LAKE MICHIGAN AND ITS COAST IN INDIANA

Lake Michigan covers 234.5 square miles of the northwest corner of the state of Indiana, and 45 miles of its coast are also within the state boundaries. The Lake and its coast are encompassed within the Lake Michigan Region as defined in this report.

The present configuration of Lake Michigan and the other Great Lakes is mainly the result of erosion by continental glaciers during the Pleistocene Epoch. The glaciers gouged large depressions into the preglacial lowlands, removing layers of rock in many places. Water filled the large depressions during retreat of the ice sheets at the end of the Wisconsinan glacial period, thus forming the Great Lakes.

The physiography of the Lake Michigan drainage basin is the expression of surficial sediments deposited during the late Pleistocene and Holocene Epochs. Lake-bed deposits in the southern part of Lake Michigan, including the portion of the lake that lies within the state of Indiana, include sand near the shore, gravel from 50 to 100 feet deep, and mud in the deep parts (Great Lakes Basin Commission, 1976b).

Elongated sand dune ridges landward of the south shore of Lake Michigan represent late Pleistocene and Holocene shorelines of ancestral Lake Michigan. Three of the ridges are major dune and beach complexes which developed during periods of high semi-stable lake level.

Natural processes

Lake-level fluctuations

Fluctuations in Great Lakes water levels have occurred continually since the Great Lakes formed at the end of the Ice Age. A summary of the late Pleistocene and Holocene lake-level history in the Lake Michigan Basin is presented in the box on the next page. The level of each of the Great Lakes, including Lake Michigan, depends on the balance between the quantities of water received and the quantities of water removed. As the supply of water changes under natural outlet conditions in a lake, the lake-level and outflow adjust continually to restore a balance between the net supply of water to the lake and the outflow through its outlet.

Lake level records have been kept for Lake Michigan/Huron since 1860, at Harbor Beach, Michigan. The lowest monthly average lake level recorded during that time, 575.35 feet *International Great Lakes Datum* 1955 (576.05 IGLD 1985), occurred in March 1964. The highest monthly average lake level recorded, 581.94 feet IGLD 1955 (582.64 IGLD 1985) occurred in June 1886. This is a difference of 6.59 feet in water level since records have been kept.

In this century, the highest monthly average lake level recorded, 581.62 IGLD 1955 (582.32 IGLD 1985), occurred in October 1986. This century's instantaneous record high lake level, recorded at Calumet Harbor, Illinois was 582.76 IGLD 1955 (583.46 IGLD 1985) at 8:00 am on October 4, 1986.

Lake levels affect extent of flooding, shoreline erosion and shoreline property damage, wetland acreage, depth of navigation channels and hydroelectric power output.

There have been record water level lows for Lake Michigan and the other Great Lakes occurring in the 1920s, 1930s, and 1960s and record highs occurring in the 1950s, 1970s, and most recently, in 1985 and 1986. As a result of the high water levels of the 1950s, the U.S. House of Representatives requested that the U.S. Army Corps of Engineers determine the feasibility of measures to prevent the recurrence of damages. The Corps study (1965c) consisted of two phases: the first, to look at the advisability of adopting local projects for flood control at specific areas along U.S. shores and tributary streams of the Great Lakes to reduce damage due to water level fluctuations; the second, to examine the feasibility of lake-regulation measures to reduce damage. The Corps report contained recommendations regarding local shoreline protection projects but had no conclusions or recommendations on the second phase of the study. The study, however, provided information on various lake-regulation plans and associated cost.

Extremely high lake levels occurring again in the early 1970s generated a lot of concern. A report was presented to the International Joint Commission (IJC) by the International Great Lakes Levels Board (1973) concerning potential changes in lake-level regulation plans at existing regulatory sites on the lakes as a means

ANCESTRAL LAKE MICHIGAN

The complex history of ancestral Lake Michigan began during the late Wisconsinan deglaciation when the Lake Michigan ice lobe retreated a short distance from the Lake Border Moraine. Subsequent episodes of advance and retreat by the ice margin into and out of the north and central parts of the basin caused considerable changes in the water level and areal extent of ancestral Lake Michigan.

Evidence for major lake events in the Lake Michigan Basin comes from the extent and altitudes of wave-cut cliffs, beaches, spits and deltas, and from altitudes of abandoned lake outlets (Hansel and others, 1985). In addition, radiocarbon evidence has proved helpful in determining the timing of glacial and post-glacial events in the basin (Hansel and Mickelson, 1988).

Factors that affected glacial and postglacial lake levels in the Lake Michigan Basin include: 1) the advance and retreat of ice margins that blocked or uncovered outlets, 2) downcutting of outlets, 3) major increases and decreases in the volume of water entering the lake, and 4) differential *isostatic* changes in the altitudes of parts of the basin or outlets (Hansel and others, 1985). Generally, these mechanisms work in combination to control the major lake events (lake phases) in the basin.

Reliable information on lake levels in the Lake Michigan Basin indicates that high semi-stable levels first occurred during the Glenwood II lake phase. Initially, the lake level in the basin rose during the early part of the phase when the northern outlets at the Straits of Mackinac and the Indian River lowland became closed off during readvance of the ice margin. The rising lake level activated the Chicago Outlet, an overflow channel through the Valparaiso Morainic System and the Tinley Moraine southwest of present-day Chicago. Conditions at the Outlet were probably partly or entirely responsible for controlling the high semi-stable lake levels in the Lake Michigan Basin (Wright, 1918; Bretz, 1951, 1955; Hansel and others, 1985).

The high semi-stable lake level of the Glenwood II phase, which occurred about 12,900 to 12,700 years before present (BP) (Hansel and others, 1985), resulted in considerable development of the Glenwood Beach in northwestern Indiana and northeastern Illinois. Based on the internal architecture of the beach deposits, Thompson (1987) concluded that the elevation of the semi-stable Glenwood level ranged from about 620 to 630 feet (189 to 192 meters) above m.s.l.

The end of the Glenwood II lake phase and the beginning of the Two Creeks lake phase corresponds in time with the deglaciation of the northern outlets about 12,400 years BP. Drainage through the northern outlets lowered the level in the Lake Michigan Basin below the present level from about 12,000 to 11,800 years BP (Hansel and others, 1985).

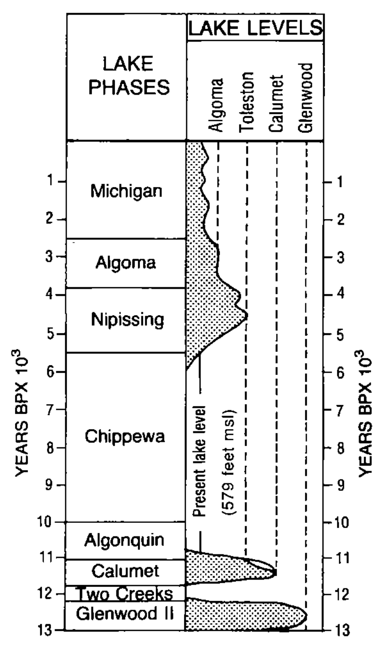
Readvance of the ice margin soon after 11,800 years BP marked the beginning of the Calumet lake phase. After the northern outlets became blocked, the Chicago Outlet was reactivated as the lake level rose and then stabilized about 11,500 years BP. The Calumet Beach in northwestern Indiana developed during the Calumet lake phase when the lake level stabilized at elevations ranging from 603 to 610 feet (184 to 186 meters) above m.s.l. (Thompson, 1987).

