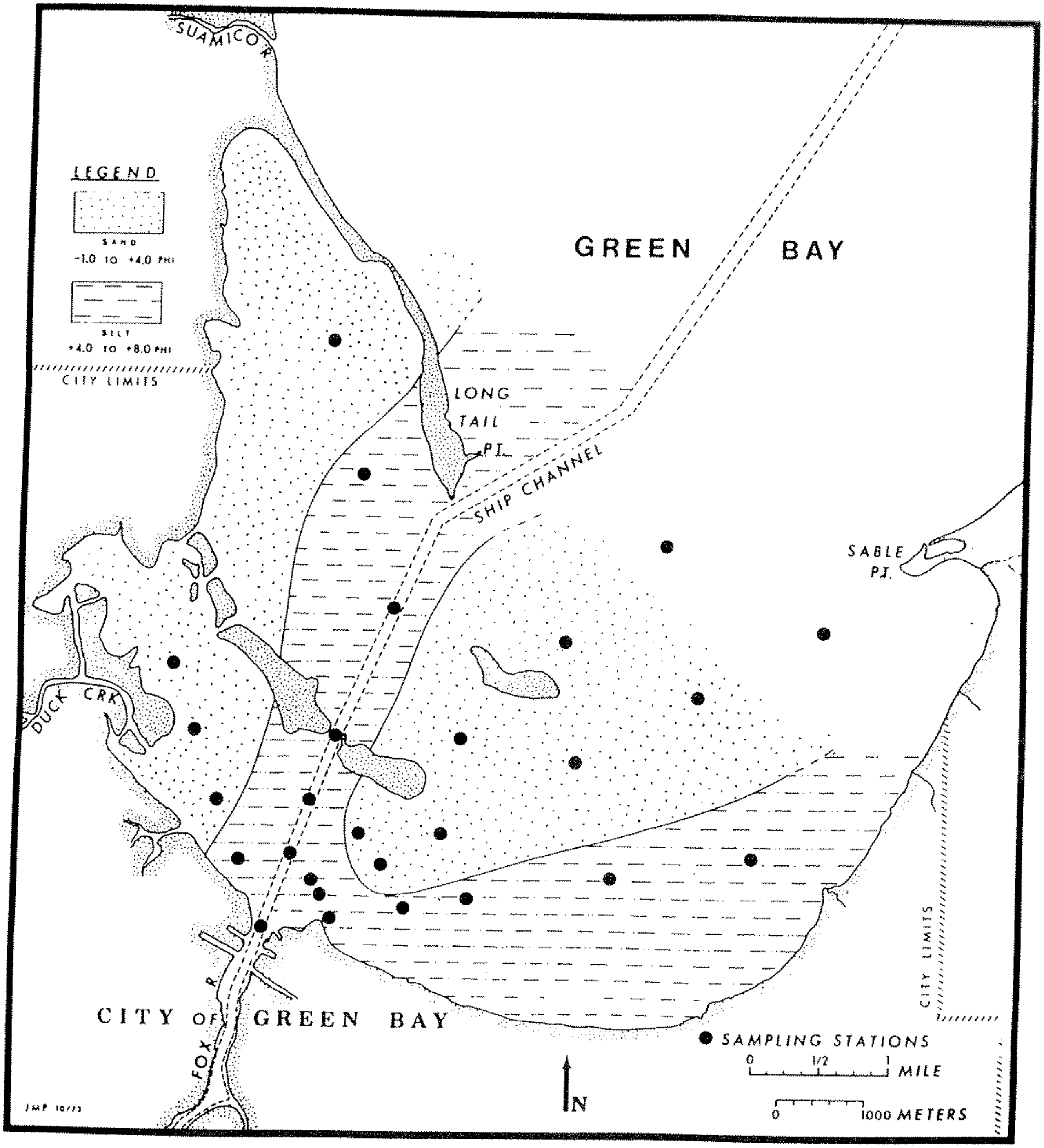


Figure 8. Barriers in southern Green Bay, Wisconsin (Bertrand et al. 1976).

than Lake Superior, Lake Huron is the least developed of the Great Lakes. Lake Huron's shoreline may be divided into two morphologic regions. The area outlined by Saginaw Bay is characterized by broad, poorly-drained lake plains composed of fine silt and clay. To the south and north, glacial deposits, mainly recessional moraines, dominate the coastal landscape.

Several of the islands in the northern portion of the lake are composed of glacially scoured bedrock or drumlins. Adjacent to many coastal barriers are older beach deposits representing higher than present lake levels.

It is difficult to generalize about the barrier morphology of Lake Huron because of the diversity of physiographic settings and source areas of sediments. With the exception of Tawas-Saginaw Bay and Alcona County, the coastal barriers occur in isolated settings and take any of several forms, including bay-head barriers, parallel dune ridges and arcuate dune ridges. The Black River barrier, the most continuous barrier on the Lake Huron shoreline, consists of a series of arcuate beach ridges and a densely vegetated lagoon. The upland to the west is composed of an older beach-ridge complex.

Tawas Point at the north end of Saginaw Bay is a linear complex spit characterized by low parabolic dunes. The adjacent wetland is sporadically vegetated with submersed aquatic plants which vary in areal extent depending on lake level conditions. Nayanquing Point is of similar origin and extent. The longshore currents in Saginaw Bay are counterclockwise, which explains the southerly extension of these sand barriers.

In spite of the relatively high sediment discharge of the Saginaw River, the barriers in southern Saginaw Bay exhibit a sand deficiency and are erosional in origin. Lakeward, along the south shore, an extensive marsh composed of emergents such as bulrush (Scirpus spp.) and cattail (Typha spp.) occurs in the nearshore zone. The barriers are rich in organic sediments, less than 6.5 ft above existing lake level, and reflect low energy wave conditions.

Northern Lake Huron contains several island groups of which the Les Cheneaux complex is the largest. The islands are composed of gravel and sand drumlins which were deposited and reworked by glacial ice. The islands are generally 65 ft above Lake Huron. Barrier deposits consist of narrow spits about 3,000 ft long or sinuous features oblique to the shoreline.

Figures 9 through 12 reveal the contrasting barrier morphologies in northern and southern Saginaw Bay in map and stratigraphic views. The Tobico Barrier (Figure 9) in northern Saginaw Bay is an arcuate dune-ridge barrier characterized by distinctive curved dune ridges on the downdrift portion of the island. Stratigraphically (Figure 10) the barrier is thick, suggesting a depositional process for this feature. In contrast, Figure 11 suggests that on the south shore of Saginaw Bay erosion is occurring in spite of lower wave energy conditions. The barriers there are thin and are composed of surficial washover deposits of sand, fine gravel, and organic debris (Figure 12). The nearshore area, however, is characterized by several sand bars. South of Saginaw Bay the Lake Huron shoreline is composed of bluffs of glacial origin and coastal barriers have not been deposited.

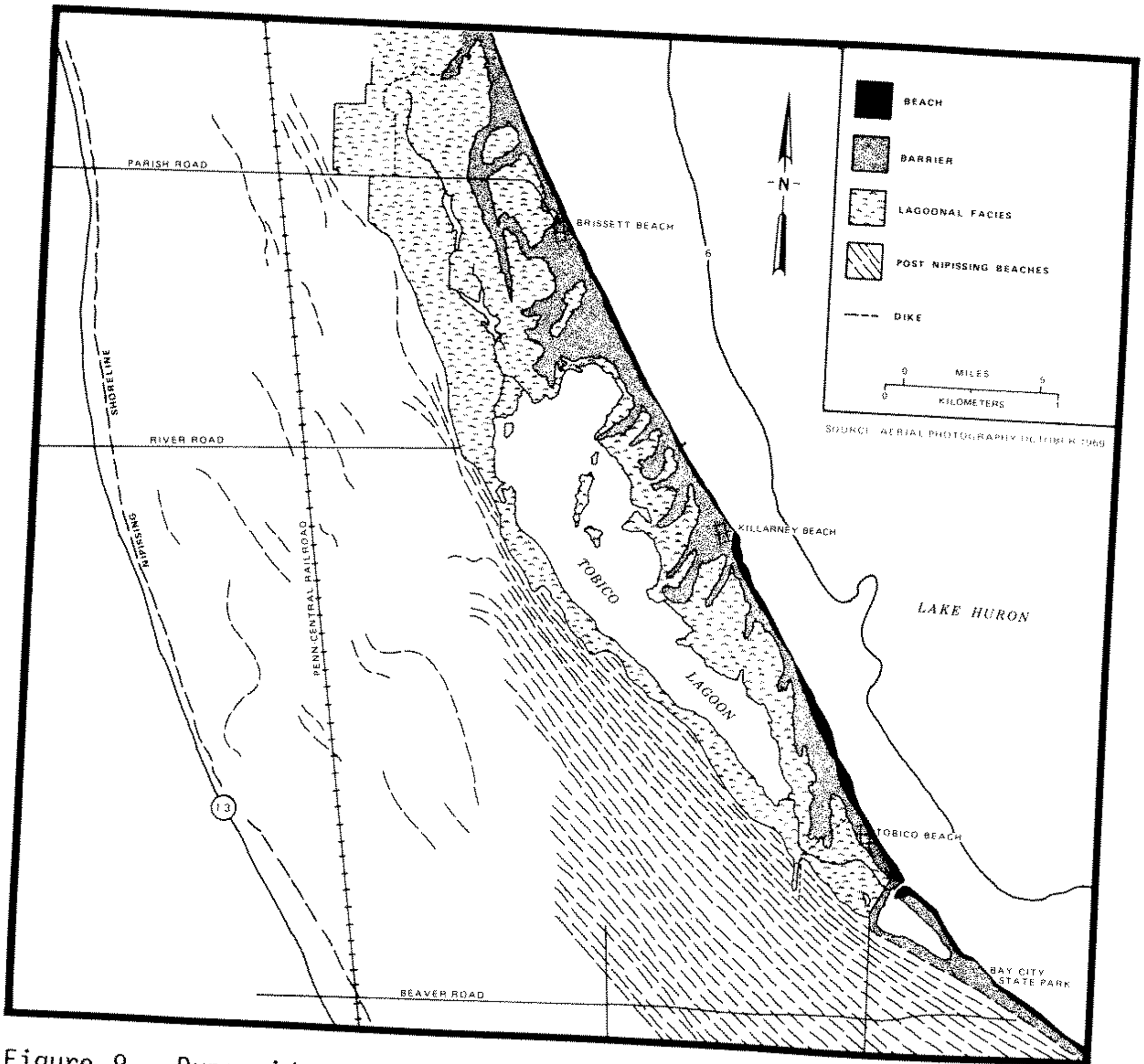


Figure 9. Dune-ridge barrier on Saginaw Bay, Michigan (Jaworski and Raphael 1979).

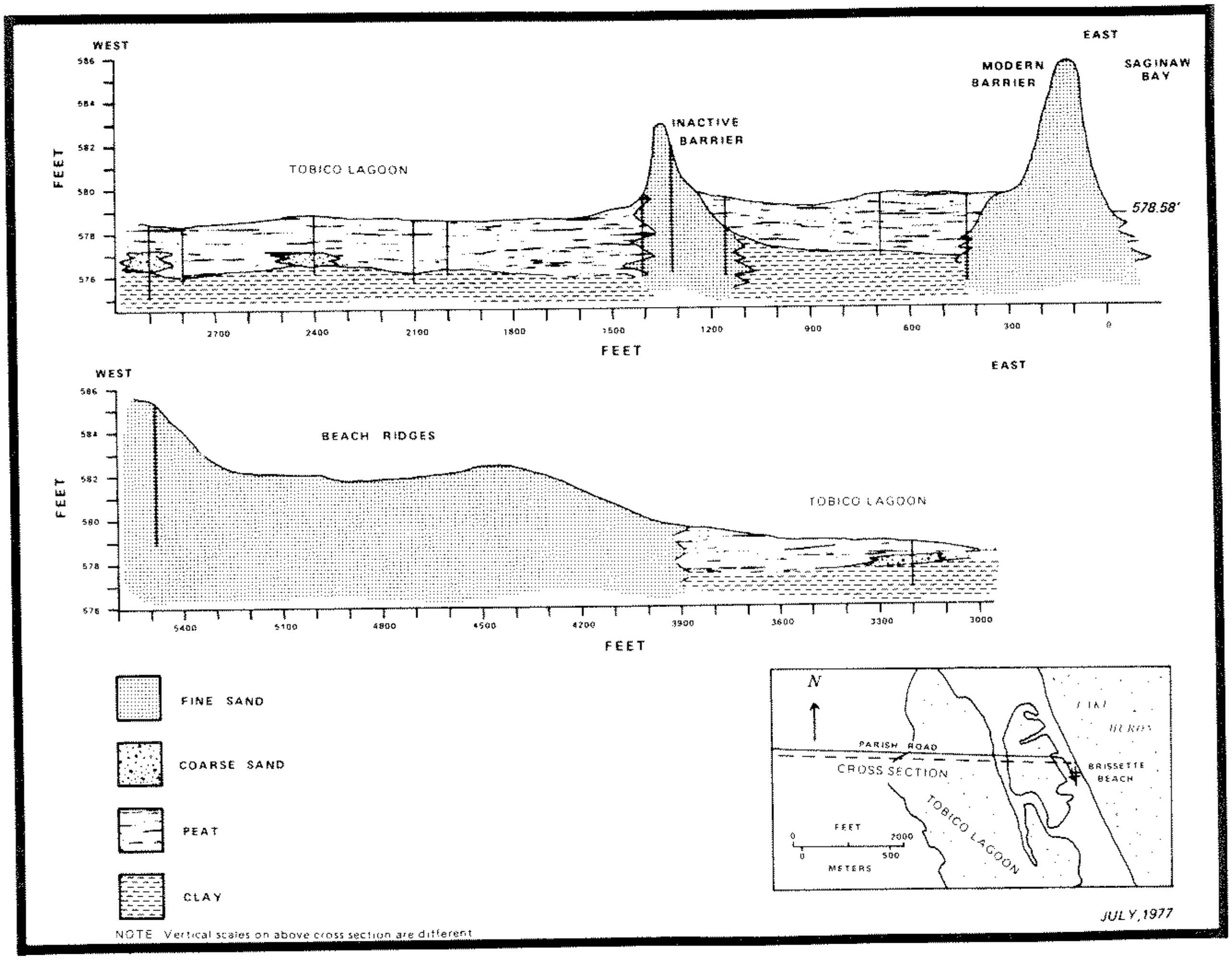


Figure 10. Barrier stratigraphy in Saginaw Bay, Michigan (Jaworski and Raphael 1979).

