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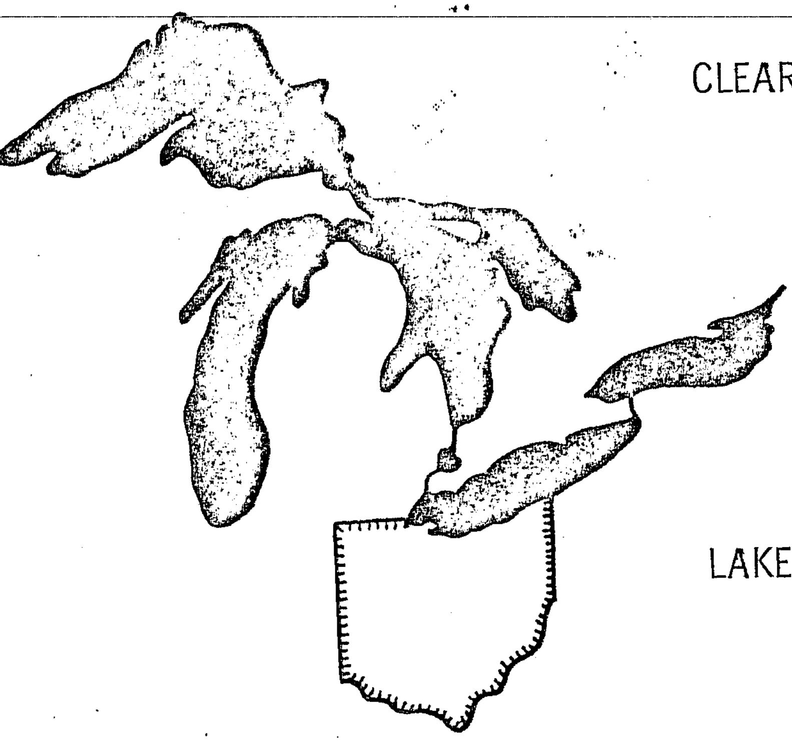

LAKE ERIE AND THE ERIE ISLANDS

by

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Introduction

In the last decade, Lake Erie has become the focus of considerable attention because of deterioration in lake water quality. Many of the problems of Lake Erie exist because it is shallow and has a relatively small volume for a lake of its size. These factors, coupled with waste discharges from eleven million inhabitants, have accelerated eutrophication of the lake.

Lake Erie is geologically the oldest of the Saint Lawrence Great Lakes. It is by far the shallowest, with its entire water mass above sea level, and has the smallest volume with the shortest retention time. The water temperatures of Lake Erie have the widest seasonal fluctuations of any of the Great Lakes, and it is the only lake that typically freezes from shore to shore. In comparison to the other Great Lakes, Lake Erie is also the southernmost, warmest and most turbid, biologically productive, and eutrophic of all.

Basin Morphometry

Lake Erie lies between 41°20'N to 42°50'N latitude and 78°50'W to 83°30'W longitude. It is a relatively narrow lake, with its long axis oriented southwest-northeast. This axis parallels the prevailing wind direction which subjects the lake to violent storms, with waves over 12 feet high, and wide fluctuations in water level (over 15 feet between record high and low levels at Toledo, Ohio). Lake Erie is approximately 240 miles long and 57 miles wide, with a mean depth of 60 feet. The water covers an area of 9,919 square miles, and has a volume of 113 cubic miles. Lake Erie has three major physiographic provinces: western, central and eastern basins (Table 1).

The western basin, lying west of a line from the tip of Cedar Point, Ohio northward to Point Pelee, Ontario, is the smallest and shallowest basin with most of the bottom at depths between 25 and 35 feet. In contrast with the other basins, a number of bedrock islands and shoals (locally called reefs) are situated in the western basin and form a partial divide between it and the central basin. The bottom is flat except for the steep-sided islands and shoals. The deepest sounding is 62 feet in a small depression north of Starve Island Reef. The western basin possesses only 12.8 percent of the area and 5.1 percent of the volume of Lake Erie.

The central basin is separated from the western basin by the island chain and Point Pelee, and from the eastern basin by a relatively shallow sand and gravel bar between Erie, Pennsylvania and the base of Long Point, Ontario. The central basin has an average depth of 61 feet and a maximum depth of 84 feet. Except for the rising slopes of a low morainal bar extending south-southeast from Point Pelee, Ontario, the bottom of the central basin is extremely flat. This basin is the largest, containing 62.9 percent of the area and 63.0 percent of the volume.

The eastern basin is relatively deep and bowl-shaped. A considerable area lies below 120 feet, and the deepest sounding of 210 feet is about eight miles east-southeast of Long Point, Ontario. This basin comprises 24.3 percent of the lake's area and 31.9 percent of its volume.

Bedrock Geology

The varying depths of the Lake Erie basins have been attributed to differential erosion by preglacial streams, glaciers, and postglacial lacustrine processes. The rock strata of the central and eastern portions of Lake Erie dip slightly to the southeast. Lake Ontario is separated from Lake Erie by resistant Silurian limestones and dolomites of the Niagara Escarpment. The central and eastern basins of Lake Erie are underlain by nonresistant shale, shaly limestone, and shaly sandstone of Upper Devonian Age. Inland along the south shore, eastward from Cleveland, the Portage Escarpment, composed largely of Mississippian sandstone, rises several hundred feet above the level of the lake and forms the northwest front of the Appalachian Plateau.

Glacial ice invaded the Lake Erie region from the northeast during the Pleistocene Epoch. The ice front was obstructed by the Portage Escarpment and deflected western along the outcrop of the softer Upper Devonian shales.

These shales were deeply scoured to form the narrow eastern basin. Farther west where the dip of the beds is less and the width of the soft shale belt is greater, glacial erosion resulted in the broader but shallower central basin.

The outcrop belt of Devonian shales swing inland between Cleveland and Sandusky and continues southward through central Ohio. The shallow western basin is underlain by Silurian and Devonian limestones and dolomites on the northward plunging end of the Findlay Arch (Cincinnati Anticline). Glacial erosion had relatively slight effects on these resistant rocks other than to form impressive grooves such as those found on Kelleys and the Bass Islands. The glacial scour was probably controlled by the pre-glacial stream valleys, resulting in the shallow basin and the island chains.

The islands and reefs are arranged in three roughly north-south belts or chains. The most westerly belt lies north of Locust Point and includes approximately 12 reefs and West Sister Island. The middle belt extends from Catawba Island through the Bass and Sister Islands, and includes at least 14 reefs and 10 islands. The easterly belt encompasses Johnson Island, Middle Island and Pelee Island, and about seven reefs and shoals. This arrangement and the cuesta shape of the islands are controlled by the structure and relative resistance of the underlying bedrock.

The shoreline of Catawba Island from Rock Ledge to West Harbor is six miles long and consists of an alternation of rocky headlands and glacial till bluffs. The dolomite headlands rise to 70 feet above lake level, whereas the glacial till is much less resistant to erosion and has been cut back into coves and indentations along the coast. Pebble and cobble beaches have formed locally in the coves. The four miles of shore from West Harbor to Lakeside is low and bordered by sand beaches. The beaches lie on marsh deposits which formed in the shallow bay between Catawba Island and Marblehead Peninsula. The underlying material is glacial till and lacustrine clay. An extensive sand deposit has accumulated in the East Harbor area and low sand dunes have formed behind the beach.

The Marblehead Peninsula shore arcs for four miles from Lakeside to the base of Bay Point and is lined with limestone and dolomite bluffs, generally less than 20 feet above lake level. Sections of the shore are composed of thin-bedded rock which yields to wave attack; elsewhere the rock is massively bedded and more resistant to erosion. Glacial till commonly caps the bluffs. The narrow pebble beaches which line the shore at the base of the bluffs have been largely derived from the bedrock. Bay Point extends southward from Marblehead Peninsula for two miles into Sandusky Bay. This point is a compound spit that is growing from sand contributed by littoral currents moving along Cedar Point and around the end of the Sandusky Harbor jetty.

The shores of all of the major islands are rockbound, chiefly rugged in character, with bluffs along the major portions of the island perimeters. The highest elevations are normally adjacent to the west shores, except West Sister Island where the bluffs are highest along the east shore. The upland area adjacent to the west shore of South Bass Island (Victory Woods) reaches a height of 70 feet above lake level, the highest elevation in the islands. Small sand, cobble, or boulder beaches are situated at indentations in the shoreline. The most extensive sand beach lies along the north bay of Kelleys Island.

Johnson Island, lying in Sandusky Bay adjacent to Bay Point, is composed of low limestone and glacial till shores. The shore is bordered by discontinuous cobble beaches. Turtle Island, in Maumee Bay, is the only natural island in western Lake Erie not composed of bedrock. Turtle Island is an elevated terminous of a sand spit that was formed by littoral currents. Erosion of this sandy material has reduced the size of the island from seven acres to its present 1.5 acres in the past fifty years. The island is now protected by a seawall and has no beaches.

The reefs consist of submarine bedrock exposures and associated rock rubble and gravel. The topography of the reef tops varies from rugged surfaces caused by bedrock pinnacles and large boulders to smooth slabs of nearly horizontally bedded rock. In places the exposed bedrock has the appearance of low stairs with the "steps" dipping slightly to the east from the fringe of the reefs to its crest. All of the bedrock formations that form the reefs are carbonate rocks which contain abundant solution cavities. Most of the reefs are conical in shape and elongated, as are many of the islands, in a northeast-southwest direction. Two factors appear to have influenced this elongation: (1) vertical joint systems in the bedrock which are oriented parallel to the elongation and (2) the elongation is in general agreement with the major trends of glacial ice movements as deduced from grooves found on the islands.

The bedrock in the island region of western Lake Erie is sedimentary in origin and was deposited as lime muds in shallow, warm Silurian and Devonian seas, which covered the region from 410 to 375 million years ago. The warm, clear conditions of the sea can be inferred from the abundant fossil corals and other invertebrates found in the rocks on Kelleys and Johnson Islands. The abandoned limestone quarries in Kelleys Island State Park are excellent sites for fossil collecting and have yielded over 70 species of marine organisms.

The dominant structural feature of the bedrock underlying western Lake Erie is the Cincinnati Arch. The nearly north-south axis of this arch passes through the island region and then plunges gently to the north. A study of the structure of Precambrian or basement rock of Ohio indicates that the crest of the arch lies a few miles east of West Sister Island. As a consequence of the alignment of the arch, the overlying Paleozoic bedrock dips to the east at approximately 20-40 feet per mile in the Bass-Kelleys Islands area. For this reason, the oldest rocks are exposed on West Sister Island and successively younger formations crop out to the east along the flank of the arch.

The bedrock exposed on West Sister Island and on the reefs in the vicinity of Locust Point as far east as Niagara Reef is the lower portion of the Tymochtee Dolomite. This formation is highly variable in its resistance to weathering, a factor that may explain the lack of bedrock reefs between

Niagara Reef and the Bass Islands.

The middle and eastern belts of bedrock islands (Catawba-Bass and Johnson-Kelleys) are characterized by high elevations and cliffs at their western shorelines; elevations generally decrease eastward resulting in shelving rock along the eastern shorelines. The resulting topographic form is that of a cuesta or asymmetrical ridge, where the gentle slope agrees with the dips of resistant beds and the steeper slope is an eroding cliff maintained partly by undercutting of less resistant rocks. Because West Sister Island lies on the west flank of the Cincinnati Arch the dip of the strata is also to the west. This has resulted in the development of a cuesta with its steep cliff on the east side of the island, the opposite of those formed on the more easterly islands.

Catawba and the Bass Islands are underlain by a band of resistant dolomites of the Bass Island Group. The Put-in-Bay Dolomite of this group is responsible for most of the rugged features of the shoreline. The Tymochtee Formation, which underlies the Put-in-Bay Dolomite at the base of the cliffs, is more readily eroded by waves and results in the undermining of the rock above, which fall away in large blocks, forming nearly vertical walls.

