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ABSTRACT

The purpose of this volume is to present a body of basic information about the Great Lakes that is current and based on sound research. Such information is frequently difficult to locate, especially in one reference, and equally difficult to decipher and evaluate. The 16 essays contained in this book deal with a variety of topics including the geology, botany, climate, coastal politics, economics, ecology, and pollution of the Great Lakes basin. Over 200 references are included. (CW)

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The Great Lake Erie

A Reference Text for Educators and Communicators

Edited by

Rosanne W. Fortner
Victor J. Mayer

Columbus, OH 43210

Sponsored by The George Gund Foundation, Cleveland, Ohio

A volume such as this is not possible without the assistance of numerous individuals and organizations. In addition to the sponsor, The George Gund Foundation of Cleveland, and The Ohio State University School of Natural Resources and College of Education, the following made significant contributions to this publication:

Technical Editors:	Marcia L. Seager Marjorie Pless
Layout and Design:	Jerri Shafer
Content Reviewers:	James P. Barry, The Ohioana Library Sally Cole-Misch, International Joint Commission Frank Quinn, Great Lakes Environmental Research Laboratory Fernando Rosa, Canada Centre for Inland Waters S. Yaksich, Dept. of the Army, U.S. Army Engineer

The editors welcome comments and suggestions. Contact them through The Ohio State University, School of Natural Resources, 2021 Coffey Road, Columbus, Ohio 43210-1085.

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Preface

The Great Lake Erie was conceived as a means of drawing together for a single purpose information from a group of experts in areas that characterize the importance of the Great Lakes. Thus the scientists, historians, resource managers and policy analysts represented by this group reflect the scientific, historical, environmental and political value of the Great Lakes to North America and the world.

The purpose of this volume is to present a body of basic information about the Great Lakes that is up to date, based on sound research, and interpreted by experts in the subjects involved. Such information is frequently difficult to locate, especially all in one reference, and equally difficult to decipher and evaluate. Educators and media communicators as a result may avoid Great Lakes topics.

We believe that information in hand, especially if well presented and applied to real needs, has a strong potential for use in communication and education. The chapter authors were selected not only for their subject matter expertise but for their ability to communicate to the public as well. With the vitality and interest apparent in this work, they have provided a substantial information base about where the Great Lakes have been and what their future may be. This volume is a beginning set of answers for what we hope will be a growing interest among educators and communicators to learn and tell more about the Great Lakes.

There is a great deal more to tell than this. The story of the importance of the Great Lakes does not end at the back cover of the book. It is a personal story, not only for those who share in the immediate grandeur of the lakes, but for every world citizen who shares the freshwater birthright. As stewards of the world of water, we can do no less than stand in awe of the resource portrayed here and pledge ourselves to its wise management in decades to come.

Rosanne W. Fortner
Victor J. Mayer

About the Authors

Lee Botts is an environmental consultant in Chicago. Among her current projects are analyzing how Chicago deals with the environment, working with the Chicago City Council on Energy and the Environment, consulting with the National Geographic on its 1987 Great Lakes article, and helping with Citizen's Review for a Great Lakes Water Agreement. In 1978 President Carter appointed her as Chairperson of the Great Lakes Basin Commission. From 1981 to 1986 Ms. Botts was a research assistant on Great Lakes issues for the Center for Urban Affairs and Policy Research at Northwestern University, a position from which she is currently on leave.

Jane L. Forsyth is Professor of Geology at Bowling Green State University and is a well-known lecturer on the geology of Ohio. In addition to her teaching, lecturing and research in geology, she served on both the Ohio Geological Survey and as Editor-in-Chief of *The Ohio Journal of Science* for 10 years, has twice been vice-president for Geology in the Ohio Academy of Science, and was selected by two Ohio governors to serve on the state's Natural Areas Council. She is active in the Ohio Chapter of The Nature Conservancy.

John J. Furlow is Curator of The Ohio State University Herbarium in the Department of Botany, where he has been since 1980. He is currently writing Volume 2 of the *Vascular Flora of Ohio*. Before coming to Ohio State he was a Professor of Biology at Capital University, Columbus, Ohio. He has also taught high school biology. Furlow's research specialty is the evolution and systematics of the Birch Family.

Val I. Eichenlaub is Professor of Geography at Western Michigan University, Kalamazoo, and author of *Weather and Climate in the Great Lakes*. His articles on lake effect snow appear in meteorological journals, and he is currently involved in research related to climate change and changes in relative percentages of sunshine and cloudiness in Michigan. Eichenlaub is editor of the forthcoming *Atlas of Michigan Climate*.