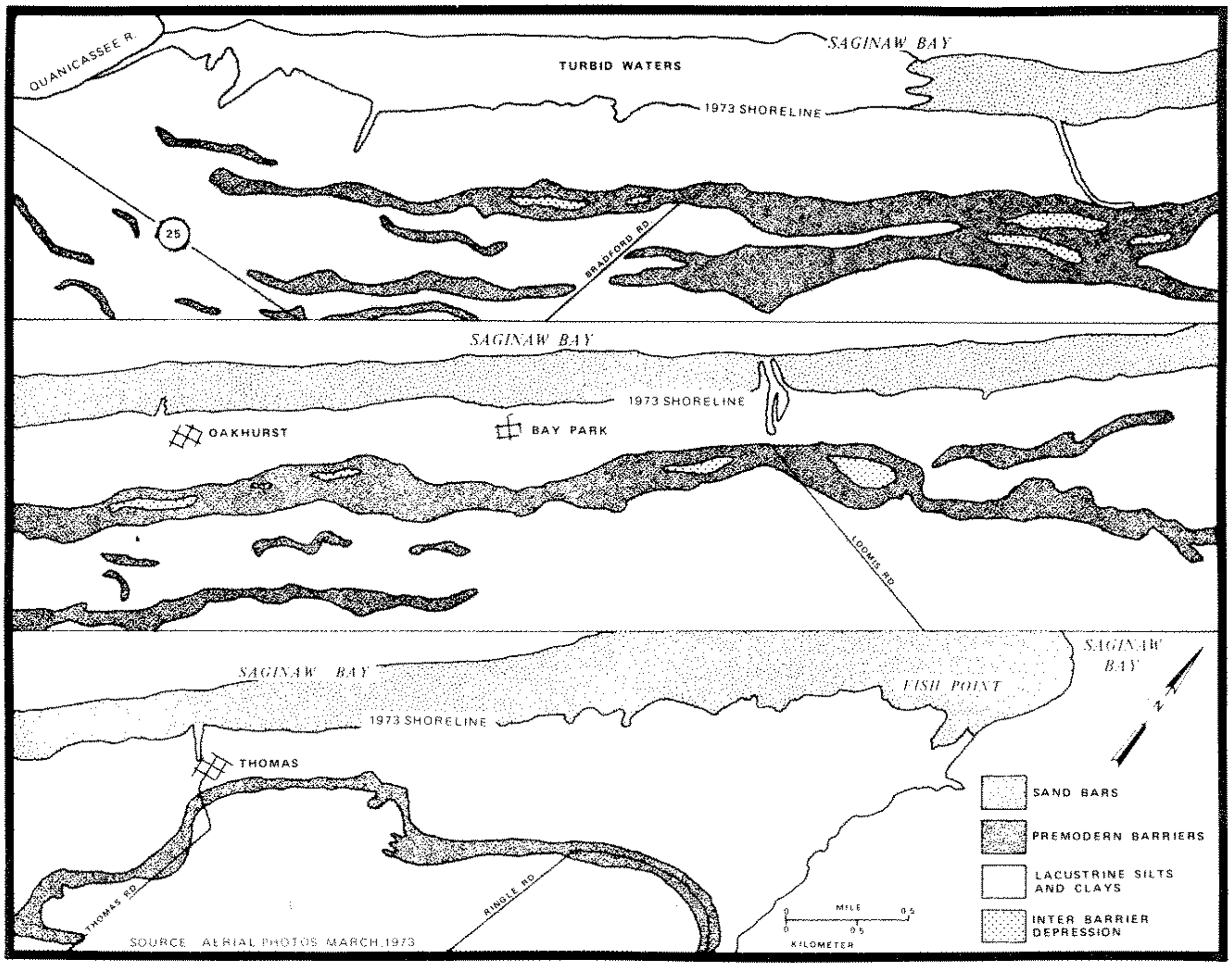


Figure 11. Barrier development on the south shore of Saginaw Bay, Michigan (Jaworski and Raphael 1979).

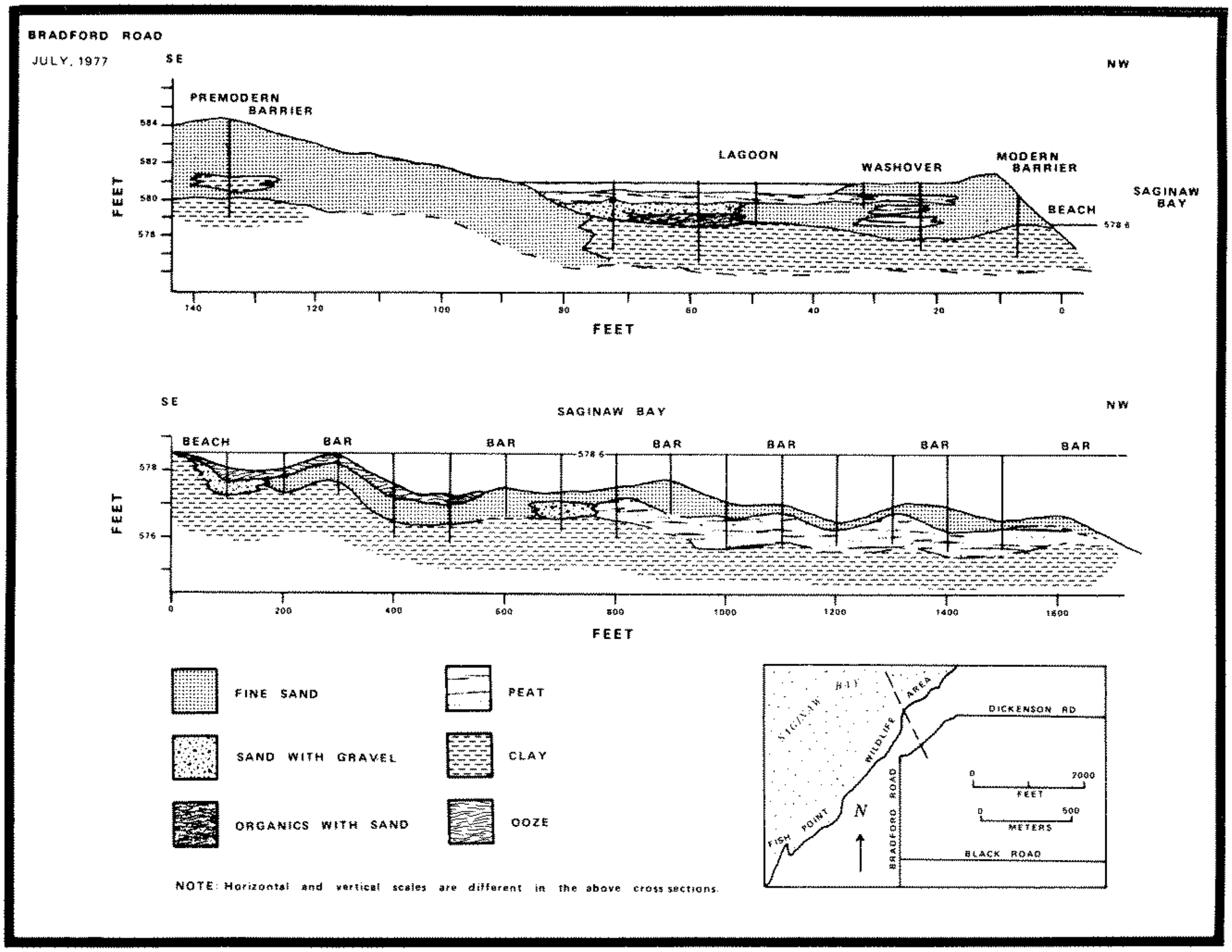


Figure 12. Barrier stratigraphy on the south shore of Saginaw Bay, Michigan (Jaworski and Raphael 1979).

LAKE ERIE BARRIERS

Lake Erie surpasses only Lake Ontario in size. It has the shallowest maximum depth of all the Great lakes, only 210 ft. The length of the shoreline from the Detroit River to Niagara Falls is 388 mi. Western Lake Erie is shallow, generally less than 33 ft deep, which contributes to the great fluctuations in water level. These fluctuations are greater than those on any of the other Great Lakes. A westerly wind setup on March 22-23, 1955 over Lake Erie caused a 5 ft rise in water level at Buffalo and a corresponding 7.5 ft lowering of the lake at Toledo (Figure 13) (U.S. Army 1975). This event was exceptional since a water level rise or fall of an inch or so is the norm.

The shoreline may be divided into two distinct regions based upon physiography. The western one-third of the coastal zone is situated on a low clay plain; the eastern two-thirds is adjacent to the northern margin of the Appalachian Plateau. The western end of the shoreline developed on ancestral lake bottom deposits. The plain is bisected by the Maumee River, the largest fluvial system to the Great Lakes. Sediments in the western section are mostly silt and clay. East of Cleveland, Ohio, the plain eventually narrows to a point where the shoreline abuts higher premodern shorelines and occasionally bedrock which has been dissected by deep river valleys.

The coastal barriers of the Lake Erie shoreline may be divided into two sections similar to the regions described for Saginaw Bay in Lake Huron. From the Detroit River eastward to Mentor, Ohio, the barriers are thin and have low elevation. Farther east, an abundant sediment source for barrier development is evident in larger, wider barriers such as Presque Isle.

The contrasting barrier morphologies may be attributed, in part, to the subsidence of the western Lake Erie Basin. As noted by Shaffer (1951) it appears that the western basin is subsiding at a rate of 6-24 inches per century. Drowned river mouths of major streams flowing into Lake Erie (e.g., Sandusky Bay, Ohio, and Swan Creek, Michigan) have been cited as evidence of such subsidence. Commercial sand dredging operations in the Maumee Bay area may have deprived the basin of a sediment source as well (Ohio Department of Natural Resources 1960). Maintaining barrier stability on a subsiding shoreline is difficult, especially since the sediments being discharged into Lake Erie are quite fine.

The coastal barriers of western Lake Erie display a diversity of forms. Originally linear in shape, the Woodtick Peninsula and Cedar Point deposits have been altered to form cuspate forelands, washover-inlet islands, and simple dune-ridge islands. At Sandusky, the deposit effectively blocks the entrance of Sandusky Bay and forms a bay-mouth barrier some 2.7 mi along the shoreline.

The geomorphic character of the Ottawa barrier has been investigated in detail (Jaworski and Raphael 1979). Washover deposits and breaches suggest that flooding is a recurring problem (Figure 14). Riprap is used on much of the low barrier to protect against further erosion. In cross section, the barrier is approximately 10 ft thick and sits atop older lake clays (Figure 15). Lenses of organic sediment occasionally mixed with silt and clay are

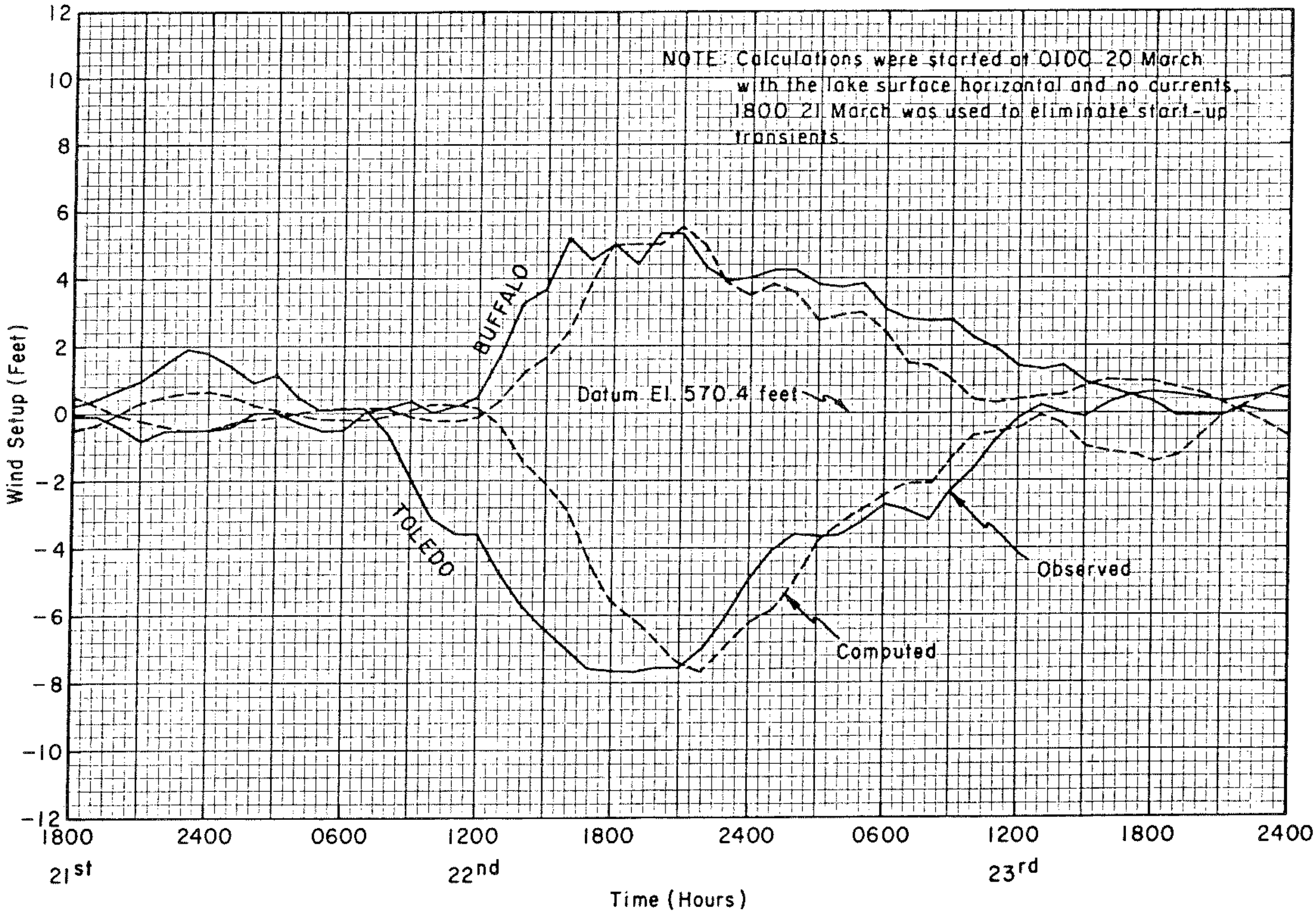


Figure 13. Wind setup hydrograph for Buffalo and Toledo, March 1955 (U.S. Army Corps of Engineers 1975).