Retreat of the ice margin from the Straits of Mackinac about 11,000 years BP caused water in the Lake Michigan and Lake Superior Basins to be confluent with Lake Algonquin in the Lake Huron Basin (Hansel and others, 1985). As a result, the lake level in the Lake Michigan Basin was lowered below the present-day altitude of Lake Michigan during most of the Algonquin lake phase. Low lake levels also continued into most of the Chippewa lake phase which ended about 5,500 years BP.

The transition from the Chippewa lake phase (low lake level) to the Nipissing lake phase (high lake level) after 6,000 years BP corresponds approximately in time with the end of the *Hypsithermal* episode of Holocene climatic history, when warmer drier conditions of early Holocene were replaced by cooler and wetter conditions in the northern Midwest (Bartlein and Webb, 1982). Initially, water in the basins of Lakes Michigan, Superior and Huron were confluent during the early part of the Nipissing lake phase. As differential uplift elevated the northern outlet at North Bay, lake levels rose and the Chicago Outlet was reactivated. Lake levels in the Lake Michigan Basin rose above the present-day level between 6,000 and 5,000 years BP and attained a maximum level between 4,700 and 4,000 years BP (Hansel and others, 1985). The high semi-stable lake levels during the Nipissing phase of ancestral Lake Michigan resulted in the formation of the Toleston Beach. Thompson (1987) indicated that the elevation of the Toleston level of ancestral Lake Michigan ranged from about 597 to 603 feet (182 to 184 meters) above m.s.l.

A lowering of the lake level about 3,800 years BP marked the end of the Nipissing lake phase and the beginning of the Algoma lake phase in the Lake Michigan Basin (see figure). Incision of the St. Clair River channel at Port Huron was considered to be responsible for the end of the Nipissing *transgression*, but a more gradual process in which the rate of erosion of the outlet channel partly kept pace with ongoing differential uplift probably occurred (Hansel and others, 1985). Lake level fluctuations occurring on a scale of 200 to 300 years characterize the Algoma and Michigan lake phases. The fluctuations can be thought of as climate-related changes in lake levels that were adjusted to channel depths of the St. Clair River at Port Huron (Hansel and others, 1985).

Lake levels during the Algoma phase fluctuated as high as 587 feet (179 meters) above m.s.l. about 3,200 years BP. In addition, fluctuations as high as seven feet (two meters) above the present lake level occurred about 1,500, 1,000, and 450 years BP (Hansel and others, 1985).



of alleviating problems caused by high lake levels. The Board found that only small improvements are practicable without costly regulatory works and remedial measures. The Board also concluded that the most promising measures for minimizing future damages to shore property are strict land-use zoning and structural setback requirements.

In 1981, the International Great Lakes Diversion and Consumptive Use Study Board, established by the IJC, examined effects of **consumptive use** and **diversions** on water levels and flows of the Great Lakes Basin. The Board found that consumptive uses of water reduce the net water supply to the lakes, thereby lowering lake levels, resulting in economic benefits to coastal zone interests and losses to navigation and power interests. The Board concluded that the diversion rates into, within and out of the basin cannot be altered to reduce threat of extreme high levels on the Great Lakes without causing an overall long-term net economic loss and that diversion rates cannot feasibly be altered to reduce threat of extreme low levels on the Great Lakes during periods of low supplies. The IJC did, however, recommend to the governments surrounding the lakes that a mechanism be established for institutional consultation, so that monitoring could be undertaken and appropriate public policies formulated, to address potential impacts of new or increased diversions and consumptive uses.

Record high lake levels, occurring again in 1985 and 1986, resulted in a series of studies and publications concerning Great Lakes water levels. Bixby (1985) prepared, for the Center for the Great Lakes, an overview of Great Lakes Water levels. The U.S. Army Corps of Engineers (1984a) prepared a publication on Great Lakes water level facts. Briefings were held by the Corps (1985) and the International Joint Commission (1985) with Senators and representatives of the Great Lakes basin states concerning water levels of the lakes. The Great Lakes Commission (1986) published a report concerning water level changes and factors influencing the Great Lakes.

A recent investigation has been undertaken by the IJC at the request of the United States and Canadian governments to re-examine and report on methods of alleviating the adverse consequences of fluctuating water levels in the Great Lakes-St. Lawrence River Basin using the most up-to-date techniques and information. Phase I of the International Great Lakes Level Board (IJC) investigation was completed (1989). Phase II was completed in March, 1993.

Phase I (1989) is a progress report which consists of an Executive Summary, Main Report and seven subject-specific Annexes. The major conclusions reached in the Phase I report are that: 1) the Great Lakes water level fluctuation situation must be approached on a system-wide basis; 2) that specific measures aimed at affecting system-wide water level fluctuations are probably futile; 3) and that there must be a recognition of need for a fundamental change in the conventional approach to alleviating adverse consequences. Phase I identified the priority goals of developing a set of principles to guide decision-making, a strategy that could promote effective government action, and a methodology for evaluating measures for specific, local situations in a broad and systemic context. Secondly, Phase I also concludes that measures, particularly combinations of measures, may have high potential for alleviating adverse consequences at specific locales.

Phase II aimed at four collective objectives: 1) a set of binational principles as guides for decision-making; 2) an overall strategy and general plan of action; 3) improvements in governance; 4) refinements in understanding of critical aspects of the system.

As part of Phase II, an options document was completed and circulated for public comment in November 1992 and a series of public meetings were held in February, 1993 for public comment on a Draft Final Report which contained recommendations. The final report was released in March, 1993. The documents include information on the following topics: 1) key results of technical studies; 2) guiding principles for governments; 3) measures to reduce impacts of fluctuating water levels; 4) emergency actions in response to crises conditions; 5) institutional arrangements; and 6) communications practices.

Coastal processes and erosion

The intensity of storms on Lake Michigan plays a primary role in determining the amount of erosion that occurs in any given year. Without storms, there would be no waves or currents to move large quantities of sand along the beach and lake bottom. Lake level affects whether waves attack low on the beach face when lake levels are low, or waves attack high on the back beach at the base of the erodible dune-bluff (figures 23 and 24), when lake levels are high.

In general, times with high lake levels and severe storms usually result in the highest erosion rates along the unprotected portions of Indiana's shoreline. Times of low lake levels and mild storms usually result in low erosion rates.

Long term records covering both types of erosion conditions are needed to get a reasonable estimate of the 'background' erosion rates that can be expected for a particular portion of the shoreline, for use in coastal zone management planning.