Charles H. Carter worked as a scientist for the Ohio Geological Survey for ten years. He has been a Professor of Geology at the University of Akron since 1982. Dr. Carter's specialties are coastal geology, sedimentology and stratigraphy. He takes a special interest in the historic changes that the Lake Erie coastline has undergone.

Gerard T. Altoff is the Historian and Chief Ranger for the National Park Service at Perry's Victory and International Peace Memorial on South Bass Island, Lake Erie. He joined the National Park Service in 1972 after completing four years in the United States Coast Guard, including a tour of duty in Viet Nam. For the past six years he has conducted research on the Battle of Lake Erie, particularly on previously unknown stories of the men who volunteered to serve on the American fleet during the War of 1812. Altoff has published several articles on the naval aspects of the War of 1812 in newspapers and military periodicals.

Alexander C. Meakin is retired pastor of the Parma-South Presbyterian Church in Cleveland. For thirteen years he served as President of the Great Lakes Historical Society, and he is currently Chairman of its Board of Trustees. Dr. Meakin is a writer and lecturer on Great Lakes history, and author of several books on the the corporate histories of steamship companies. He is currently completing a book about the Wilson Marine Transit Company.

Jeffery A. Bryant is the marketing specialist for the Toledo-Lucas County Port Authority. His responsibilities include marketing and special projects for the Port Authority's maritime and aviation divisions. He also edits the Port of Toledo *News*. Bryant holds a Master of Divinity degree in practical theology and journalism from the Cincinnati Christian Seminary. He joined the Port Authority in 1985 after serving as the regional sports editor at the Freeport *Journal-Standard* in Freeport, Illinois. Bryant's work has appeared in national and regional publications including *Reader's Digest*, *Toledo Metropolitan Magazine*, and various newspapers.

Richard Bartz is Special Assistant for Lake Erie in the Division of Water, Ohio Department of Natural Resources. He also serves as an advisor to the Great Lakes Commission, coordinator on harbor dredging with the U.S. Army Corps of Engineers, and advocate for coastal management in the Department. He served on the Water Diversion Task Force to the Council of Great Lakes Governors that developed the Great Lakes Charter. He has been working on Lake Erie and Great Lakes issues since 1974.

Thomas E. Croley II is a Research Hydrologist with the Great Lakes Environmental Research Laboratory in Ann Arbor, Michigan. He worked on water resources systems problems for nine years as a professor and research engineer at the University of Iowa's Institute of Hydraulic Research, including work in New Zealand on surface runoff kinematics at the University of Canterbury and Lincoln college. In 1980, he joined GLERL's Hydrology Group to develop rainfall-runoff models for each of the Great Lake basins. These models are part of his recently completed near real-time lake level forecast package used both for research simulations and operational forecasting on the Laurentian Great Lakes as well as other large lakes systems.

Elliot J. Tramer, Professor of Biology at the University of Toledo, was born in Cleveland and has spent most of his life on the shores of Lake Erie. Dr. Tramer is the author of 40 papers on a variety of ecological topics, including avian diversity and distribution, succession in plant communities, and the biology of stream fishes. His recent Lake Erie related research includes studies of the effects of dredge spoil disposal on aquatic bird life and patterns of reproductive success in a Ring-billed gull colony, both in the Toledo harbor.

Andrew M. White is a Professor of Biology at John Carroll University. He has been active in Fisheries Research in Lake Erie since 1970. Interested in habitat and environmental effects on fish, his research has been conducted in many states, including Ohio, Indiana, Illinois, New York, Pennsylvania, Michigan and Texas. Past projects address such topics as dredging and its effects on fish for the Army Corps of Engineers and the causes of fish mortality at power plants. Dr. White is currently researching the causes of winter mortality in fish. Author of the book, *Fishes of the Cleveland Metropolitan Area*, he is also President of the Ohio Academy of Science.

Charles E. Herdendorf is a former Professor of Geology and Zoology at The Ohio State University. During his years at OSU he also served as Director of the Center for Lake Erie Area Research (CLEAR), the Ohio Sea Grant Program, and the Franz Theodore Stone Laboratory, the University's biological field station on Lake Erie. He served as Geologist and Lake Erie Section Head for the Ohio Department of Natural Resources, Divison of Geological Survey from 1960 to 1971. Dr. Herdendorf has over 25 years of research experience on the Great Lakes. He has served on the Board of Directors of the International Association of Great Lakes Research, the Advisory Council for Old Woman Creek National Estuarine Sanctuary, and several committees and task forces of the International Joint Commission.