The resistant lower beds of the Columbus Limestone are responsible for the easterly chain of bedrock highs, including Johnson and Kelleys Island. Between South Bass Island and Kelleys Island three formations crop out: Raisin River, Amherstburg, and Lucas Dolomites. All three formations are less resistant than the Put-in-Bay Dolomite and the Columbus Limestone which explains the depression between the islands.

Most of the Michigan and Ohio shore of western Lake Erie is low and marshy, and lacks shore cliffs except for the bold headlands, composed of limestone/dolomite capped with a thin glacial till in the Erie island area. All stream valley mouths are flooded with lake water, forming freshwater estuaries indicating that they have been submerged in a geologically recent time. The south shore of the central basin has wave-cut bluffs rising to 65 feet near Cleveland and 80 feet near Conneaut. Shale bedrock crops out near lake level and forms the basal bluff structure at several locations. The bedrock forms much of the lake bottom out to one mile offshore east of Vermilion. Most of the bluffs, however, are composed of gray till, capped with brown lacustrine silts and fine sands.

Origin of Lake Erie Basin and Islands

The Great Lakes owe their origin to physiographic changes induced by Pleistocene glaciation. As the ice sheets paused in their advance or retreat, ridges or moraines of glacial till were built up at their margins, thus damming the natural drainage and forming large glacial lakes in scoured depressions. Lake Erie is the remnant of such a lake, which at its highest stage (Lake Maumee) was over 800 feet above sea level (present elevation of Lake Erie is 570 feet) and extended as far southwest as the present location of Fort Wayne, Indiana. At its highest state, drainage from the lake was toward the southwest via the Wabash and Mississippi Rivers to the Gulf of Mexico. As the ice retreated, other outlets were uncovered and several lake stages were formed at successively lower levels, except for minor readvances of the ice which blocked outlets and caused temporarily higher levels (Table 2).

The foregoing sequence of events occurred in a 2,000-year span of time from 14,000 to 12,000 years before the present (B.P.). When the last glacier retreated from the vicinity of Buffalo, New York, a new drainage outlet became available via the Niagara River. However, the new outlet was as much as 100 feet lower than at present because the land surface had been depressed by the weight of glacial ice (approximately one mile thick). This new and very low outlet caused a massive flood of water exiting the lake basin toward the east, resulting in the nearly complete drainage of the western end of the lake and the formation of separate, shallow lakes in the central and eastern portions of the lake basin. The Niagara outlet gradually rebounded to its present elevation, and Lake Erie correspondingly rose from this low stage (470 feet) to the modern level.

During low lake stage (11,000 to 4,000 years ago) much of the lake bottom in the western basin was exposed to subaerial erosion, which greatly altered and reshaped the till and lake sediment surface. In the interval since the drainage of the large glacial lakes, waves and currents of modern Lake Erie have cut into the lake deposits, locally excavating the surficial glacial deposits and exposing the least deeply buried bedrock. The exposed bedrock now forms the islands and reefs.

Sediments

The bottom deposits of Lake Erie consist of silt and clay muds, sand and gravel, peat, compact glacio-lacustrine clays, glacial till, shoals of limestone and dolomite bedrock and rubble, shale bedrock shelves, and erratic cobbles and boulders composed chiefly of igneous and metamorphic rocks. The distribution of bottom sediments is closely related to the bottom topography. The broad, flat areas of the western and central basins, and the deep areas of the eastern basin have mud bottoms. Midlake bars and nearshore slopes are comprised mostly of sand and gravel or glacial till. Rock is exposed in the shoals of western Lake Erie and along the south shore of the central basin and both shores of the eastern basin. In general, sand is limited along the shoreline, but extensive dunes have been formed at several places, notably at the base and southwestern side of Long Point, Point Abino, and Sturgeon Point, all in eastern Lake Erie. These dunes were formed presumably under the influence of the prevailing southwest winds. Littoral currents have concentrated sand spits, baymouth bars, and harbor breakwalls at such places as Point Pelee, Pointe Aux Pins, and Long Point, Ontario; North Cape, Michigan; East Harbor, Cedar Point, Vermilion Harbor, and Fairport Harbor, Ohio; and Presque Isle, Pennsylvania.

The bottom surface material of the Ohio portion of central Lake Erie consists of silt and clay (77 percent), sand and gravel (22 percent), and shoal bedrock (one percent). The unconsolidated material appears to have been derived mainly from glacial deposits, with bedrock supplying a lesser amount of material. Sand and gravel lag deposits and till occur near the south shore, particularly eastward from Cleveland. Extensive glacial clay deposits are exposed along the north shore of the basin. Large quantities of sand and gravel occur north of Vermilion, nearshore from Cleveland to Fairport, and midlake off Ashtabula and Conneaut. Commercial sand and gravel dredging areas have been designated on both sides of the international boundary on a low morainal ridge between Vermilion and Point Pelee and on the bar between Erie, Pennsylvania and Long Point. Ohio has also assigned another dredging area five miles northwest of Fairport in an ancient delta deposit from the Grand River when its mouth was in the vicinity of Mentor Marsh.

The bottom deposits of the Ohio portion of western Lake Erie are composed mainly of mud, semifluid silt- and clay-sized material (58 percent). Sand (17 percent), mixtures of mud and sand (12 percent), mixtures of sand, gravel, and coarser material (7 percent), glacio-lacustrine clay (3 percent), and limestone/dolomite bedrock (3 percent) account for the remaining bottom material. Peat and plant detritus occur in isolated areas along the low, marshy shores. Sand concentration in Maumee Bay and near the entrance to Sandusky Bay are sites of commercial dredging.

Test borings into the subsurface bottom deposits in the vicinity of the Lake Erie islands show a predominance of lake-deposited material with only thin glacial till overlying bedrock. Preglacial buried valleys are indicated by bedrock topography, which in places has 200 feet of relief. Some boring also indicates the possibility of interglacial or postglacial buried valleys and lower lake stages. Beach deposits and peat have been found 35 to 80 feet below the present lake level, buried under more recent deep-water sediments. A radiocarbon date of 6550 B.P. (Before Present) was obtained for a sample of oak wood buried 23 feet below the lake bottom. This date permits the calculation of a sedimentation rate of 0.35 feet/century. A deep boring in the central basin 30 miles north of Cleveland (water depth of 84 feet) yielded bottom surface sediment of gray-brown mud. Successively lower sampling at five-foot intervals yielded soft gray-brown clay that became stiffer downward. At 111 feet of bottom penetration, rock or hard glacial till that could not be penetrated was reached. Seismic reflection surveys have revealed a maximum unconsolidated sediment thickness of 275 feet in the central basin and 130 feet in the western basin.

Recent sedimentation in Lake Erie can be attributed to two primary sources: suspended solids from inflowing streams and bluff material contributed by shore erosion. Over six million tons of clay, silt and sand are transported annually to Lake Erie from its tributaries. Shore erosion of glacial till and lacustrine clay bluffs is an acute problem at many locations along the shoreline. Maximum shore erosion based on volume of material removed occurs along the north shore of the central basin between Port Stanley and the base of Long Point, although the low-lying south shore of Maumee Bay has experienced the maximum rate of shore recession, which has been as high as 20 feet per year. Estimates of erosion rates for the Ohio shoreline indicate that about 10,000 cubic yards of bluff material per mile of shore eroded each year. Extended for the entire shore of the lake, 8,500,000 cubic yards are contributed to the lake each year, which would equate to a thickness of 0.01 inches if spread uniformly over the lake bottom.

Caves

The Lake Erie islands, including Catawba and Marblehead, possess a rather unusual cave and sinkhole topography. The carbonate bedrock of these islands is soluble in weak, naturally-occurring acids, such as carbonic acid and various organic acids. These acids have slowly dissolved portions of the rock producing caves, sinkholes, and other solution features. This process has taken place for millions of years, starting soon after the time when the lime muds which had accumulated in the ancient ocean were drained of sea water. The solution process initially resulted in sinkholes which became filled with dolomite fragments that had broken off the rim, producing a rock called breccia. Exposures of these ancient breccia-filled sinkholes are common on the west shore of South Bass Island.

Solution has also occurred more recently, producing many small caves in the bedrock. Thirty seven such caves have been reported for the islands. Most of the caves are the result of solution and then the collapse of the surrounding and overlying rock into the void. The exact origin of the caves and sinkhole features has been a matter of speculation. The most widely accepted theory states that the structure of the rock materials combined with their mineral composition and contact with water has probably resulted in cave and sink formation. Specifically, the Put-in-Bay Dolomite is underlain by the Tymochtee Formation which contains lenses or pockets of anhydrite gypsum. At some time in the past, water filtered down through the surface materials, the Put-in-Bay Dolomite, and eventually into the Tymochtee anhydrite gypsum. Anhydrite gypsum has the property of swelling when in contact with moisture. Hydration increases the volume from 33 to 63 percent. The drastic increase of volume exerted approximately one ton of pressure per square inch on the surrounding materials. Such pressure caused a doming of the overlying Put-in-Bay rock structure. Later, the gypsum was dissolved away by solution leaving a large, unsupported subterranean cavern. Eventually, the roof of the cavern collapsed, forming crescent shaped caves and caverns around the perimeter. The collapse generally formed large shallow circular depressions on the land surface and created small caves around the margins of these collapse features. In areas of Catawba and Marblehead, the lenses of anhydrite may have been thinner and less extensive producing only a slight doming, and eventually resulting in the formation of a sinkhole rather than a cave. The lower levels of many of the caves, formed either by solution or collapse, are now flooded by water coming in, along cracks and solution openings, from the lake and thus causing ground water pollution problems. Perry's Cave on South Bass Island is the only cave of this type open to the public.

Crystal Cave is the most unusual cave on South Bass Island because of its mineral deposits. The walls are completely covered to a thickness of two feet by beautiful blue celestite crystals ($SrSO_4$). These are very large, usually ranging from eight to fifteen inches in length and are tabular in form. The appearance of the interior of this cave is that of an immense geode. This cave was discovered by Gustav Heineman in 1891, while digging a water well. The cave is about 30 feet below ground level and consists of two small connected rooms. It had an original height of about three feet; crystals removed from the floor when the cave was deepened were sold to fireworks manufacturers for the strontium. Crystal Cave is open to the public during summer months.

Water Circulation

Circulation in western Lake Erie is dominated by the large inflow of water from the Detroit River (mean flow approx. 176,000 cfs), particularly west of the islands. The midchannel flow of this river penetrates deep into the western basin, with a branch that flows eastward toward Pelee Passage on the north side of Pelee Island. 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, and to a lesser extent, the Ontario side, these eddies tend to retain the water, causing a high concentration of contaminants. The Maumee River, with an average flow of 4,700 cfs, is the second largest stream flowing into the lake and carries 37 percent of the sediment loading to the lake, but accounts for less than three percent of the total water drainage to Lake Erie.

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 parts of the basin bottom currents are commonly the reverse of and compensate for strong wind-driven currents. Current meter data indicates that bottom currents in the vicinity of the islands form a counterclockwise gyre to balance the clockwise surface flow. Both the surface and subsurface rotary flows in the island region appear to circulate clearer, cooler 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. 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 of 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.

Major sinking of water masses can depress the thermocline and upwellings can raise hypolimnion water. Pressures caused by these opposing movements force the displaced hypolimnion water to spread across the basin.

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. Automatic current meter data indicates that during the periods of stratification a current system exists below the thermocline and the reverse of that at the bottom of the lake.

Physical properties, such as temperature and conductivity, of 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 ten 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 predominantly eastward. In the fall and early winter when the lake becomes nearly isothermal the cooler tributary water is free to move lakeward and underrun 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.

Inflow and Discharge

The Lake Erie basin, exclusive of drainage from the upper lakes, comprises about 34,000 square miles, of which nearly 10,000 square miles are lake surface. The lake receives an average replenishment of approximately 219,000 cfs of water from tributary streams and precipitation over the lake (Table 3). Approximately 90 percent of stream flow or 80 percent of the total replenishment comes from the Detroit River, the drainage outlet for Lake St. Clair and the upper lakes. The average discharge of the Detroit River, as gaged by the U.S. Lake Survey, is 176,000 cfs, equivalent to 20.9 feet of water over the surface of the lake per year. Surface runoff from the other streams in the basin is estimated at 20,000 cfs. Runoff and overlake precipitation together yield an equivalent of 4.3 feet per year over the lake surface.

