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SHORELINE CHANGES OF LAKES ERIE AND ONTARIO

with Special Reference to Currents, Sediment Transport and Shore Erosion

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INTRODUCTION

The record high water levels in Lake Erie and near record levels in Lake Ontario during the past year have contributed greatly to increased erosion of the shores. Narrow beaches fronting the shore bluffs of these lakes have been submerged exposing the bluffs to direct wave attack and material removal by alongshore currents. Severe storms have resulted in profound changes in shoreline configuration and disruption of man's use of the coastal zone. Over 100 homes along Lake Erie's southern shoreline have been extensively damaged, many completely destroyed, resulting in millions of dollars of property loss. The high water levels of the lakes have not abated and the threat of renewed storm attack is ever-present.

To understand the mechanics of shore retreat and advance it is necessary to first examine the water movements in the lakes. Waves and alongshore currents have produced the major changes to the shorelines of Lakes Erie and Ontario in historic times. It is the intent of this paper to look at the hydrodynamic processes in the nearshore zone as they impact the materials forming the shores of these lakes. Specific reaches of the coasts will be used as examples of where erosion, sediment transport and accretion persist.

WATER MOVEMENTS

A knowledge of water level changes and movements in the Great Lakes is fundamental to our understanding and ability to predict sediment transport and the erosion and accretion processes which are constantly changing the shorelines of Lakes Erie and Ontario. The important components of level changes and circulation for Lake Erie are outlined in this section (Table 1). Much work has been done on defining currents in the Great Lakes ranging from drift card studies by Harrington (1895) to sophisticated modeling techniques of Mancini and O'Connor (1973). It is not the intent of this paper to review this literature but more to confine the detailed discussion to investigations of the nearshore zone.

Lake Erie

Water level changes on Lake Erie are of two principal types: long period and short period oscillations. Long period fluctuations are related to volumetric changes of the lake, caused principally by variation in precipitation, evaporation, and runoff. These changes include both seasonal changes and those occurring over a period of several years. Short period fluctuations are due to a tilting of the lake surface by the wind or possibly by atmospheric pressure differentials over the lake. Wind tides, seiches, surges, and harbor resonance, which have periods from a few seconds to several days, are examples of short term oscillations. Sun and lunar tides are negligible, resulting in maximum fluctuation of about 0.11 foot (Verber, 1960).

Water levels at the ends of Lake Erie (Toledo and Buffalo) have a greater fluctuation than at the center of the lake where tilting of the lake surface results in a nonoscillating nodal zone. High water levels coupled with northeast storms have produced a maximum fluctuation of 9 feet above Low Water Datum at Toledo. Conversely, low levels and southwest winds have lowered the level to 7 feet below Datum, a range of 16 feet. Under the influence of wind, currents tend to bank up water on the windward shore. The forced movement of the lake surface is known as wind tide and the amount of rise produced is the wind setup. The resulting free oscillation of the lake surface caused by the inequality of water level is called a seiche. The feature that distinguishes the wind tide from the seiche is the extreme variation in the time period of the wind tide. Wind tide may pile up water for only a few hours or for as long as 48 hours during severe storms (Verber, 1960). Seiches have a more regular period, governed by the existing lake level and by the length of the oscillation, which is controlled by the wind direction or location of pressure centers.

The major seiches on Lake Erie are essentially parallel to the longitudinal axis of the lake. Seiches along this axis have a period of approximately 12 to 14 hours. Seiche periods as recorded for three years at a water level gauge at Put-in-Bay on South Bass Island indicate that longitudinal seiches were in operation about 44 percent of the year. Surface winds from the southwest and northeast are likely to produce such seiches along the longitudinal axis of the lake. Wind records for Sandusky, Ohio are in agreement with the frequency of seiche periods; surface winds from the southwest and northeast occur approximately 150 days (42 percent) of the year (Herdendorf and Braidech, 1972).

Seiches with periods shorter than 12 hours are generally transverse or oblique to the major axis. Wind tide combined with seiche activity can also shorten the oscillation period or prolong it several times the normal period.

Wave action follows wind action very closely on Lake Erie because of the shallowness of the lake. Swell, however, often continues into the next day after a storm subsides. The depth of the water and the direction, velocity, duration, and open water fetch of the wind collectively determine the characteristics of waves at a given location. The U. S. Army, Corps of Engineers (1953), estimates that, with a fetch of 150 miles and a wind velocity of 30 miles per hour, the maximum wave for Lake Erie is developed in 20 hours. With this wind velocity and duration, a wave 12.5 feet high and with a 6.5 second period can be developed. Waves of this height break well offshore, but re-formed waves up to 3.5 feet in height can reach the shoreline.

Wave motion is a series of orbital movements, decreasing in diameter downward from the surface to zero at a depth equal to half the wave length. As a result there is only slight net transport of water in the direction of wave progress. However, as waves approach the shoreline the water level rises slightly and the excess water escapes as alongshore currents. These currents can be particularly rapid when the waves approach the shore at angles other than normal and result in the transport of beach materials.

Circulation in western Lake Erie is dominated by the large inflow from the Detroit River, particularly west of the islands. The midchannel flow penetrates deep into the western basin, with a branch that flows eastward toward Pelee Passage. Eddies occurring on the sides of the Detroit River result in sluggish movement that causes the water to cling to the shoreline. Adjacent to the Michigan shore, and to a lesser extent the Ontario side, these eddies tend to retain water, causing a concentration of contaminants.

East of the dominating effect of the Detroit River, the prevailing southwest winds produce a clockwise surface flow around the islands. However, this surface flow is often altered by changes in the direction, intensity, and duration of the wind. Strong winds from any direction can drive the surface currents over most of the basin toward the windward shore.

Bottom currents have essentially the same pattern as surface flow in that part of the western basin influenced by the Detroit River. However, in other areas of the basin bottom currents are commonly reverse and compensate for strong wind-driven surface currents. Current meter data indicate that bottom currents in the islands area form a counter-clockwise gyre to balance the clockwise surface flow. Both the surface and subsurface rotary flows in the islands area appear to circulate central basin water into the adjoining part of western Lake Erie.

In the central basin of Lake Erie wind is the outstanding factor in the circulation of water. Owing to the prevailing southwest winds and the orientation of the long axis of the lake in the same direction, the dominant surface flow is rather streamlined toward the east end of the lake. As in the western basin, changes in the wind can and do alter the dominant flow pattern a considerable percentage of the time.

Energy is transferred from the wind to the water by frictional drag on the lake surface. Although the wind directly affects only the surface, drag of the surface water extends downward with decreasing effect. Coriolis deflection causes a progressive change of direction with depth known as the Ekman spiral. Theoretically, surface currents deviate 45° to the right of the wind and drag the water immediately below, which also undergoes Coriolis deflection, producing a continuous swing to the right and decrease in velocity with depth. As a result, subsurface currents generally are at variance with the surface currents. In addition, the wind tends to drive greater volumes of water than are compensated for by discharge from the basin, causing a balancing subsurface return flow in opposition to the surface current. Therefore the dominant subsurface flow appears to be toward the west to balance the water economy of the lake. The process described above probably takes place at the bottom of the lake in the winter and in the lower epilimnion water in the summer when the lake is stratified.

Currents in the hypolimnion appear to be generated by vertical motions of the thermocline. Parmenter (1929) theorized that, during the summer stratification, wind action drives the upper layers of water toward the windward shore of the lake, a process which tends to incline the thermocline. The depth and angle of inclination of the thermocline are dependent upon the amount of warm epilimnion water above it. When this force is removed or overbalanced by gravity, the thermocline swings back toward a horizontal position and an oscillation (internal seiche) is set up in the cold hypolimnion water as it is released from its deformed shape. Ayers (1962) reasoned that major sinking of water masses can depress the thermocline and upwellings can raise hypolimnion water. Pressures caused by these opposing movements force the displaced hypolimnoin water to spread across the basin. Ayers also believed that tilting and oscillations of the thermocline which are initiated by wind or barometric changes can supply energy to generate currents to the deep water. These bottom currents can reach velocities over one foot per second, and can resuspend bottom sediments.

In the eastern basin circulation is also primarily wind-controlled and is similar to that in the central basin. Gradient flow is significant only near the head of the Niagara River. Current meter data indicate that during periods of stratification a current system exists below the thermocline and that the flow in the upper part of the hypolimnion is similar to that just above the thermocline and the reverse of that at the bottom of the lake.

Synoptic water property surveys have demonstrated that distinct water masses, particularly those created by major inflows, can be mapped in Lake Erie (Hartley, Herdendorf, and Keller, 1966). Conductivity measurements in western Lake Erie show that three distinct masses of Detroit River water enter the lake. Midchannel flow, which is characterized by water of low conductance, can be traced as far south as the Ohio shore, northward west of the Bass Islands and into central Lake Erie through Pelee Passage. Temperature and conductivity on inflowing water masses in the central and eastern basins allow the masses to be traced for limited distances once they have entered the lake. Tributary streams along the south shore contribute about 10 percent of the total inflow into the lake, but the highly conductive water masses from these streams cannot generally be traced more than a mile or two offshore. Harbors such as Lorain, Cleveland, Fairport, Ashtabula, and Buffalo, where large water areas are confined by massive structures, act as effective dispersal or mixing areas for highly conductive water. These structures are apparently impermeable to the passage of water masses; radical differences in conductivity are observed on lakeward and shoreward sides. East of inflowing streams the highest conductivity readings are commonly found near the shore, indicating that most of the tributary flow clings to the shoreline rather than moving lakeward. In the late spring and summer, when stratification sets up a thermal barrier within a few miles of the shore, most of the tributary discharge tends to stay near the shore and moves predominately eastward. In the fall and early winter when the lake becomes nearly isothermal the cooler tributary water is free to move lakeward and under-run the lake water. Midlake water in central and eastern Lake Erie is very uniform in nature and is little affected by north and south shore streams. Minor variations in the dissolved material occur between the epilimnion and hypolimnion water masses. Restricted circulation and solutioning of the bottom sediments may account for the slightly higher bottom water conductivity.

Alongshore (littoral) currents are generated by waves in the nearshore zone of Lake Erie and can attain velocities up to 4 ft/sec. Such currents are capable of eroding and moving beach materials as large as pebbles along the bottom. Littoral drift is the net alongshore movement of sediment by these currents. The currents and associated drift are discussed in more detail in the following section.

TABLE 1

CHARACTERISTICS OF MAJOR CURRENTS IN LAKE ERIE

I. Horizontal circulation

- A. Natural flow (hydraulic current)
  1. Is a result of hydraulic gradient from west to east.
  2. Has net eastward movement (unidirectional throughout water column).
  3. Has low velocity (maximum estimate: Verber (1952) for western basin, 0.15 ft/sec and central basin 0.03 ft/sec; Parmenter (1929) for eastern basin, 0.11 ft/sec).
  4. Has no compensating return flow.
  5. Has other currents superimposed on it and often masking natural flow.
  6. Is important in distribution of dissolved substances. (84 percent introduced at its source).
  7. Is unimportant in transport of suspended material except in restricted channels.

- B. Wind driven currents
  1. Are caused by wind stress on water surface.
  2. Are variable in direction.
  3. Have high velocity (up to 2.0 ft/sec).
  4. Move large volumes of water in short period of time (wind tide and wind setup).
  5. Have subsurface return flow often associated.
  6. Are modified by geostrophic deflection, remnant currents, basin topography, air and water temperatures, and characteristics of the wind.

- C. Alongshore (littoral) currents
  1. Are generated by breaking waves in the nearshore zone.
  2. Have movement generally parallel to shoreline (controlled by nearshore topography).
  3. Have direction at an angle to wind or wave progress.
  4. Have rapid velocity (up to 4 ft/sec).
  5. Are capable of transporting sand- and gravel-sized particles (littoral drift).
  6. Dissipate rapidly when storm subsides.

- D. Seiche currents
  1. Are created by standing wave motion of seiches (oscillating waves without progression).
  2. Are degenerated by friction (seldom complete because of modification or rejuvenation).
  3. Have minimum velocity at area of maximum amplitude.
  4. Have maximum velocity at nodal zone.