Clayton J. Edwards has been a Fisheries Biologist for the International Joint Commission since 1980. His previous work includes positions with the Federal Energy Regulatory Commission and the U.S. Fish and Wildlife Service. Much of his work focuses on the effects of physical and chemical degradation on Great Lakes aquatic ecology. Dr. Edwards is Secretary to the Great Lakes Science Advisory Board and to the Lake Superior and Lake Erie Task Forces, Divisions of the Great Lakes Water Quality Board.

Kathleen L. Barber is Professor of Political Science at John Carroll University. She is a member of the Board of Trustees of Ohio Environmental Council, Center for the Great Lakes, The George Gund Foundation, and the Barnett R. Brickner Memorial Foundation. She is also Chairperson of the Board of Cleveland Public Radio (WCPN-FM, 90.3). Dr. Barber is a former member of Shaker Heights City Council and Vice Mayor of the City of Shaker Heights.

The Great Lake Erie, Editors

Rosanne W. Fortner is an Associate Professor of Natural Resources and Science Education at The Ohio State University, where she is responsible for instruction and research in Environmental Communications. Since 1978 she has been involved as a curriculum developer and teacher educator in the Ohio Sea Grant Education Program. Her other activities include consulting editorships for *The Journal of Environmental Education*, *The Ohio Journal of Science* and *Science Activities*, as well as editorship of *The Biosphere*, newsletter of the International Society for Environmental Education. Dr. Fortner is President-elect of the National Marine Educators Association.

Victor J. Mayer is Professor of Science Education, Geology and Mineralogy, and Natural Resources at The Ohio State University. He has been involved in curriculum development in earth science through the Crustal Evolution Education Project, and aquatic sciences through Oceanic Education Activities for Great Lakes Schools, an Ohio Sea Grant project. He is a recognized leader in science education internationally. Dr. Mayer is a candidate for president-elect of the National Science Teachers Association and has served as Regional Director of NSTA, as well as being President of the Science Education Council of Ohio and Executive Director of the Consortium of Aquatic and Marine Educators of Ohio (CAMEO).

Marcia L. Seager is a Research Associate in the School of Natural Resources at The Ohio State University where she is pursuing a Master of Science degree with a specialization in Environmental Communications. Her research focuses on teacher knowledge and attitudes about freshwater topics in Ohio elementary and secondary school curricula. She holds a Bachelor of Science degree in Environmental Education from Cornell University and is presently working as an assistant curriculum developer and editor for the Ohio Sea Grant Education Program.

Marjorie Pless received the degree of Master of Science in Natural Resources from The Ohio State University in 1986 with a specialization in Environmental Education. Her research for the thesis dealt with the knowledge and attitude impact of displays in the visitor center at Old Woman Creek National Estuarine Research Reserve in Huron, Ohio. Ms. Pless has extensive experience in public education programs for marine facilities. She is currently a Sea Grant Intern in the U.S. House of Representatives.

1/ These are the Sweetwater Seas

by Lee Botts

When Jacques Cousteau calls the Great Lakes the cradle of the ocean, he acknowledges that the Great Lakes are the largest freshwater system on the globe. Each of the five separate but connected individual lakes is so large that together they are known as inland seas. Like the oceans, the Great Lakes are an international resource, dividing Canada and the United States as political jurisdictions but uniting them in joint resource management.

One-fifth the population of the United States and three-fifths of Canada's live in the Great Lakes region. The lakes supply drinking water to about 25 million people, as well as water for power production, recreation and manufacturing in eight states and two provinces. They are the reason North America is the only continent with ocean ports a thousand miles inland.

The lakes opened the interior of the continent to Europeans for trade and later for permanent settlement. As both countries developed, lumber, sandstone and steel from Great Lakes shores helped build cities, and fish from the lakes helped feed their inhabitants. The lakes are also the reason the Great Lakes region has so many great cities of its own and such a large part of the industrial capacity and agricultural production of North America. And they are beautiful, with a majesty no other body of water achieves.

Collectively the Great Lakes contain one-fifth of the world supply of fresh surface water, so much that the quantity is usually expressed in cubic miles. Lake Michigan alone holds over 1,100 cubic miles (4,900 cubic kilometers) of water. It would require a square tank that covers the United States from the Mississippi River to the east coast and reaches the same distance into the stratosphere to hold the water from just this one Great Lake.

All the Great Lakes are huge storage reservoirs of fresh water, with narrow connecting channels and only a small outlet to the ocean. Each year only about one percent of the water in the lakes flows out the St. Lawrence to the Atlantic. Appreciation of the Great Lakes requires understanding of how the size and the closed nature of the system have made these sweetwater seas especially vulnerable to environmental damage and how the damage has occurred.