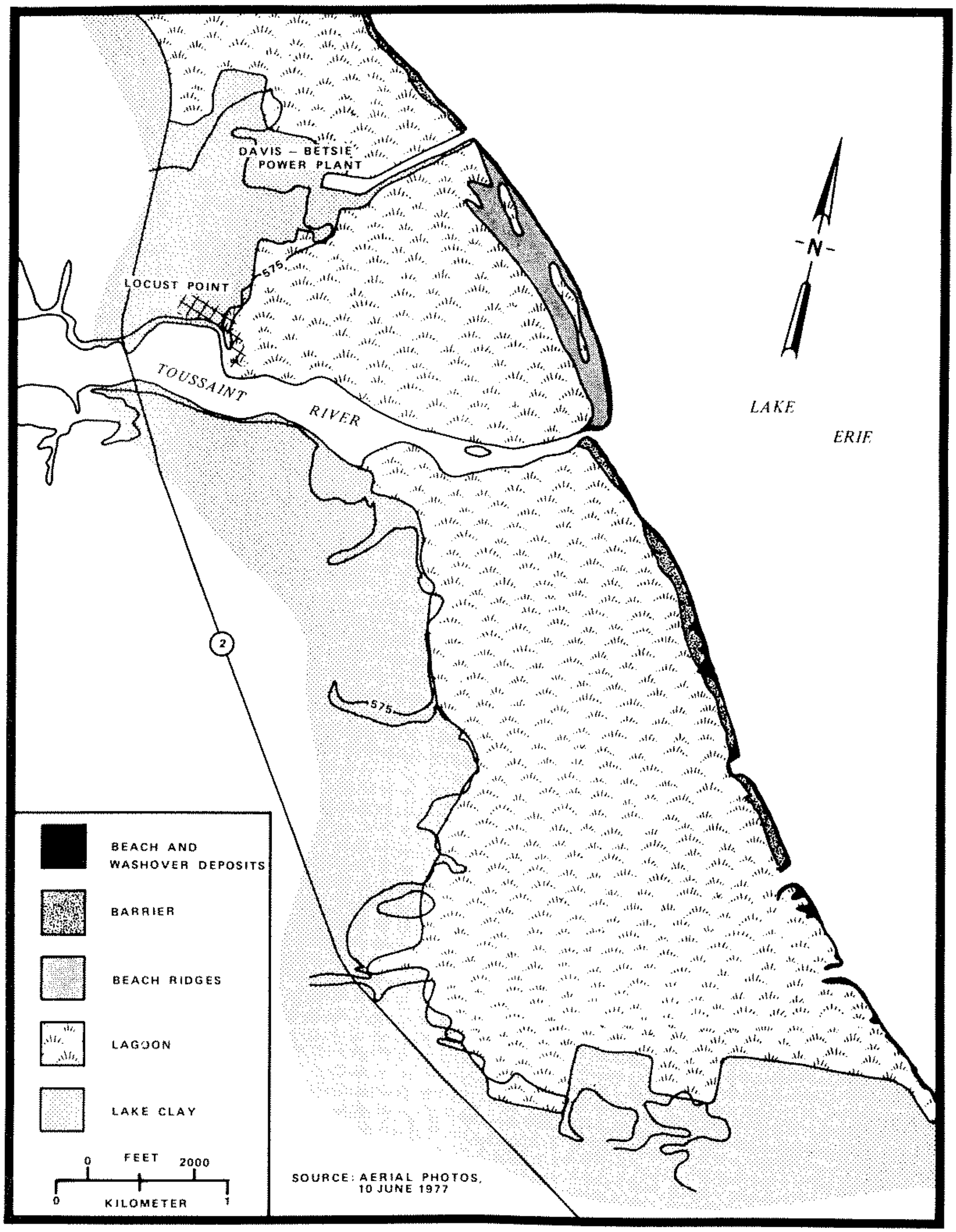


Figure 14. Barriers on the south shore of Lake Erie, east of Toledo, Ohio (Jaworski and Raphael 1979).

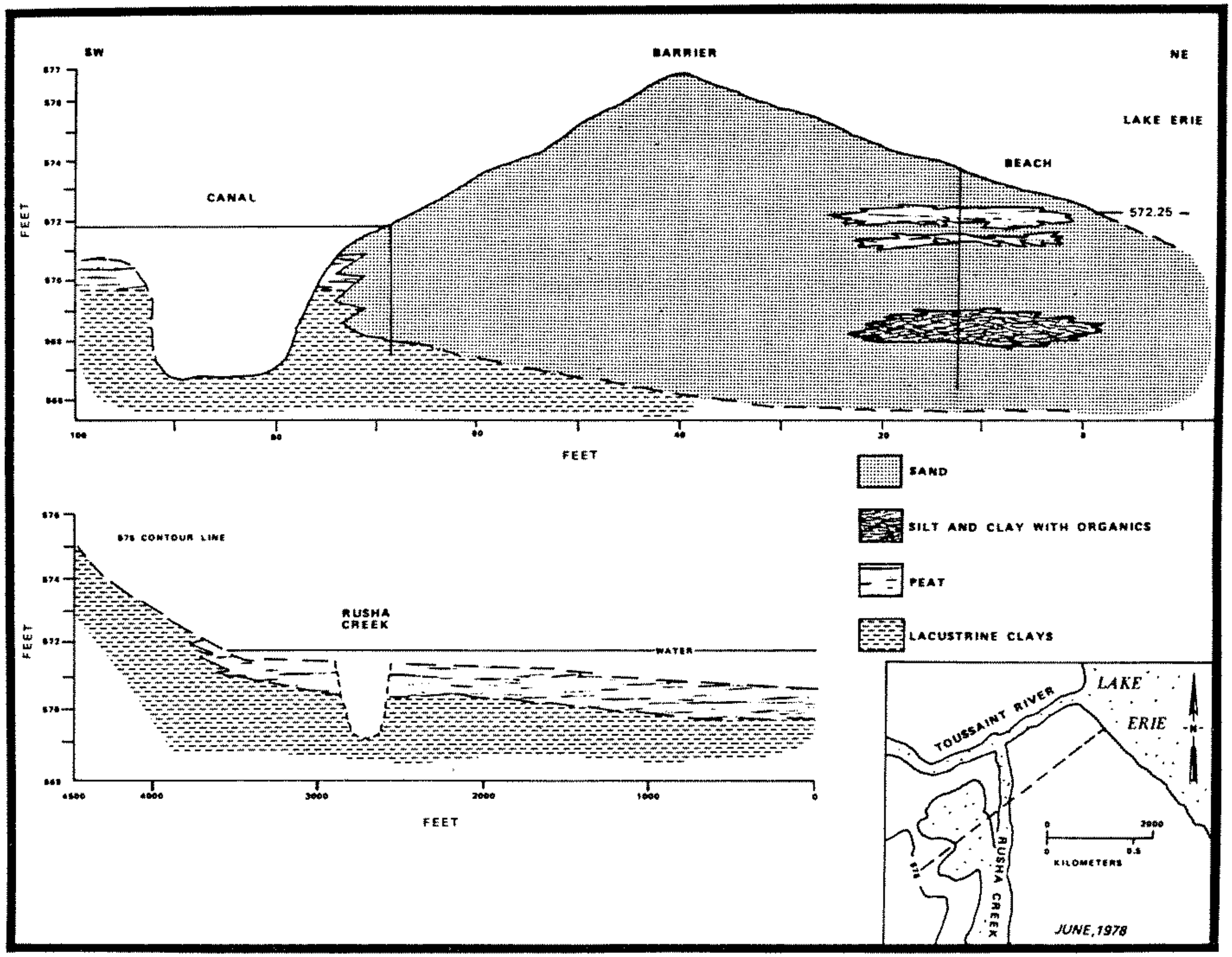


Figure 15. Barrier stratigraphy, south shore of Lake Erie (Jaworski and Raphael 1979).

interspersed with the barrier sands. Profiles in other western Lake Erie barriers reveal similar sedimentary and stratigraphic relationships, indicating that, with few exceptions, the western Lake Erie barriers are generally erosional in origin.

Presque Isle is the largest coastal barrier in Lake Erie in both length (6.8 mi) and area (5,014 acres). An arcuate dune-ridge complex, it is composed of many accretionary ridges cresting 20 ft above lake level and separated by linear ponds vegetated by wetland plant communities. The longshore currents are from the west, skewing the barrier to the east. Several breaches have occurred in the narrow neck of Presque Isle over the past 150 years which have been maintained by dredging.

LAKE ONTARIO BARRIERS

Lake Ontario, the smallest of the Great Lakes, has the shortest shoreline (290 mi) within the United States. The lake has the smallest surface area, but has a mean depth that is second only to that of Lake Superior. The basin perimeter is part of the Erie-Ontario Lowlands. The glacial deposits here are thicker than those generally found around other lakes and consist of lacustrine sediments and intermittent gravel beach deposits laid down during higher lake levels. In the western coastal counties, broad lagoons (locally called "ponds") and wetlands occur between old shorelines and the present Lake Ontario shoreline. Many of the bluffs along the shoreline are truncated drumlins or other glacial landforms. Bedrock outcrops are confined to the shoreline east of Niagara Falls and to the confluence of Lake Ontario and the St. Lawrence River (Jefferson County, New York).

Rivers flowing into Lake Ontario are short and have relatively steep gradients. From Rochester eastward the rivers flow into embayments which are the principal commercial harbors on Lake Ontario. Coastal barrier development is more prominent within this geomorphic setting.

The barriers generally are bay-mouth barriers or dune-ridge barriers adjacent to open bays or small coastal lagoons. In the coastal zone from Braddock east to Sodus Bay, narrow bay-mouth barriers are anchored to adjacent glacial deposits. The lagoons landward of these coastal deposits are often deep, in some cases in excess of 16 ft. The sediments for barrier development are derived from glacial bluff erosion along the lake shoreline. Eastward, shallow depressions of glacial origin are blocked from Lake Ontario by narrow bay-mouth barriers.

Northward from Pulaski to Sandy Creek there is a series of linear dune-ridge barriers separating flood ponds from the lake. Flood ponds or lagoons in depressional areas are physically separated by barriers with sand or cobble beaches (Geis and Kee 1977). The ponds are hydrologically connected to the lake by subsurface seepage or through stabilized breaches in the barriers. The barriers are classic "barrier islands," unconnected to the glacial uplands.

North of Henderson Bay, the coastal zone contains numerous northeast-southwest oriented embayments. Small curved bay-mouth barriers have been deposited at the mouths of these embayments. The barriers are composed of a single ridge and do not have significant dune or overwash deposits. Wetlands occur inside the embayments.

BARRIER MORPHOLOGY

To better comprehend the coastal barrier framework of the Great Lakes, morphologic models have been developed (Jaworski and Raphael 1979). These models represent map views and illustrate topographical relationships of Great Lake barriers and lagoons (Figure 16).

Figure 16A represents a lagoon and wetland habitat isolated from the lake by a bay-mouth barrier. Around the inland perimeter of the wetland, upland sediments are encountered which may represent premodern lake terraces or glacial features. The nearshore zone is composed of gently sloping submarine topography often characterized by emergent wetlands. Representative coastal zones include selected areas of western Lake Erie, Saginaw Bay and Lake Superior.

The morphology represented in Figure 16B commonly occurs along sectors of eastern Lake Michigan where glacial moraines and lake terraces represent former shorelines. Rivers have cut deep valleys during lower still-stands of the lake. As the lake rose towards its present level, sediments were deposited and linear floodplains developed. Barriers occurring on such coasts are usually capped with low dune hummocks and the landward side is often composed of water too deep to support emergent wetland plants. Also, along eastern Lake Michigan, excessive wave energies and ice scouring inhibit wetland colonization lakeward of the barrier.

Figure 16C shows a typical barrier in a sediment deficient coastal environment. The barrier is transgressive in nature and impinges on higher land, frequently a former shoreline. The terrain is often undulating and local depressions, often below the ground water table, support isolated wetlands. Low and narrow incipient barriers and offshore bars may develop along the shore line. The secondary barrier deposits often contain organic debris. Nearshore sand bars vegetated with emergent wetland plants probably supply this organic material. Green Bay and the south shore of Saginaw Bay have examples of this barrier setting.

Figure 16D is a map view of a fourth type of coastal barrier. The barrier may be a recurved spit, a series of beach ridges or a transgressive feature. The lagoon is typically vegetated with robust emergents such as cattail (Typha spp.). An important difference between the physical setting for this barrier type and the others is that the upland zone is characterized by a gently rising slope to the uplands. Such barrier habitats commonly occur on ancient lake plain environments and are found in eastern Lake Ontario and western Lake Erie.