Storm winds generate waves by transferring some of the wind energy to the surface of Lake Michigan. The wind energy is stored in the form of waves moving across the lake surface. Waves grow bigger as more wind energy is added. Out in deep water, very little wave energy is lost from waves as they move from one side of the lake to the other. But, when the waves reach shallow water at the coast, the stored wave energy is converted into 'breaking waves' and 'water currents' capable of eroding and moving sand (figure 23).

The strongest and fastest currents found in Lake Michigan are concentrated around the edge of the lake in a narrow 'breaking wave zone', starting in water depths between 18 to 20 feet deep and extending to the beach. This zone is also the location of the greatest volume of sand transport (littoral drift).

If wave crests approach the coast parallel to the beach, sand movement is primarily onshore and offshore. But, when waves approach the coast at an angle, water currents move 'alongshore' and can carry sand in the direction the storm waves are moving. The amount of sand that moves depends on sand availability, the size of the waves and the length of time the waves are present to drive the water currents in one direction.

The 'net' direction of sediment movement is the direction that the largest volume of sand moves over a given period of time. If a small amount of sand moves east during the first part of a storm, but more sand moves west during the latter part of the same storm, the net direction of sand movement would be toward the west. If this pattern persists storm after storm, a net direction of sediment movement is established for that part of the coastline.

From the Michigan state line to Gary, Indiana, the net direction of sand movement (littoral drift) along Indiana's coast is from the east toward the west (figure 25). But, from the Illinois state line to Gary, Indiana, the net