In addition to contributing to national wealth, the Great Lakes have provided an early warning system for global environmental problems and an unmatched example of success in resource management across an international border. The lessons cover eutrophication, atmospheric transport of pollutants and bioaccumulation of toxic chemicals in the food chain. Today the binational community committed to protection of the lakes is working to apply the concept of an ecosystem approach to management.

The classic definition of an ecosystem is a complex of physical resources and the living organisms that depend on them. Ecosystem stability depends on evolution of a balance between physical resources and the biological community. The community maintains itself by adapting to the constraints and opportunities provided by available space, energy and food. The ecosystem approach assumes that humans are part of and must adapt to the limits of the ecosystem in which they live.

In the past 200 years human activities have caused fundamental change in the Great Lakes ecosystem that evolved during the 10,000 years

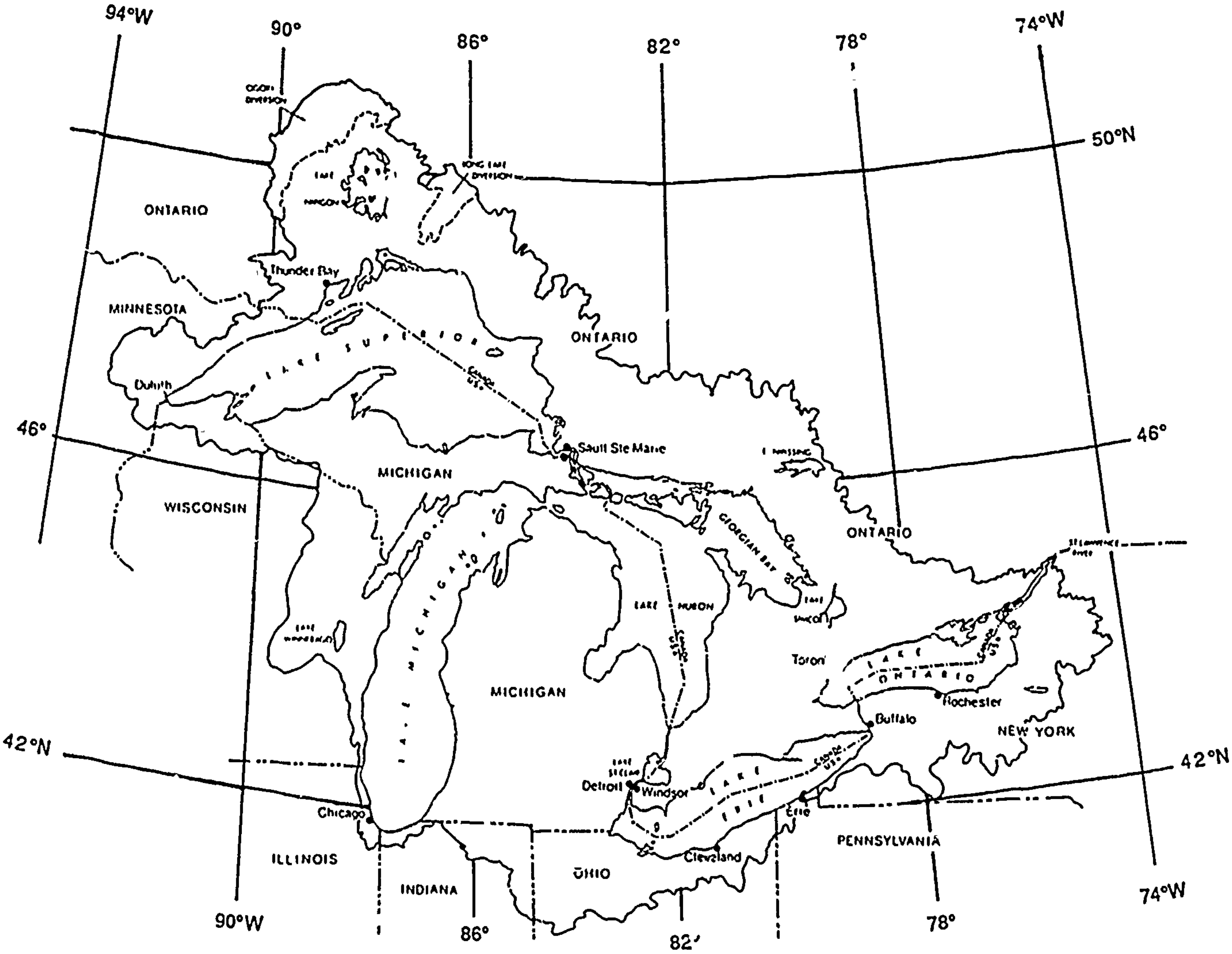

Figure 1.1. The Great Lakes Basin

after glaciers left the lakes behind. The forces that shaped the Great Lakes region began eons before the glaciers arrived.