TABLE 1 (cont'd)

5. Accomplish no net transport of water (balanced by to-and-fro motion).

E. Hypolimnion currents
  1. Are generated by thermocline depression or elevation as a result of:
    a. wind setup and ensuing internal seiche,
    b. sinking water masses,
    c. upwelling water masses.
  2. Have normally low velocity, but can have velocity as high as 2 ft/sec during severe storms and upwelling.
  3. Can occur only in summer when lake is stratified (restricted to hypolimnion by thermocline).
  4. Are not present when lake is isothermal.
  5. Accomplish no net transport of water.
  6. Have high velocities capable of resuspending bottom sediments.

F. Inertial currents
  1. Are related to 18-hour inertial rotary period for Lake Erie (Verber, 1966).
  2. Have right hand acceleration to the existing currents because of earth's rotation.
  3. Have various flow patterns (straight-line, oscillatory, and rotary).
  4. Occur at all depths and in all seasons as well as under ice cover.
  5. Have period similar to internal wave periods on thermocline during summer stratification (Verber, 1964).
  6. Have imperfectly known mechanism.

II. Horizontal and vertical circulation
  A. Density currents
    1. Are the result of density differences between lake water and inflowing water.
    2. Have density differences caused by temperature, and be dissolved solid content and suspended material content differentials.
    3. Provide mechanism for rapid distribution of tributary inputs.
    4. Under-run lake water when water is cooler and solids-laden (turbidity current).
    5. Can over-ride lake water when warmer if solids content is not too high.

TABLE 1 (cont'd)

6. Have movement lakeward with no compensating return flow of same water (thermal bar, Rodgers, 1965).

- B. Turbulence
  1. Has random motion with horizontal and vertical components.
  2. Is associated with other types of currents (particularly pronounced with wind-driven and wave-generated currents).
  3. Is effective in mixing and dispersing water masses.

III. Vertical circulation
- A. Temperature gradient currents
  1. Are caused by heat transfer (convection cell).
  2. Are most important during cooling period (September to January) and warming period (March to June).
  3. Are characterized by cooled surface water sinking as warmer water rises to replace it, a process that continues until water column reaches temperature of maximum density (4° C) or by lakeward progression of a thermal bar as the lake is warmed.
- B. Sinking and upwelling currents
  1. When sinking, are caused by convergence of horizontal currents, forcing a downward movement to balance the water level.
  2. When upwelling, are caused by divergences of horizontal currents, resulting in an upward movement to balance the water level.

ALONGSHORE CURRENTS AND LITTORAL DRIFT

Alongshore, or littoral currents are important agents of erosion, transportation, and deposition of sediments along the shorelines of Lake Erie and Lake Ontario. They are normally generated by waves in the nearshore area. As waves approach the shoreline under the influence of wind, the water level rises slightly near the shore and the excess water that is pushed shoreward escapes as alongshore currents. These currents are generally set up parallel to the shoreline, are controlled by the nearshore topography, and move in a direction away from the wind. When wind and wave conditions are favorable, the resulting alongshore currents may attain velocities capable of eroding and moving particles as large as sand and gravel along the bottom.

Littoral drift is the net alongshore movement of sediments over a long period of time. The major cause of littoral drift is wave action and the resulting alongshore currents. A study of the long-term movement of sediments along the shore is therefore a useful method of determining the predominant nearshore current movement.

The combination of direction, velocity, duration, and open water fetch of the wind determines the strength of the waves and of the resulting currents. When these factors are balanced for two opposing directions, a neutral or nodal zone occurs.

Neutral zones may be classified as areas of either divergence or convergence. Those of divergence are areas where littoral currents flow away from each other and erosion generally occurs; those of convergence are areas where drifts of opposing directions meet, producing accretion or sedimentation.

The predominant drift-producing forces are weakest at the divergence areas and strongest near the convergence areas. For example, on Lake Erie the area between Avon Point and Cedar Point has a known predominant westward drift (Figure 1). Near Avon Point the opposing littoral forces nearly balance, but to the west the forces become more and more unbalanced and a maximum westward movement occurs at Cedar Point. This movement then loses its energy rapidly upon meeting the opposing force coming southward from Marblehead and deposition takes place. Deposition does not normally take place at divergence areas because the opposing forces move away from each other, both carrying material away from the neutral zone. Each area of predominant drift is independent of all others and material does not appear to move permanently from one to the other.

The relative strengths of predominant drift and the positions of nodal zones can be computed for the shorelines of Lake Erie and Lake Ontario by converting wind records to associated wave heights and calculating the wave energy for different directions. The amount of energy utilized in producing littoral drift in one direction is then compared to the opposing energy. The difference gives the theoretical direction and relative strength of the predominant drift.

The areas of convergence and divergence are generally marked by distinct configurations of the shoreline: elongated spits are found in areas of convergence and broad gently rounded headlands in areas of divergence. The most pronounced areas of convergence in Lake Erie are on the Canadian shore at Pelee Point and Long Point, Ontario. There are no comparable areas on the south shore. However, areas of divergence are better marked on the Ohio shore than on the north shore. These are Locust Point, Catawba, Marblehead, and Avon Point. Catawba and Marblehead appear to be pre-existing land forms that have controlled the littoral drift, but it is questionable whether Locust Point and Avon Point are antecedent land forms or are products of shore erosion.

The following descriptions of the Lake Erie and Lake Ontario shorelines treat littoral movements in specific areas with more detail. These shorelines have been described in numerous U.S. Lake Survey, Army Corps of Engineers documents and a review of the coastal features of both lakes was presented by the International Joint Commission (1969). Other notable studies of the shorelines have been conducted by Wilson (1908), Kindle (1933), Coleman (1937), Wood (1951), Langford (1952), Pincus (1954, 1960), Hartley (1964), Herdendorf (1966), Sutton et al (1970), Rukavina (1969), Coakley and Cho (1972), St. Jacques and Rukavina (1972), Lewis (1972), and Gelinas and Quigley (1973). The following is presented as a summary of these studies and relies heavily on the synthesis provided by the International Joint Commission. The major locations referred to in the text are shown on Figure 1. Figures 2 and 3 show a generalized view of the dominant alongshore drifts that are thought to exist in Lakes Erie and Ontario.

Lake Erie

Detroit River to Maumee Bay

Along the 30-mile stretch of shoreline between the Detroit River

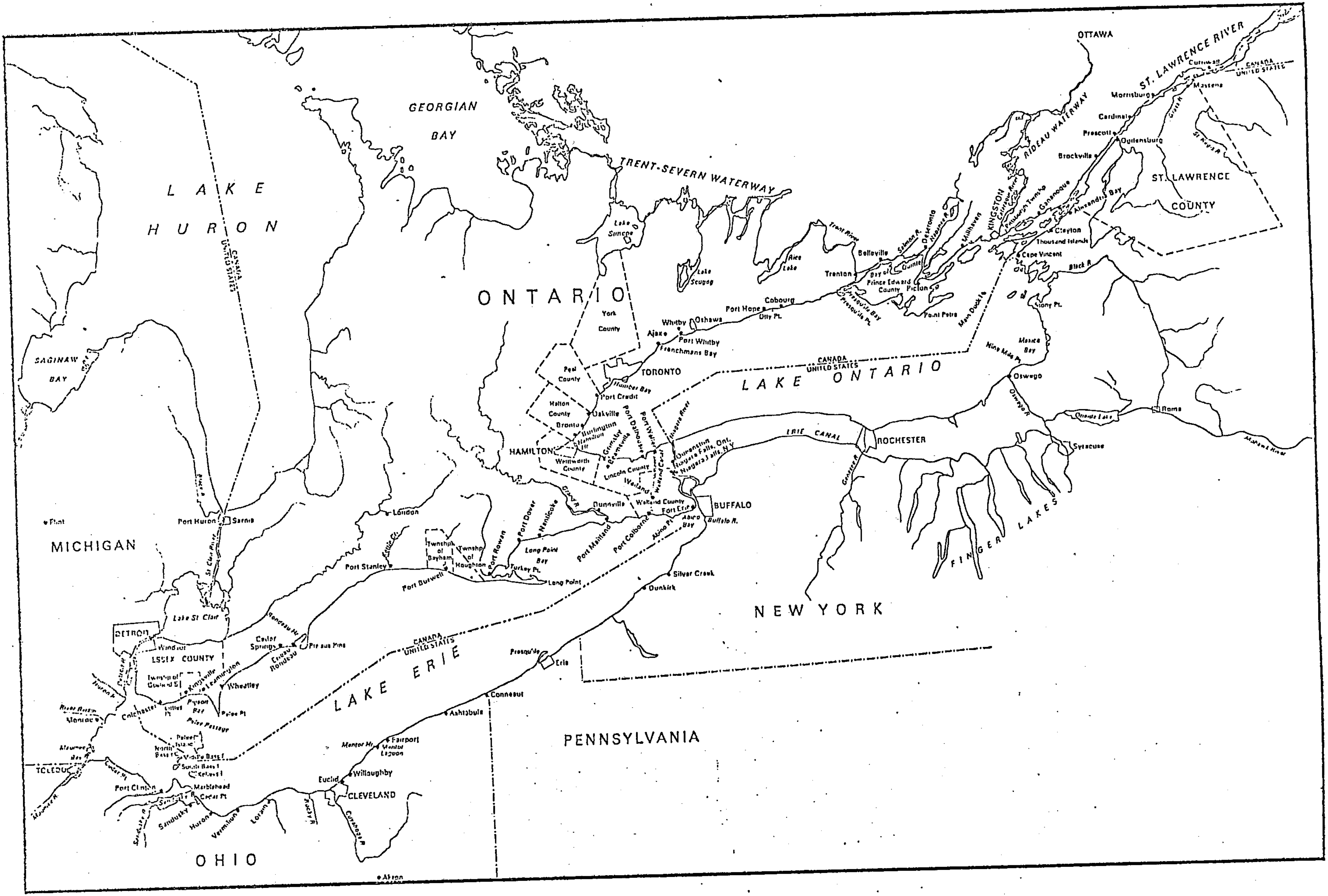


Figure 1. Geographical reference map for Lakes Erie and Ontario.

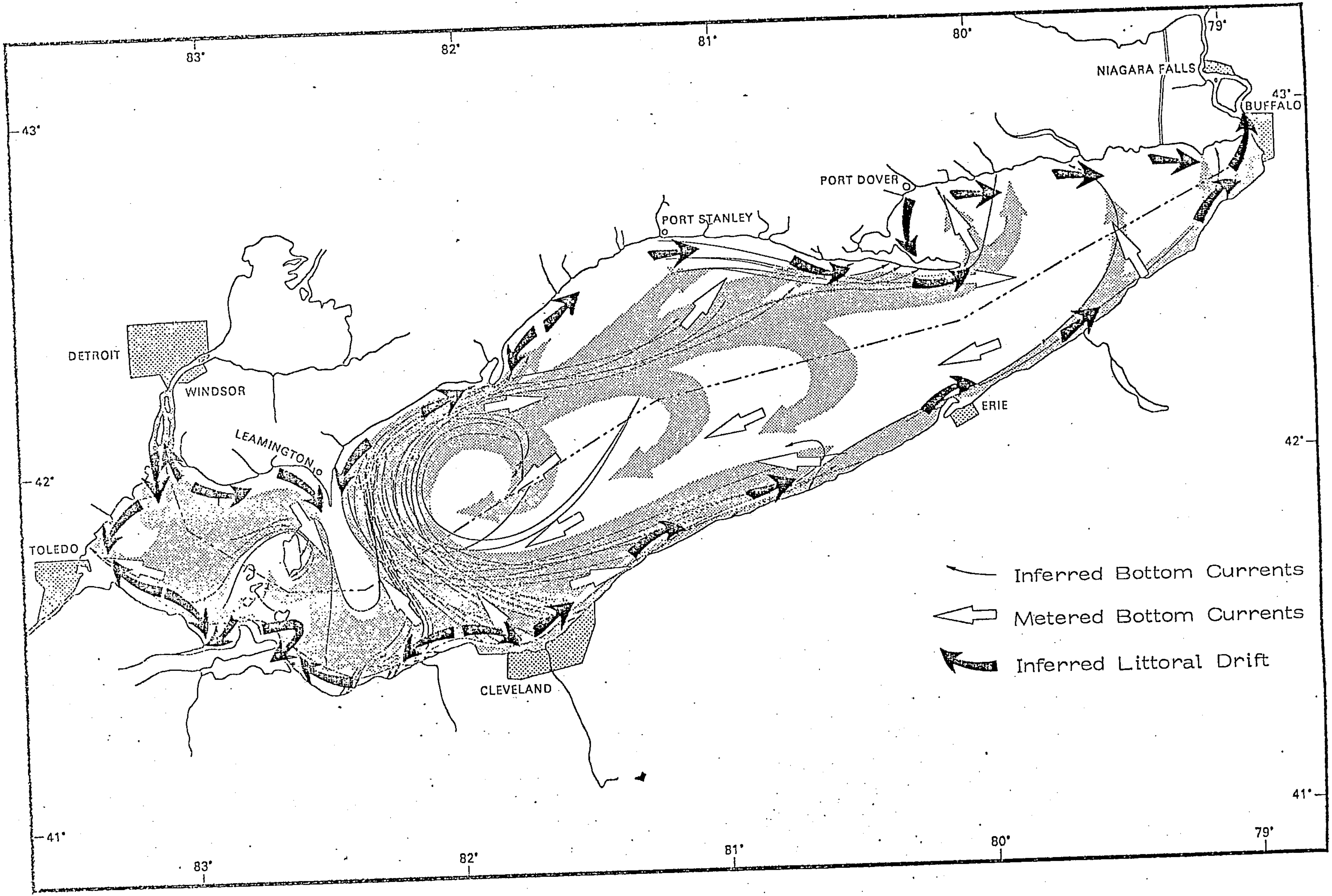


Figure 2. Generalized map of dominant alongshore drift and bottom currents in Lake Erie.