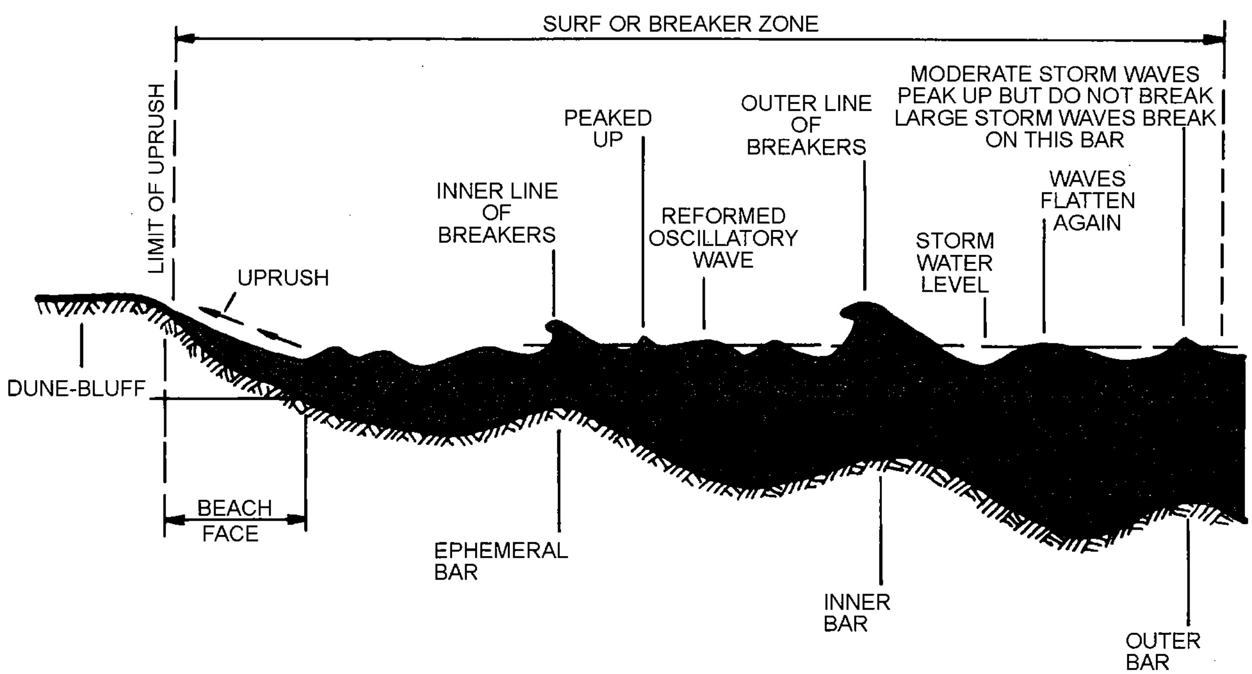


Figure 23. Representative profile across Lake Michigan coastal area

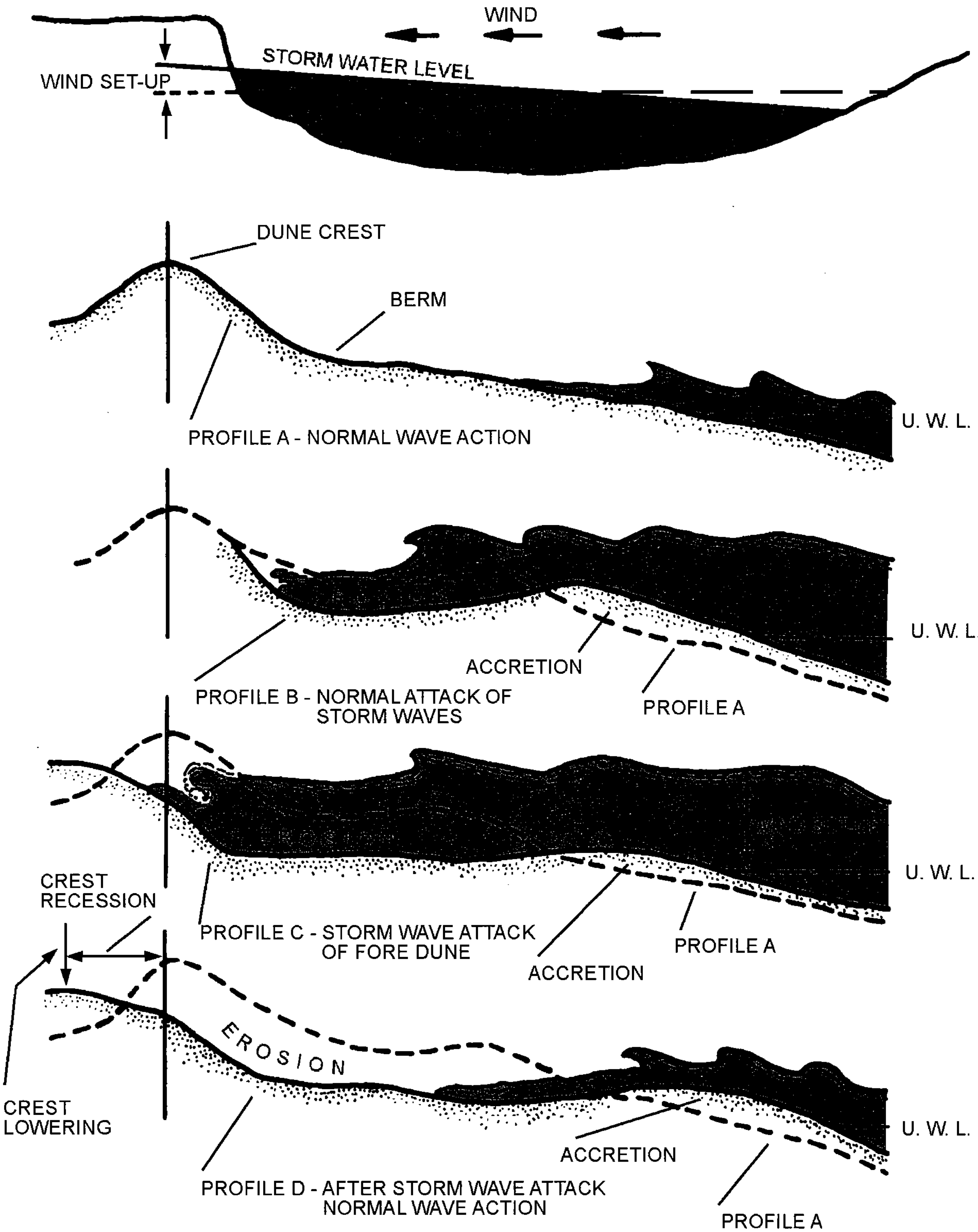


Figure 24. Schematic of wind set-up and resulting erosion

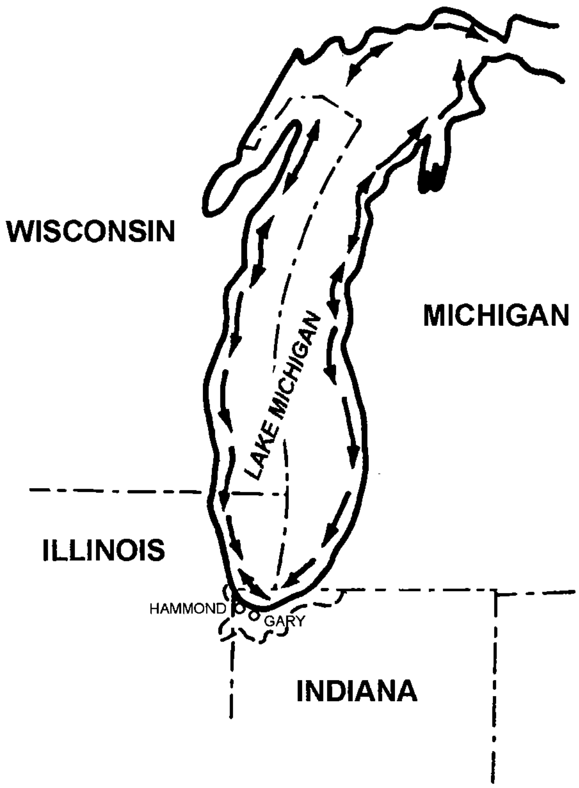


Figure 25. Net direction of littoral transport, Lake Michigan shoreline

direction of sand movement is from the west toward the east. These opposite directions of net sediment movement is expected, due to two determining factors (figure 25).

The first factor is that the most powerful storm waves approach both portions of Indiana's coast from the north, since the strongest storm winds blow out of the northwest, north and northeast directions. These winds are able to transfer considerable energy into waves coming from the north because there is approximately 300 miles of open water between the north end of Lake Michigan and the Indiana coast.

The second factor actually responsible for the opposite net directions of sand movement, east and west of Gary, is the different orientation of the shorelines. Since Gary is located at the southern-most tip of Lake Michigan, the shoreline east of Gary is oriented in a northeast by southwest direction. The shoreline west of Gary is oriented in a northwest by southeast direction. As storm waves approach from the north, the different orientation of the shorelines results in both currents flowing toward Gary, Indiana.

Seasonal climate and erosion

Winter storms are generally high-intensity and destructive in nature, resulting in 'narrow winter beaches' along the Indiana coast. During the summer, some storms may be intense, but these are also accompanied by gentler, constructive wave events resulting in 'wide summer beach' widths.

This seasonal difference in storm intensity results in beaches coming and going in a yearly cycle of narrow winter beaches and wide summer beaches. Once cold winter weather has lowered the surface water temperature of Lake Michigan to near 0 degrees Celsius (32 degrees Fahrenheit), periods of air temperature at or below 0 degrees Celsius can initiate the formation of lake ice. When this coincides with winds blowing onshore, ice can begin to form along the lake's frozen beach. The first winter lake ice has been recorded as early as late December. By January, constant low temperatures combined with strong winter winds and waves can push enough ice toward the coast to form an 'ice complex' as wide as the breaking wave zone, composed of alternating high 'ice ridges' and low lagoons. The general location of the ice ridges coincides with the location of the lake bottom sand bars.

Coastal ice provides a buffer between winter storm waves and the erodible beaches and dune-bluffs, reducing the amount of damage that would occur if the ice had not formed. Usually by March, warm air temperatures have caused the ice ridge complex to break up. Occasionally, a winter season is too warm to allow the normal formation of the protective shore ice, allowing winter storm waves to reach the erodible coast that year.

Human influence

Man-made lands

The Surveyor General of the United States conducted a survey of Indiana's Lake Michigan shoreline between 1824 and 1849. Between the time of the survey and 1900, the shoreline was altered significantly by "reclamation" of approximately 700 acres of "submerged land". These "submerged lands" were filled either as a result of human activity to create valuable lake frontage or by natural *accretion.*

When industry began to expand around the southern end of Lake Michigan at the beginning of the twentieth century, land having the potential for industrial development was in great demand. Hence, several companies planned substantial encroachments into the lake to expand their facilities. In anticipation of industrial expansion into Lake Michigan, Congress passed a joint resolution in 1906 which required permits from the federal government prior to filling of the lake bottom. The resolution required approval by the Secretary and Chief of Engineers of the Department of War for the planned man-made lands in Lake Michigan.

In 1907, the littoral (riparian) owners along Lake Michigan were given the right by the state of Indiana to fill in submerged land adjacent to their shoreline property (I.C. 4-18-13). The legislation stipulated that man-made fills could not extend beyond lines established by the U.S. Army Corps of Engineers; and it required that accurate surveys of the proposed fills be made. The legislation further stipulated that after the survey had been filed with the secretary of state, the governor **shall** issue authority to fill in and improve such land. After the in-fill had been completed, accurately surveyed, and fees paid, the governor was required to issue a patent for the man-made land.

Over the years, the filling of the lake bottom along the Indiana shoreline proceeded at a rapid and steady pace creating peninsulas of land extending into the lake. In 1973, the legislation was amended to provide a discretionary **may** instead of the mandatory shall in the issuance of state permits to fill in submerged lands.