The storage capacity of Lake Erie is approximately 2.5 times the average annual inflow. The shallow western basin has a volume of 5.8 cubic miles and a retention time of 45 days; the central basin has a volume of 71.8 cubic miles and a retention time of 559 days; and the deeper eastern basin has a volume of 36.4 cubic miles and a retention time of 283 days.

Discharge from Lake Erie is through the Niagara River at Buffalo and the Welland Canal diversion at Port Colborne. Combined outflow averages 202,000 cfs, annually equivalent to 23.3 feet of water over the lake. Evaporation accounts for between two and three feet of water loss annually from the lake surface.

The water budget for Lake Erie can be summarized as follows: (1) the Detroit River supplies 80 percent of the water to the lake, precipitation on the lake surface 11 percent, and stream runoff 9 percent; (2) annual evaporation nearly equals precipitation on the surface of the lake and exceeds runoff, exclusive of the Detroit River flow; and (3) loss of water from the lake is about 90 percent outflow and 10 percent evaporation.

<u>Water Temperature and Lake Ice</u>

Water temperatures in Lake Erie undergo wide seasonal fluctuations, ranging from 33°F in the winter to about 75°F in late summer. During severe winters, such as 1976-1977, up to 95 percent of the lake is ice covered. Frequently the western basin freezes across, but only rarely do the other basins freeze from shore to shore. The ice cover breaks up in March or April and gradual warming continues through the spring. Warming generally proceeds faster along the shore because of warm runoff water and, particularly along the south shore, because of the prevailing southwest winds which push the warm surface water to the right toward the south shore (geostrophic deflection). When the nearshore water has heated to the temperature of maximum density (39.2°F), a vertical thermal bar of water near that temperature forms a boundary between midlake waters that are less than 39.2° in temperature and the continually warming inshore waters. During a period of several weeks, as heating progresses, the thermal bar moves toward the middle of the lake in a contracting motion. As the bar moves offshore the midlake region remains nearly isothermal. In the central and eastern basins a thermocline (zone of rapid temperature decrease with increasing depth) develops in the region shoreward of the thermal bar. The thermocline separates the warmer epilmnion layer of the water from the deeper cooler hypolimnion layer.

Water Quality

The water of the western basin is usually uniform in temperature, top to bottom (isothermal), but because of its shallowness it responds more quickly to atmospheric temperature changes than the other basins. Occasionally in summer the basin stratifies thermally for short periods which deprives the lower layer of water a supply of oxygen from the atmosphere leading to rapid oxygen depletion near the bottom, drastically affecting bottom organisms.

Nutritional overenrichment is the single greatest water quality problem in western Lake Erie. Overenrichment has caused undesirable interference with water supplies, recreation, and fishing. Nutrients (such as phosphorus and nitrogen) are generally not harmful in themselves, but in excess they can result in tremendous overproduction of aquatic plants, especially the microscopic forms. Phosphorus concentrations in the western basin are often 20 times or more the amount needed to trigger offensive algal blooms. The common attached algae Cladophora grows in dense mats in the shallow rocky areas adjacent to many of the islands. Severe storms have broken these mats loose and washed them ashore to decay on the beaches. During low water periods (such as 1964) this has been a problem at Kelleys Island State Park by rendering the swimming beach unfit for bathers.

In general, the islands are far enough away from areas of industrial discharge and agricultural runoff that the levels of toxic substances, such as heavy metals and pesticides, in the water are low. Because of their locations in shallow bays near large communities, Johnson and Turtle Islands have the poorest surrounding water quality. Turbidity is also much higher in the bays than in the open lake. The water surrounding North Bass and Kelleys Islands is the clearest, at times having a transparency of up to ten feet.

The most abundant chemical constituents of Lake Erie water are listed in Table 4. Lake Erie waters are alkaline, having a total alkalinity of 95 ppm as $CaCO_3$ and an average pH of 8.3. Total dissolved solids in the water average 173 ppm, with the highest concentrations along the south shore.

In general, the concentrations of the major cations and anions increase from west to east. Total dissolved solids, and calcium, sulfate, chloride, sodium, and potassium have all increased significantly in the past 50 years.

Dissolved oxygen in the surface water varies considerably depending on the time of day and the season of the year. It is supplied to the surface water by absorption from the atmosphere (aeration) and is transferred to the lower layers by mixing until the saturation level is reached for water of a particular temperature. Supersaturation can occur from a sharp increase in temperature or as a result of photosynthesis in aquatic plants. In the past 15 years several periods of temporary thermal stratification and accompanying low dissolved oxygen concentrations have been reported in the western basin of Lake Erie. Severe oxygen depletion has been observed since 1958 in the bottom waters of central Lake Erie during periods of stratification. Concentrations of less than 2 ppm have been found over extensive areas.

Climatology

The climate of the Lake Erie basin is classified as temperate humid-continental. The location of the Great Lakes between the source regions of contrasting polar and tropical air masses gives the region rapidly changing and complex weather patterns. The average annual air temperature for Lake Erie land stations ranges between 47°F and 51°F. The highest average monthly temperature occurs in July (70°F to 75°F) and the lowest average monthly temperature in January (24°F to 28°F). Approximate extremes are -20°F and 100°F.

The average annual precipitation in the Lake Erie basin is about 35 inches and ranges between 32 and 38 inches. The total land area which drains into Lake Erie, excluding that above the Detroit River, is only about three times the area of the water surface of the lake. The large expanse of water affords a great opportunity for evaporation, and the amount of water lost in this manner is nearly equivalent to the average precipitation over the lake. During dry periods more water may be evaporated from the lake than flows into it from all of its tributaries. Under these conditions Lake Erie delivers into the Niagara River a smaller quantity of water than it receives from the Detroit River.

Of the total possible hours of sunshine for the Lake Erie basin, the amount is greatest in midsummer (70 percent) and least in winter (40 percent), even though 70 percent of the precipitation occurs between March and August. The proximity of the cool lake water and the large amount of moisture put into the air by evaporation cause frequent periods of fog.

Lake Erie, because of its comparative shallowness, its northeast-southeast orientation, and strong winds from these directions, can raise a dangerous sea in a short period of time. Prevailing winds (most frequent direction) are from the southwest. The strongest winds come from the westerly quadrants with a secondary maximum from the northeast. The average monthly wind speed ranges from about 8 mph to 18 mph, with the highest average occurring during the winter months and in the eastern part of the lake.

The predominant southwest and west winds over Lake Erie are explained in terms of "streamlines" of air movements in the Great Lakes region. Masses of air moving from the west are abruptly shifted toward the northeast, producing a southwest wind.

The Lake Erie islands have a climatic variation which is unlike that of the mainland region around the lake. The annual mean temperature range is greater, the daily range between the maximum and minimum temperatures is smaller, the precipitation is less, wind velocities are greater, and the frost-free seasons are longer. The western basin of Lake Erie, the warmest large body of water in the Great Lakes, has a pronounced effect upon the climate of the islands compared with the climate of nearby mainland stations.

Based on the data for 1950, the mean monthly temperature range between the maximum and minimum temperatures was 13.7°F for Put-in-Bay compared with 21.5°F for Bucyrus, within 50 miles of the lake. The great thermal stability of the water acts as a damper between sudden heating or cooling. The mean temperatures for January, the coldest month, and the mean temperature for July, the warmest month, are given for the five stations from the islands and the mainland. Put-in-Bay has the lowest mean temperature in January and the highest mean temperature for July, accounted for by the frozen lake and the greater solar radiation at Put-in-Bay compared to other stations at the same latitude.

The annual precipitation is noticeably less on the islands than at the other adjacent mainland stations. The variation in precipitation for three of the islands and four mainland stations compared, shows a progressive decrease from Bucyrus to South Bass Island. Climatological data show that North Bass Island, for the years recorded, had the lowest annual amount of precipitation, 27.82 inches compared to 30.04 for South Bass. The decrease in summer rainfall is due to the deflection of thunderstorms around the lake rather than passing over the islands. The storms that do cross the lake do not form as much rain because higher air temperatures over land can maintain the energy needed to develop thunderstorms whereas cooler temperatures over the lake do not provide enough energy. Because of low rainfall, high solar radiation, and continued movement of the air, evaporation actually exceeds precipitation in June, July, and August. The evaporation/precipitation ratio affects the seasonal aspect of the flora in that the dryness of the late summer and fall is reflected by the paucity of terrestrial herbaceous vegetation.

Although nearly the most northern portion of the state, South Bass and the other islands have the longest frost-free period of any area in the state of Ohio. South Bass Island has an average frost-free period of 205 days, while Bucyrus has an average of 154 days. North Bass has a frost-free period of 206 days. The high heat capacity of the lake prolongs the summer temperature far into fall, while the small range of temperature between the maximum and the minimum daily temperature permits a long spring. The long frost-free period, however, does not indicate a long growing season. The spring temperatures are retarded, and the threshold temperature, or temperature denoting the beginning of the blooming period of the flora, in the spring, occurs much later on the islands than on the mainland. This retardation is reflected by the average date of the last killing frost, which is around April 15 for the islands, contrasted with May 20 for the interior of Ashtabula County, nearly in the same latitude, and with April 30 as far south as Columbus. Similarly, the average date for the first killing frost in the fall is around October 30 for the islands, contrasted with September 30 for Ashtabula County, October 15 for Columbus, and October 20 for Cincinnati. Thus, the average length of the growing season for the islands is over 192 days.

Shore Erosion

The record high water levels in Lake Erie during the past five years have contributed greatly to increased erosion of the shores. The narrow beaches fronting the shore bluffs of the islands have been submerged exposing the bluffs to direct wave attack and erosion by alongshore currents. Severe storms have resulted in profound changes in shoreline configuration and disruption of man's use of the coastal zone.

Lake Erie's shores are characterized by easily eroded banks of glacial till and lacustrian clay and sand and lesser reaches of resistant shale bluffs. The shore of western Lake Erie consists of low banks of lake clay, while the bluffs of the central basin are more typically till capped by lake clay and sand which rises to 75 feet above lake level on the south shore and over 150 feet on the north shore. Limestone and dolomite crops out in 20-30-foot cliffs along the Ohio shore between Port Clinton and Sandusky, on all of the western Lake Erie islands, and in low headlands along much of the Ontario shore of eastern Lake Erie. Shale bedrock forms nearly vertical bluffs, 20-50 feet high, between Vermilion and Cleveland and from Erie to Buffalo.

Water level changes on Lake Erie are of two principal types: (1) long period and (2) short period oscillations. Long period fluctuations are related to volumetric changes of the lake, caused principally by variations in precipitations, evaporation and runoff. These changes include both seasonal fluctuations and those occurring over a period of several years. Short period fluctuations are due to a tilting of the lake surface by wind or atmospheric pressure differentials. Wind tides, seiches and harbor surges, 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 fluctuations of 0.11 feet.

Water levels at the ends of Lake Erie (Toledo and Buffalo) have a much greater fluctuation than near the center. Tilting of the lake surface is analgous to the up and down movement of the ends of a teeter-totter while the center is stable. High water levels coupled with northeast storms have produced a maximum rise in level of 9 feet above Low Water Datum at Toledo. Conversely, low water 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. This forced movement of the lake surface is known as <u>wind tide</u> and the amount of rise produced is the <u>wind setup</u>. The resulting free oscillation of the lake surface caused by the inequality of water level is called a <u>seiche</u>. Such free oscillations are nearly continuous in the islands region and most often have a period of 12 hours and amplitude of less than 2 feet (maximum amplitude: 5-6 feet).