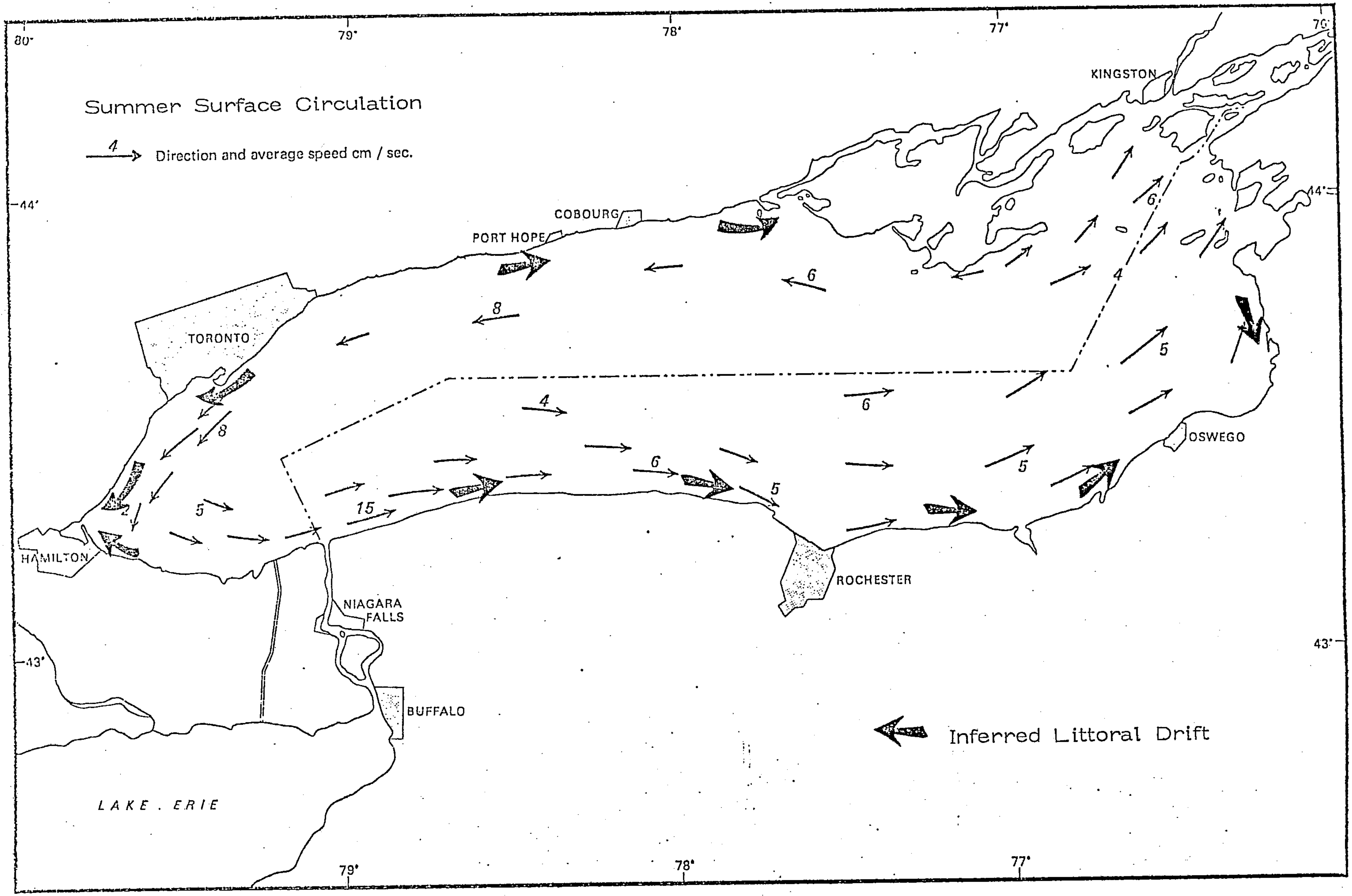


Figure 3. Generalized map of dominant alongshore drift and surface currents in Lake Ontario.

and Maumee Bay the dominant drift is southwest. The shore is low and composed of unconsolidated till and lake deposits except for a outcrop of Silurian dolomite at Stoney Point seven miles north of Monroe. A sandy spit, North Cape, has formed a baymouth bar at the northern margin of Maumee Bay from material eroded from the low bluffs along the Michigan shoreline. The source of beach-building material is small and therefore the spit is not extensive.

Maumee Bay

Maumee Bay is characterized by a low clay shore which is easily eroded by currents and by wave attack. Numerous protective structures, including dikes, seawalls, and groins, have been built in developed areas. There is little or no littoral drift within Maumee Bay, but its low banks may be experiencing the maximum shore recession rate, as much as 20 feet per year, on Lake Erie. The bottom sediment offshore is lacustrine clay with a thin overburden of silt, except near Little Cedar Point where the clay is overlain by a relatively thick layer of fine sand. The Maumee River, with an average flow of 4,740 cfs, is the second largest stream flowing into the lake and carries 37 percent sediment loading to the lake but accounts for less than 3 percent of the total drainage into Lake Erie.

Maumee Bay to Locust Point

The 15-mile stretch of shoreline between Little Cedar Point, at the east margin of Maumee Bay, and Locust Point is characterized by a predominant northwestward drift. This is due to the long easterly fetch that extends to the islands area and to the corresponding shorter fetch of westerly winds. Except for a few short stretches, beaches are lacking. Sand extends only a short distance offshore and in many places clay is exposed during low-water stages. The only sources of additonal beach material within the area are the low shore banks composed of lacustrine clay and marsh deposits which contribute very minor quantities of sand when eroded. Fortunately the currents which control the drift are weak and the existing beaches are not being eroded rapidly.

The littoral force reaches its maximum near Little Cedar Point spit. However, only a small amount of sand is being carried into this area and the spit has apparently stopped growing. The strength of the westerly movement diminishes eastward from Little Cedar Point. In the vicinity of Locust Point the currents are practically negligible. The westerly currents have caused some accretion on the east side of the larger structures and are also responsible for the westward migration of several stream mouths. The varied and numerous groins and jetties in this area have now nearly stopped the slow drift of beach material. Some accretion patterns, particularly those on the west sides of the smaller groins, indicate movement from the west. However, these appear to be only short-term reversals of the dominant trend and may be the result of strong northwest storms.

In summary, littoral currents are northwest and comparatively weak throughout this stretch of shoreline, with groins acting more as detainers than as accumulators of sand under present conditions. Recent high-water storms have completely inundated much of this shoreline resulting in extensive damage or loss of over 100 homes.

Locust Point to Port Clinton

The shore in the vicinity of Locust Point is within a nodal zone of predominant diverging currents and shows no appreciable drift in either direction. From Locust Point east to Port Clinton Harbor, a distance of ten miles, the current is southeastward and relatively weak. Unlike the banks to the west the low shore banks in this area are composed of glacial till which produces beach-building material when eroded. Groins built in this area generally trap beaches on their western or updrift sides because sand is still being supplied to alongshore currents by erosion.

The most extensive beach in the area fronts Port Clinton, east and west of the harbor entrance. The beach east of the harbor marks the position of converging littoral currents, resulting in the extensive beach accumulation. The beach on the west side of the harbor jetties apparently lies west of the convergence because it does not extend as far lakeward as the beach on the east side of the jetties.

Port Clinton to Catawba Island

The direction of littoral drift along the six miles of shoreline between Port Clinton and Scott Point is to the southwest toward the convergence area at Port Clinton. Currents are weak and sand is practically absent in the littoral zone because of the limestone and dolomite bluffs along this reach of shore. Scattered pocket beaches are composed of well-sorted limestone and dolomite pebbles. The small amount of sand from the thin mantle overlying the bedrock of this area has been carried away by alongshore currents to the convergence area. The pebble beaches have been left behind because most of the currents are not strong enough to erode them. Small accumulations of pebbles are found, however, on the northeast sides of some of the shore structures and are probably the results of storm waves and strong currents.

Lake Erie Islands

All of the islands are rockbound and are undergoing very slow erosion by scour from waves and currents. Fish Point, a spit at the southern tip of Pelee Island, is the largest sand deposit in the island area. It is likely that the bulk of this sand has come from large morainic sand and gravel deposits east and west of the island. Converging sourtherly littoral currents along the east and west sides of the island have built the nearly two-mile-long spit.

In North Bay of Kelleys Island some local accretion is forming a bayhead beach. The sand and gravel is small in quantity and is derived from the bay shore by wave action. Rattlesnake and Green Islands have pebble bars extending eastward from their eastern shores. The bars were probably formed by strong eastward-moving currents along the north and south shores of the islands. Sand and gravel beaches occur in small pockets on Middle Bass and South Bass Islands. The beaches are thin and are probably either residual material from the underlying till or are deposits trapped between bedrock headlands. Wave and current action is vigorous throughout this area.

Catawba Island to Marblehead

The section of shoreline from Scott Point to Marblehead is approximately eight miles long. A barrier beach has been built in the area of East and West Harbors by the convergence of opposing littoral drifts originating at Scott Point and Marblehead. The beach has formed across a low marshy area and is built of materials that are products of erosion of the higher flanking areas. Limestone pebbles and sand are both found in the barrier beach. The pebbles are from the bedrock and the sand from the thin overlying till. The currents in this area are comparatively weak and, because of the resistant bluffs and accretion in the area, erosion presents no great problems. Little sand is being added to the area at present and accretion may be reaching its maximum.

The barrier beach and nearshore bottom is a repository for fine sand. The dominant direction of drift at the East Harbor entrance channel is west. West of the channel the current diminishes rapidly and the sand fronting East Harbor State Park has no apparent drift. In the vicinity of West Harbor the current is weak and to the east. Sand in the offshore area has no dominating drift and appears to be trapped in a pocket between Scott Point and Marblehead. Waves and currents produced by northwest storms are effective in moving some of this sand shoreward.

Marblehead to Cedar Point

The mouth of Sandusky Bay is an area of convergence. The dominant drift of sand is southward from Marblehead Point to Bay Point. The beach sand has been removed from the low limestone shore from Marblehead to the base of Bay Point Spit. Bay Point is now growing from sand contributed by littoral currents moving northwest along Cedar Point and around the jetty. During a rising water level, sand is carried into Sandusky Bay and deposited in an arcuate bar southwest of Moseley Channel; falling level produces currents which erode the cusps of the bar (Figure 4).