The Indiana Department of Natural Resources in 1979 attempted to inventory man-made lands and compile a complete record of authority-to-fill permits and patents (IDNR, 1979a). Since the 1907 legislation, approximately 6515 acres of man-made lands have been authorized by the state. At the time of the IDNR inventory in 1979, patents for 3604.436 acres were located. As of November, 1994, patents for an additional 448.45 acres have been located and three patents are pending for an additional 57.593 acres (Personal communication, James Lewis, Indiana Land Office). Table 8 provides additional details.

The enabling state legislation for permitting filling-in submerged lands was further amended in 1990. The recent amendments provide that old lake-fill permits were to expire December 31, 1991, unless extensions were requested. Initially, after the change in legislation, three permit holders requested extension; however, as of November 1994, only one permit holder was requesting a right-to-fill. The permit for extension is currently under administrative appeal.

The 1990 amendment also stipulated that any permit for filling or reclaiming land issued after June 30, 1990 now expires five years after the date the permit was issued.

Structures perpendicular to the shoreline

Man-made lakefill structures and breakwaters, oriented perpendicular to the shoreline, divide the Indiana coastline into five segments called 'littoral cells' (figure 26). This report is adopting the same littoral cells defined by the U.S. Army Corps of Engineers for Indiana's Lake Michigan coast. Large structures can restrict or even block the movement of sand into and out of these cells. Reaches 1 and 2, between Michigan City and the Port of Indiana comprise a single littoral cell.

If a structure extends far enough out into Lake Michigan that it reaches beyond the lakeward boundary of the breaking wave zone, the structure may block virtually all (100 percent) of the sand from passing that point. This structure is called a 'primary sand trapping

Table 8. Man-made land along the shoreline of Lake Michigan

Man-made lands	acres
Authorized by the state of Indiana in 1907	6515.783
Filled and patented (1979 IDNR study)	3604.436
Filled, but no patent located (1979 IDNR study)	84.469
Filled, but exempted from state permit	87.000
Additional filled and patented (to Jan. 1993)	448.450
Filled, patent pending	57.593

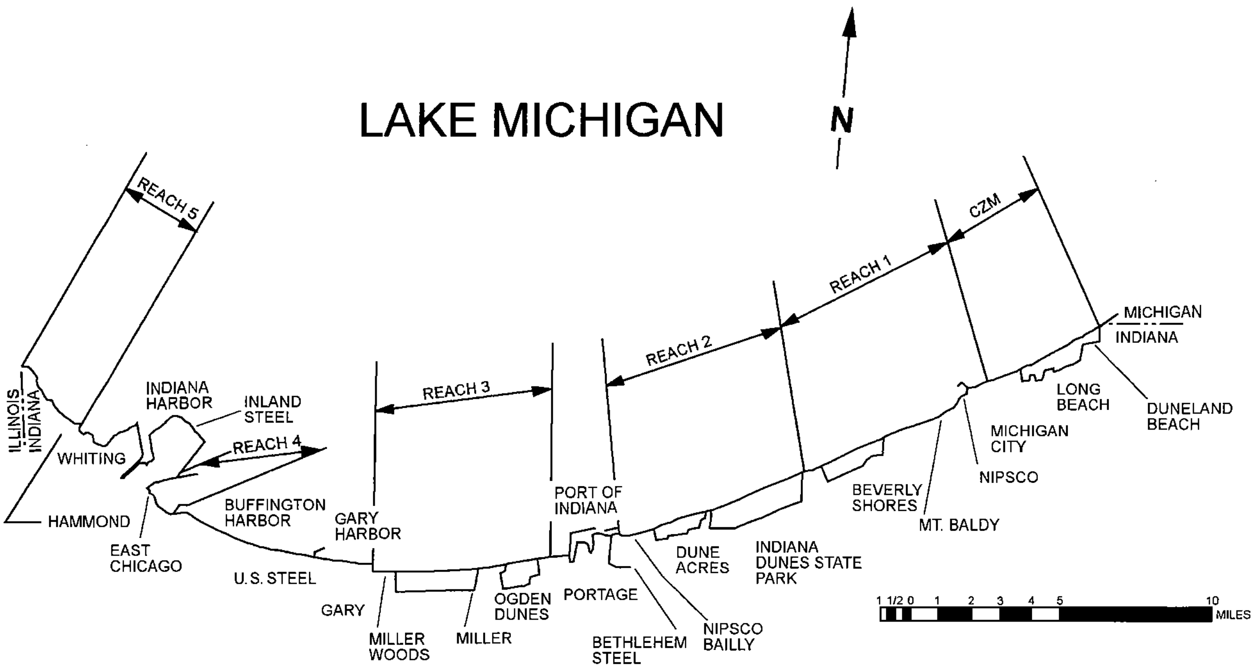


Figure 26. Location of five littoral cells along the Lake Michigan shoreline in Indiana
(adapted from Wood and others, 1988)

structure' and is classified as a 'total littoral barrier'. If little or no sand can enter or leave either end of a cell, a 'closed littoral cell' is created. The sand in a closed cell can move back and forth within that cell, but that sand is not available to contribute sand to an adjacent cell. Erosion of beaches and dune-bluffs continues to add sand to the littoral drift, replacing sand that is lost to deeper water offshore during intense storm events.

Smaller structures which do not extend out beyond the lakeward boundary of the breaking wave zone may form a 'partial littoral barrier'. These are called 'secondary structures' if they block and retain only 25 to 75 percent of the sand moving along the coast. In this case sand leaks around the lakeward end of the structure, from one littoral cell to another. 'Tertiary structures' are smaller still, and usually affect less than 25 percent of the breaking wave zone width. On the updrift side of a littoral barrier, erosion may decline or stop as an accretional 'fillet' (figure 27) forms a widening beach in response to sand being trapped. The volume of sand retained determines the size of the fillet. If sand accumulation continues over a long period of time, wind transport of dry sand to the back beach area can begin to create new sand dunes. This blowing sand is usually trapped and stabilized by native dune grasses which contribute to dune height growth. This process occurs at three locations along Indiana's shoreline; east of Michigan City, east of the Port of Indiana in Portage, and east of the U.S. Steel lakefill breakwater in Gary.

In response to sand accumulating against the east side of the U.S. Steel breakwall due to net westward sand transport, new vegetated dunes have grown 117 feet lakeward and beach widths have grown 170 feet lakeward between 1967 and 1979 in this accretional area.

When sand (littoral drift) is abundant enough to maintain wide beaches and broad offshore sand bars, the erodible portions of the Indiana coast are provided considerable protection from storm waves. However, erosion may still occur even under ideal conditions if severe storms and high lake levels occur together.