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 12-14 hours. Seiche periods as recorded for three years at a water level guage at Put-in-Bay on South Bass Island indicated that longitudinal seiches were in operation about 44 percent of the year. Surface winds from the southwest or northeast are likely to produce such seiches along the long axis of the lake. Wind records from Sandusky, Ohio are in agreement with the frequency of seiche periods; surface winds from these directions occur approximately 150 days (42 percent) of the year.

Wave action follows wind action very closely on Lake Erie because of the shallowness of the lake. Swells, however, often continue 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 United States Army Corps of Engineers estimates that off Marblehead Peninsula, 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. Given these conditions a wave 12.5 feet high with a 6.5 second period can be developed. Waves of this height break offshore, but reformed waves up to 3.5 feet in height can reach the shoreline of the islands.

As waves approach the shoreline the water level rises at the shore and the excess water escapes as alongshore (littoral) currents. These currents can be particularly rapid when waves approach the shore at angles other than perpendicular (up to 4 ft/sec) and result in the transport of beach materials as large as cobbles and boulders. The currents are important agents of erosion, transportation, and deposition of sediments in the island region.

All of the islands are rockbound (or protected by a seawall as in the case of Turtle Island) and are undergoing very slow erosion by scour from waves and currents. However, during the recent period of high water many large blocks of dolomite have fallen from the high cliffs of several of the islands. This problem has become particularly acute at the south point of South Bass Island in 1976 and necessitated the relocation of the U.S. Coast Guard navigation light tower which was in danger of falling into the lake. The highest incident of erosion appears to take place in the spring and fall. Ground water seeping into cracks and joints in the rocks freezes, expands, and tends to split the rock from the cliffs, a process known as frost wedging. This process, coupled with frequent and severe storms in the spring and fall, has resulted in many offshore blocks of dolomite which ring the west shores of several of the islands.

The low eastern shores have experienced another problem during the high water period, flooding. Several homes and cottages have been destroyed or severely damaged during northeastern storms which have caused the lake to inundate the eastern shores. This problem has lessened in the past few years as the lake level has fallen to a nearly normal level.

Alongshore currents also produce excellent beaches. The best example in western Lake Erie is on one of the Canadian islands. Fish Point, a spit at the southern tip of Pelee Island, contains the largest deposit of sand in the island region. It is likely that the bulk of the sand has come from glacial moraine deposits of sand and gravel lying east and west of the island. Converging southerly currents along the east and west sides of the island have built the nearly two-mile-long spit.

In the north bay of Kelleys Island at the State Park some local accretion has formed a bayhead beach, the largest sand deposit in the Ohio islands. The sand and gravel is mainly derived from erosion of the low glacial till banks of the bay shore. Rattlesnake, Green and West Sister 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 either residual material from the underlying till or are deposits trapped between the bedrock headlands. Wave and current action is vigorous throughout the island region.

Eutrophication

Lake Erie, as all other lakes, is undergoing a natural aging process or eutrophication. Aging is accelerated by man's inputs of nutritive materials (carbon, nitrogen, phosphorus, etc.) that enrich the aquatic environment. Fertilizers carried into the lake by land runoff, along with municipal and industrial water discharges have, in a few decades, aged Lake Erie by the equivalent of several thousand natural years.

In the last ten years a great number of papers have been written referring to Lake Erie as a dead or dying lake. Such articles have often led to misunderstanding and misinterpretation. Lake Erie has reached the stage in its life history where nutrient concentrations are insufficient to make "blooms" of algae common. Some species produce noxious odors, clog intake pipes, and appear as unsightly scums on the water surface. The nature of the problem is not that Lake Erie is dead; on the contrary, it has an overabundance of life.

Concurrent with the development of algae blooms, other significant changes have taken place. In the deeper central and eastern basins of the lake where thermal stratification occurs, dissolved oxygen levels have become depressed near the bottom. In the shallow western basin, bottom-dwelling fauna have changed from clean water forms to pollution-tolerant forms. Drastic changes have also taken place in the fisheries with game fishes such as whitefish, pike and walleye becoming scarce while the coarse, less valuable fishes such as carp and drum are becoming dominant.

Examination of chemical data shows alarming changes in water quality. There has been a 30-35 percent increase in dissolved solids in the last 50 years. The increases have been greatest for chlorides and sulfates, both of which are conspicuous in domestic and industrial wastes.

All of these changes have occurred even though nearly 40 percent of the lake volume flows over Niagara Falls annually, giving Lake Erie a flushing time of about two and one-half years. The primary reason for the inability of Lake Erie to cleanse itself is that nearly 90 percent of the water flowing into the lake is via the Detroit River, which is grossly polluted in the short distance between Lake Huron and Lake Erie. This situation has been termed the "Detroit Disaster." For example, 80 percent of the total dissolved solids, 70 percent of the chlorides, 65 percent of the nitrogen, and 60 percent of the phosphorus entering Lake Erie comes from the Detroit River, representing a several-fold increase in the chemical pollution of the water flowing from Lake Huron.

Other major tributaries carrying high loads of pollutants enter the Lake at Toledo and Cleveland. The large volume of silt entering the lake from the Maumee River has already been mentioned. The Cuyahoga River is grossly polluted with industrial and municipal waste.

Many other pollution problems are attributed to agricultural, municipal, and industrial wastes. Examples of these types of problems in the lake include pesticides, bacterial contamination, and heavy metals. Runoff is the major lake pollution problem associated with agriculture. The process erodes the soil and carries millions of tons of silt to tributaries and eventually into the lake each year. Perhaps a greater concern than that of the silt load is the concern for the presence of fertilizers which are unwanted nutrients in the lake. Soil particles also contain pesticides and the possibility of some heavy metals which are becoming increasingly persistent and worrisome in Lake Erie.

Natural Resources

Lake Erie, its tributaries and bays provide habitats principally for two wildlife groups--waterfowl and aquatic fur-bearing animals. Large areas of marsh border the western portion of the lake and certain tributaries are highly attractive to the variety of water-oriented wildlife. Both waterfowl and fur-bearing animals are plagued by two problems on or along Lake

Erie: drastically fluctuating water levels and pollution. The change in water level is the most important single factor adversely affecting muskrats and dabbling ducks. For diving ducks, pollution is the main problem.

The mineral resources of the Lake Erie Basin are few in number, but are significant to the economy of northern Ohio. Mineral deposits within the basin, but unrelated to the lake include: 1) limestone and dolomite, 2) sandstone, 3) shale and glacial clay, 4) gypsum, 5) salt and brines, and 6) gas and oil. Minerals directly related to Lake Erie are: 1) sand and gravel from beach, dune, and bottom deposits, 2) lake clay, 3) peat, marl, and bog ores, and 4) water itself.

The Ohio Shore Erosion Act of 1955 provides for leases and permits for persons desiring to remove sand, gravel, stone, gas and oil, and other minerals from and under the bed of Lake Erie. The royalties derived from the sale of minerals on and below the lake bottom are used for the support of Lake Erie research activities, the protection of Lake Erie shores from erosion, and for planning and construction of facilities for the recreational use of Lake Erie.

At present, Ohio has established six commercial sand and gravel dredging areas in Lake Erie. Two are located in Maumee Bay on either side of the Toledo navigation channel; one is northwest of the Sandusky channel off Cedar Point; two are at areas 6 and 12 miles offshore between Lorain and Vermilion; and the last is five miles offshore near Fairport Harbor. Several companies presently extract over half a million cubic yards of sand and gravel from the bed of Lake Erie annually.

Average annual production is distributed as follows:

1) Lorain-Vermilion areas - 53 percent

2) Maumee Bay areas - 20 percent

3) Fairport area - 20 percent

4) Cedar Point area - 7 percent

The International Salt Company on Whiskey Island in Cleveland and Morton Salt Company at the mouth of the Grand River in Fairport Harbor extract over two million tons of salt from beneath Lake Erie per year. The mine at Fairport was opened in June of 1956 and has a capacity of 12,000 tons per day. It is considered to be one of the world's biggest salt mines, and is the deepest salt mine, extending to a depth of 2,025 feet. The producing horizon is in the Salina Formation of Silurian age and is about 22 feet thick. The mining technique employed is the "room-and-pillar method," providing for the excavation of large "rooms" and the retention of blocks or "pillars" of salt between the rooms, which serve as natural support for the mine. By this technique, approximately 50 percent of the salt will remain untouched in the mine. Eventually, a system of tunnels will provide a five-mile subterranean network extending under Lake Erie. Estimated reserves of salt exceed 200 million tons, or the equivalent of nearly 200 years of production at the present rate. Full production capacity of the mine is between 300 to 500 tons per hour. The Cleveland mine was opened in 1962 after considerable difficulty in grouting an 88-foot-thick layer of Oriskany Sandstone at 1300 below ground level. Estimates indicate that flows of 20,000 gallons of water per minute could have been expected in the shaft if the grouting program had not been carried out. The producing horizon is also in the Salina Formation but the updip location of the mine requires only a 1816 shaft to reach the producing zone. Similar mining techniques to those used at Fairport and employed in the Cleveland mine. The rooms are 17 feet high and 45 feet wide. The production hoist, with two 20-ton-capacity skips in balance, can deliver salt from the mine to the surface at a rate of 700 tons per hour. Present extraction of salt from under Lake Erie is taking place in the vicinity of the harbor breakwall.

Over 500 off-shore gas wells have been drilled during the past 30 years in the Canadian waters of Lake Erie. Approximately 60 percent of the wells were successful. Canadian gas production in the Long Point Bay area is found at a depth of about 1,200 feet (Clinton Formation-Silurian) and additional gas is believed to be present in deeper formations. Annually, four billion cubic feet of gas are produced from beneath the Canadian water and prospects for reserves under the Ohio side of Lake Erie are considered excellent.

Peat is found locally along the lake shore and on the vicinity of the abandoned glacial lake ridges where palludal conditions have existed. The broad level topography near the lake and the irregular lake shore favors the development of marshes. The lower courses of the streams are usually sluggish and before the advent of harbor dredging were commonly clogged with vegetation. In general, such accumulations of plant debris are shallow and of little commercial significance. Marsh areas in Lucas, Ottawa, Erie and Lake Counties contain the majority of the peat deposits associated with

Lake Erie. Peat has been utilized, to a limited extent, in the past as a low grade fuel. It is now used extensively for humidity control in greenhouses, for adding acidity to soils, and for a moisture and mineral retention agent in fertilizers, and for a packing filler.

Marl is a mixture of clay material and calcium carbonate in varying proportions. Marl is also found in shallow lakes and marshy areas, and is usually overlain by peat deposits. Marl forms by the incorporation of calcium carbonate, which is precipitated from the water by aquatic life, into the lacustrine bottom sediments. The most notable deposit of marl in the vicinity of Lake Erie is found near Castalia in Erie County. A marshy prairie of over 3,500 acres extends north and west toward Sandusky Bay. Spring water, highly charged with lime, has given rise to this extensive marl deposit which in the past was used on large scale to produce Portland cement. Travertine or calcarious tufa are also associated with the Castalia marl beds.

Bog iron ores are formed by precipitation in springs and in surface waters in swamps and marshes. The iron is derived initially from the country rock (commonly the Bedford and Ohio shales) through the action of organic acids which cause the iron to be carried in a reduced state as a solution of ferrous bicarbonate. Bog ore is later precipitated as ferrous or ferric carbonate or hydroxite, depending upon the local conditions. These ores are found as scattered nodules or thin layers, one to two feet thick, up to several acres in extent. Bog ores have been found along the abandoned beach ridges from west of Vermilion to the Pennsylvania line. Bog iron ore deposits were used extensively during the early 1800's. At least 12 smelting operations were located along the lake shore during this period. These bog ores are not utilized today, but remain as potential resources because of their high manganese and phosphorus contents.

The most basic natural resource of the lake is water. Lake Erie contains more than 100,000 billion gallons of water. In Ohio, nearly 2.7 billion gallons of water per day is withdrawn from Lake Erie for municipal and industrial uses. Approximately 70 percent of this amount is used for cooling in manufacturing processes. Nearly 15 percent (about 400 MGD) is used for public water supply and the remaining 5 percent is used as process water in manufacturing.