The dominant current along the east side of Bay Point, generated by northeast winds and refracted waves of northwest wind, flows in a southerly direction around the tip into Sandusky Bay. It then flows northward between Bay Point and Johnson Island or southward along the bay side of Cedar Point.

Two conductivity surveys of the surface water of Sandusky Bay, performed by the Ohio Geological Survey in 1964, revealed that during rising water levels, masses of lake water with low conductance moved southward along Bay Point and the Cedar Point jetty and then into the bay (Herdendorf, 1966). The water seemed to divide into three masses upon entering the bay. One mass moved up along the bay side of Bay Point and then divided again with a flow north and south of Johnson Island; a second mass moved southeast along Cedar Point; and a third flowed westward across the Sandusky water front. As lake water of low conductance wedged into the bay, the highly conductive bay water was apparently forced to the west end of the bay. Current meter measurements taken at the same time, one mile south of Bay Point, correlated well with the mass moving southeast along Cedar Point.

The currents along the north shore of Sandusky Bay in the vicinity of Johnson Island vary in direction with the prevailing wind, but small accumulations of sand on the west sides of jetties and groins point toward a dominant eastward drift. The limit of the eastward drift appears to be a westward projecting point on the west side of Bay Point. Here the eastward drift meets the northward drift coming around the lake side of Bay Point to form a tombolo-like convergence that is building toward the northeast point of Johnson Island.

Current measurements taken in the vicinity of the mouth of Sandusky Bay and eastward offshore from Cedar Point by the Ohio Geological Survey in 1961 yielded velocities as high as 38 cm/sec. The average velocity of surface currents was 20 cm/sec; five feet below the surface, 13 cm/sec; 10 feet below the surface, 12 cm/sec. On days with only a moderate breeze from the east-northeast, bottom currents with velocities up to 24 cm/sec were recorded. Velocities of this magnitude are capable of eroding and transporting sand from 0.1 to 1.0 mm in size. Velocities as low as 20 cm/sec, which were common, are effective in the transportation of sand in the medium size range (Table 2). During storms the velocities are undoubtedly much higher and the currents are able to set large particles in motion.

In summary, the area from Marblehead to the base of Bay Point is one of erosion, but this process is slow because of natural resistance of the rockbound shore. The tip of Bay Point is accreting at a rate of about ten feet per year at the southern end. Cedar Point is also an area of accretion with an average accumulation rate of nearly five feet per year at the northeast end. The accretion is not as rapid as it has been in the past because of the depletion of source material to the southeast. Apparently material passes through, over, and around the outer end of the Cedar Point jetty so that some accretion is also occurring in the Sandusky Bay entrance channel and in the vicinity of the commercial dredging area northwest of the jetty. This accretion will continue to occur as long as there remains a source of materials. In unprotected stretches, particularly along the south shore, the Sandusky Bay shoreline shows rapid retreat, as much as 10 to 15 feet per year. Populated areas have been protected by groins and walls and show little retreat.

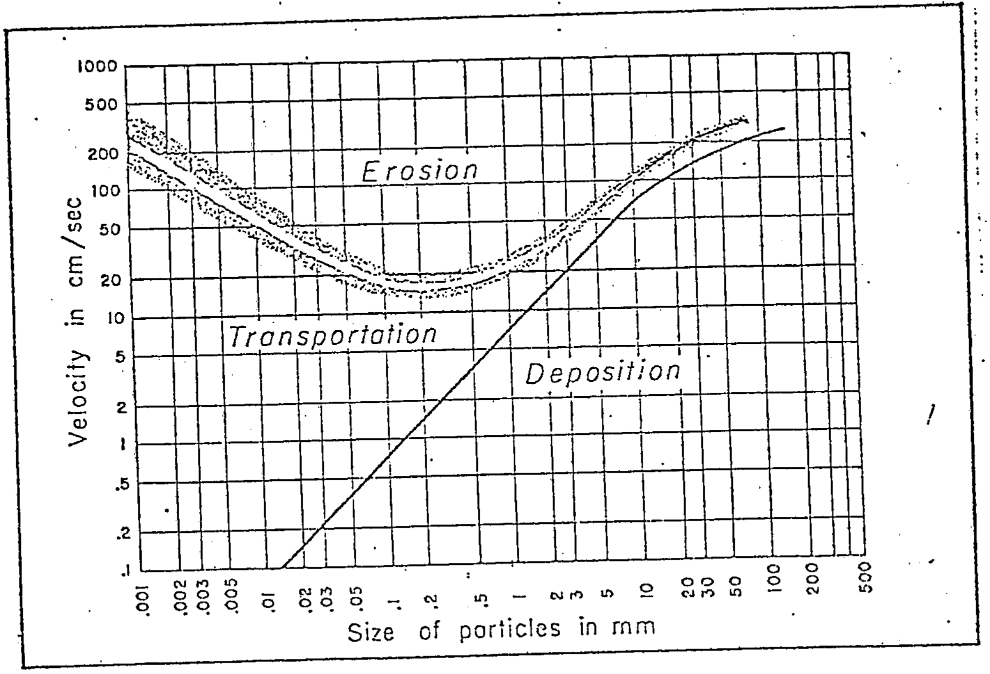
Cedar Point to Avon Point

The area from Cedar Point to Avon Point, a distance of about 40 miles, is the longest region of westward drift along the southern shore of Lake Erie. The shores along this area are composed of lacustrine clay or shale and do not produce a supply of beach materials. Till is restricted to thin deposits on top of the shale banks and below water level in the lacustrine clay bank areas. Littoral forces become increasingly effective westward from Avon Point because of the increase in easterly fetch and a corresponding decrease in westerly fetch. The shore fronting Lorain, Sheffield Lake, and Avon Lake shows little or

TABLE 2

SEDIMENT GRADE SIZES AND VELOCITIES AT WHICH SEDIMENT WILL BE ERODED, TRANSPORTED OR DEPOSITED

Class	Grade limits			Grade name
	microns (approx.)	mm	in	
GRAVEL		4096	160	
				Very large boulders
		2048	80	
				Large boulders
		1024	40	
				Medium boulders
		512	20	
				Small boulders
		256	10	
				Large cobbles
		128	5	
				Small cobbles
		64	2.5	
				Very coarse pebbles
		32	1.3	
				Coarse pebbles
		16	0.6	
				Medium pebbles
		8	0.3	
				Fine pebbles
		4	0.16	
				Very fine pebbles
		2	0.08	
SAND				Very coarse sand
	1000	1		
				Coarse sand
	500	1/2		
				Medium sand
	250	1/4		
				Fine sand
	125	1/8		
				Very fine sand
	62	1/16		
MUD				Coarse silt
	31	1/32		
				Medium silt
	16	1/64		
				Fine silt
	8	1/128		
				Very fine silt
	4	1/256		
				Coarse clay
	2	1/512		
				Medium clay
	1	1/1024		
				Fine clay
	1/2	1/2048		
				Very fine clay
	1/4	1/4096		



Modified from Dunbar and Rodgers (1957).

no predominant drift and slight accumulation at shore structures. This is indicative of proximity to a nodal zone of divergence. Groins in this area serve only as beach retainers and are not very useful in accumulating beaches. This also indicates a lack of sand in the littoral zone.

A local reversal in the predominant drift of sediments is apparent in the area immediately west of the mouth of the Black River at Lorain. Sand accumulating in the southwest portion of the harbor has caused shoaling in the vicinity of the electric power plant water intake and inside the west breakwater. The sand apparently passes through the permeable shore arm of the west breakwater under the influence of westerly winds and is protected from removal by easterly currents by piers and breakwaters to the east. It is suspected that storms from the northeast may also produce littoral movements from west to east through the west breakwater by the refracting of waves around the lakeward end of the breakwater. Conductivity patterns obtained from three surveys in 1964 show an influx of lake water with low conductivity into the harbor through the west breakwater. The influx apparently forces the highly conductive water coming from the Black River to flow to the east and north. Current measurements during one of the surveys also indicated flows to the north and east inside the west breakwater.

West of Lorain the westerly drift begins to be felt and except at the long jetties the rate of removal of beach material exceeds the rate of supply. These conditions exist until Cedar Point is reached at the western end of the area near a zone of convergence. If the Cedar Point jetty did not exist it is probable that the spits of Cedar Point and Bay Point would converge into a barrier beach and nearly block Sandusky Bay from the lake.

Cedar Point is the largest sand deposit along the Ohio shore. The sand for the deposit is derived almost entirely from erosion of the banks to the east. When it is realized that the spit is approximately six miles long and several hundred feet wide and that the bluffs to the east are low in sand content, it is apparent that a vast amount of erosion must have occurred in the bluff area. Rather large deposits of sand have also accumulated on the east sides of jetties at Huron, Vermilion, and Beaver Creek with resulting accelerated erosion on the west sides. There is a conspicuous lack of beach material in the intervening areas. This is indicative of sand being carried lakeward and westward from its place of origin. The long jetties reach far enough lakeward to interrupt the littoral flow and thus accumulate material on their updrift sides. Short groins have been relatively unsuccessful as beach builders between Lorain and Cedar Point.

Avon Point to the Niagara River

From Avon Point eastward to the eastern end of Lake Erie the predominant littoral drift is to the east. This is shown by nearly all major structures which have beach accumulations on their west sides. In the Cleveland area the predominant currents are weak but they become progressively stronger to the east. Beaches are consistently lacking throughout the area except for rather extensive deposits at the sites of major structures at Fairport, Ashtabula, and Conneaut. A recently constructed water intake jetty at Eastlake is rapidly accumulating beach material. All these structures have accelerated erosion on their eastern sides. The predominant currents take a more active part in erosion along the shore east of Cleveland than anywhere to the west. When a bluff is eroded the material is immediately moved eastward along the shore or out into the lake. The result is a scarcity of beaches even where the bluffs are composed of glacial till, the most prolific source of beach material. The veritcal or nearly vertical face of glacial clay bluffs prevents material from accumulating along the shore. Waves tend to rush up the face of the bluff and rebound with an almost equal force scouring out any beach material at the foot of the bluff and moving it either into deeper water or along the shore. Very short groins do not have much effect in these areas; many such groins exist with no beach.

Presque Isle, an extensive compound sand spit over six miles long, at Erie, Pennsylvania, has been formed by the deposition of sand and gravel eroded from bluffs to the west. Progressive eastward migration of the spit illustrates the predominant northeastward littoral drift. Old surveys of the shoreline in 1790 and 1837 show that the spit has migrated steadily more than a mile to the east during the past 176 years and in the process has formed numerous ponds by lagoon closure (Jennings, 1930).

A wide beach backed by sand dunes nearly 30 feet high and several hundred feet across has accumulated at Angola-on-the-Lake, New York. Sturgeon Point to the north seems to act as a barrier for the eastward littoral transport of sand and has caused the beach to be built. The abundance of sand along this north-south oriented shoreline, coupled with the prevailing westerly winds, accounts for the formation of the dunes.

Niagara River to Long Point

The northeast shoreline of Lake Erie between the Niagara River and Long Point is approximately 95 miles long. This reach is characterized by low limestone bluffs with pocket beaches of sand and gravel between rock headlands. Sand beaches have been trapped on the west sides of jetties at Port Dover and Port Maitland, indicating a net eastward drift. Massive dunes have accumulated on the west side of Point Abino, a combination of sand being delivered to the shore by west-to-east alongshore currents and inland formation of the dunes by southwest winds. West of Port Dover, westerly currents appear to have built Turkey Point spit, which projects southward into Long Point Bay. The mouth of Long Point Bay is an area of convergence, with baymouth bars such as Potohawk Point and Bluff Bar, on the north side of Long Point, accreting northward into the bay.

Long Point to Pte. aux Pins

The 110-mile shoreline between Long Point and Pte. aux Pins forms an arcuate embayment along which the most severe shore erosion in Lake Erie occurs. The bluff in this area reaches a height of 200 feet above lake level and is composed of glacial till and lake deposits capped by dune sand. From a broad headland about 20 miles northeast of Pte. aux Pins to Long Point the dominant currents are easterly and strong. The headland area lies within a zone of diverging drifts. Westward to Pte. aux Pins the drift is to the southwest.