Effects of shore-parallel man-made structures

Shore protection structures, oriented parallel to the shore, tend to increase erosion rates on adjacent property by creating a non-eroding coast of sheet steel,

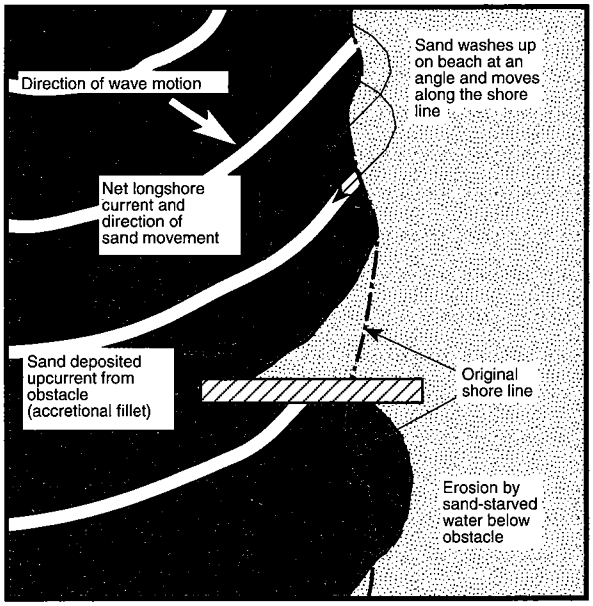


Figure 27. Diagram of shore-perpendicular structure impact on shoreline

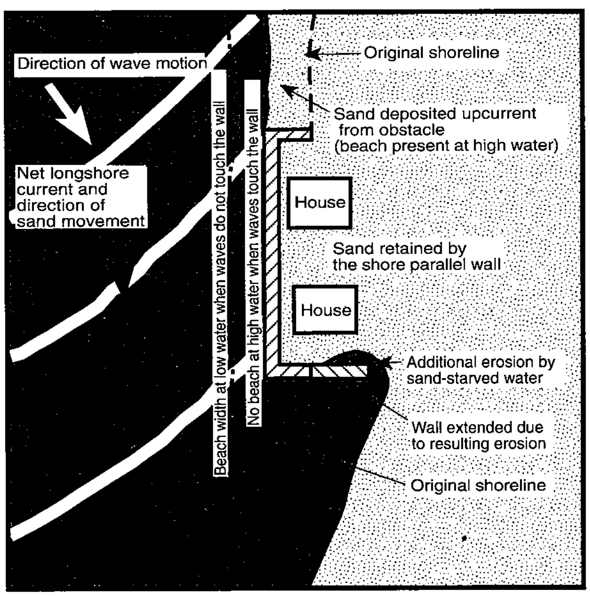


Figure 28. Diagram of shore-parallel bulkhead/ seawalls impact on shoreline

concrete, and wooden walls or rock revetments. While these structures do not stop sand from moving along the beach and lake bottom, they prevent erosion which normally would have contributed sand to the littoral drift necessary to maintain protective beaches and offshore sand bars. This lack of sand contribution creates a 'sand-starved' condition in front of the erosion protection structure. Reduction of this 'sand deficit' is usually accomplished at the expense of the adjacent erodible coast (figure 28).

In general, areas of Indiana's coast that are continually 'sand starved' usually have 'long-term erosion rates' consistently higher than other parts of the coast.

Erosion on the downdrift side of man-made structures

If sand (littoral drift) is not abundant enough to maintain wide beaches and broad sand bars at a particular location, erosion rates may be higher there compared to other parts of the coast, even though the same wave energy and lake levels are present at both sites. The deficit of sand may be due either to natural or man-made conditions.

Erosion rates usually increase dramatically on the downdrift side of a new structure as a result of severe sand-starved conditions created by sand being retained on the opposite (updrift) side of the littoral barrier. When no input of sand is available to replace sand that continues to be moved away from the structure in the downdrift (net) direction, beach widths become narrow and the offshore sand bars lose height and width. This allows more wave energy to reach the shoreline, increasing erosion of the erodible beach and dune-bluffs.

In July 1986, The Great Lakes Coastal Research Laboratory, Purdue University initiated a study to assess shoreline conditions and lake dynamics along Indiana's 45 miles of coast (Wood and others, 1988). The study was designed to incorporate existing beach and nearshore survey data bases, recent aerial photography, wave climatology, and coastal dynamics models to produce an evaluation of present coastal conditions and potential coastal hazards. The following general discussion about erosion rates was taken from the completed study. Appendix 4 contains additional details of structural impact to sand movement at specific sites along the shoreline of Lake Michigan in Indiana.

BEACH NOURISHMENT

Protecting the natural shoreline from erosion using breakwalls, bulkheads and rock revetments creates detrimental "sand-starved" conditions by retaining sand that would normally have eroded and provided the sand necessary to maintain beaches and offshore sand bars. While these "hard" structures control erosion in one location, the resulting sand-starved conditions cause increased erosion on unprotected adjacent properties.

An alternative method of reducing or temporarily stopping excessive erosion of the natural coast is to provide a "man-made" beach and dune-bluff. Feeding sand to a coast is referred to as "beach nourishment". Beach nourishment works by reducing sand-starved conditions by supplying sand needed for waves and currents to rebuild and maintain the natural protective beach and sand bar system.

"Hard" structural methods of erosion prevention directly oppose powerful erosive wave forces right at the shoreline. In contrast, beaches and sand bars are nature's way of gradually dissipating storm wave energy across the width of the breaker zone before the waves reach erodible dune-bluffs.

The supply of beach-nourishment sand can come from many sources. When a coastal structure traps sand on one side, creating erosion problems on the downdrift side, the trapped sand can be dredged and moved (by-passed) around the structure. This mechanical by-passing of sand places the same sand on the downdrift shoreline that would have arrived there naturally if the structure was not present. Sand trapped by a structure can also be moved back updrift (back-passed) to the portion of the coast where it eroded.

In some areas, sand deposited by glacial ice or by coastal processes during ancient lower lake level stages, may exist offshore and could be used as nourishment material. However, it is essential to insure that removal of offshore material does not adversely affect the way waves approach the shoreline. If deepening offshore water depths results in more wave energy reaching the shore, the benefits of placing that sand on the beach may be offset by increased erosion rates.

When potential sources of natural sand serve a more useful purpose where they are, or there is no other readily available source of beach-nourishment sand along the coast, sand can be obtained from inland sources, like quarries, and trucked to the beach.

Quarry sand can be "sized" to either match the natural beach material, or be slightly or significantly larger than the native beach sand. Properly sized sand is able to remain on the shoreline and move between the beach and offshore sand bars just like the native sand would. If the nourishment sand is too small, it may be carried so far offshore during a storm, that it is lost from the littoral transport system.

Beach nourishment sand must be free of contaminants that might be suspended or dissolved in the water as the sand is reworked by storm waves.

The most significant advantage of beach nourishment over "hard" coastal structures is that beach nourishment does not cause sand-starved conditions; it actually reduces the deficit of sand.

Erosion and reworking of nourishment sand provides three important beneficial effects. First, beach-nourishment sand directly protects the natural dune-bluffs from wave attack by serving as a sacrificial dune and beach buffer zone between the waves and the previously eroding natural coast. Second, beach nourishment reduces erosion on adjacent properties by supplying sand to the regional beach and sand bar system. Both the beach nourishment project site, and the adjacent shoreline benefit from the placement of nourishment sand. This contrasts with the construction of "hard" structures which protect one area from erosion while increasing erosion in another. Third, beach nourishment creates beaches that can be used for recreation. The gentle slope of the beach face helps dissipate wave energy as waves rush up the surface. These lower energy conditions allow sand to settle out and remain close to and rebuild storm damaged beaches.