Non-withdrawal water uses include navigation, recreation, commercial and sport fishing, and waste disposal. The Great Lakes have become the fourth coastline of the United States since the advent of the St. Lawrence Seaway. Several of Ohio's ports have facilities for ocean vessels. International and interlake waterborne commerce is essential to the economy of northern Ohio. The navigation season on Lake Erie generally opens in March or April and closes in mid-December, depending on ice conditions.

Lake Erie is used extensively for swimming and pleasure boating. Over 50,000 persons per day are attracted to Lake Erie beaches during the summer season. The only large natural beaches along Ohio shoreline are found in the East Harbor and Sandusky Bay areas. Other large beaches, which are partially man-made, are found in the Painsville and Ashtabula areas. Numbers of smaller and non-owner beaches are scattered along the remainder of the Ohio shoreline. Approximately 100,000 pleasure boats are licensed each year in Ohio for use on Lake Erie and connecting waterways.

Traditionally, the Lake Erie commercial fishery has produced over one-third of the Great Lakes production. Annual production for the past 50 years has averaged about 50 million pounds. Until recent years, the Ohio fishery accounted for the bulk of total lake production. Ontario has now taken the lead with an annual catch of 35 million pounds of fish, compared with 11.5 million pounds for Ohio. It is estimated over 200,000 sport fishermen catch 5 million fish annually in Ohio water of Lake Erie.

Plankton

Phytoplankton. The algae population of Lake Erie is composed largely of diatoms (generally about 75 percent). Two periods of peak plankton abundance occur yearly. A spring pulse consists almost entirely of diatoms and the most predominant diatom genera are Asterionella, Fragilaria, Melosira, Synedra, and Stephanodiscus. In August and September blooms of blue-green and green algae are common, although diatoms are still dominant. Anabaena and Anacystis are among the most abundant blue-green algae, while Pediastrum and the attached form Cladophora are the most conspicuous green algae. Pulses are very important in the primary production of the lake and generally account for well over 50 percent of the year's standing crop.

A consistent increase in the peak abundance of algae and changes in the composition of phytoplankton at the Cleveland water supply intake has been observed since 1919. In the 1920's Asterionella was the dominant diatom in the spring and Synedra in the fall. Melosira replaced them both and is itself being replaced in the fall by Fragilaria. The blue-green algae, Anabaena, is also increasing in importance in the fall. The Cleveland data shows that the plankton counts have increased from a yearly average of 200-400 cells/ml between 1920 and 1930 to a recent average of 1,500 to 2,000 cells/ml.

The phytoplankton is the island area consists mainly of diatoms (Bacillariophyceae), green algae (Chlorophyceae), and blue-green algae (Myxophyceae). Diatoms comprise the greatest percentage of the total phytoplankton population with a major pulse in the spring and a smaller pulse in the fall. They are present almost exclusively during the winter. All the species occurring in the greatest numbers, such as Melosira, Fragilaria, Asterionella, and Synedra are indicators of eutrophic conditions. The planktonic green algae becomes most plentiful during midsummer as the lake water warms up. Studies indicate Chlorophyceae as the most diverse member of the phytoplankton community. The dominant species in the most recent study is Pediastrum. A fair amount of fragments of the filamentous, attached green algae, Cladophora glomerata, which covers the rocky shoreline, also occurs in the plankton. The blue-green algae is most common during late summer. A bloom of Oscillatoria and Aphanizomenon often occurs during the "dog days" of August.

Zooplankton. The planktonic animals of Lake Erie consist mainly of microscopic crustaceans (copepods and cladocerans), rotifers, and protozoans. The zooplankton population in the lake has doubled in the past 50 years. The dominant genera include: _Cyclops_ and _Diaptomas_ (Copepoda); _Daphnia_, _Bosmina_, and _Leptodora_ (Cladocera); _Keratella_, _Polyarthra_, and _Asplanchna_; and _Diffugia_, _Ceratium_, and _Paramecium_ (Protozoa). The western basin is superior to the central basin in numbers of zooplankters, where populations can exceed 200,000 organisms per cubic meter.

Zooplankton populations are low during the winter months. Adult crustaceans are rare in the spring and fall, but nauplius (immature copepods) are most abundant in late spring and form an important part of the diet of larval fish. The adult crustaceans achieve the greatest abundance during the summer and also serve as significant link in the food chain of Lake Erie fishes.

Microbiology. The bacterial load has increased markedly at the mouth of the Detroit River in the past half century. In 1913 the average concentration of coliform bacteria was about 175 per 100 ml, in 1946-48 it was nearly 450 per 100 ml, and by 1964 it was over 1,000 per 100 ml. Throughout most of the western basin in 1964, the concentrations ranged from 10 to 100 organisms per 100 ml, whereas most of the central basin remained at less than 10 per 100 ml, except along the Ohio shore where concentrations of over 100 per 100 ml were found. The presence of 5,000 coliforms per 100 ml as a monthly pretreatment average is considered sufficient contamination to condemn water as not potable in Ohio, whereas the limit for water contact recreation is 1,000 counts per 100 ml.

More recent studies indicate that the bacteriological quality of the main body of Lake Erie is excellent. However, several inshore areas do have pollution problems associated with the occurrence of enteric bacteria pathogenic to humans. These areas are immediately adjacent to principal population centers and at the mouths of the large tributaries entering the lake: Detroit River, Cuyahoga River at Cleveland Harbor, and Maumee River at Toledo Harbor. Samples from both the Cleveland and Toledo areas have coliform counts of greater than 2,000 per 100 ml.

Benthic Fauna

The bottom fauna of the western basin is composed principally of Oligochaeta (aquatic earthworms or sludge worms), Chironomidae (midge larvae), Sphaeriidae (fingernail clams), and Valvatidae (snails). Most of these forms, particularly oligochaete worms of the family Tubificidae, are pollution tolerant and occur in greatest concentration near the mouths of the Detroit, Maumee, and Raisin Rivers. Pollution-sensitive organisms such as amphipods, Mayfly nymphs, larger clams, and caddisfly larvae are scarce near the river mouths and more abundant in the islands area. The community of bottom animals in the lake and ponds around the Erie Islands is an accumulation of diverse and abundant organisms occurring on several different substrates: mud, sand, clay, gravel, and rock. The species and abundance or organisms present are dependent upon substrate, water quality, and dissolved oxygen.

Oligochaetes and chironomids are the most abundant (up to 5,000 per square meter) and most widely distributed. The tubificid oligochaete, Limnodrillus, dominates the bottom fauna (comprising over 60 percent of the total fauna), particularly in soft mud which is the most common sediment. Chironomid larvae make up less than 20 percent and sphaeriid clams 10 percent of the benthos. The remaining percentage of the benthic community includes isopods, leeches, amphipods, polychaete worms, mysids, coelenterates, flatworms, mollusks, crustaceans, and caddisflies. The aquatic isopod, Asellus r. racovitazi, accounts for most of this remaining percentage. At certain times of the year, huge gelatinous colonies of bryozoans are found along the bottom and occassionally wash up on the beaches. The benthic population of western Lake Erie is representative of eutrophic but not grossly polluted waters.

Freshwater mussels occur in small numbers throughout most of the island area, with more extensive populations found in the more sheltered habitats. One such area of concentration is Fishery Bay on the north side of South Bass Island, which has been the site of extensive investigations. At least 25 species occur in this bay. The species around the islands are found predominantly on gravel bars in shallow water. Some freshwater mussels are also found on silt bottoms in deeper water, but they are generally smaller and slower growing than those of gravel bars. The lake mussels appear stunted when compared with their stream counterparts and were formerly thought to be separate species.

The bottom fauna of the central basin is generally similar to that of the western basin, but is characterized by a decreasing number of genera and increasing number of individuals from east to west. The benthos is more sparse and is composed mainly of midge larvae and oligochaetes, with lesser numbers of clams, snails, amphipods, and caddisfly larvae. The clear-water amphipod Pontoporeia affinis and the cold-water opposum shrimp Mysis relecta, occur in low number and only in the central and eastern basins. The fauna of the deeper eastern basin is more nearly like that of the upper lakes, and is composed largely of amphipods, mysids, deep-water species of chironomids and oligochaete worms.

The major biological changes in Lake Erie have occurred in the bottom fauna of the western basin. Prior to the early 1950's the population of mayfly larvae in the islands region averaged about 400 per square meter of lake bottom. In the summer of 1953 a prolonged period of vary calm weather resulted in thermal stratification that was accompanied by severe oxygen depletion in the bottom water. After the stratification the mayfly population was only about one-tenth of the original size, and by 1959 the average number of mayfly larvae per square meter had been reduced to 11. During the same period oligochaetes increased from 12 to over 500 per square meter and midge larvae from about 50 to nearly 300 per square meter. Caddisfly larvae were also abundant in the early 1950's, but averaged less than one per square meter by 1957. West of the islands region, Oligochaeta, Chironomidae, Sphaeriidae, and Gastropoda populations have increased several-fold, while the mayfly, Hexagenia, has been reduced to less than one percent of its former abundance.

Data from 1930 and 1959 surveys in the central basin indicate that the midge larvae replaced the mayfly numph as the dominant benthic organism. Oligochaetes and fingernail clams also showed an increase. Eastern Lake Erie has apparently experienced less change in its bottom fauna.

Fish

Lake Erie, in its nearly 200-year history of commercial fishing, has produced greater numbers and varieties of commercial species of fish than any other Great Lake, accounting for at least a third of the total fish production from the Great Lakes. Annual production in the past 50 years has averaged approximately 50 million pounds and at least 17 species have been significant in the landings at one time or another. Compared to the other Great Lakes, Lake Erie has apparently always experienced an advanced trophic state, which is responsible for its greater productivity.

The western basin has long been considered to have the most valuable fish spawning and nursery grounds in the lake, and is the site of extensive sport fishing. Ninety-five species of fish have been reported from the lake waters surrounding the islands. These species have differed in abundance and dominance throughout recorded time. When the area was first settled lake sturgeon, cisco, whitefish, blue pike, and walleye were the most important members of the fish community. Dominant species today are perch, bass, channel catfish, alewife, gizzard shad, carp, goldfish, fresh-water drum, and emerald shiner. Experimental gill net catches in western Lake Erie are often dominated by rough fish species. The gizzard shad is the most abundant rough fish species captured. Other rough fish contributing significantly to the total catch are: alewife, carp, and fresh-water drum. Forage fish include spottail shiner and emerald shiner. Important commercial and sport fish in the bay area include: walleye, yellow perch, white bass, and channel catfish (Table 5).

Early catch records suggest a fairly stable fishery until shortly after the turn of the century. The sturgeon almost disappeared from the catch statistics about 1900. The cisco, once the dominant commercial species, experienced a sudden decline in 1926 and is now rarely caught. Whitefish catches declined rapidly in 1955 and are presently insignificant. The blue pike, which constituted a considerable portion of the fishery up to 1958, has become extinct in Lake Erie. The walleye production increased to a peak in 1956, only to decline drastically in 1959, but is now showing signs of recovering.

The yellow perch has contributed consistently to the commercial landings from the earliest days of the industry. In recent years the smelt has become commercially exploitable and it, along with yellow perch and, to a lesser extent, freshwater drum, white bass, catfish, and carp, is sustaining the fishing industry in Lake Erie.

The deterioration of the fisheries resources of Lake Erie appears to be related to these principal factors: 1) changes in the watershed, such as erosion and siltation of stream beds and inshore lake areas, and construction of dams in tributaries, 2) physiochemical enrichment of the lake water and bottom through natural eutrophication and man-accelerated pollution causing a reduction in dissolved oxygen, 3) changes in the primary and secondary productivity of the lake, brought about by and compounding the environmental stress, 4) competitive and predatory activities of invading species, and 5) technological advances in the field of commercial fishing resulting in landing of desirable fish in greater numbers than can be naturally replaced.