Long Point is a 20-mile-long compound spit built of sand eroded from the high bluffs to the west. The spit is accreting rapidly because of extensive erosion along the unprotected shoreline. The most massive dunes formed along Lake Erie are located on Long Point.

Pte. aux Pins to Pelee Point

Both Pte. aux Pins and Pelee Point are areas of converging littoral drifts with a zone of divergence midway along the 50 miles of shoreline between the points. Both points are extensive sand spits formed by erosion of the adjacent bluffs. Pelee Point is probably built on a frontal moraine crossing the lake and Pte. aux Pins on till or a high bedrock area.

Pelee Point to the Detroit River

Along the northwest shore of Lake Erie from near the mouth of the Detroit River to the convergence area at Pelee Point the littoral drift is easterly. The formation at Bar Point of a sand spit that hooks upstream indicates a drift toward the northwest at the mouth of the river.

Lake Ontario

Niagara River to Sodus Bay

The 110-mile southern shore of Lake Ontario from the Niagara River mouth to Sodus Bay, approximately 30 miles east of Rochester, is composed of extremely regular bluffs with a narrow beach of sand or gravel at its base. The eroding bluffs are largely composed of glacial and lacustrine clay and fine sand layers overlying shale bedrock and are generally 10 to 30 feet high, locally rising to 80 feet at Devils Nose. Along most of this shore where bedrock lies below lake level, shoreline recession is rapid, 5 feet per year. In the vicinity of Thirty Mile Point where rock forms most of the bluff, erosion proceeds at a reduced rate, less than 1 foot per year.

Eastward to Rochester low eroding bluffs of unconsolidated glacial sediments alternate with barrier beaches fronting marshes along the lakeshore. Shore bluffs of unconsolidated glacial sediments ranging in height from 10 to 50 feet stretch continuously from Rochester to Sodus Bay. Littoral drift in this reach is toward the east.

Sodus Bay to St. Lawrence River

Between Sodus Bay and Oswego the shoreline truncates a well-developed glacial drumlin field oriented north-south. Because the eroding lakeshore trends northeast, the shore is characterized by undulating bluffs rising from near lake level in embayments between drumlins to over 150 feet on drumlin crests.

Low, resistant shore bluffs composed of glacial till overlying bedrock at or near lake level comprise much of the 20-mile lakeshore from Oswego through Nine Mile Point to Little Salmon River. The eastern shore of the lake, aligned north-south from Little Salmon River to Stony Point, is a sandy coast and differs markedly from the remainder of the shoreline. The low shore, which is underlain with glacial tills, is characterized by numerous embayments with barrier beaches and massive sand dunes rising 50 to 100 feet behind the beaches. The irregular coastline from Stony Point to Cape Vincent at the head of the St. Lawrence River is largely bedrock bluffs of variable heights. The stable configuration of the shoreline is controlled by resistant Lower Ordovician limestones.

St. Lawrence River to Prince Edward County

The shoreline westward of Kingston at the head of the St. Lawrence River and Prince Edward County is irregular but stable because of the resistant Ordovician carbonate bedrock which is exposed almost continuously throughout this reach. The limestone and shaley limestone beds which dip gently south to southwest were severely scoured and excavated during Pleistocene glaciations resulting in embayments and low shores. Rock bluffs predominate in areas of resistant bedrock layers. Sands from the once overlying tills have been accumulated in barrier beaches which have been built across several bays on the east coast of Prince Edward County.

Prince Edward County to Toronto

Westward of Prince Edward County the bluffs increase in height and continuity. The shoreline consists of headlands rising 10 to 50 feet above the lake separated by sandy beaches. Bedrock outcrops are scarce but glacial boulder concentrations are common off headlands. The reach between Cobourg and Frenchman's Bay continues as bluffs composed of clay and sandy till sheets, in places overlain or interbedded with glaciolacustrine sands and varved clays. The bluffs are generally low but variable in height undulating between 10 and 100 feet to form a shoreline that is moderately irregular because of small headlands where zones of compact glacial sediment resist erosion.

East of Toronto the shore bluffs rise to over 300 feet at Scarborough and are composed entirely of unconsolidated glacial and interglacial strata of sands, silts and clay. These bluffs are actively eroding at a rate of two feet per year. Because of their height, the bluffs are contributing large amounts of sediment to the littoral system of Lake Ontario. These high bluffs start at Frenchman's Bay where their height is less than 100 feet.

Toronto to Burlington

The Toronto shoreline was originally low, but now it is comprised largely of fill and is protected by seawalls and breakwaters. Toronto Harbor lies behind a hooded sandy spit which has been built from the east by littoral currents. Erosion of high bluffs to the northeast has contributed to the material for the spit.

The northern lake shore from Toronto to Burlington is a comparatively straight 33-mile reach without prominent headlands or deep bay. From the west side of Toronto to Oakville a gray shale intermittently crops out at the base of the bluffs but most of the material is unconsolidated till, varved clay and sand layers. The shore bluff generally does not rise above 30 feet along this reach. The 10 miles of shore between Oakville and Burlington is characterized by low bluffs, 10 to 20 feet high, which are composed of red shale (Queenstone) at the base with a thin covering of till or sand.

Burlington to the Niagara River

A massive bar of sand and gravel over four miles long and 300 to 1,300 feet wide, join the southern and northern shores between Stoney Creek and Burlington and impounds Hamilton Harbor to the west. This bar apparently represents the convergence of littoral drifts.

The 40-mile shore from Hamilton Harbor to the Niagara River is one of long smooth curves without prominent headlands or deep bays. The bluffs which occur along much of the shore range from 20 to 30 feet in the eastern part but decrease westerly and disappear at Stoney Creek on the east side of Hamilton. The shore bluffs are composed entirely of unconsolidated glacial tills and lacustrine clay, silt or sand except for a short reach two miles west of Grimsby where red shale bedrock constitutes the bluff.

SEDIMENT TRANSPORT AND SHORE CHANGES

There appears to be two primary sources of recent sediments transported to the nearshore zone of Lakes Erie and Ontario: (1) suspended solids from inflowing streams and (2) material contributed by shore erosion. Over 6,000,000 tons of clay, silt and sand are deposited annually in Lake Erie by its tributaries (Table 3). Unfortunately less than 5 percent of this material is suitable for beach building. Shore erosion of the glacial till and lacustrine deposits is an acute problem at many areas along the shore of Lake Erie, where bluffs recede up to 3 meters per year. The maximum material loss to shore erosion occurs along the north shore of the central basin between Port Stanley and the base of Long Point, whereas the greatest recession is along the low south shore of Maumee Bay, up to 6 meters per year. Estimates of erosion rates for the Ohio shoreline indicate that approximately 2,000,000 cubic meters of shore material or an average of about 10,000 cubic meters per mile of shore are eroded each year (Table 4). If this average is extended for the entire Lake Erie shoreline (850 miles), 8,500,000 cubic meters of shore materials are contributed to the littoral drift system of the lake each year.

However, Lake Erie shore materials, whether consolidated or unconsolidated, are generally very poor sources of potential beach materials. The glacial tills are usually made up of no more than 10 percent of sand suitable for beaches. Occasionally, as in the Cedar Point area, beach materials may be exposed on the lake bottom as an active modern beach migrates landward; or, suitable materials from older lake deposits may be exposed in shore bluffs as along the Canadian shoreline of the central basin. Large offshore deposits (between Lorain and Point Pelee and between Erie and Long Point) must be ruled out as sources of beach materials because there is little evidence to indicate that they are contributing appreciably to nearshore deposits (Pincus, 1954).

Lake Erie shore changes have been a concern to scientists for at least 135 years. Whittlesey (1838) reported in the First Geological Survey of Ohio that when the first settlers came to northern Ohio in 1796 they used the sandy lake beach as a road from Buffalo to the area of Cleveland. By 1838 the lake encroachment between the Cuyahoga and Chagrin Rivers was from 165 to 330 feet and the average from the Pennsylvania line to the Huron River (120 miles to the west) was 130 feet. Records are inadequate to trace shore changes at all places along the shoreline but enough information is available to establish some trends. The following discussions of specific areas are presented as examples of the shoreline changes under various situations.

TABLE 3

RUNOFF DATA FOR STREAMS TRIBUTARY TO LAKE ERIE

	Drainage Area (sq. mil)	Average Discharge (cu.ft/sec)	Estimated Suspended Solids (tons/year)	Estimated Dissolved Solids (tons/year)
Streams in Michigan				
Detroit River	------	176,000	1,570,000	33,580,000
Huron River	890	570	1,800	73,000
Raisin River	1,020	673	4,700	91,200
Others	1,200	720	4,000	25,000
Streams in Ohio				
Ottawa River	180	119	1,000	5,000
Maumee River	6,586	4,740	2,270,000	1,370,000
Toussaint River	108	76	700	4,000
Portage River	587	392	120,000	91,200
Sandusky River	1,421	1,060	270,000	446,400
Huron River	403	310	12,000	50,000
Vermilion River	272	218	9,000	40,000
Black River	467	388	15,300	66,400
Rocky River	294	275	29,500	131,400
Cuyahoga River	813	800	260,000	419,800
Chagrin River	267	315	35,000	90.000
Grand River	712	769	212,000	1,340,000
Ashtabula River	136	166	5,500	32,000
Conneaut Creek	192	235	4,000	20,000
Others	1,100	880	200,000	300,000
Streams in Pennsylvania				
Otter Creek	176	200	4,000	20,000
Others	193	219	4,500	25,000
Streams in New York				
Cattaraugus Creek	500	800	137,600	226,700
Buffalo River	375	545	74,500	357,300
Others	325	488	60,000	150,000
Streams in Ontario				
Grand River	3,000	2,490	375,000	500,000
Others	3,160	2,530	350,000	450,000
Totals for Lake Erie Tributaries	24,357	195,978	6,030,100	39,859,400
Municipal and Industrial (outflow direct to Lake Erie)	-----	--------	87,200	179,000
Precipitation over Lake Erie	9,919	23,300	---------	---------
Grand Totals for Lake Erie	34,276	219,278	6,117,300	40,038,400

Data sources: U. S. Geological Survey; Ontario Water Resources Commission; Ohio Department of Natural Resources and; Federal Water Pollution Control Administration.

TABLE 4

AREAS OF EROSION ALONG THE OHIO SHORE OF LAKE ERIE

Location	Shore Length[1] (feet)	Erosion Rate (ft/yr)	Bluff Weight (feet)	Volume Eroded (cu.ft/yr)	Degree Of Problem[2]
Maumee Bay	35,000	10	5	1,750,000	S
Little Cedar Point to Cooley Creek	20,000	10	5	1,000,000	S
Cooley Creek to Rock Ledge	130,000	2	5	1,300,000	M
Sandusky Bay	150,000	5	5	3,750,000	S
Cedar Point (east half)	20,000	10	5	1,000,000	M
Rye Beach to Huron	10,000	5	10	500,000	S
Oberlin Beach to Cranberry Creek	10,000	5	25	1,250,000	C
Mitiwanga to Vermilion	30,000	2	25	1,500,000	S
Vermilion to Brownhelm Creek	2,000	4	30	240,000	M
Beaver Creek to Lorain	5,000	3	30	450,000	M
Lorain to Sheffield Lake	2,000	2	25	100,000	M
Sheffield Lake to Rocky River	50,000	1	35	1,750,000	M
Euclid to Chagrin River	30,000	5	35	5,250,000	S
Chagrin River to Grand River	40,000	3	40	4,800,000	C
Grand River to Ashtabula River	120,000	5	40	24,000,000	C
Ashtabula River to Pennsylvania Line	70,000	5	60	21,000,000	S
			TOTAL	69,640,000[3]	

[1] Length includes only shore reaches of marked erosion

[2] Degree of Problem

- C - Critical
- S - Serious
- M - Moderate

[3] Equal to 2,579,00 cubic yards per year or an average of 12,290 cubic yards per mile of Ohio shoreline per year.

Maumee Bay South Shore

The south shore of Maumee Bay is characterized by a low clay shore, highly developed as a residential area on the west, and grading through less intense development on the east to marsh and swamp near Little Cedar Point. Except for a 7,500-foot-long stretch of sand and beach on the bay side of Little Cedar Point the shore has practically no beaches. There are many protective structures, some of which are associated with small accumulations of sand beaches. The bottom sediment offshore is lacustrine clay with a thin overburden of silt, except near the point where the clay is overlain by a relatively thick layer of fine sand.