In contrast, "hard" structures tend to reflect some wave energy back offshore. This reflected wave energy interacts with incoming waves, increasing the amount of wave energy immediately offshore of the structure. Higher energy conditions tend to push sand away from the wall, creating deeper water instead of a beach. Consequently, beaches tend to disappear from in front of "hard" walls that come in direct contact with waves.

The decision of which method of erosion protection to use depends on whether the presence of a beach is important to the use of the shoreline, and whether erosion on the shoreline adjacent to the project is of concern.

With time, beach-nourishment sand is completely mobilized as it moves down the shoreline providing protection to downdrift property owners as new beaches and sand bars. When all the

The Mt. Baldy shoreline, located immediately downdrift of the Michigan City breakwater complex has been observed to erode more than 20 feet in one storm season. This Mt. Baldy area has a 'long-term' background erosion rate of approximately 10 feet per year, compared to the average background erosion rate of 3 feet per year or less along most of Lake Michigan's coastline.

In the central portion of Mt. Baldy, a total of -65 feet of dune-bluff recession occurred from July 1983 to July 1985. This excessively high loss rate occurred during the time Lake Michigan was approaching its recent October 1986 high lake level. This short-term average erosion rate of over 30 feet per year far exceeds the long-term average of 10 feet per year mentioned above.

The dune-bluff recession rate on a survey station west of Mt. Baldy (SR-12, Wood and others, 1988) was only 21.5 feet per year from 1983 to 1985. The recession rates farther to the west (survey stations SR-10 and SR-8) are approximately -5 feet per year for the same period. This decrease in short-term erosion rates from the east toward the west is expected because erosion rates are generally highest immediately downdrift of a sand-trapping structure where sand-starved conditions are most severe (Mt. Baldy). With increasing distance from the breakwater structure (survey lines SR-12, SR-10 and SR-8, respectively) the contribution of sand from erosion of the beach, dune-bluff beach-nourishment sand is carried downdrift, the project site must be "renourished". The life of a nourishment project may vary depending on many factors, including: the volume of sand placed, lake level, intensity of storms, protection from severe winter storm waves by shore ice, proximity to "hard" shore protection structures, the sand sizes used, and the extent of sand depletion of the natural beach and offshore sand bar system before the nourishment was placed.

In a similar fashion, every "hard" structure must be maintained and repaired after being exposed to the forces of Lake Michigan over a given time period. Small scale beach nourishment projects, as part of routine and emergency dredging projects, occur on a nearly yearly basis along the Indiana shoreline. Maintaining open boat channels, keeping water intake crib facilities clear of clogging sand and new construction are the primary reasons for dredging.

The State of Indiana has taken the position that beach nourishment is beneficial, and should be encouraged along the Lake Michigan shoreline whenever possible.

State law IC 14-3-15-2, called the "Sand Nourishment Fund" provides a mechanism to protect and increase sand in Indiana along Lake Michigan. Coastal communities can obtain funds through their local state representatives which can then be used for 1) the deposit of sand along the coast of Lake Michigan in Indiana, 2) the design and establishment of systems that cause sand to be deposited along the coast of Lake Michigan in Indiana, and 3) the prevention or reduction of the degradation of sand along the coast of Lake Michigan in Indiana.

Under another State law, IC14-3-1-14.4, the IDNR imposes a royalty fee for Lake Michigan dredge permits for removal of minerals from its bed. However, as an incentive, this royalty fee can be waived if dredging projects agree to place suitable dredge materials along the Lake Michigan shoreline as beach nourishment for the beneficial use of the general public. Unfortunately, in the past, clean lake sand used to be barged to deep water and dumped because it was a cheap method of disposal. Downdrift shorelines in Indiana suffered severe erosion as a result of this past practice.

While beach nourishment is encouraged, "hard" coastal erosion prevention structures may serve as a backup line of defense in case funding or sand to renourish a beach is not readily available. Therefore, a combination of beach nourishment and a "hard" structure might be used in residential coastal communities where a rapid loss of beach nourishment and dune-bluff might threaten a home in a single storm event.

Industrial property and many houses located on Indiana's coast already use "hard" walls and rock revetment to protect their property from destruction by erosion. But only the communities of Ogden Dunes and Beverly Shores have been actively using the combined protection of "hard" protective measures and beach nourishment. The nourishment sand is regularly provided by the dredging efforts of the Northern Indiana Public Service Company (NIPSCO). NIPSCO (Bailly Plant) must dredge to keep its water intake from being clogged by Lake Michigan sand trapped updrift of the Port of Indiana. Seventy-five percent of the dredged sand is "by-passed" to Ogden Dunes and deposited on the outer sand bar in approximately 12 feet of water. The other twenty-five percent is "back-passed" to Beverly Shores.

Two designed beach nourishment projects have been conducted by the Federal government in Indiana. The first was in 1974 when 227,000 cubic yards of sand was placed along 3000 feet of the shoreline in front of the Mt. Baldy sand dune downdrift of Michigan City. One mile downdrift of this site, 13,000 linear feet of rock revetment was placed along the shoreline of Beverly Shores. The second beach nourishment in 1981 was at the same Mt. Baldy location but on a smaller scale of only 80,000 cubic yards. Both were extremely successful at stopping the devastating erosion while the nourishment sand lasted. There is a third beach nourishment project under study by the Chicago District of the U.S. Army Corps of Engineers which proposes to nourish the entire two miles of shoreline between Michigan City and Beverly Shores. The time of implementation is uncertain at this time.

Another alternative gaining support on Federal and State levels is the establishment of "set-back" criteria creating zones where construction in "high erosion hazard" areas is regulated. Indiana does not yet have set-back legislation as of this writing. However, if Indiana becomes part of the federal Coastal Zone Management program, passage of this type of law would be recommended.

A set-back line is determined by taking the "long term average erosion rate" (such as 10 ft/yr) and multiplying it by 30 years. This "30 Year Set-Back" line would then be 300 feet back from the top of the dune-bluff. Theoretically, this would give a structure built behind that line a life expectancy of 30 years, before it would have to be torn down or moved before it fell into the lake due to erosion. The use of beach nourishment could possibly extend the life expectancy of a house built in a set-back restricted zone.

and offshore sand bars gradually reduces the severity of the sand-starved conditions, resulting in lower erosion rates.

In Portage, sand accumulation updrift (east) of the Port of Indiana caused beach widths to expand lakeward more than 500 feet between the time construction began in 1967 to 1984 (Wood and others, 1988). Immediately downdrift of the Port of Indiana, the Ogden Dunes shoreline began to erode at a rate higher than historical background rates shortly after the Port of Indiana breakwater and bulkhead complex was begun. As sand was trapped and retained on the updrift (east) side, sand-starved conditions were created toward the west at Ogden Dunes.