Island Fauna

Unfortunately there are no records to indicate what the fauna may have been when the first settlers arrived on Erie islands in the early 1800's, but it is probable that there were only a small number of large animal species and individuals present. It is likely that the indigenous fauna included grouse, porcupines, deer, bears, foxes, squirrels, rabbits, quail, raccoons, and muskrats. Deer, bear, and grouse were probably eliminated by early hunters before the islands were permanently settled.

Ringneck pheasants were brought to the Bass and Kelleys Islands in the early 1920's, and a large number of these birds are harvested annually by hunters. Cottontail rabbits are also abundant on the islands and attract hunters each autumn. Muskrats are locally trapped in the wetlands and marshes which are scattered throughout the islands.

The islands serve as "stepping stones" for many species of birds in their migration hops over Lake Erie each spring and fall. Several species of fish-eating birds prey upon the fishes of Lake Erie. Some of these piscivorous birds merely pause as they pass on their way north or south, while others nest in colonies on the islands.

The dominant groups of insects present on the Erie islands are Trichoptera (caddisflies), Diptera (flies), Hymenoptera (bees and wasps), Coleoptera (beetles), and Odonata (dragonflies). The distribution of dragonflies in the vicinity of the island wetlands shows a distinct species preference for wetlands in different successional stages, with Put-in-Bay harbor being the most open area and Fox's Pond (marsh) being the most advanced successional area studied. The distribution of spiders on the Lake Erie islands has been studied intensively. This effort has resulted in the listing of over 200 species.

Early each summer there is an extensive emergence from aquatic larvae of two groups of insects, Ephemeroptera (mayflies) and Chironomidae (midges). The mayflies of the genus, Hexagenia, known locally as "Canadian Soldiers," emerged in such great numbers prior to 1956 that they were a great nuisance along the shoreline. Their slippery first- and second-cast skins washed on to the beaches to rot or accumulated under light posts, becoming a hazard to vehicular traffic. The mayfly population have decreased dramatically but the midges still continue as a minor nuisance to island dwellers.

A large number of snails cover the ground throughout the islands. The lack of leaf litter in the island woodlots has been attributed to the large local snail populations and to extreme weather conditions. Nine species of snail occur only in the island area. One species, Triodopsis albolabris goodrichi, is found only on South Bass and Kelleys Islands. The islands also support a number of unique subspecies. Anguispira kochi strontiana is confined to Green Island.

Amphibians and Reptiles

The amphibians and reptiles of the Erie Island fauna are found in the open lakes, ponds, marshes, caves, along the shore, and on dry land. The mudpuppy is fairly common in the open water, burrowing into the muddy bottom. Several species of salamanders, frogs, toads, and newts are found in a variety of habitats.

At one time the islands supported a dense population of snakes. Many journals of early explorers and settlers tell of such great numbers of rattlesnakes that one could practically tread on one with every step. After years of being slaughtered on sight and hunted by herds of hogs shipped to the islands, the timber rattlesnake has not been sighted since 1951 and has probably been extirpated. Also mentioned was a "hissing snake" which was said to blow a nauseous wind upon its victim that could prove fatal if inhaled. This snake has been compared to the common water snakes (Natrix sipedon) of the area which bite viciously when attacked and secrete a foul smelling substance from musk glands as a defense mechanism. The inland water snake (Natrix sipedon insularum) remains fairly common around the islands, particularly the uninhabited ones, and can be seen swimming along the shore with its head above water or sunning on the flat rocks or vegetation near the water's edge. In contrast to the distinctly banded pattern of the northern water snake (N.s. sipedon), large specimens of the Lake Erie water snake are usually a uniform green-brown pattern. The shift towards unbanded pattern types on the islands has been attributed to strong post-natal selection, demonstrable without regard to selective agent.

In 1948 the most common snakes on South Bass Island were the water snake, De Kay's snake, ringneck snake, gartersnake, and blue racers. At that time a few timber rattlesnakes, limited in their range to the highlands of Victory Woods, managed to persist in spite of efforts to exterminate them. No poisonous snakes have been reported for the islands in the past decade.

Populations of rare triploid salamanders of the genus Ambystoma sp. exist on Kelleys, Middle Bass, and North Bass Islands. More common amphibians include snapping turtles, map turtles, pointed terrapins, and mudpuppies.

Waterfoul and Other Birds

The islands in western Lake Erie have a wide variety of birds and waterfoul. These fall into four categories: permanent residents, winter visitors (most often found only in winter), half-hardy birds (transients or summer residents which sometimes stay through the winter), and accidental visitors. Bird watching is a popular sport on the islands for visitors and islanders alike.

A rookery of black-crowned night herons, common egrets, great blue herons, and green herons exists on West Sister Island which is a National Wildlife Refuge. Thousands of birds nest here every year, occupying nearly every available space. With such a concentrated population in this small area, the birds are forced to go great distances to feed and are seen feeding in the mainland marshes and around the other islands. An occasional nest will be found on the other islands, particularly the uninhabited ones, but never to the extent of the colonies on West Sister Island.

Rocky, largely barren Starve Island was a favorite nesting site for common terns until they were crowded out by the herring gulls. In 1939, 1,052 tern nests were counted on this island, but by 1964 the island was completely taken over by herring gulls. It is interesting to note that in 1926 there was only one herring gull nest on Starve Island and no record of herring gulls nesting anywhere along the Ohio shoreline. Other favored nesting sites include the Rattles of Rattlesnake Island, Lost Ballast, and several rock outcroppings occurring around the islands. The nearby Canadian islands are also popular nesting areas for herons, gulls, egrets, and cormorants. An occasional tern can be seen amid the flocks of gulls following the ferry boats, but their numbers have been drastically reduced since the arrival of the herring gulls.

In 1921 the ring-necked pheasant was stocked on South Bass Island by the Ohio Division of Fish and Game. They multiplied and have become a nuisance to the farmers and grape growers, but are a great attraction for hunters in late fall. The other islands also support a fairly large pheasant population, and together with the northern marshes in the state, represent the only sites of any significant numbers of ring-necked pheasants remaining in Ohio. Rattlesnake Island was stocked with golden pheasants and wild turkeys about thirty years ago, but neither remain today, although the ring-necked pheasant is still common.

No endangered species nests on the islands. Twenty-five years ago single nests of the northern bald eagle were located on South Bass, Green, Kelleys, Rattlesnake, and West Sister Islands. The following species found in the Erie Islands are considered to be rare: common egret, least bittern, hooded merganser, king rail, common tern, and orchard oriole. Ten species common to the islands are listed as being of undetermined status due to noticeable decreases in populations in recent years, and bear further surveillance. The species include: pied-billed grebe, American bittern, ring-necked pheasant, common gallinule, black tern, purple martin, crow warbling vireo, Baltimore oriole, and rough-winged swallow.

Mammals

The species diversity of mammals inhabiting the Erie Islands is understandably low considering their isolation from the mainland and the small area involved. Only thirteen species have been recorded as being permanent residents, and these are all small animals. Several species of mice exist, usually in areas of human population. The Norway rat is particularly dependent upon human habitation as its main centers of repopulation are dumps. A campaign to eliminate the high number of rats on South Bass

Island by poisoning in 1952 severely depleted the population of eastern gray squirrels. Concerned islanders imported several black squirrels from Belle Isle Park in Detroit to help reverse this situation. The two species interbred to the extent that the only squirrels present today are the melanistic eastern gray squirrels. The cottontail rabbit accounts for a large percentage of the mammal population of the islands. Racoon, red fox, and muskrat occur in small numbers due to lack of suitable habitat. The little brown bat is a permanent resident of the islands, but its secretive nature prevents it from being obvious. It remains dormant throughout the winter and is able to withstand extreme cold temperatures. Empty cottages, boathouses, sheds, barns, and caves provide an abundance of sites suitable for habitation. A herd of African Mountain sheep roam wild on Rattlesnake Island where they were introduced in the 1960's. During the severe winter of 1976-1977 the herd was reduced from nine to three. A small number of deer live in the remaining wild areas of Catawba Island and the adjacent Marblehead Peninsula. During cold winters when the lake freezes over they occasionally cross the ice to some of the islands. Several were sighted on Kelleys Island in December of 1976 soon after the ice had formed.

Resource Value

Lake Erie is perhaps Ohio's most valuable water resource. The abundant natural resources of the coastal zone have attracted activities such as fishing, farming, commerce, and industry. The lake, its bay, and estuaries are the source of a wide variety of fish for both commercial and recreational fishermen.

More than thirty endangered wildlife species known to inhabit these waters and nearby coastal areas are being protected. The prolonged growing season and an average of nearly six months of frost-free weather, make the region an ideal area for field crops, fruits, and vegetables. Gas, oil, limestone, sandstone, salt, gravel, clay, gypsum, and peat are all found in commercial quantities in the region. Over 90 million tons of goods are shipped through Ohio's lake ports each year. The lake also serves as a source of water for homes, industry, and power generation. The 262 miles of shoreline within the state provides many fine beaches, scenic vistas, and opportunities for recreational pursuits. Three million of Ohio's eleven million people have found the lake region an ideal area in which to live.

TABLE 1

MORPHOMETRY OF LAKE ERIE[1]

	Western Basin	Central Basin	Eastern Basin	Entire Lake
Maximum length (miles)	50.0	132.5	85.0	241.0
Maximum breadth (miles)	40.0	57.2	47.5	57.0
Maximum depth (feet)	67.0	84.0	210.0	210.0
Mean depth (feet)	24.2	60.7	79.9	60.7
Maximum depth/mean depth	2.8	1.4	2.7	3.4
Area (square miles)	1265.0	6246.0	2408.0	9919.0
Volume (cubic miles)	5.8	71.8	36.8	113.0
Shoreline (miles)	268.3	373.3	263.3	844.9
Percent of area	12.8	62.9	24.3	100.0
Percent of volume	5.1	63.0	31.9	100.0
Percent of shoreline	31.7	37.1	31.2	100.0
Development of volume[2]	1.2	2.2	1.1	0.9
Development of shoreline[3]	2.3	1.3	1.7	2.1
Longitudinal axis bearing	N67°W	N67°E	N67°E	N67°E

[1]Modified after Verber (1960, p. 6).

[2]Development of volume is the ratio of the volume the lake to that of a cone of basal area equal to that of lake and a height equal to the maximum depth of the lake (Hutchinson, 1957, p. 166).

[3]Development of shoreline is the ratio of the length of the shoreline to the length of the circumference of a circle of area equal to that of the lake (Hutchinson, 1957, p. 166).

TABLE 2

GLACIAL LAKE STAGES IN THE LAKE ERIE BASIN[1]

Date (yrs. B.P.)	Lake stage	Elevation (feet)	Reason for change in level	Outlet	Glacial Event
6,000	Erie (modern)	570	Retreat of ice and isostatic uplift	Niagara River, N. Y.	
	Erie (early)	535?	Readvance of ice and isostatic uplife	Niagara River, N. Y.?	Valders moraine
11,400	Low water stage	490?	Retreat of ice	Niagara River, N. Y.	Two Creeks interval
	Algonquin	605	Continued retreat of ice	Mohawk River, N. Y.	
	Lundy	620	Continued retreat of ice and erosion of outlet	Mohawk River, N. Y.	
	Grassmere	640	Retreat of ice	Mohawk River, N. Y.	
	Warren II	670	Readvance of ice (minor)	Grand River, Mich.	
	Wayne (minor stage)	660	Retreat of ice	Grand River, Mich.	
	Warren I	680	Retreat of ice	Grand River, Mich.	
	Whittlesey	735	Readvance of ice	Grand River, Mich.	Port Huron moraine
13,000	Low water stage	?	Extensive retreat of ice	Niagara River, N. Y.?	Cary-Port Huron interval
	Arkona	710-695	Retreat of ice and erosion of outlet	Grand River, Mich.	
	Maumee III	780	Readvance of ice	Wabash River, Ind.	Lake Border moraine
	Maumee II	760	Continued retreat of ice	Grand River, Mich.	
14,000	Maumee I	800	Formation of first stage	Wabash River, Ind.	Defiance moraine

1. Modified after Hough (1958, 1963, and 1965).

TABLE 3

RUNOFF DATA FOR TRIBUTARY STREAMS TO LAKE ERIE*

	Drainage Area (sq. mi.)	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	33,530,000
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

RUNOFF DATA FOR TRIBUTARY STREAMS TO LAKE ERIE, continued

	Drainage Area (sq. mi.)	Average Discharge (cu.ft/sec)	Estimated Suspended Solids (tons/year)	Estimated Dissolved Solids (tons/year)
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	39,857,400
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, Division of Water and; Federal Water Pollution Control Administration.