With the exception of Little Cedar Point the entire south bay shoreline in its natural state is a lacustrine clay which is very weak and easily eroded. It is affected by frost action, by slaking upon drying, by rain wash and by wave attack. The crumbly outer surface produced by slaking, or by frost action, is easily removed on simple contact with water, leaving a new surface exposed to the cycle of slaking and erosion. Wave attack accelerates this process, but slumping erosion of the bank will occur even without appreciable wave action. When eroded, the silt and clay are placed in suspension to be deposited only in calm water. As periods of calm occur frequently in Maumee Bay, it can be expected that suspended mud, silt and clay will be deposited on any sand beaches established in the area, with a consequent deterioration in the quality of the beach. Further, this shore is subject to frequent flooding by reason of the large range of water level fluctuation caused by wind set-up. Maximum elevations of 9 feet above Low Water Datum have been recorded at Toledo.

Along the Maumee Bay shore the direction of the drift of beach material varies from place to place and from time to time with little evidence of appreciable amounts of material moved. Shoreline changes at Little Cedar Point indicate a westward and southward movement of moderate quantities of sand around the point and into Maumee Bay. Stock piles of material placed where they can be eroded and transported by littoral currents to areas where shore protection is needed are not suitable in Maumee Bay where there is no evidence that sufficient littoral current exists to insure the transportation of material required for successful operation of an artificial nourishment system.

Numerous protective structures, including earth dikes; steel, timber or concrete bulkheads; groins and jetties of wood or steel sheet piling, or a combination of both types of construction; and many minor structures, including small, rock-filled timber cribs and groins, have been built in this area with public and private funds. In particular, the Maumee Bay shoreline has been protected in many places by seawalls or bulkheads of various design. It has been necessary in most instances to protect the walls with riprap placed at the toe. No coordinated plan of protection has existed, and the design of many of the structures was poor. To cite an example, near South Shore Park, a series of concrete groins 50 to 100 feet long and 2.5 to 3.5 feet above datum were built in 1915. These structures have been flanked and within 30 years were located about 150 to 200 feet offshore. The history of the structures has been, generally, one of failure, and the natural changes in the shoreline have been little affected by them.

The original United States Land Survey of the south shore of Maumee Bay was made in 1834. The shoreline at the time was approximately 1000 to 1500 feet lakeward of the present shore. Hydrographic surveys of the area were made by the U. S. Lake Survey in 1877, 1915, 1950, and 1962. In addition, surveys of the shoreline and the offshore hydrography were made in 1943 and 1956 under a cooperative agreement between the State of Ohio and the District Engineer. It was the conclusion of the 1943 survey that in Maumee Bay erosion was general except on the westerly side of Little Cedar Point, where the shore progressed. Erosion on the westerly part of the south bay shore was accompanied by a slight deepening near shore and a general shoaling in the offshore area. Progression of the shore on the westerly side of the point was accompanied by a general shoaling offshore. The distal end of the point showed a marked westward movement accompanied by a slight deepening offshore in the 3-to 6-foot depths and a shoaling farther to the northeast in 12-foot depths. Changes in the far offshore areas of Maumee Bay have been greatly influenced by operations to maintain the entrance channel to Toledo Harbor. It was also noted that ice in Maumee Bay, because of its sheltered nature, does not cause any particular damage to shore structures.

In the 1956 survey, profiles were re-established corresponding to similar profiles established during the 1943 survey. Indications were that erosion of the south shore is continuing in those areas not protected. The maximum loss of shore in the 13 years between the two surveys was 260 feet or an average of approximately 20 feet per year. An over-all deepening of the offshore lake bottom was also noted. The 1956 survey indicated that along the south shore of Maumee Bay there appeared to be general erosion in effect averaging approximately 4 cubic yards of material per foot of shore per year.

Sandusky Bay Mouth

It is a natural process for a shoreline to have a tendency toward straightening itself. Where headlands extend into the lake they are strongly attacked by wave action. When these waves strike the shoreline at an angle, which is often the case, they create alongshore currents which transport sand and seal off the mouths of relatively quiet bays. This is apparently the process that has taken place in the past and is still continuing at the mouth of Sandusky Bay. This bay lies in northcentral Ohio and is bounded by the mouth of Sandusky River on the west and Lake Erie on the east. The bay is separated from the lake by a sand spit on each side of its mouth (Figure 4). The spits have each been built out toward the center of the bay mouth from headlands areas.

Bay Point spit extends southward from the rockbound headlands of Marblehead Peninsula. It extends over 7500 feet into the bay and is nearly 2000 feet across at its widest point. Bay Point is classified as a compound spit because of the series of beach ridges at the southern end of the point. These ridges represent the crests of beaches formed by waves along successive positions as the spit built southward. Moseley Channel, connecting Sandusky Bay and Lake Erie, separates Bay Point from Cedar Point to the southeast. Cedar Point spit is the eastern end of Sandusky Bay. The spit is connected to the shoreline at Rye Beach which lies about one mile west of a shale headlands at Oak Point in Huron, Ohio. The termination of the spit is at the base of the nearly 6000-foot-long Cedar Point jetty which protects the entrance to Sandusky Harbor. The jetty was built in 1897-98 to stabilize the entrance channel. It has also prevented a northward extension or a southward recurving of the spit and has caused a lakeward build-up of sand so that the present shoreline is several hundred feet farther lakeward than in the late 1800's. The northwestern end of the spit is the widest part, exceeding 3000 feet. It is made up of a series of nearly parallel beach ridges. Fine sand comprises the majority of the beach material on the lakeward side of the spit. Southeastward the spit narrows rapidly to a width of less than 400 feet at Beimuller's Cove, about 9000 feet from the jetty. From there southeast to the base of the spit the width averages between 100 and 300 feet.

The Sandusky harbor jetty has trapped a great amount of sand on its southeast side, to the advantage of the amusement park and residents along the spit to the southeast. The mouth of Sandusky Bay is northwest of the jetty and there have been no detrimental effects. This is the only large structure along the Ohio shore which appears to be completely beneficial to the adjoining shore (Hartley, 1964). It has had no measureable effect on the Marblehead shore on the northwest side of the bay mouth. However, it now appears that sand in increasing amounts is being moved around the outer end of the jetty into the mouth of the bay and toward the Marblehead shore. The jetty has also trapped a great amount of sand offshore in addition to that on the shore.

The littoral drift in the area is predominantly northwest and very strong. Most of the sand in the littoral drift originates along the shore between the jetty and Huron, ten miles to the southeast, although some may come from as far away as Lorain, 30 miles eastward. Other large structures at Huron and Vermilion, however, have nearly stopped the long-distance drift.

The federally-owned breakwater jetties at Huron protect the Huron River harbor from storm activity and alongshore sediment drift. The west jetty is 3,200 feet long and the east jetty is 1,450 feet in length. Both are impermeable to the passage of sediment. The east jetty has trapped and maintained a wide beach which extends eastward about one mile. Thus this section has been stabilized by a permanent beach derived from erosion of the shore and nearshore bottom to the east.

The predominant littoral drift in the Huron area is toward the west. Because the jetties effectively stop the movement of beach materials in the drift, the shore west of the jetties is starved of sand. Beaches are scarce or absent along the shore for 3 miles west of the jetties. The scarcity of protective beaches has necessitated the construction of bank protection. Protected banks add to the problem by eliminating the only important source of beach supply, for the nearshore bottom supplies a small amount of sand through the action of wave scour. However, the sand on the bottom is mainly very fine and will not long remain on the shore. In addition, much of the nearshore bottom in the 3 mile stretch is bare rock which contributes little or nothing to the beach supply.

West of the beach-poor area, the Cedar Point spit begins and sand is much more plentiful on the shore. However, the shoreline is receding rapidly as the beach advances into the marsh at the southeast end of Sandusky Bay. Sand is being slowly lost from the shore by longshore drift toward the northwest. This area supplies most of the sand which is accumulating farther northwestward near the tip of Cedar Point. Therefore, it is evident that the jetties at Huron, have caused a good, mile-long beach to be built to the east, while adversely affecting, by sand starvation, about five miles of shore to the west.

Early topographic surveys of the Sandusky Bay area show that in 1847 and 1877 Bay Point was considerably smaller and shorter than at present and that Cedar Point was somewhat smaller and differently shaped (Figure 4). Figure 5 is a comparison of the bottom topography between Bay Point and Cedar Point for the years 1877 and 1963. It will be noted that the cross-sectional opening of the bay mouth was reduced an estimated 19,300 square feet in 86 years or approximately 200 square feet per year. In estimating the volume of fill that has occurred since 1877 an average width of 1000 feet for Bay Point spit was used to yield a total of about 713,000 cubic yards or 8,200 cubic yards per year. Figure 6 is an aerial view of Bay Point in 1949. The successive beaches representing the southward growth are clearly visible. There is only a slight development of offshore bars shown in this photograph. Figure 7 is a similar view eight years later in 1957. A very extensive system of spits and offshore bars can be seen on the lakeward side of the point eventhough the lake was slightly higher in 1957. Most of the accretion since 1877 appears to have taken place on the Bay Point side of Moseley Channel. The channel itself seems to have been virtually unchanged during this period and probably maintained its depth through natural scour. The completion of the Cedar Point jetty around 1900 caused accretion on the east side of the jetty but prevented a farther extension of the point into the bay mouth.

Sandusky Bay has only one outlet to Lake Erie which is approximately one mile wide at times of normal water level and is reduced considerably during periods of low water levels. In 1964 water levels averaged slightly below Low Water Datum for Lake Erie. This cut the width of the Moseley Channel between Bay Point to only 1/4 mile. As shown in Figure 5 the opening at the mouth of Sandusky Bay has been closed by 39.5 percent since 1877. This is an average decrease of 0.5 percent per year. It appears that the Bay Point spit is approaching its limit of growth below Low Water Datum. Approximately only 4,000 square feet of cross-sectional area remains to be filled between Bay Point and the deep hole of Moseley Channel. It is not anticipated that any fill will take place in the deep part of the channel. No noticeable fill has taken place in this part of the channel since 1877 and it is likely that natural scour will maintain it in the future. When Bay Point reaches its maximum development below datum, the channel will probably be restricted to about 50 percent of its 1877 cross-sectional area. Projecting its past rate of growth, this should take about 20 years. Indications point to a diminishing supply of sand from the area to the east of Cedar Point. With this in mind, the present rate of growth of Bay Point is probably considerably less than the yearly average since 1877.