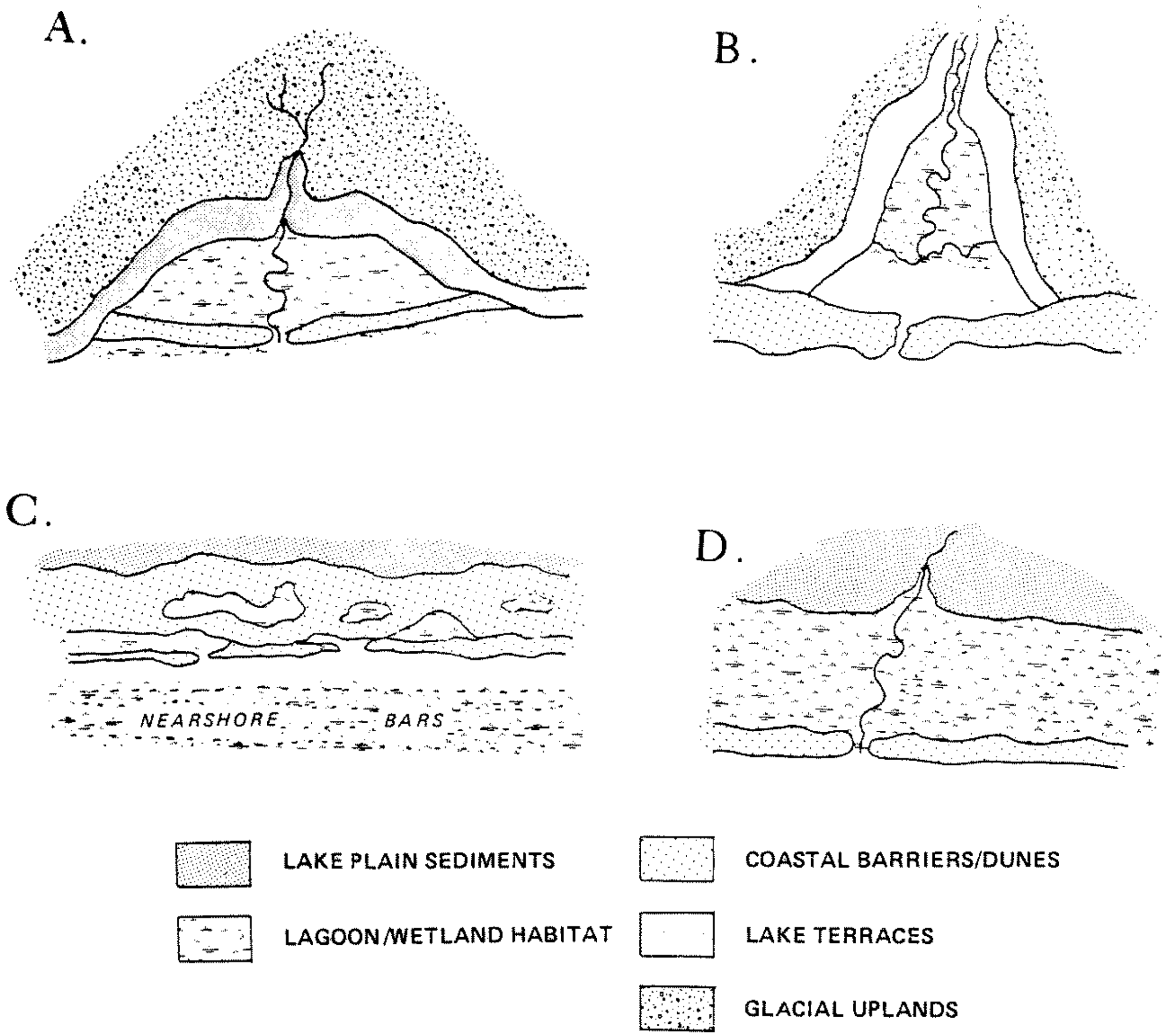


Figure 16. Common barrier morphologies in the Great Lakes (Jaworski and Raphael 1979).

The barrier models reveal the spatial relationships among the nearshore zone, barrier, lagoon, and upland. Barrier thickness, the nature of the barrier and basal (subsurface) sediments, and other factors may vary from one coastal setting to the next. Examples of the types of coastal barrier stratigraphies found along the Great Lakes are presented in Figure 17 (Jaworski and Raphael 1979). Stratigraphic sequences can be used to determine how barriers developed and are a clue to their stability.

Figure 17A represents a narrow barrier deposited directly on marsh clays or silty organic deposits. This type of barrier is erosional in origin and subject to overwash, breaching, and lateral displacement during storms and high-water periods. Normally the thickness of such barriers does not exceed 6.5 ft.

Figure 17B represents a barrier of quite different origins. A relict barrier is rooted in marsh deposits, suggesting that it originated as a depositional landform at present lake level. Subsequently, a younger barrier was created lakeward. The more recent feature is usually poorly developed and characterized by a lens of organic debris. During higher water levels it is inundated or pushed back to an adjacent relict beach ridge.

Figure 17C represents a stable shoreline. The sand barrier is interfingered with the adjacent lagoon sediments and the base of the barrier is a few inches to several feet below mean lake level. This suggests that the barrier was deposited in a nearshore environment and has not been severely eroded. Such a barrier is often 8 ft above mean lake level and capped with poorly developed parabolic dunes or dune hummocks.

A fourth barrier/lagoon complex is illustrated in Figure 17D. The active barrier is wedged against a higher surface, usually a premodern shoreline. The base of the barrier is at lake level and is erosional in origin. Often the barrier is composed of lenses of pea-sized gravel and decomposed organics within a matrix of coarse sand.

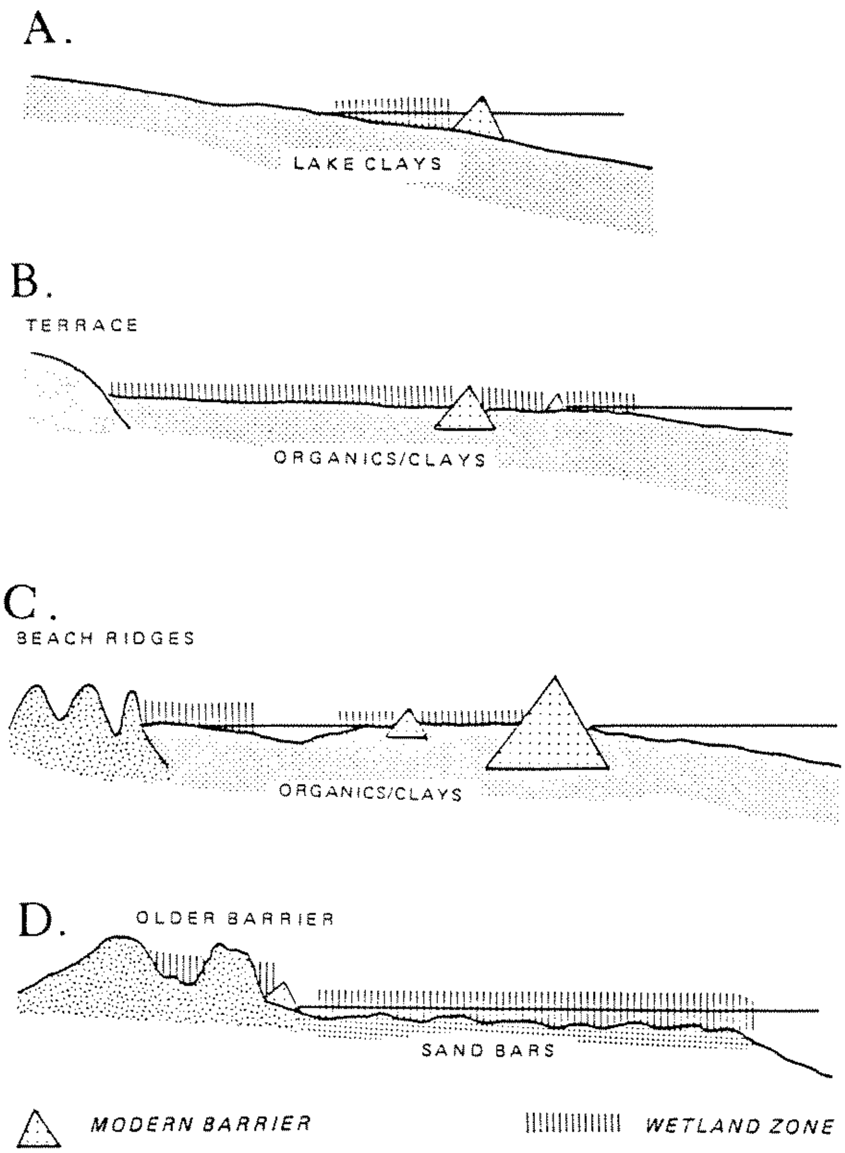


Figure 17. Cross sections of coastal barrier types in the Great Lakes (Jaworski and Raphael 1979).

AN ECOLOGICAL EXAMINATION OF COASTAL BARRIERS ALONG THE U.S. GREAT LAKES

A number of ecosystems are associated with Great Lakes barriers. These ecosystems are oriented parallel to the lake shoreline and arranged in zones. Idealized views of the profiles or cross-sections of two main types of Great Lakes barrier systems are shown in Figure 18.

Both profiles contain similar ecosystems, but the relative positions of the ecosystems in the profile zonation is different. Two major physical factors cause the zonation patterns seen in these profiles: wave energy and water depth. The two types of barriers arise under different intensities of both of these physical factors, but wave energy is especially influential. Along most of the shoreline, where wave energy can be high during storms, barrier type A is found. In this barrier system the beach and island function to absorb wave energy and protect the wetland ecosystems behind them. Barrier type B is found in protected areas, such as in Saginaw Bay, Green Bay, or smaller embayments, where wave energy is not usually as severe as along the open lake shoreline. Under these conditions, wetland plants can grow out into the bay in front of the barrier. Forested wetlands often occur behind barriers in the northern Great Lakes. Below, each main ecosystem type from Figure 18 is briefly described, followed by discussion of some important ecological features of Great Lakes coastal barrier systems.

BEACH ECOSYSTEM

A beach is an accumulation or deposit of wave-washed sediment which extends from the nearshore zone landward to the limit of wave and swash action. In the Great Lakes, beaches can be composed of a broad range of particle sizes from fine organic matter to gravel or cobbles. As an ecosystem, the beach is dominated by physical processes. A typical feature of this system is an accumulation of organic detritus just above the swash zone, referred to as beach wrack. This detritus generally originates from terrestrial plant material flushed in to the lake along with aquatic plant material uprooted from the nearshore zone. Decomposer organisms such as beetles, flies, and isopods inhabit this detritus, and are preyed upon by shorebirds. Dense growths of Cladophora and other attached filamentous green algae are also characteristic below the water line of Great Lakes beaches where hard substrates are available (International Association For Great Lakes Research 1982a). Cladophora growth can be dense enough in some areas to reach nuisance levels. In the upper Great Lakes the nearshore zone is used extensively by trout and salmon species for feeding.

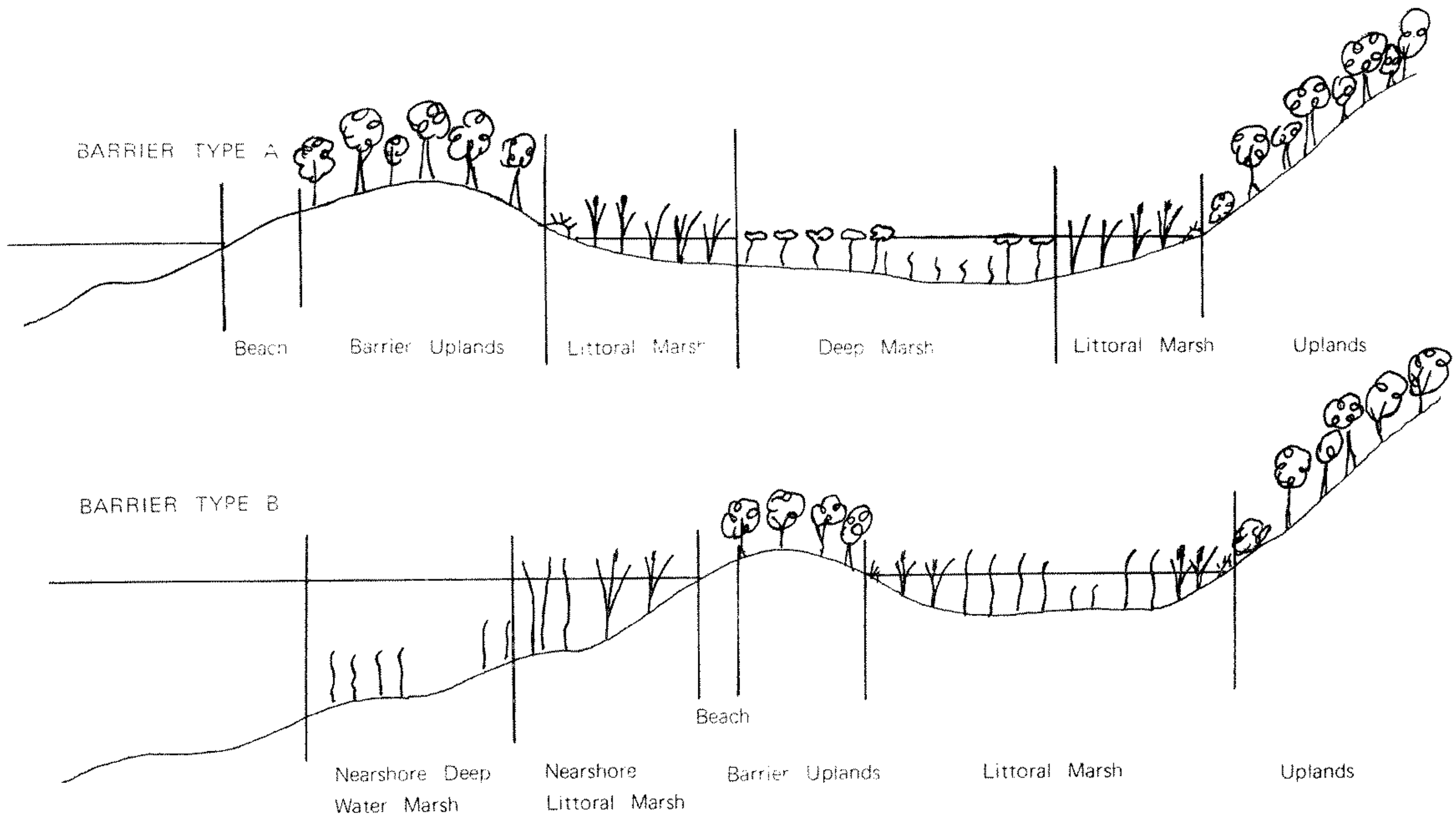


Figure 18. Profile of ecosystems on Great Lakes barriers. Barrier Type A is found where wave energy is high and Barrier Type B where wave energy is lower.

Low, hummocky wind deposited dunes are sometimes found along the beach and on the upland part of the barrier. These may be free of vegetation or colonized with grasses or shrubby forest. Some of the classical work on plant succession across physical gradients has been carried out in Great Lakes dune systems (Cowles 1899; Olson 1958).

BARRIER UPLAND ECOSYSTEM

Coastal barrier uplands are elevated 3-10 ft above lake level. The elevation controls the vegetation type. Low elevation barriers are dominated by herbaceous plants (grasses and sedges) while higher elevations support woody communities. Common species are willow, aspen, maples and ash on wetter sites, and oaks and hickories on dry sites.

Soils of barrier uplands can be sand size and without much clay, similar to barriers along the Atlantic and Gulf Coasts. On the sandy soils of the barrier upland, rainfall drains quickly through the soil, leaching nutrients out of the root zone. This characteristic of barrier upland soils causes most of the nutrients to be stored in the leaf litter layer. Plants respond to this condition by developing a high concentration of fine roots in the upper soil to maximize the surface area for uptake of nutrients that leach through the litter and soil.