TABLE 4

CHEMICAL CONSTITUENTS OF LAKE ERIE WATER

	Western basin[1]	Central basin[1]	Eastern basin[1]	Entire lake[1]	Water supply intakes[2]
Specific conductance (micromhos/cm at 25°C)	272	300	301	291	311
Dissolved solids (ppm)	162	178	179	173	182
Suspended solids (ppm)	19	7	9	12	---
Total alkalinity (ppm as $CaCO_3$)	94.2	95.5	96.5	95.4	132
Bicarbonate (ppm)	---	---	---	---	113
Calcium (ppm)	33.9	39.5	40.5	38.0	39.0
Chlorides (ppm)	21.3	24.5	24.5	23.4	24.0
Sulfates (ppm)	17.7	22.4	23.4	21.2	28.0
Sodium (ppm)	9.91	11.05	10.86	10.61	11.0
Magnesium (ppm)	8.7	10.0	10.0	9.6	8.6
Potassium (ppm)	1.47	1.31	1.34	1.37	(with sodium)
Silica (ppm as SiO_2)	1.20	0.68	0.47	0.78	2.0
Total nitrogen (ppm)	0.71	0.43	0.43	0.52	---
Ammonia (ppm)	0.159	0.086	0.086	0.110	---
Organic nitrogen (ppm)	0.36	0.25	0.24	0.28	---
Nitrate (ppm)	0.124	0.090	0.090	0.101	---
Iron (ppm)	---	---	---	---	0.04
Phosphate (ppm soluble PO_4)	0.032	0.010	0.010	0.017	---
Hydrogen-ion concentration (pH)	8.4	8.3	8.3	8.3	---
Chemical oxygen demand (ppm)	10.37	7.10	7.45	8.31	---

1. Average of chemical analyses of water from 1963 and 1964 Lake Erie cruises. Federal Water Pollution Control Administration
2. Average of chemical analyses of water at 16 water supply intakes on the Ohio shore of Lake Erie, September 1950 to February 1952. Ohio Department of Natural Resources, Division of Water.

TABLE 5

ECOLOGICAL AND ECONOMIC IMPORTANCE OF LAKE ERIE FISHES

Fish	Spawning Habitat	Spawning Time	Adult Feeding Niche	Importance to Man
Walleye *Stizostedion vitreum* (Mitchill)	rocky shoals in lakes and rivers	Spring (6–11°C) pre-spawn migration 1.1°C	fish predator	perhaps the most important commercial and sport fish in Lake Erie
White bass *Morone chrysops* (Rafinesque)	rocky shoals in lakes and rivers	Spring (12–20°C)	fish predator	important commercial and sport fish
Yellow perch *Perca flavescens* (Mitchill)	weedy shallows or sand and gravel	Spring (8–13°C)	fish and bottom	important commercial fish and a food fish for Walleye
Freshwater drum *Aplodinotus grunniens* Rafinesque	over mud or sand bottom in shallow water	Summer (20+)	bottom and some fish	commercial fish and a food fish for Walleye
Carp *Cyprinus carpio* Linnaeus	weedy or grassy shallows	Spring (17–26°C)	benthic omnivore	environmentally a destructive pest species but also a commercial fish
Goldfish *Carassius auratus* (Linnaeus)	warm, weedy shallows	Late Spring	benthic omnivore	little to no value
Channel catfish *Ictalurus punctatus* (Rafinesque)	in dark nests in holes, log jams in shallow area of turbid waters	Summer (24–30°C)	bottom	commercial fish
White sucker *Catostomus commersoni* (Lacepede)	quiet, gravel shallows of lakes and rivers	Spring (10°C)	benthic omnivore	minor commercial; fish when abundant a major food item for predatory fish
Quillback *Carpiodes cyprinus* (Lesueur)	shallow quiet, mud or sand areas of lakes and rivers	Late Spring	benthic omnivore	of little value either directly to man or in the food chain to important species

ECOLOGICAL AND ECONOMIC IMPORTANCE OF LAKE ERIE FISHES

continued

Fish	Spawning Habitat	Spawning Time	Adult Feeding Niche	Importance to Man
Gizzard shad *Dorosoma cepedianum* (Lesueur)	probably over sand or gravel bottom	Late spring to summer	phytoplankton feeders	Small gizzard shad are an important forage fish for game and commercial species.
Alewife *Alosa pseudoharengus* (Wilson)	shallow beaches, ponds and quiet rivers	Spring	zooplankton feeders	Generally considered a nuisance due to annual die-offs but can be an important forage fish for game and commercial species.
Rainbow trout *Salmo gairdneri* Richardson	fine gravel in a riffle above a pool, in a small stream or outlet of such a stream	Spring	predator on fish	one of the top five sport fish in North America
Northern pike *Esox lucius* Linnaeus	in weedy flood plains of rivers and in marshes and weedy bays	Early Spring	fish predator	important but rare commercial and sport fish
Mooneye *Hiodon tergisus* Lesueur	pools in turbid rivers, backwater lakes and ponds	Late spring to early summer	omnivore	minor commercial and sport fish
Emerald shiner *Notropis atherinoides* Rafinesque	midwater	Late spring to summer	plankton	major food item for several sport fish; used as bait minnow by man
Spottail shiner *Notropis hudsonius* (Clinton)	over sandy shoals	Spring and early summer	omnivore	an important forage fish; used as bait minnow by man
Logperch *Percina caprodes* (Rafinesque)	sandy inshore shallows	Late spring	benthic carnivore	unknown importance as forage fish for game and commercial species

Data Source: Fraleigh, et al. (1975); Scott and Crossman (1973) also forms dense reddish mats. Species with large floating leaves, white water lilies and the large yellow-flowered water lotus are not common, but where they do grow they may form extensive colonies, as does the large emersed leaved yellow-flowered spatterdock. Emersed species with showy flowers or large distinctively shaped leaves, such as cat-tails, bur-reed, flowering-rush, arrowhead, swamp mallow, water smartweed, and pickerel-weed, line the edges of the ponds often in segregated zones.

Drastic changes have occurred in the aquatic flora in the past 80 years. For example, in Put-in-Bay harbor, 50 percent (20 out of 40) of the species of aquatic vascular plants have disappeared. As a whole, the flora of the bays, and in particular, Put-in-Bay, has been disturbed severely because of increased turbidity of the water, building of retaining walls and docks, dredging operations, and man's multi-uses of these aquatic habitats ranging from recreation to dumping grounds for wastes. Several of the ponds on the islands have been destroyed to build marinas and housing developments. In those ponds that remain, most of the submersed aquatic species ever known to be present, still survive and represent one of the few refuges for this segment of the flora. Local changes in the aquatic flora have been very evident during the past 10 years during which the highest water level ever in Lake Erie has been recorded. This temporary environmental condition has affected the aquatic flora by reducing the size of populations of most of the emersed shoreline species and increasing the size of populations of some submersed and floating-leaved species.

Before the coming of the European settlers, the marshes behind the sand and gravel beaches were much more extensive than they are today. Originally in wet places and in shallow, clear water, vast stands of tall grasses, such as wild rice, prairie grass, blue-joint grass, and cord or slough grass dominated. Sedges were also plentiful, including spike-rushes, hard- and soft-stemmed bulrush, river bulrush, and three-square. Broad-leaved cat-tail was much more extensive than the then rare narrow-leaved cat-tail. Plants with large showy flowers, such as the yellow water lotus, white water lily, spatterdock, swamp mallow, pickerelweed, and arrowhead grew in large colonies and gave color to the marsh. Scattered throughout the marshes, among the cat-tails and sedges, were monkeyflower, swamp milkweed, hedge-nettle, skullcap, and marsh cress. On the exposed mud-flats were annuals--false pimpernel, beggar-ticks, water plantain, obtuse spike-rush, and several species of umbrella sedges. In the clear open water were submersed species, wild celery, waterweed, white-stemmed water milfoil, stiff water crowfoot, flexed naiad, and many species of pond-weeds.

The waters of the marshes and most of the bays have become quite muddy and turbid within the past century. These conditions have come about by (1) the extensive erosion of the soil in the once-forested uplands of the watershed, (2) the dredging, diking, and drainage of large portions of the marshes for private, industrial, agricultural, and wildlife areas, (3) the building of docks and retaining walls that in combination with dredging channels have changed shorelines in many of the bays which are now used for commercial or recreational purposes, (4) the introduction of carp, a species of fish that uproots and destroys aquatic plants and contributes to the overall continued turbidity by stirring up the bottom silt and keeping it in suspension.

These physical changes, silted conditions, and continued high turbidity levels bring about a situation in which submersed sensitive species of open, clear waters are eliminated or are drastically reduced in numbers. These submersed species are the more sensitive, mostly northern species of clear, cool, well-oxygenated waters. Examples of these are large-leaved pondweed, grass-like pondweed, robbins' pondweed, flat-stemmed pondweed, fries' pondweed, strict-leaved pondweed, white-stemmed water milfoil, flexed naiad, water marigold, and in some places the wild celery. Species diversity is drastically reduced.

Surviving are only a few tolerant native submersed species, such as coontail, sago pondweed, leafy pondweed, small pondweed, waterweed, stiff water crowfoot, and water star-grass. These turbid conditions provide favorable habitats for the invasion of tolerant European species, such as spicate water milfoil, curly pondweed, minor naiad, and flowering-rush. These foreign species are on the increase. Mainly because of the physical changes in the marshes, coupled with the ever-changing water-level conditions of Lake Erie, most of the grasses and sedges mentioned above are also becoming scarce and even the wild rice may now be extirpated. The species with large showy flowers, doubtlessly reduced in numbers of plants from 100 years ago, undergo considerable fluctuation in size of individual populations today because of the changing water-level conditions. In years of low water, when dikes artificially maintain the marshes and mudflats, bulrushes, arrowhead, swamp mallow, reed canary grass, barnyard grass, panic grasses, and narrow-leaved cat-tail flourish. In many places during years of low-water level, narrow-leaved cat-tail is dominant, almost to the exclusion of all other species. On newly created dikes, the smartweed, canada thistle, sweet clovers, ragweeds, wild carrot, black mustard, and reed canary grass dominate during the early years following construction. In the marshes, walter's millet has been planted for wildlife food, and several European invaders, flowering-rush, purple loosestrife, bittersweet nightshade, great hairy willow-herb, and European water hore-hound, are spreading and increasing in numbers. In some places acres of purple loosestrife now dominate to the exclusion of most other species.

The swamps, dominated by woody vegetation, occur in small units in the low wet areas along the lake shore. Probably because of continued fluctu-ating water levels, this vegetation type was never as extensive as the marshes. Trees consisting of willows, cottonwood, sycamore, silver maple, and ashes dominate. Formerly, American elm was more prevalent, but most of these trees have since been destroyed by the dutch elm disease. Shrubs are mostly dogwoods, elderberry, willows, buttonbush, and roses. Diver-sity of herbaceous species in the swamp is low. Among the more common occurring ones during the summer season are nettles, false-nettle, and spotted touch-me-not.