The U.S. Steel lakefill breakwater, located at the southern-most tip of Lake Michigan in Gary does not have a high erosion condition associated with either end of its structure, even though it extends approximately 2000 feet out into Lake Michigan. On the east side, sand accumulates due to the net westerly movement of sand. Toward the west there is approximately 6.8 miles of armored harbors and industrial bulkheads protecting the coast, extending well into the part of Indiana's coast where net littoral drift is in an easterly direction. Therefore, both ends of the structure, stretching from the Gary Harbor complex (in the east) to Buffington Harbor (in the west), could be considered 'updrift' ends.

Shoreline management in Indiana

Management of Indiana's shoreline is subject to a diverse array of federal, state and local jurisdictions. Both the State and Federal governments have co-jurisdiction over the waters and bed of Lake Michigan in Indiana, and the navigable streams, rivers and other tributaries that drain water from Indiana's portion of the Lake Michigan watershed. The Indiana Dunes National Lakeshore federal park also has concurrent jurisdiction over a portion of Lake Michigan's waters within 300 feet of the shoreline within park boundaries.

The boundary between State and local jurisdiction is defined by a fixed elevation, the *Ordinary High Water Mark* (OHWM) of 581.5 feet IGLD 1985. This boundary lies along the line where the OHWM elevation meets either the sand of the shoreline or the face of a coastal structure.

Since coastal processes are dynamic, the location of the boundary between State and local jurisdiction changes with accretion or erosion of a particular portion of the shoreline. When sand accumulates and the shoreline expands lakeward into Lake Michigan, the boundary line also moves lakeward, increasing the area under local jurisdiction. In contrast, when erosion occurs, the boundary line moves landward, decreasing the area of local jurisdiction. Therefore, when the area of local jurisdiction increases, the area of State jurisdiction decreases. When the area of local jurisdiction decreases, State jurisdiction increases. The fourty-five mile strip of Indiana's Lake Michigan shoreline is a truly unique resource of the state. It provides vast opportunities, even though it is a relatively short, narrow corridor of land. An otherwise landlocked state, Indiana is provided opportunities by its lakeshore that might not ordinarily be realized by a mid-continent state: a vast fresh-water supply for the coastal population and industry, food supply, international commerce and economic potential, energy, recreation, and places of great natural beauty and unique ecological relationships.

Although a very limited resource, Indiana's shoreline has much to offer to many diverse users; hence, competition and conflicts are inevitable. Historically, significant changes have occurred along the shoreline as a result of the competition for use; and the shoreline now accommodates a diversity of uses, ranging from heavy industry to environmental preservation.

During the past two decades, numerous situations have focused public attention on the lakeshore. High lake levels in the mid-1970s and mid-1980s, severe erosion of the lakeshore, and destruction of homes and beach property have caused citizens to have a more than casual interest in coastal processes and dynamics. Changes in the steel industry have affected the economy, the population, and the land use adjacent to the lakeshore. Conflicts among users of the lake, for example, swimmers vs. watercraft have resulted in questions of lake access. Water quality concerns for the lake and its shore have caused changes in business practices and waste treatment and discharge.

Significant economic, social and physical changes are once again occurring along the coast. A six-city Lake Michigan Marina Development Commission is developing marinas, and local governments are anxious to use their shorelines to stimulate economic diversity. Steel mills are downsizing and citizens are urging preservation and restoration of the shoreline environment. It is predictable that conflicts and problems associated with changing use of Indiana's Lake Michigan lakeshore will persist.

If Indiana's Lake Michigan shoreline is to fulfill its potential for recreational and economic growth, a balance must be found among diverse land and water uses. For nearly two decades, there has been a growing recognition of the need for a sound coastal management strategy, policy and plan to protect and, where possible, to reclaim Indiana's coastal zone by managing and using this environmentally sensitive area wisely.

Coastal Zone Management Program

In the late 1970s, Indiana received program planning funds from the federal Coastal Zone Management program. A number of important technical studies resulted, but the state did not meet all requirements for ongoing participation in the federal program.

A new initiative is currently underway to build a coastal zone management program for Indiana. Much of the discussion in this report related to Coastal Zone Management is taken from a document entitled "Toward a Management Plan for Indiana's Shoreline on Lake Michigan" prepared for the Indiana Department of Natural Resources by the Northwestern Indiana Regional Planning Commission, January 1993. The initiative was undertaken to compile a body of knowledge about the coastal zone and to determine whether an Indiana coastal zone management plan would conform to requirements of an existing federal program or be independently developed by a state-local consortium or other mechanism.

The completed report is in two volumes. Volume I consists of four chapters. The first chapter discusses statements and written submissions, which were solicited as part of a series of public meetings held in Whiting, Gary, Portage, and Michigan City, to discuss the future of Indiana's shoreline. The second chapter is a survey of federal, state and local statutes which govern Indiana's coastal zone. The third chapter assesses the federal Coastal Zone Management program and the opportunities and constraints it offers the state of Indiana. The fourth chapter recommends steps toward the development of an Indiana shoreline management program. Volume II presents a bibliography of existing plans, studies and reports about Indiana's coastal zone.

Major conclusions reached by the preparers of the coastal zone management report are: 1) Existing and emerging Indiana shoreline problems and opportunities require regional comprehensive planning and policymaking. Such issues as demand for public access, conflicts among shoreline users, development pressures on remaining natural areas, development of marinas and related facilities, residential versus recreational development, changing land and water uses due to surplus industrial lands, the need for environmental remediation and restoration, shoreline erosion, tourism and economic development, can best be addressed through the planning and policymaking framework of a shoreline management program; 2) The land and water uses of Indiana Lake Michigan shoreline are regulated and controlled by a piecemeal scheme of federal, state and local statutes, rules and regulations. A comprehensive, shoreline-wide plan is needed. 3) Indiana's participation in the federal Coastal Zone Management program would be of assistance in the above regards.

During the course of researching the Coastal Zone Management (CZM) program, staff of the Northwestern Indiana Regional Planning Commission (NIRPC) concluded that the federal program offered Indiana the necessary regulatory framework and incentives to properly manage its shoreline. Thus, NIRPC staff felt that preliminary findings regarding the CZM program warranted the early attention of the Indiana Department of Natural Resources (IDNR).

Thus, in January, 1992, NIRPC staff met with representatives of the IDNR to apprise them of the opportunities and requirements of the federal CZM program and the potential for obtaining a grant in fiscal year 1993 to begin development of an Indiana Coastal Zone Management program. Steps were consequently taken to acquire a program development grant under Section 305 of the Coastal Zone Management Act. Indiana has received a federal grant for $166,000 for October 1993 through September 1994 to begin development of an Indiana CZM program. An additional grant has been pursued for 1994-1995 and it is anticipated that an approvable Indiana CZM program will be submitted for inclusion in the federal CZM program in the fall of 1995.