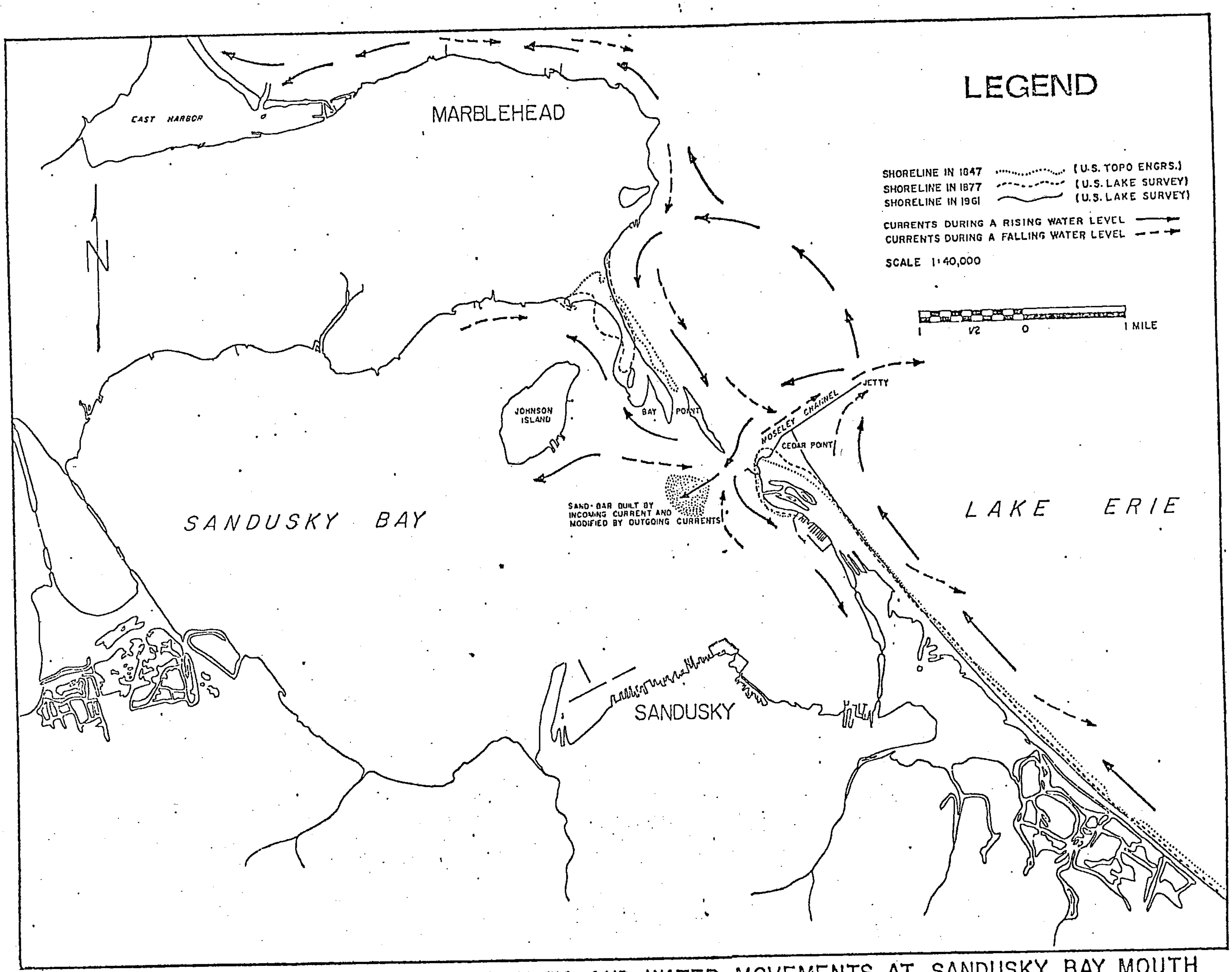


FIGURE 4 SHORELINE CHANGES AND WATER MOVEMENTS AT SANDUSKY BAY MOUTH

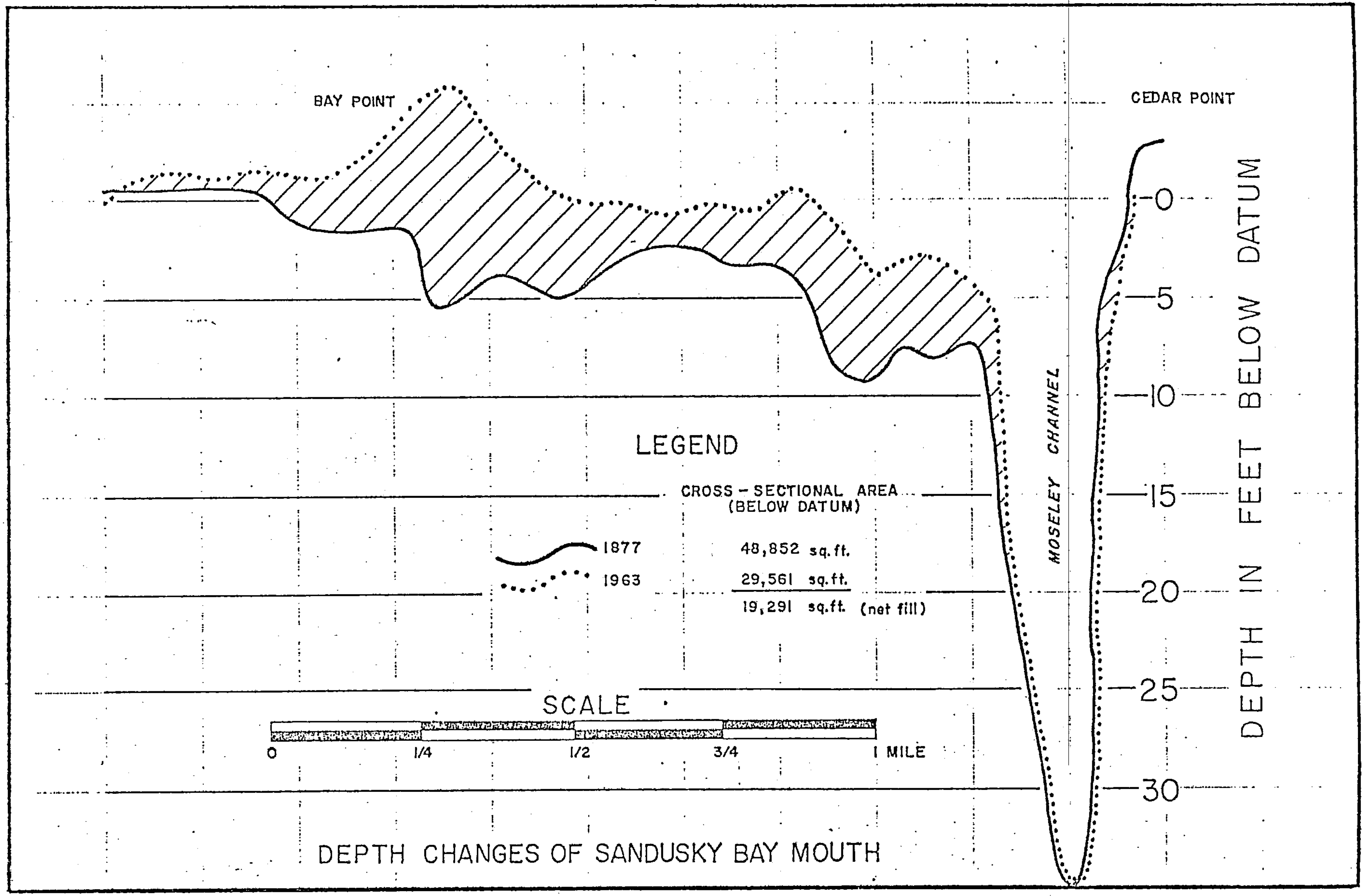


Figure 5. Depth change at the mouth of Sandusky Bay between 1877 and 1963.

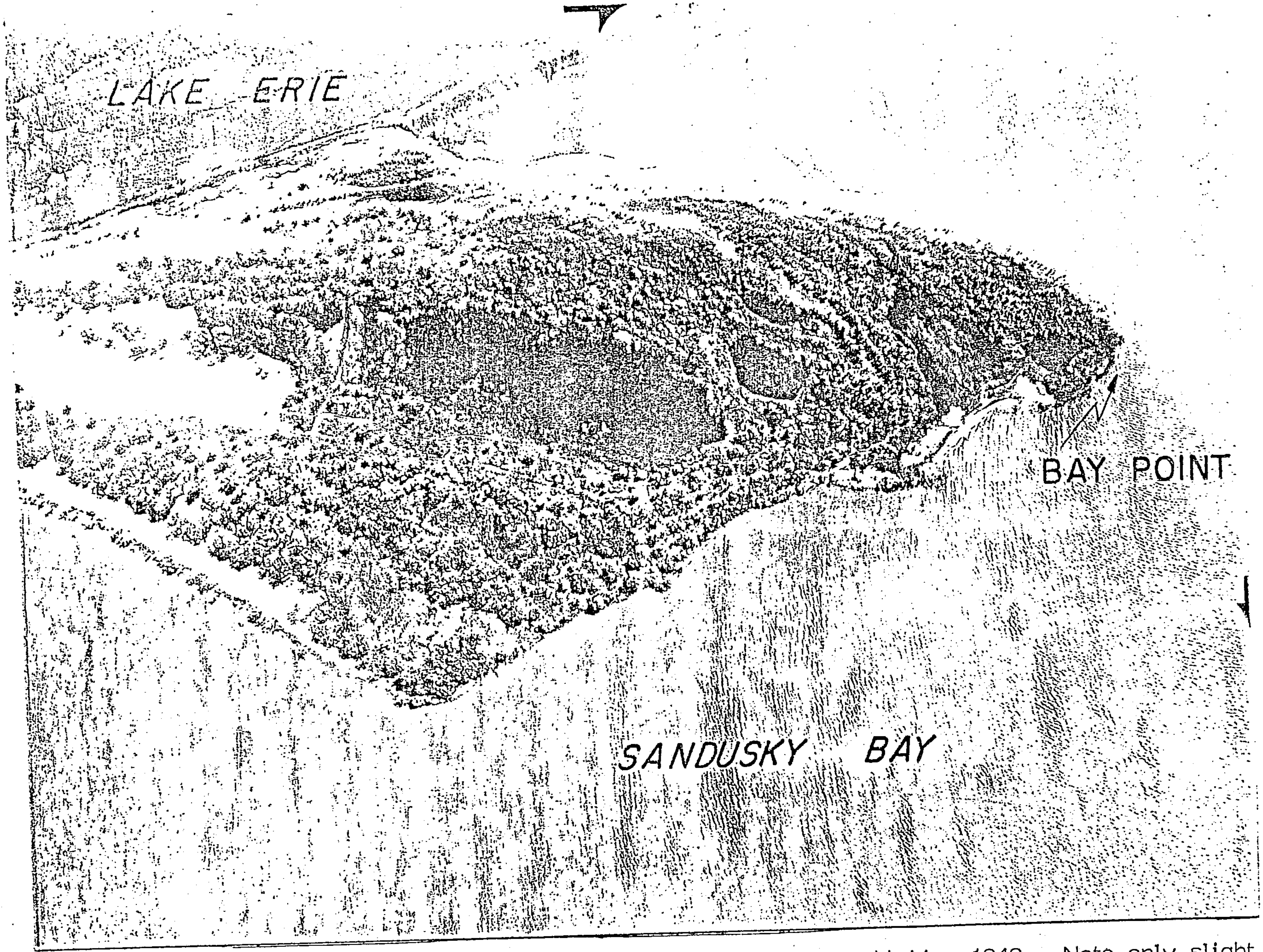


Figure 6. Aerial photograph of the southern tip of Bay Point on 11 May 1949. Note only slight development of an offshore bar on the Lakeward side of the point. Water level 570.8 (IGLD). Scale 1:4800 (1 in. = 400 ft.). Flight 198.