Sand beaches. Sand beaches are scattered and not extensive along the Ohio shoreline. The sand deposits are low, not forming dunes. Consequently, they are particularly vulnerable to fluctuating water levels, continuous wave action, and erosive action by ice in the winter. Most of the sand beaches are now used for recreation as swimming beaches and camping areas. Because of these natural and artificial disturbances, most of the species unique to this type of habitat have disappeared. Distinctive herbaceous species now rare or extirpated are sea rocket, seaside spurge, beach pea, sand grass, sand dropseed, beach grass, wormwood, prickly pear, and Schweinitz's and Houghton's cyperus. Distinctive shrubs that are today also rare or eliminated are sand-dune willow, sand cherry, buffalo-berry, ground juniper, kinniinick, and Canadian milk-vetch. Common trees present are cottonwoods, willows, dogwoods, and ashes, and among these are often thick growths of lianas including wild grape, virginia creeper, poison ivy, bittersweet, and trumpet creeper. In the open areas, invasion of foreign herbaceous species has also occurred, and Russian thistle, winged pigweed, umbrella-wort, and sandbur grass now form a new distinctive beach flora. Ubiquitous European weeds are ever present, including quack and crab grass, pigweed, lamb's quarters, wild carrot, hairy brome grass, white sweet clover, foxtail grass, catnip, bouncing bet, and mullein.

Rocky Shoreline cliffs. Perhaps the most dramatic of the shoreline habitats are the high rugged calcareous cliffs mostly confined to the north and west shores of many of the islands and completely surrounding Green and Mouse Islands. These cliffs have two vegetation zones, one along the the wave-splashed lower portion of the cliffs and the other on the drier upper portion. Plants inhabiting the lower portion, which are also characteristic of the low shelving rocky shores, are filamentous algae, mainly Cladophora and Bangia. Distinctive herbaceous vascular plants are Dudley's rush, Kalm's lobelia and St. John's wort, prairie and winged loosestrife, mountain mint, heath aster, grass-leaved goldenrod, golden ragwort, and beardtongue. On the upper portion are such distinctive herbaceous species as ivory sedge, nodding onion, barrens chickweed, purple and hairy rockcress, alumroot, harebell, and smooth cliff brake fern. Bluegrass is abundant. Xeric mosses and foliose lichens are pioneers in this habitat. Shrubs and small trees line most of the tops of the cliffs. Among the more common ones are nine-bark, choke cherry, hoptree, bladdernut, staghorn sumac, mulberry, honeysuckles, dogwoods, hop hornbeam, and red cedar. Serviceberry and American yew are very rare. Dense growths of lianas, such as poison ivy, virginia creeper, and wild grapes, cover large portions of the cliffs.

Gravel beaches. The gravel beaches and bars are a common habitat on the islands. Because these beaches are subjected to severe ice scouring and wave rush, no permanent vegetation becomes established within this continuously agitated zone. Mats of the alga *Cladophora* often wash ashore, die, and decay on the gravel beaches. Farther up on the beach where waves reach only during storms and periods of high water, willows, cottonwood, dogwood, and ashes are dominant woody members. Lianas, such as wild grape, poison ivy, and virginia creeper become entangled on the beach. Herbaceous species are few, but usually germander and smartweeds are present.

Woodlands. Originally the islands were covered with forest, probably predominantly of oaks, hickories, and maple, with subdominants of hack-berry, elms, basswood, and ashes. Red cedar was extensive on the driest sites. These virgin forests were cut to supply firewood for woodburning lake vessels of the nineteenth century or to clear the land for agriculture. No original forests remain today on the islands, although secondary forests have developed within the past 100 years. These secondary forests represent successional stages leading back to the original type. The most prevalent of these is a sugar maple-hackberry-basswood community covering the largest wooded areas of the islands. Oak and hickroy occur only sparingly. Subdominant species are blue ash, Kentucky coffee tree, hop hornbeam, and shrubs such as hoptree, choke cherry, and bladdernut. Wild hyacinth, dutchman's breeches, wild leek, appendaged waterleaf, wild liquorice, leafcup, and herb robert geranium are cistinctive members of the herbaceous understory flora. Garlic mustard is a pestiferous recent invader that is replacing many of the understory species.

Where the soils are deeper and more mesic, the forests were cleared for agricultural and viticultural purposes. Only now through various successional stages is this community slowly returning to the islands following abandonment of these land cultivation practices. Where the soils are thin and drier over the bedrock, the sugar maple-hackberry-basswood community is well represented. With the exception for cutting of the trees for timber, this community has remained nearly intact. The species composition is comprised of many floodplain species reminiscent of what may have been the dominant plant community 4,000 or more years ago on the islands. At that time when the western end of Lake Erie was dry, this characteristic floodplain vegetation would have existed in the low areas around the surrounding hills. As the water of the lake rose, these plants became stranded on the hills that became isolated as islands.

Other smaller forest communities on the islands are young hackberry, hackberry-blue ash, boxelder-green ash, which are all considered to be early stages in the successional sequence. In low wet places around the edges of ponds is a swamp forest community of white ash, swamp white oak, silver maple, and formerly American elm. Red cedar occurs along the edges of rocky shorelines, in abandoned quarries, and in a few small places where the vegetation has been subjected to grazing animals that eat the leaves of broad-leaved plants retaining exclusively the red cedar.

Abandoned fields, vineyards, and orchards. During the nineteenth century the cleared land was first used for agriculture of grain and vegetable crops, but it was soon learned that the climate moderated by the lake and the shallow calcareous soil was best suited for the development of orchards and vineyards. Agricultural production and the fruit crop industry, especially grape culture, flourished in the late 1800's. The acres of active vineyards, for example, on South Bass Island since cultivation began there in 1858, shows a rise to a total of 600 acres by 1890. A steady decline has occurred to the present with only about 30 acres in active cultivation. Today no commercial orchards exist, and no field crops, hay, or extensive pasture lands occur. True forest land has probably remained about the same since recovery from the original cutting, but a tremendous increase in the acreage of idle land, including abandoned orchards, vineyards, and old fields now exist. These areas are in various stages of secondary succession ranging from recently disturbed fields, recently abandoned vineyards, to vineyards having been abandoned for 40 or more years.

Studies of the succession in the active and abandoned vineyards have shown that, with respect to growth forms, the percentages of annuals in the active vineyards are high (9-28 percent) and are low (0-9 percent) in the abandoned vineyards. Conversely, the percentage of perennial woody species is high (32-46 percent) in the abandoned vineyards and low (8-20 percent) in the active vineyards. The percentages of the herbaceous perennials remain approximately the same when the active and abandoned vineyards are compared. A successional trend can be determined by using the total numbers of species of each growth form that occurred in each of the different age vineyards, beginning with a cultivated field not yet planted with grape plants to vineyards abandoned at various intervals throughout the past 35 or more years. Because of continued cultivation in the active vineyards, many of the annual species continually reinvade these disturbed sites. They reach their peak in numbers during this time. As the vineyards are abandoned, the annual plants disappear. The annual grasses are gone after 10 years, and the annual forbs are gone after 25 years. Herbaceous perennials invade both active and abandoned vineyards, reaching a peak in numbers about five years after vineyard abandonment, with a small number persisting through the latter years. Because of continued cultivation in the active vineyards, species of woody perennials are slow in becoming established, but ultimately they do become established and may even slightly increase in numbers after about 25 years of abandonment.

The active and abandoned vineyards have provided excellent man-disturbed habitats for the invasion and establishment of the non-indigenous species. Half of the species recorded from the vineyards are non-indigenous. Some examples are wild carrot, pigweed, lamb's quarters, sweet clovers, and many different grasses. In these habitats, these aggressive species are the major component of the flora in the early successional stages, namely 75 percent of the annual grasses, 63 percent of the annual forbs, 82 percent of the biennial forbs, 58 percent of the perennial grasses and sedges, and 49 percent of the perennial forbs. As the vineyards are left abandoned and return to the shrub and tree successional stages, the perennial woody species replace the annual and perennial herbaceous plants, a slow return to the native forest community begins to occur. The non-indigenous flora has had a large impact on the flora of the islands, particularly in the early successional stages as the flora returns from disturbed pioneer herbaceous species to the more stable climax woody flora.

Waterfoul and Other Birds

The islands in western Lake Erie have a wide variety of birds and waterfoul. These fall into four categories: permanent residents, winter visitors (most often found only in winter), half-hardy birds (transients or summer residents which sometimes stay through the winter), and accidental visitors. Bird watching is a popular sport on the islands for visitors and islanders alike.

A rookery of black-crowned night herons, common egrets, great blue herons, and green herons exists on West Sister Island which is a National Wildlife Refuge. Thousands of birds nest here every year, occupying nearly every available space. With such a concentrated population in this small area, the birds are forced to go great distances to feed and are seen feeding in the mainland marshes and around the other islands. An occasional nest will be found on the other islands, particularly the uninhabited ones, but never to the extent of the colonies on West Sister Island.

Rocky, largely barren Starve Island was a favorite nesting site for common terns until they were crowded out by the herring gulls. In 1939, 1,052 tern nests were counted on this island, but by 1964 the island was completely taken over by herring gulls. It is interesting to note that in 1926 there was only one herring gull nest on Starve Island and no record of herring gulls nesting anywhere along the Ohio shoreline. Other favored nesting sites include the Rattles of Rattlesnake Island, Lost Ballast, and several rock outcroppings occurring around the islands. The nearby Canadian islands are also popular nesting areas for herons, gulls, egrets, and cormorants. An occasional tern can be seen amid the flocks of gulls following the ferry boats, but their numbers have been drastically reduced since the arrival of the herring gulls.

In 1921 the ring-necked pheasant was stocked on South Bass Island by the Ohio Division of Fish and Game. They multiplied and have become a nuisance to the farmers and grape growers, but are a great attraction for hunters in late fall. The other islands also support a fairly large pheasant population, and together with the northern marshes in the state, represent the only sites of any significant numbers of ring-necked pheasants remaining in Ohio. Rattlesnake Island was stocked with golden pheasants and wild turkeys about thirty years ago, but neither remain today, although the ring-necked pheasant is still common.

No endangered species nests on the islands. Twenty-five years ago single nests of the northern bald eagle were located on South Bass, Green, Kelleys, Rattlesnake, and West Sister Islands. The following species found in the Erie Islands are considered to be rare: common egret, least bittern, hooded merganser, king rail, common tern, and orchard oriole. Ten species common to the islands are listed as being of undetermined status due to noticeable decreases in populations in recent years, and bear further surveillance. The species include: pied-billed grebe, American bittern, ring-necked pheasant, common gallinule, black tern, purple martin, crow warbling vireo, Baltimore oriole, and rough-winged swallow.

Mammals

The species diversity of mammals inhabiting the Erie Islands is understandably low considering their isolation from the mainland and the small area involved. Only thirteen species have been recorded as being permanent residents, and these are all small animals. Several species of mice exist, usually in areas of human population. The Norway rat is particularly dependent upon human habitation as its main centers of repopulation are dumps. A campaign to eliminate the high number of rats on South Bass

Island by poisoning in 1952 severely depleted the population of eastern gray squirrels. Concerned islanders imported several black squirrels from Belle Isle Park in Detroit to help reverse this situation. The two species interbred to the extent that the only squirrels present today are the melanistic eastern gray squirrels. The cottontail rabbit accounts for a large percentage of the mammal population of the islands. Racoon, red fox, and muskrat occur in small numbers due to lack of suitable habitat. The little brown bat is a permanent resident of the islands, but its secretive nature prevents it from being obvious. It remains dormant throughout the winter and is able to withstand extreme cold temperatures. Empty cottages, boathouses, sheds, barns, and caves provide an abundance of sites suitable for habitation. A herd of African Mountain sheep roam wild on Rattlesnake Island where they were introduced in the 1960's. During the severe winter of 1976-1977 the herd was reduced from nine to three. A small number of deer live in the remaining wild areas of Catawba Island and the adjacent Marblehead Peninsula. During cold winters when the lake freezes over they occasionally cross the ice to some of the islands. Several were sighted on Kelleys Island in December of 1976 soon after the ice had formed.

Conclusion

Lake Erie is perhaps Ohio's most valuable water resource. The abundant natural resources of the coastal zone have attracted activities such as fishing, farming, commerce, and industry. The lake, its bay, and estuaries are the source of a wide variety of fish for both commercial and recreational fishermen.