The mineral cycling of barrier upland terrestrial ecosystems is tight, with the main reserve of nutrients held in biotic components (litter and roots) rather than in abiotic components (mineral soil) as is common in other temperate zone forests and grasslands. This kind of nutrient cycle is fragile and easily disrupted by impacts to the litter layer, such as trampling by grazing animals or by people.

A unique nutrient source for barrier upland ecosystems along marine coasts is aerosols deposited by wind (Etherington 1967; Clayton 1972; Art et al. 1974; van der Valk 1974). Whether or not nutrients are transported from the Great Lakes to the surrounding terrestrial ecosystems through aerosols has apparently not been examined. Most Great Lakes research on atmospheric deposition has concerned its role as a non-point source in lake pollution (International Association for Great Lakes Research 1982b).

Food webs of the barrier uplands are mostly detritus-based, centering on the leaf litter layer and dominated by soil invertebrates and small mammals. A small portion of energy is transferred along grazing pathways, primarily from leaves to insects to birds. Overall, net primary productivity of the barrier uplands may be less than in surrounding wetland ecosystems. However, when forested, the barrier upland ecosystem may have more biomass or standing crop than the wetlands. Forested uplands can also help stabilize the barrier and protect the back-barrier ecosystems.

Terrestrial ecosystems surrounding the barrier and back-barrier are similar to the barrier upland in structure and function. Their special role is as a buffer area, providing additional habitat for mammals and birds that forage over large areas.

LITTORAL MARSH

The littoral zone extends from the land edge to a water depth of approximately 6.5 ft. Important plant species are emergent, with leaves extending out of the water. Dominants include robust cattail, burreed, arrowhead, and pickerelweed. These usually occur as dense monocultures of single species. Littoral marshes have the highest net primary productivity of any ecosystem.

An important feature of this marsh is the thick rhizome (underground stem) mat in the top layer of sediment. The mat has several roles in maintaining high productivity. It stabilizes the shoots, allowing them to reach heights of up to 10 ft. This height provides for large leaf surface area, which is important in photosynthesis. Since aboveground shoots die back each year due to low temperatures, emergent plants store food reserves in the below ground rhizomes over winter. During spring, this reserve allows rapid development of leaves for high productivity early in the growing season. The mat and dense structure of stems also helps to increase sedimentation from water flowing into the marsh from upland sources. This property causes the littoral zone marsh to act as a filter, buffering the lake water from runoff pollution.

Food webs in littoral marshes are mostly based on detritus. However, muskrats consume rhizomes and cut aboveground shoots for lodge construction, creating a significant grazing pathway.

DEEP MARSH ECOSYSTEM

Plants whose leaves float on the water form a zone beyond the littoral marsh in intermediate depths. Submerged plants grow in the deeper waters, extending lakeward until limited by insufficient sunlight penetrating to the bottom. Together these two groups make up the macrophyte vegetation of the deep marsh ecosystem. Common floating-leaved plants are duckweed, water lily, and water smartweed; common submerged species include curly leaved and sago pondweed, water milfoil and wild celery. The deep marsh is less productive than the littoral marsh. However, an important feature of the deep marsh is the epiphytic algae that attach to the surfaces provided by the macrophytic plants. Grazing food chains based on epiphytes and benthic algae dominate deep marshes, with top carnivores being fish, turtles, and some ducks. Macrophytes of the deep marsh are especially important in providing structural complexity for fish and cover or refuge for waterfowl.

Although the deep marsh is usually a mosaic of open water and plant patches, a distinct open water ecosystem often occurs in bays or lagoons behind the barrier island. The water is usually relatively shallow in these areas, but without rooted plants. Sediments of the bottom are fine, often with high organic content. Winds can easily stir up the sediments causing significant turbidity in the water column. Rooted plants are excluded from open-water areas because of the combination of water depth, fine sediments and turbidity. The biotic part of the open water ecosystem is dominated by planktonic algae and crustaceans that are fed upon by fish that filter them out of the water. Benthic algae can also be important as primary producers at times of low turbidity. A detritus food web of invertebrates capable of surviving low oxygen conditions exists in the sediments. These animals feed on organic matter that settles out of the water or benthic algae. Carp are major secondary consumers in this ecosystem.

ROLE OF COASTAL BARRIERS IN HABITAT PROTECTION

A primary function that coastal barriers serve is to protect landward aquatic habitats. The barrier, along with associated beaches and dunes, presents an obstacle to wave energy from the lakes. Certain ecosystems behind the barrier would not exist without the barrier. The most common ecosystems in the back-barrier environment are various wetlands which are sensitive to erosion by waves. Many marsh plants can only colonize stable sediments in quiet environments.

The total length of barriers along the Great Lakes represents 8.6% of the total coastline. This means that barriers protect 8.6% of the total shoreline. While this percentage is not large, the particular areas that are protected (wetlands) are important. About 12% of the Great Lakes shoreline has been classified as wetland (Great Lakes Basin Commission 1975) and many of these wetlands are found behind barriers. For example, four of the seven types of wetland that have been used in the wetland classification for Lake Erie are associated with barrier island landforms (International Joint Commission 1981).

BARRIER LANDSCAPE INTERACTIONS

Landscape ecology is a developing discipline within the field of ecology (Naveh 1978; Forman 1983; Risser et al. 1983). Landscapes are a higher level of organization than ecosystems and are characterized by interactions between ecosystems. The ecosystems associated with barriers in Figure 18 are integrated into landscapes by physical factors and the movement of animals. All of the ecosystems in the zonation pattern make up the barrier landscape. As mentioned, physical factors such as wave energy and water level determine the relative positions of different ecosystems in the zonation pattern. The width and off-shore extent of the littoral and deep marshes are determined primarily by the slope of the lake bottom. Runoff also provides a medium for moving organic detritus and sediment from uplands to the aquatic systems.

Through their differential use of ecosystems, large animals (such as mammals, raptors, and waterfowl) also influence the barrier landscape. Because of their high productivity, wetlands provide food for many of these wildlife species. Mahon (1979) suggests that there is "a net flow of aquatic protein into the terrestrial system via piscivores and scavengers ..." in Great Lakes barrier environments. Examples of piscivores are bald eagles and osprey, which nest in trees or other vertical structures such as cliffs, docks, or navigation markers over water, and feed on fish. Scavengers include raccoon, skunk, and opossum. The barrier upland and surrounding upland terrestrial ecosystems provide access to wetlands for these and other wildlife species.

Bays and wetlands behind barriers provide resting and feeding areas for migratory ducks. Certain waterfowl species also use harvested corn and grain fields and deposit nutrients in wetlands through excretion. The greatest diversity of waterfowl, birds, and furbearers such as muskrats occurs at a 50/50 ratio of open water to aquatic vegetation. This condition, which is frequently found in back-barrier environments, has been termed a "hemi-marsh" (Weller and Spatcher 1965; Weller and Fredrickson 1974). Because migratory waterfowl use barrier systems, Great Lakes barriers are also connected at the continental scale with wintering grounds in the southern United States and Mexico.

ECOLOGICAL DYNAMICS OF BARRIER LANDSCAPES

Geomorphic changes in barrier systems were discussed previously. Ecological dynamics are also important in Great Lakes barrier systems. Barriers are subject to temporary short-term water level changes, such as seiches, and to longer-term changes related to water budgets of the lake basins. Although both types of water level fluctuation affect coastal ecosystems, the longer-term changes, on the order of 7 to 10 years, have more impact. These water level changes can cause vegetation dieback, erosion of wetlands or lateral displacements of wetlands. Long-range water level fluctuations over the period of record vary from 48 inches in Lake Superior to 78 inches in Lake Ontario. The average seasonal range varies from 13 inches on Lake Superior to 23 inches on Lake Ontario.

Water level fluctuations have the greatest effect on wetland ecosystems. Many inland freshwater wetlands undergo senescence and filling as a result of the deposition of organic and inorganic sediments. Great Lakes wetlands do not appear to exhibit the aging process associated with inland freshwater wetlands. Because of the fluctuating water levels of the Great Lakes, constant rejuvenation of wetland communities occurs. As lake levels oscillate, the wetland communities alternately undergo succession and retrogression. In general, during low-water conditions the deep-water marsh communities decrease in extent along with the total area of open water. In comparison, during high-water periods, the open water and floating-plant communities expand while all other communities decrease in extent. Examples of vegetation dynamics caused by fluctuations in water levels in the Great Lakes have been described by Jaworski and Raphael (1979) and Harris et al. (1981). As plant communities change with the oscillation of lake levels, so does the mix of wetland uses and functions. During low-water periods, wildlife such as redwinged blackbirds, short-billed wrens, and muskrats are abundant. In contrast, during high lake levels, aquatic and open-water communities become more abundant, including fish, frogs, turtles, piscivorous birds, and diving ducks.

Two case studies are described below. Figure 19 reveals the beach, barrier, and shallow and deep marsh environments at Tobico Marsh in Saginaw Bay in 1963, 1975, and 1977. These dates represent a low water, high water, and a falling stage of Lake Huron. As water levels fell, the beach increased in width and cattails and sedges aggressively invaded the deeper water marsh. Woody shrubs such as redosier dogwood colonized former sedge areas, and the

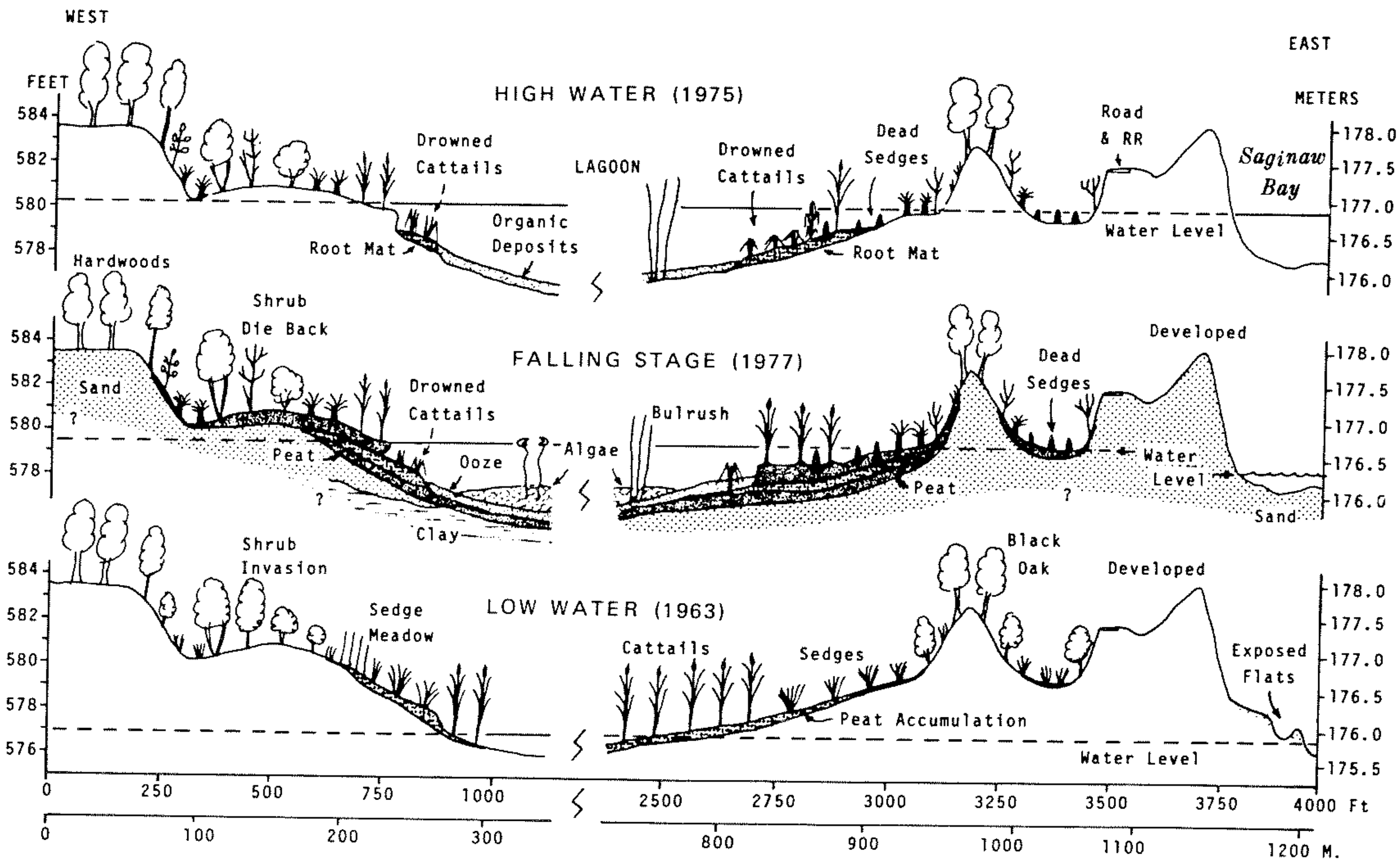


Figure 19. Photo-transects of the Tobico barrier and wetlands, Lake Huron (Jaworski and Raphael 1979).

deep water marsh was severely limited in extent. Marsh and upland plant zonation is maintained, but geographical redistribution occurs.

Figures 20-22 reveal barrier and wetland modifications in 1937, 1964, and 1975 of the Woodtick Peninsula in Lake Erie. The map sequence represents low, average, and high water levels respectively. As lake levels rose, barrier breaching, overwash, and loss of the beach zone occurred. Furthermore, vegetation changes were evident. Table 2 illustrates the percent change in marsh and swamp vegetation. As lake levels rose there was an increase in open water and floating and submersed aquatics and a decrease in all other species. Human impact caused by the construction of an impoundment behind the peninsula can be seen in Figures 21 and 22.

Table 2. Plant community changes at Woodtick Peninsula, in Lake Erie by percent of total area (from Jaworski and Raphael 1979).

	Wetland Types			
Lake Level	Open water floating or submerged vegetation	Emergent marsh	Sedge meadow	Shrub/ forest
Low	44%	25%	3%	11%
Average	54%	20%	2%	9%
High	68.5%	15%	0.5%	6.5%

A characteristic dynamic feature of coastal barriers along the Atlantic and gulf coasts is the "oceanic overwash" cycle (Godfrey et al. 1979; Godfrey and Godfrey 1974). Occasionally the combination of high tides and high waves succeeds in eroding the low-lying foredune and carries sand and shell completely across the barrier and into the back-barrier marshes. This process of "oceanic overwash" has been documented to play an important part in marsh formation because of its role in replenishing sediments and creating new land on the sound side of barrier islands. Overwash cycles have also been described for Great Lakes barrier landscapes by Bayly (1979).