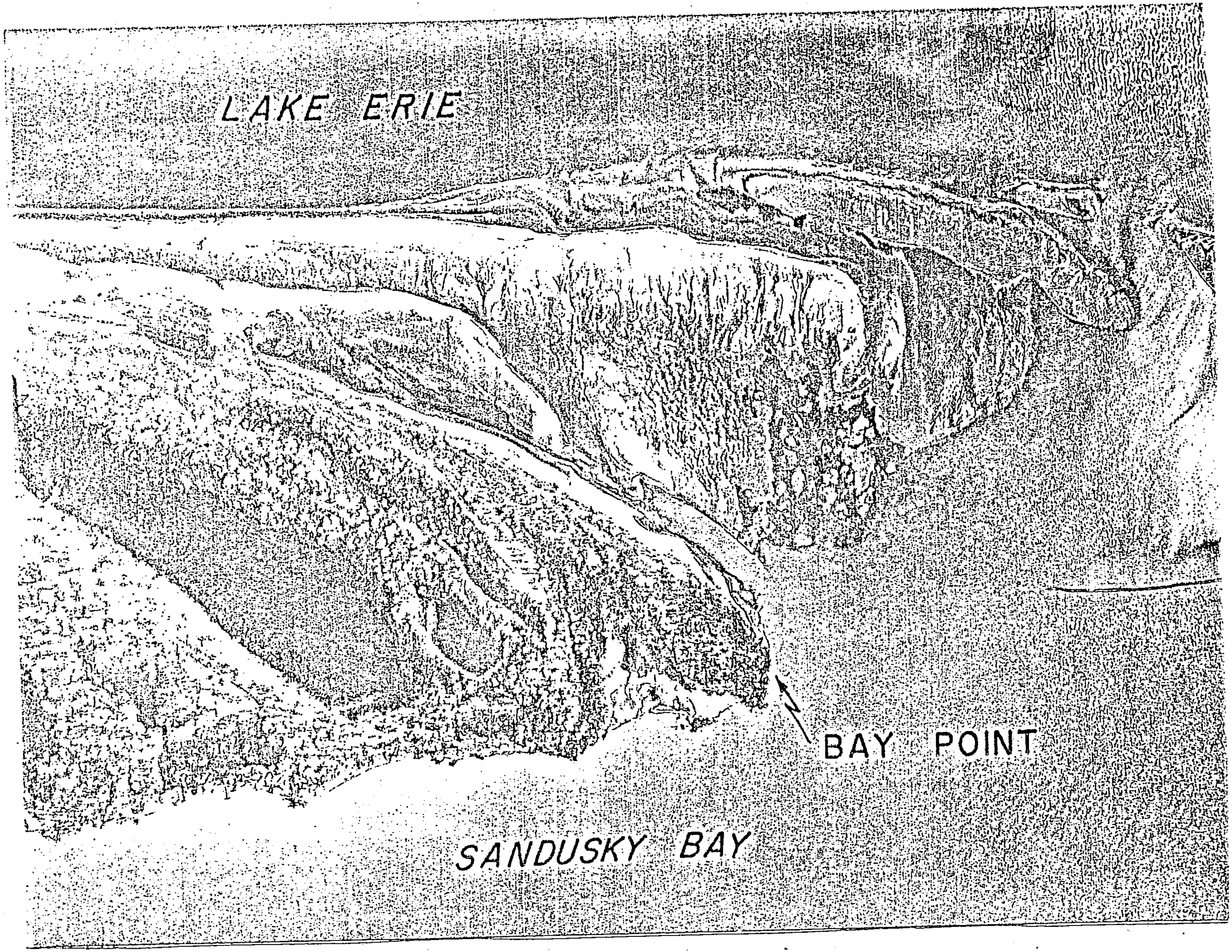


Figure 7. Aerial photograph of the southern tip of Bay Point on 15 April 1957. Note extensive development of spits and offside bars on the lakeward side of the point. Water level 571.1 (IGLD). Scale 1:4800 (1 in. = 400 ft.). Flight 850.

Chagrin River Mouth

Parallel jetties have been built normal to the shore at an electric power company in Eastlake 2500 feet east of the Chagrin River Mouth. These structures extend about 1,100 feet into the lake and provide protection for a high-volume water intake (Figure 8). They are constructed of filled cellular sheet pile, and concrete-capped, with a top elevation of ten feet above datum. Since their construction in 1952 they have virtually stopped the longshore movement of sand from the southwest and have quickly built a wide beach on the southwest side which now exceeds half a mile in length.

Hartley (1964) stated that the long jetties have probably had more far-reaching and significant effects on shore processes during their short existence than any other structures of comparable size along the Ohio shore. While quickly providing a protective beach to the southwest, they have had an extremely serious effect on the shore to the northeast. Formerly a wide beach some 3,000 feet long fronted the valley of the Chagrin River. This beach is rapidly being lost because of sand starvation. The effect is not as serious farther to the east of the Chagrin valley, but the sand starvation is apparent for at least two miles. Deepening of the nearshore bottom is occurring, and, with high lake levels, the entire area is experiencing one very rapid erosion. The high water storms of 1972 completely destroyed homes east of the Chagrin River mouth in the absence of the former protective beach.

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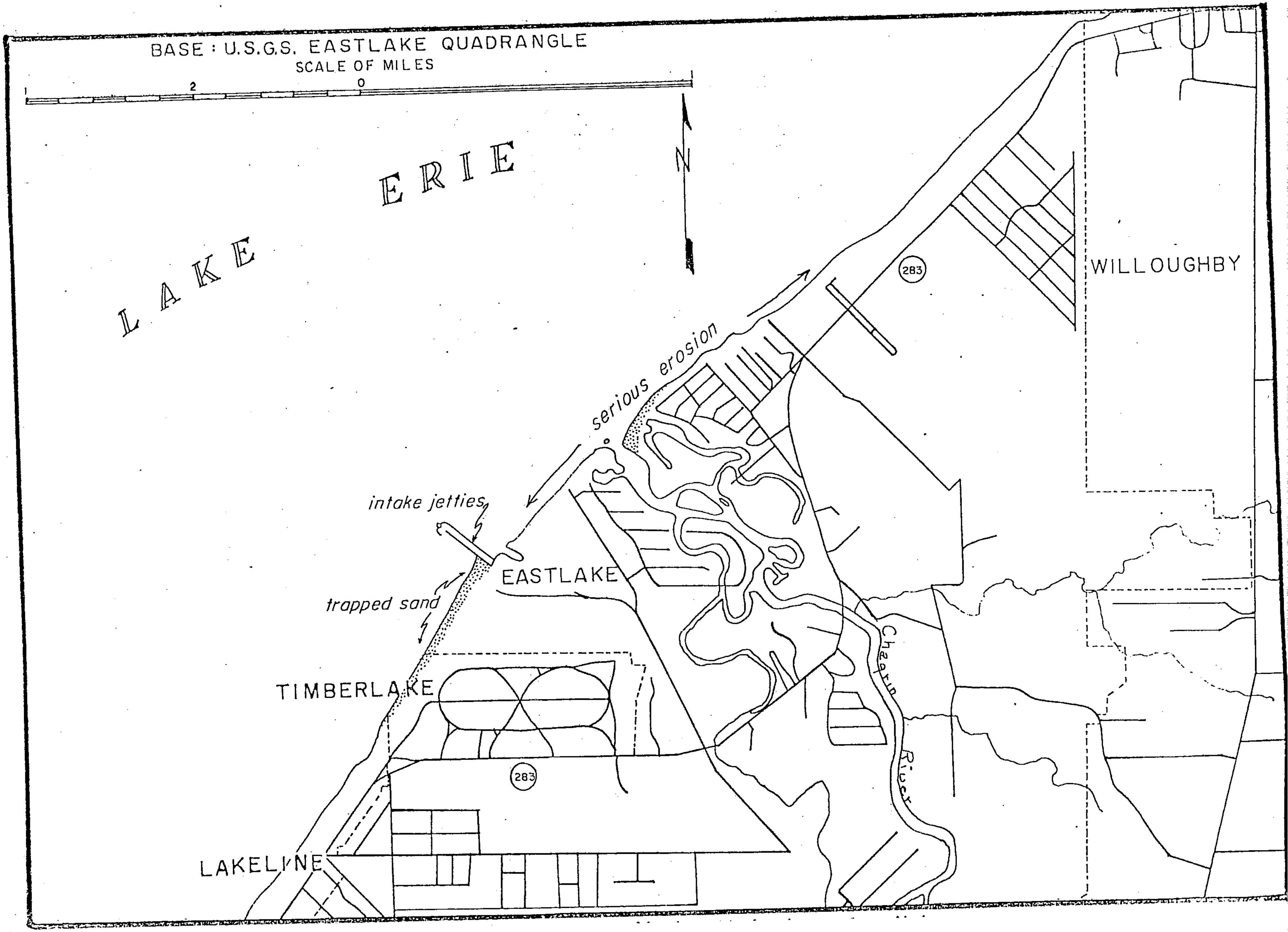
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serious erosion
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EASTLAKE
TIMBERLAKE
283
LAKELINE
Chagrin River

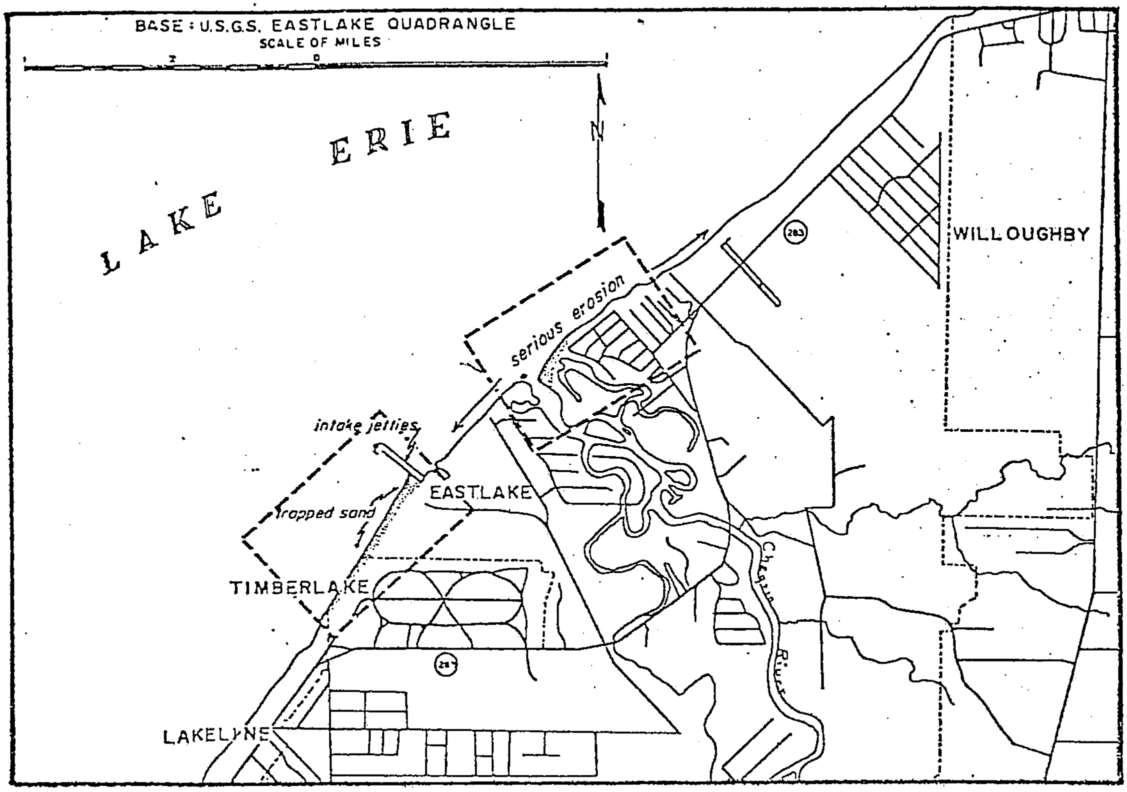

Figure 8. Chagrin River Mouth, Water Intakes and Shore Conditions.

CONCLUSIONS

The lower Great Lakes owe their origin to physiographic changes induced by Pleistocene glaciation. As the ice sheets paused in advance or retreat, ridges or moraines of glacial till were built up at their margins, damming the natural drainage and forming glacial lakes. Lakes Erie and Ontario are remnants of such lakes. As the ice retreated, other outlets were uncovered and new lake stages were formed at successively lower elevations. When the latest glacier retreated from the area new and final drainage outlets were made available. However, the bedrock sill at the Niagara River was as much as 30 meters lower than at present because of depression under the weight of glacial ice (Lewis, et al, 1966). Following deglacial unloading the outlets gradually rebounded and the levels of the lakes correspondingly rose.

As a result, the shores of Lakes Erie and Ontario show signs of recent submergence and are characterized by eroded shore bluffs. Where the bluffs are dissected by tributary streams, the mouths are often drown and possess characteristics of estuaries (Brant and Herdendorf, 1972). The smaller streams which are free of jetties and breakwaters are ofter separated from the laked by a sandy barrier beach. The estuaries predominate along the south shore of each lake, whereas high eroding bluffs are more common on the north shores. Because of prevailing southwest winds and associated waves and currents the high bluffs show the maximum volumeteric erosion loss. However, the north shores also possess the largest areas of accretion in the massive spit developments of Pelee Point, Pte. aux Pins, Long Point and Toronto Island.

Man's attempts at controlling shore erosion have met with only minimal success. Most of the large structures placed in the lakes, such as breakwaters and jetties, were designed to aid navigation and not to protect shore property outside of harbors. They serve their intended purposes well, but they have also resulted in changes of great magnitude to the adjacent shore. Most of the large structures have caused beaches to be built on their updrift sides and accelerated erosion downdrift. The effects are not balancing in that the length of eroding shore is often five or more times the length of shore protected by the accretion.

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