FISH AND WILDLIFE RESOURCES

Fish and wildlife resources of coastal barrier landscapes are highlighted in Table 3. This table includes species designated as having National significance by the U.S. Fish and Wildlife Service (1984) along with species that are commercially important. Most of the commercially important species are harvested by recreational hunters and fishermen, who contribute

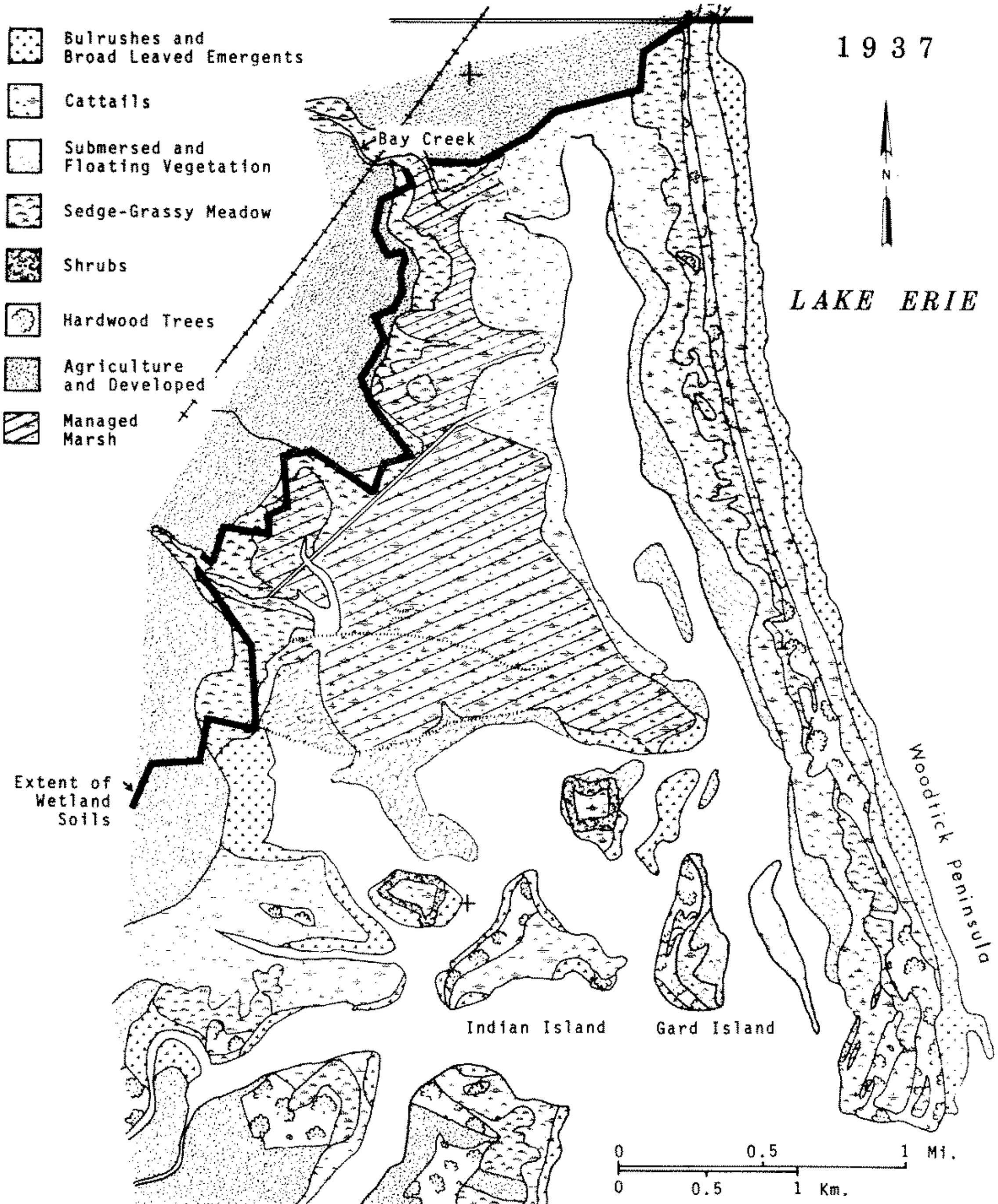


Figure 20. Distribution of vegetation at Woodtick Peninsula, 1937, Monroe County, Michigan (Jaworski and Raphael 1979).

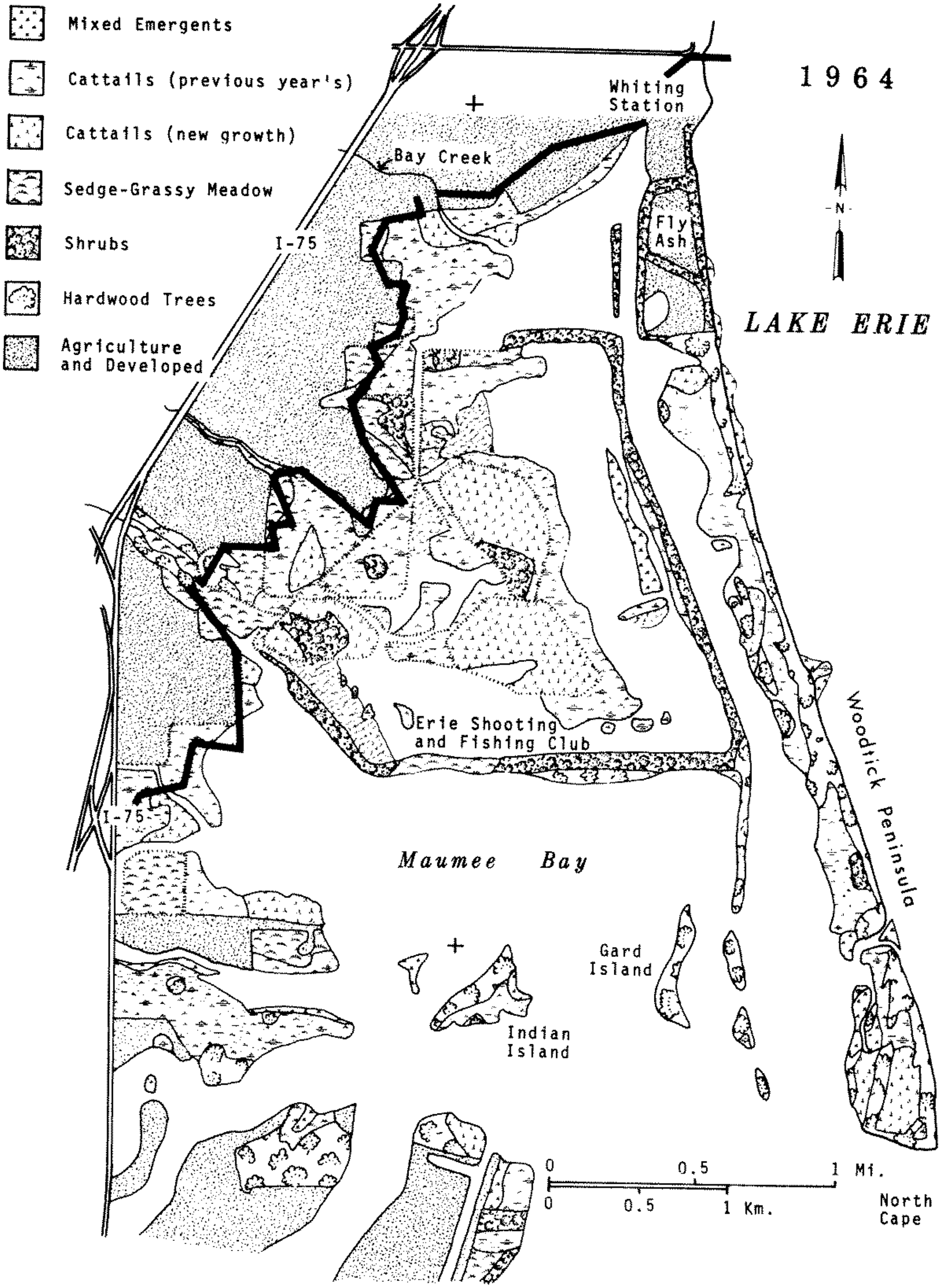


Figure 21. Distribution of vegetation at Woodtick Peninsula, 1964 (Jaworski and Raphael 1979).

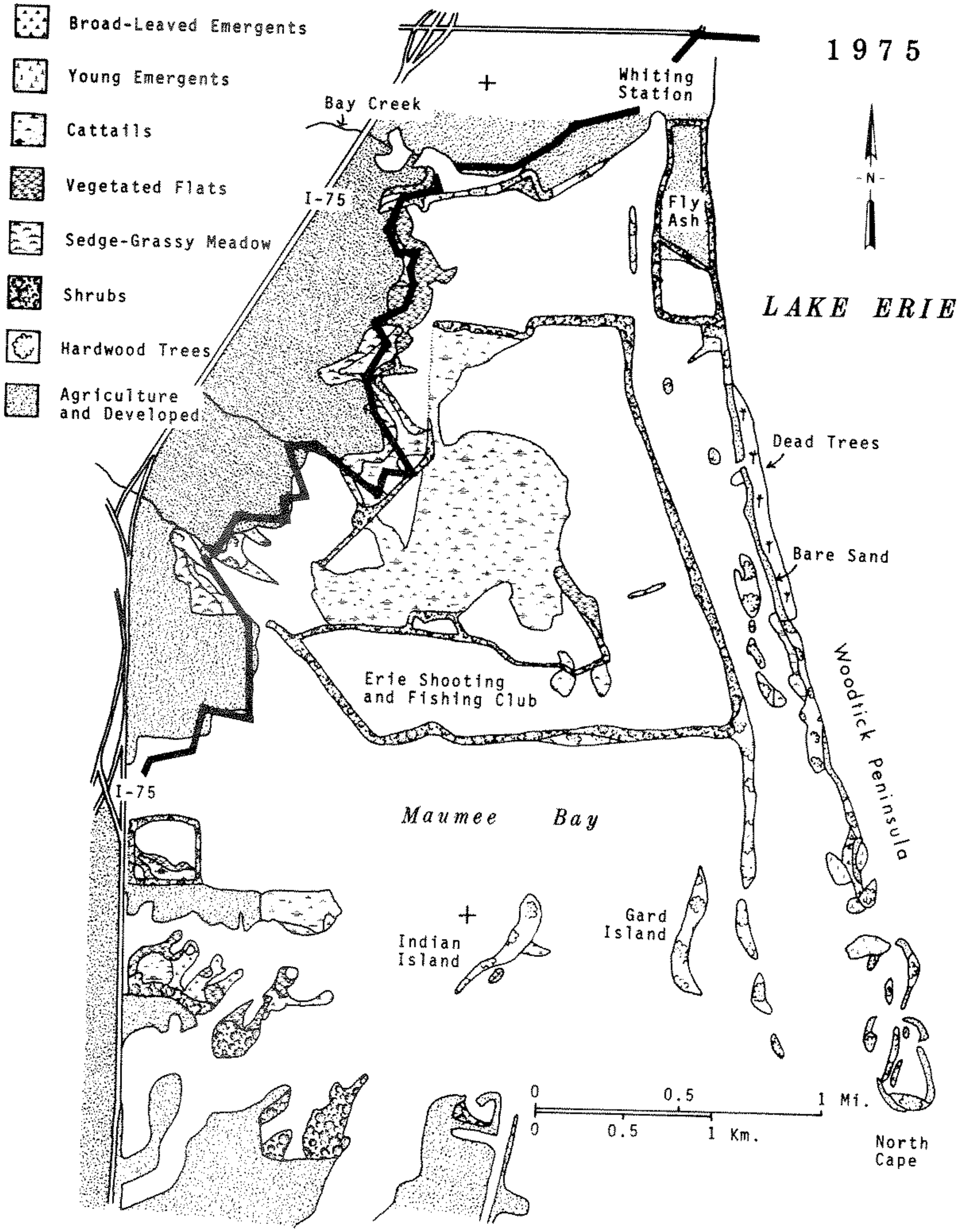


Figure 22. Distribution of vegetation at Woodtick Peninsula, Michigan, 1975 (Jaworski and Raphael 1979).

Table 3. Summary of fish and wildlife use of the ecosystems of Great Lakes barriers.

Species	Ecosystem					Species status		
	Beach	Barrier uplands	Littoral marsh	Deep marsh	Uplands	National species of special emphasis	Endangered species	Commercially important species
Walleye	X			X		X		X
Yellow perch				X		X		X
Carp				X				
Northern pike				X				X
Small and largemouth bass	X			X				X
Lake trout	X					X		X
Wood duck			X	X		X		X
Mallard			X	X	X	X		X
Black duck			X	X	X	X		X
Redhead			X	X		X		X
Canvasback			X	X		X		X
Canada goose			X	X	X	X		X
Osprey		X		X	X	X	X	
Common tern	X					X		
Great blue heron		X	X	X	X	X		
Raccoon	X	X	X		X			X
Muskrat			X	X				X
White-tailed deer		X	X		X			X
Gray wolf		X			X	X	X	
Indiana bat		X		X	X	X	X	

significantly to local economies. Particularly important species are described in the text that follows this introduction. More detailed descriptions of life histories for most of these species and others especially associated with Great Lakes coastal wetlands are given by Herdendorf et al. (1981).

Most of the important fish and wildlife species are distributed throughout the Great Lakes wherever their habitat needs are met. However, the Great Lakes do extend over a considerable range of latitude and there are examples of species being limited to, or at least more common in either the northern or southern portion of the lakes. Moose, gray wolf, and lake trout are typical species found in the northern lakes region. River otter, osprey, and bald eagle are also more prevalent in the northern lakes, but probably because of lack of human development rather than biogeographic limitation. Species more common in the southern Great Lakes are the percid fish (yellow perch and walleye) and carp. Vegetation differences are also apparent between northern and southern barriers and surrounding uplands, with spruce, fir, and birch common along the northern lakes and ash, maple, and cottonwood along the southern lakes.

Fish

All of the fish listed in Table 3 use the deep marsh habitat behind barriers. These and other coastal wetlands are important to fish production because they provide spawning and nursery habitat for wetland-dependent species, cover for juvenile fish, and feeding areas for predatory fish. Since spawning is a particularly sensitive part of the life history, the function of coastal wetlands as spawning grounds is of prime importance. All of the fish species listed in Table 3, except the walleye, are known to spawn in coastal wetlands or other nearshore zones. A recent survey of spawning behavior and distribution of Great Lakes fishes was conducted by Goodyear et al. (1982).

Two percid species, walleye and yellow perch, are important in both the offshore sport and commercial fisheries of the lower Great Lakes. Northern pike, lake trout, and the basses are important in the inshore sport fishery. These species are predators with large juveniles and adults feeding on aquatic insects, crayfish, annelid worms, mollusks, and small fish. Carp are significant in back-barrier wetlands because of their effect on the ecosystem rather than their role in a fishery. This is an exotic species which was introduced into the United States in the late 1800's from Europe. Originally carp were stocked for sport fishing but they were soon found to be a nuisance species. Carp have proved to be a superior competitor under certain circumstances, and have invaded the Great Lakes and all freshwater systems of the midwestern United States. The food source for carp is particulate organic matter and submerged aquatic vegetation. Carp are important because their feeding activity causes increased turbidity and disturbs the spawning of other species. Another significant group of fish that both spawn and feed in back-barrier wetlands are minnows and shiners. These are forage or prey for piscivorous fish and birds. Diatoms, zooplankton, and small invertebrates are the principal food for these species and for small juveniles of other species.

Birds

Perhaps the most conspicuous wildlife species of coastal barrier landscapes are birds. Avifauna using barrier habitats are a diverse assemblage of waterfowl, wading birds, raptors, and other water birds. In addition, more than 200 species of nonwater birds use the Great Lakes shoreline.

Most of the bird species listed in Table 3 are waterfowl. During fall and spring migrations waterfowl feed and rest in Great Lakes coastal wetlands using both littoral and deep marsh habitats. During migrations, lakes behind dunes are also important refuge areas during storms. It has been estimated that at least 3 million waterfowl migrate annually through the Great Lakes region from both the Atlantic and Mississippi flyways. Several species are also known to breed in coastal wetlands, including mallards, black ducks, blue-winged teals, and others. Waterfowl are usually divided as dabblers, which reach with their bills for vegetation growing on the lake bottom, and divers, which actually swim underwater. Food items are emergent and submerged plants along with benthic invertebrates. Those species listed as using the surrounding upland habitat in Table 3, also feed on waste grains. Dabbling ducks, including the wood duck, mallard, black duck, and the teals, are the most important species harvested by hunters. Diving ducks such as the redhead and canvasback and the Canada goose are generally less important but significant in local areas for recreational hunting.

Both osprey and great blue heron are primarily piscivorous species, but they use barrier habitats in very different ways. Osprey feed from flight in open water and deep marsh, while heron feed by wading through shallow wetland habitats.

Gulls and terns are another significant group of birds which use barriers. As an example, the commern tern nests in colonies on beaches, sandspits, and low barren islands. This group may be the most dependent on barriers because of their specific nesting habitat requirements. Works by Scharf (1975, 1978) are important references on the distribution of gulls and terns and other colonial nesters using Great Lakes shorelines.

Mammals

Mammals of barrier landscapes include those using a variety of habitats and others limited to specific habitat conditions. The muskrat is probably the most abundant mammal species in Great Lakes coastal wetlands. This species leads all other North American wild furbearers in numbers caught and in overall value of pelts. Rhizomes of cattail and other emergent plant species are preferred food. The muskrat is restricted to marsh systems and overwinters in lodges constructed of emergent plant shoots.

The raccoon is another important furbearer species abundant around barriers. Raccoons are omnivorous and feed in all habitats except the deep marsh. They live primarily in dens in tree holes. The white-tailed deer also ranges over a variety of habitats. This species is important because it is harvested by recreational hunters. Deer eat a diversity of plant parts such as berries, leaves and bark. Other species found primarily in upland habitats of barrier landscapes include small mammals (bats, rabbits, mice, squirrels), omnivores (skunks, foxes, opossums) and predators (wolves, mink, and weasels).

HUMAN INTERACTIONS WITH COASTAL BARRIERS

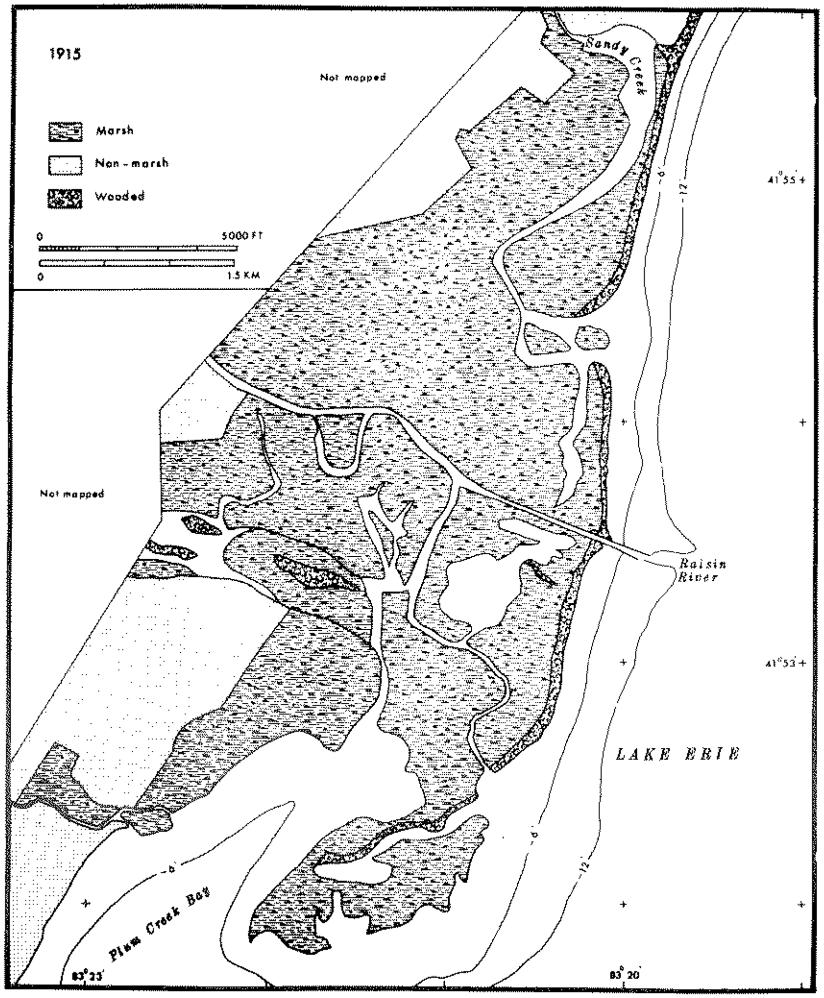
Humans are attracted to coastlines and make use of them for living space, for the harvest of natural resources, and for recreation. These uses are often accompanied by impacts which impair the ability of coastal ecosystems to function. Any decisions about the use of coastal barrier landscapes require a careful balancing of productive uses and environmental impact.

Some uses of barriers, such as development, affect the whole landscape, while others affect single habitats or, like hunting and fishing, affect single species populations. Development includes construction of buildings, either commercial or residential, roads, and the infrastructure associated with utilities. Since most Great Lakes barriers are narrow, development is usually limited to residential construction. Barriers are often a preferred location for aesthetic reasons. People like the diversity of habitats associated with coastal barriers. Historically, seasonal homes were the norm, but with increasing populations many of these have become year-round residences, especially in the lower Great Lakes.

Industrial and urban encroachment have been an important cause of barrier and wetland alteration (Jaworski and Raphael 1976). Figure 23 represents a barrier complex between Detroit and Toledo and illustrates modifications which occurred over a 59-year period. Cultural changes, including channelization, filling of marshes, and bulkheading, have degraded the coastal setting. The wooded coastal barrier has lost its diverse ecological function due to human development activities.

When the quality of a barrier is good and habitat disturbance is slight, hunting, fishing, and trapping can be successful. A study by Jaworski and Raphael (1977) lists the economic value of these uses for coastal wetlands that occur behind barriers in Michigan. They found that the economic value of recreational, or sport fishing greatly exceeds the value of commercial fishing within the coastal wetlands themselves. Since wetlands support percid species important in open lake fisheries, some proportion of the value of these fisheries can also be attributed to barrier landscapes. The other major sustained harvest activity directly associated with barrier landscapes is the trapping of furbearers in back-barrier wetlands.

Hunting, fishing, and trapping are considered consumptive uses of wetlands because there is a removal or consumption of part of the ecosystem due to the activities. Nonconsumptive uses of barrier landscapes include bird watching, interpretive studies, nature photography and art, and scientific and educational studies. These uses are more difficult to assess in terms of economic value, but they are important in terms of the number of people involved.



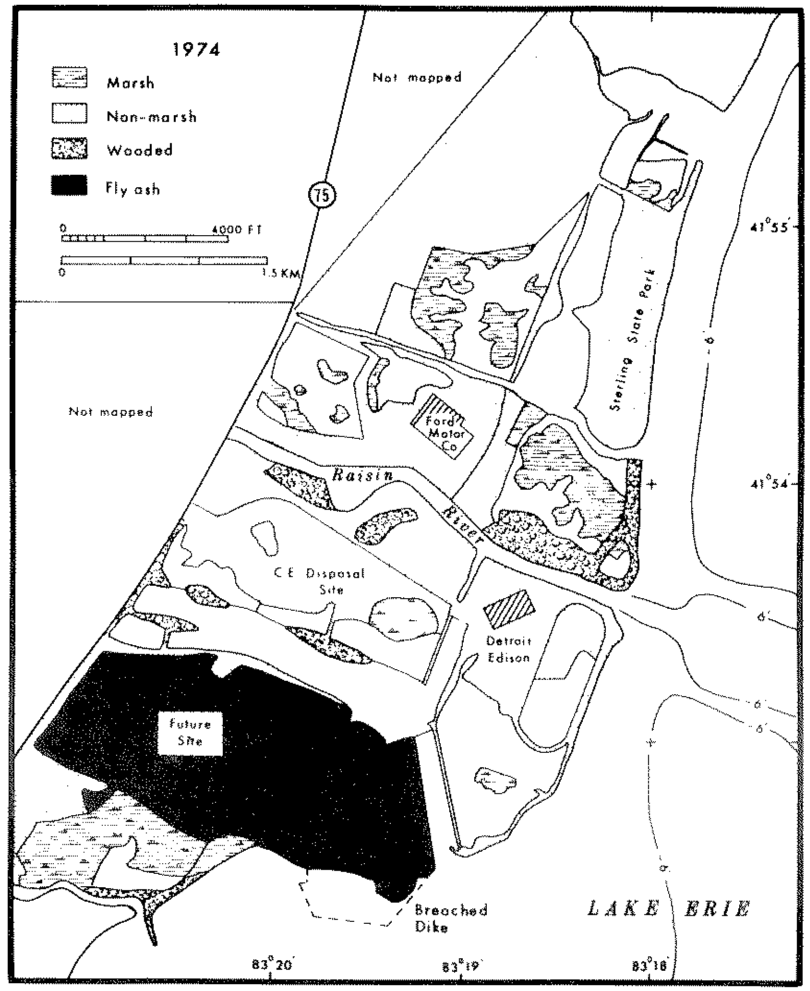


Figure 23. Impact of development at Sterling State Park, Michigan, 1915-74 (Jaworski and Raphael 1976).

Human impacts to Great Lakes barriers are generally similar to those described by Dolan et al. (1973) and Leatherman (1979) for Atlantic coastal barriers. These include a broad range of land use changes and pressures caused by recreation and over-harvesting of fish and wildlife species.

In the Great Lakes, some barriers are relatively stable while others are historically mobile, working their way back towards the uplands. The low profile of the islands, combined with their narrowness and sediment composition, creates a situation of continual physical change. While natural barrier erosion and accretion inhibits development potential, development often changes the patterns of erosion and accretion. Seawalls and groins have been used to try to maintain developments on barriers, but these static features seldom work for very long.

Disruption in sand budgets is the common result of stabilizing efforts. Two case studies illustrate this point. Bosley (1976) traced the historical changes in the Oconto River delta in Green Bay, Wisconsin. Originally the coastal wetlands of the delta consisted of a meandering river behind a coastal barrier. In the early 1900's, the river was channelized and groins were constructed to protect the harbor entrance. As a result of interference in the littoral current patterns, erosion of the barrier and a loss of wetlands have occurred immediately south of the river. At Point Mouillee in western Lake Erie, loss of wetlands through erosion of a barrier has also been documented (Sellman et al. 1974). The barrier in this case was partially supplied with sediments from the nearby Huron River, which drains a significant portion of southeastern Michigan. In the 1920's and 1930's, a number of dams were constructed on the river for hydroelectric generation. These dams created reservoirs which acted as sediment traps. The damming of the river thus decreased the sediment input to the barrier island, which subsequently eroded. As at Oconto, with the loss of the barrier the wetlands eroded because they were no longer protected.

Pedestrian trampling from recreational uses can have a significant impact on specific habitats. This impact causes a reduction in the number of species and in biomass of terrestrial vegetation. Off-road vehicle traffic has a significant effect on coastal barriers of the Atlantic and Gulf of Mexico but is less important in the Great Lakes, probably due to the narrow widths of beaches and islands.

STATE COASTAL RESOURCE MANAGEMENT PROGRAMS

Wisconsin (1978), Michigan (1978), Pennsylvania (1980), and New York (1982) all have federally approved coastal zone management programs (date of Federal approval in parentheses). Indiana did participate in the program until 1981. Since then it has relied on other Federal and State policies to manage its coastal zone. All States do have policies at the State level which address shorelines. These policies are generally directed towards reducing environmental and economic losses caused by coastal erosion and flooding. Concurrently, concern over the loss of wetland habitat and the protection of fish and wildlife has led to wetland protection policies in some states.

The management of the coastal zone varies from State to State. Minnesota, Michigan, and New York have shoreland management programs, whereas Illinois and Indiana do not. Wisconsin, Ohio, and Pennsylvania have unique legislative positions. In Wisconsin, the coastal counties are empowered to regulate shorelands, and in Ohio, the Department of Natural Resources has jurisdiction over some phases of shoreline development. The following discussion summarizes each State's coastal zone policies on coastal barriers. Since Illinois contains no undeveloped unprotected coastal barriers, its policies are not discussed in detail.

MINNESOTA

In 1969 the Minnesota legislature passed the Shoreline Management Act. As stated in the Act, its purpose is to provide guidance for the wise development of shorelines of public waters, to preserve the economic and environmental values of the State shorelands, and to provide for the wise utilization of water and related land resources of the State. Shoreline is defined in this Act as land located within 1,000 ft of the high watermark of a lake, pond, or flowage and land within 300 ft of a river or stream. Under the Act, the Department of Natural Resources has adopted minimum standards to guide the use and development of shoreland areas and each county has adopted a shoreland management ordinance which incorporates these minimum standards. In 1973, the legislature amended the Act by extending its scope to include shorelands in incorporated areas.

To mitigate coastal hazards Minnesota's policies include minimizing artificial fluctuations of Lake Superior water levels, requiring counties and municipalities to adopt shoreline management ordinances that meet statewide standards, and regulating the placement of structures, lot sizes and land uses.

The Public Water Act regulates and protects designated wetlands in the State through a permit process. However, the State approves permits for work in specified wetlands only if the wetland is replaced by another of equal or greater value, or if the proposed use will provide greater public value than an undrained wetland.

WISCONSIN

In Wisconsin, county regulation of shoreland areas within 1,000 ft of lakes and 300 ft of streams is required by the State's Shoreland Zoning Act of 1966. The State regulatory agency is authorized to adopt regulations for shoreland areas if the counties fail to adopt satisfactory controls. The State of Wisconsin has adopted administrative regulations and model shoreline zoning ordinances which encourage conservancy zoning for wetlands within shoreland areas.

The Wisconsin Shore Erosion Protection Plan is a policy to mitigate risk to public health and safety and to reduce property damage in areas subject to natural hazards. This plan includes the requirement of a 75-ft setback from the ordinary high water mark in unincorporated areas unless a previous development pattern exists. The policy requires a review of subdivision plots, roads, structures, and other facilities in flood hazard areas to ensure that citizens are not exposed to unnecessary coastal hazards and that future public expenditures for flood relief are not or will not be required. Nonregulatory policies include provisions for developing and encouraging nonstructured solutions for mitigation of coastal hazard problems by providing technical assistance to local units of government and by supporting research and education on coastal hazards. Wisconsin has, in fact, provided manuals to and worked closely with local governments (Kusler 1983). By regulating development, earth-moving, and devegetation, the problem of accelerated rates of erosion in the coastal zone is, to a degree, mitigated.

Several comprehensive State statutes protect fish and wildlife in Wisconsin. More specifically, wetland protection grew out of the 1966 Shoreland Zoning Act (NR 115). Based on its statutory authority to set standards for shoreland management, the Wisconsin DNR has taken action to revise NR 115 to include special protective provisions for wetlands located within shoreline boundaries, hence the term "shoreland-wetlands." Specific allowable activities are provided for by NR 115 in shoreland-wetlands. These include but are not limited to: passive recreation, hunting and fishing, continuing agricultural cropping practices, pasturing livestock and planting, and thinning and harvesting timber. Filling, draining, dredging, general farming, soil removal, and solid waste disposal are prohibited without a Special Exception Permit.

INDIANA

Although Indiana does not have a shoreland management program and does not participate in the National Coastal Zone Management Program, State acts promulgated in 1947 require that alteration of the shoreline or bed of any lake must be approved by the State's Natural Resources Commission.

The State of Indiana's coastal policy objective is to minimize the dangers and impacts of shoreline erosion and flooding. The State is encouraging local communities to delineate and regulate all flood hazards within their jurisdiction and to participate in the National Flood Insurance Program. Construction of landfills and structures is limited through a permit system to only those which do not adversely affect longshore currents.

Indiana does not have a comprehensive wetlands regulation law. However, it has a wetlands acquisition program for waterfowl habitat, delta wetlands, unique natural areas, and rare or endangered species habitat through its 1969 Nature Preserve Program.

MICHIGAN

In an effort to provide consumer protection and prevent needless destruction of critical shoreland habitat, the Michigan Legislature enacted the Shorelands Protection and Management Act in 1970. The Act takes a nonstructural approach to minimizing property loss instead of requiring that often costly and ineffective erosion-control structures be constructed. The Department of Natural Resources is directed to regulate selected uses and development, such as setback and construction standards of buildings, within three types of sensitive coastal areas: high risk erosion, flood risk, and environmental areas or coastal areas necessary for the preservation or maintenance of fish and wildlife.

Specifically, the Act requires that new structural development in areas designated as high risk erosion areas comply with construction setback regulations which are enforced either through local zoning ordinances approved by the State, or by State permit. Also, the State is not to issue permits in high risk erosion areas for any permanent residential, commercial, or industrial buildings, or septic facilities, or engage in any uses or activity where they are likely to be damaged by shoreline erosion in 30 years. The Act addresses the problem of coastal flooding within the 100-year floodplain of a Great Lake or connecting waterway. The objective of the Act is not to finance, engage in, or issue permits for new structural developments proposed within the 100-year floodplain if they are inadequately elevated or if precautions have not been taken to alleviate flood damage.

The Sand Dune Protection and Management Act was promulgated in 1976 to provide for study, protection, and reclamation of Great Lakes sand dunes. The sand dune areas are designated by the Department of Natural Resources and include those geomorphic features composed primarily of sand, whether windblown or of other origin (e.g., overwash deposits) which lie within 2 mi of the ordinary high water mark on a Great Lake. The intent of the Act is to discourage the removal of sand from sand dune areas for commercial or industrial purposes. Sand mining operators are required to submit an environmental impact statement to the Department of Natural Resources before obtaining a mining permit.

In 1979, the State enacted the Goemaere-Anderson Wetland Protection Act. The Act provides for the preservation, management, protection, and use of wetlands. As specified by the Act, landowners are required to obtain a permit for alteration of wetlands (e.g., coastal lagoons) contiguous to a Great Lake.

OHIO

The State of Ohio does not have a shoreland management program per se. However, there are policies and regulations which address the conservation of coastal barriers and their ecosystems. Through a permit procedure, the Ohio Department of Natural Resources can regulate erosion control structures on Lake Erie. Ohio statutes also allow for the purchase of conservation easements of private property by the State or conservation organizations (Richard Bartz, Ohio Department of Natural Resources; pers. comm.). Through the Nature Preserve Program the State may acquire land for endangered species habitat and other uses. The Ohio Conservation Easement Law imposes limitations on the use or development of designated land, water, and wetlands.

The State has the authority to construct or help finance beach erosion control works within limited prescribed circumstances. In Ohio, objectives regarding coastal hazards management include minimizing the impacts of erosion and flooding and eliminating public investment in structures in hazardous coastal areas without approved erosion protection. Although not required, local governments with federally designated flood risk areas are encouraged to participate in the National Flood Insurance Program.

PENNSYLVANIA

Pennsylvania has a modified shoreland management program which is confined to Presque Isle. The act of May 27, 1921 (Public Law 1180) of the Pennsylvania Legislature established the Pennsylvania State Park and Harbor Commission of Erie to manage and control Presque Isle Peninsula and portions of Presque Isle Bay, encompassing approximately one-sixth of Pennsylvania's Lake Erie shoreline.

The Bluff Recession and Setback Act of 1980 was instituted to encourage planning and development in bluff areas. Its purpose is to minimize the expenditure of public and private funds for shoreline protection and bluff stabilization structures and activities and to protect people and property from the hazards and damage associated with coastal recession. The Act outlines a procedure whereby the Department of Environmental Resources conducts studies to identify communities with bluff recession areas. The coastal communities are then to adopt setback ordinances concerning stationary structures such as dwellings.

The Dam Safety and Encroachment Act of 1978 requires permits for the construction, alteration, maintenance and operation of all water obstruction and fill activities. The Act includes wetland habitats as well as lakes and other watercourses. As in Michigan and Wisconsin, some local authorities have adopted conservation district zoning which includes wetlands protection.

The Open Space Lands Act of January 1968 was legislated to clarify and broaden the existing methods by which the State may preserve land or acquire land for open space in and near urban areas to meet the needs for recreation, amenity, and conservation of natural resources. Through the Department of Environmental Resources, the State may acquire or purchase property to protect and conserve natural or scenic resources and preserve sites of geologic or botanic interest such as beaches, floodplains, and marshes.

NEW YORK

New York State's coastal programs are based principally on two instruments of legislation passed in 1981; the Waterfront Revitalization and Coastal Resources Act, and the Coastal Erosion Hazards Act. Additional legislation which is directed to coastal ecosystems is the Freshwater Wetlands Act of 1975. These and 44 additional acts form the State's coastal management program.

The Waterfront Revitalization and Coastal Resources Act provides the legal authority to establish a coastal program, establish a coastal boundary, provide for optional local government waterfront revitalization programs, and establish a process for coordination of State actions and local revitalization program activities. The Coastal Erosion Hazards Area Act provides for setback requirements in highly hazardous areas. Its policy objectives are to minimize damages caused by flooding or erosion to property and to natural resources.

A nonregulatory policy of New York's Coastal Management Program calls for direct riparian-property owner representation on the International St. Lawrence River Board of Control. The State encourages the establishment of beach erosion control districts and similar property owner cooperative efforts in the development and maintenance of erosion protection structures, plantings, and other protective measures. Also, under the Program, maps are being prepared that delineate hazardously eroding areas for public review. Implementation of these hazardous area boundaries may create controversy because it will prevent new development, or redevelopment if over 50% of a given structure is destroyed, within the determined boundaries.

More directly related to the protection of coastal and aquatic flora and fauna is the Freshwater Wetlands Act of 1975. The Act requires a person to obtain a permit for proposed activities in wetlands of less than 12.4 acres (5 hectares). The wetland area subject to modification must be mapped on the basis of the State's wetland inventory and other sources (Fried 1981).

SUMMARY

In the preceding sections the barriers of the Great Lakes were discussed within a regional setting, beginning with Lake Superior and moving to the lower Great Lakes. Barrier development is limited along the Great Lakes shoreline because of the abundance of glacial uplands and exposed bedrock at the shoreline. In most instances barriers are composed of a single beach ridge. With few exceptions, the barriers are not offshore landforms like those typically found on the east coast of the United States but rather are anchored to the mainland. Great Lakes barriers are also volumetrically small. They are subdued features, with modest, incipient foredune development and they are stratigraphically quite thin.

Because of the geological and geomorphological makeup of the Great Lakes Basin, dunes, glacial deposits, and bedrock outcrops dominate the basins' shorelines. About 12% of the Great Lakes Shoreline has been classified as wetland (Great Lakes Basin Commission 1975) and many of these wetlands are located behind barriers. On average, however, only one coastal barrier occurs for every 22 mi of shoreline. Furthermore, the lack of large longshore drift volumes has generally resulted in transgressive features. Coastal research in the Great Lakes has been far from complete compared to that along marine shorelines. However, based on available data, many coastal barriers appear to be erosional in origin. Sediment input from large rivers such as the Maumee and Saginaw is fine-grained and not suitable for extensive barrier construction.

The conditions existing along the coastal Great Lakes are not unlike those occurring in marine settings. Subsidence has caused relatively higher water levels over the centuries, which has led to barrier migration, particularly along Lake Erie. Such a circumstance is parallel to rising sea level on marine shorelines (Leatherman 1979). Coastal and riverine structures such as sea walls, dams, and channelization have altered sediment budgets, which has impacted coastal barriers.

High water levels have increased the occurrence of overwash processes, coastal flooding, increased turbidity, and erosion. These physical processes are particularly severe when they are coupled with seiches or storm surges. It may be concluded that the physical problems generated by geological and lacustrine processes in the Great Lakes are indeed similar to the processes and problems encountered in the marine environment, but on a smaller scale.

Great Lakes barriers are ecologically important because they protect a complex of ecosystems. Each of the four major ecosystem types provides special functions. The beach and dunes absorb wave energy. Barrier and surrounding uplands allow access and nesting for birds and mammals. The littoral marsh has a high net primary productivity and acts as a sediment filter. A deep marsh provides structural complexity necessary for fish and waterfowl.

Water level changes play an important role in barrier-wetland dynamics. As lake levels oscillate over several years, wetlands alternately undergo succession and retrogression. Changes also occur in the beach-barrier system. Lake fluctuations continually rejuvenate the ecosystems and hence are not detrimental. However, extremely high water in the short run can be detrimental in terms of barrier erosion.

Fish and wildlife resources of barrier landscapes include many species of commercial importance. Fish depend on back-barrier wetlands for nursery and spawning habitat and as a source of food. Migratory waterfowl use back-barrier wetlands as feeding, resting, and, to some extent, nesting sites. Mammals include furbearers and deer, which benefit from the wetlands and the diversity of habitats that are associated with barriers.

People use and affect barrier landscapes in a variety of ways. Uses include development, harvest of fish, furbearers, and deer, and nonconsumptive activities like bird watching and most scientific research. A serious impact that people have on barriers involves changes in sand supply. These changes often result in erosion of the barrier with subsequent erosion of back-barrier wetlands. Other impacts include land uses in the surrounding uplands that increase sedimentation and trampling, and introduction of exotic species that often compete with and can cause extinction of local species.

The States of Wisconsin, Michigan, Pennsylvania, and New York currently are managing federally approved coastal programs. However, all Great Lakes States do have legislation aimed at coastal protection. Table 4 is a matrix of the Great Lakes States' policies. Coastal management capability in the region has been developed on an "as needed" basis rather than as part of a comprehensive, coordinated program. For this reason numerous agencies administer a wide variety of shoreland management efforts.

A diversity of management objectives and legislation may imply that some State policies are weak. Generally this is not the case. However, individual Great Lakes States do have a great deal of discretion in deciding whether preservation or development should be favored. The level at which decisions are made is variable. In Wisconsin, county rather than State regulation regarding management is required by the Wisconsin Shoreland Zoning Act.

Wetland protection through acquisition is occurring throughout the Great Lakes States. Ohio, for example, has used its Nature Preserve Program to acquire wetlands, and Federal Coastal Zone Management Act funds established Old Woman Creek, the first estuarine sanctuary in the Great Lakes.

Table 4. Summary of the coastal policies of Great Lakes States. A = statutory authority for compliance; B = compliance recommended but not required; C = statutory authority currently being sought; D = Public Waters Act regulates and protects certain wetlands designated in advance.

Policy	State							
	MN	WI	IN	IL	MI	OH	PA	NY
Permit for erosion control structure required		A	A	A	A	A	A	A
Bluffline setback required in erosion areas		A	B	B	A	C	A	C
Shoreland zoning management required	A	A			A			C
Floodplain management required	A	A	A		A	C	A	A
Mandatory participation in National Floodplain Insurance Program		A	B			C	A	A
Construction in floodway/floodplain regulated		A	A	A	A	A	A	A
Participation/interest in lake level regulations	A	A		A	A	A	A	A
Comprehensive wetland protection program	D				A			A

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