How the Lakes Were Formed

In the Precambrian era about four billion years ago, geologic forces laid down the bedrock of the Great Lakes watershed in three distinct regions. To the north is the Canadian, or [illegible] shield, where mostly thin soils lay [illegible]. Evergreen and conifer forests dom[illegible]per Great Lakes region around Lake [illegible]ron and northern Lake Michigan.

In the central lowlands to the south, thick, fertile soils are layered over limestone in the lower Great Lakes region around Ontario, Erie and southern Lake Michigan. The lowlands have broad flood plains. The original hardwood forests dominated by oak, maple and beech mixed with white pine have generally been replaced by agriculture, industry and urban development. The third region is the wide flat valley of the St. Lawrence River that is the outlet of the Great Lakes to the Atlantic.

At least four times glaciers advanced south over North America and retreated, the last one only about 10,000 years ago. Each time melting filled deep basins gouged out by the glaciers.

The Great Lakes watershed was finally formed as we know it today only about 2,000 years ago. In some places the land is still rebounding from the weight of ice.

The region has thousands of smaller lakes in addition to the Great Lakes. Although about two-thirds of the original wetlands have been drained or filled, many marshes, bogs and fens still characterize the water-rich land. One of the influences on the Great Lakes is that they are fed by hundreds of small tributaries that flow through many different kinds of soils and land uses.

The Great Lakes Hydrologic System

The most distinctive feature of the Great Lakes watershed is the high proportion of water-covered areas to land. The Great Lakes watershed contains about 295,000 square miles (764,051 sq km), with about one-third or 95,000 square miles (246,000 sq km) covered by the Great Lakes themselves.

The long shoreline of the Great Lakes enhances the influence of land over the lakes. The 9,400 miles (15,150 km) of shoreline is longer than the United States coastline on the Atlantic and the Gulf of Mexico combined.

Hydrologic traits

All of the Great Lakes are part of a single hydrologic system but each one is different. The system begins in Lake Superior, given its name by the French because it is the highest above sea level, about 602 feet (180 m), with the reference point at Father Point, Quebec. Superior is all superlatives, the largest in every way. It could hold as much water as all the rest of the lakes combined plus three more Lake Eries. It is the coldest and the deepest, up to 1,333 feet (399 m) with an average depth of about 500 feet (150 m) over all. Superior has the longest retention time for water, about 200 years. This lake also remains the cleanest, though its size and slow flushing time make it most vulnerable to permanent pollution.

Lake Huron and Lake Michigan share the same hydrologic system because their surfaces are at the same height above sea level, about 581 feet (177 m), and because they are connected through the broad Straits of Mackinac. Huron is the second largest of the five lakes, and is up to 750 feet (225 m) deep with an average of 194 feet (59 m). The retention time for Huron is only 22 years because of its relatively large outlet into the St. Clair River toward Lake Erie.

Lake Michigan is the third largest and the only Great Lake entirely within the United States. It is up to 925 feet (282 m) deep, with an average of 279 feet (85 m). Lake Michigan has a slow flushing time of 100 years because it is a cul de sac, receiving and discharging water to the system through the same outlet in the north. Like Superior, Michigan is more vulnerable to pollution because of its size and long retention time. Its problems are compounded by the largest concentration of industry and cities in the region around its southern end in the Milwaukee-Chicago-Gary metropolitan area.

Lake Erie is the shallowest of the lakes and holds the least water. Its fast flow-through time of only three to five years makes it seem like just a wide place in the Great Lakes river to the sea. Because of its small size and because of the concentration of row crop agriculture and numerous cities on its shores, Lake Erie was the first Great Lake to be affected overall by pollution. Yet Erie's fast flushing time assisted its dramatic response to cleanup of conventional pollution, and its short water column makes it less vulnerable to toxic contamination.

Below Niagara Falls, Lake Ontario is downstream from all the other lakes and thus receives pollutants from upstream as well as its own watershed. It receives large loadings of contaminants from the Niagara River, which is bordered by numerous hazardous waste landfills for the chemical industry that is dependent upon the hydropower of the falls for electricity. Ontario is smaller in area but much deeper than Erie, 282 feet (86 m) on the average and up to 804 feet (245 m). The flow-through time is only six years because it has the largest outlet of all the lakes—the St. Lawrence River.

Climate impacts

The lakes are so large that they modify the climate. They store heat as well as water. Both moisture in the air above the lakes and the heat

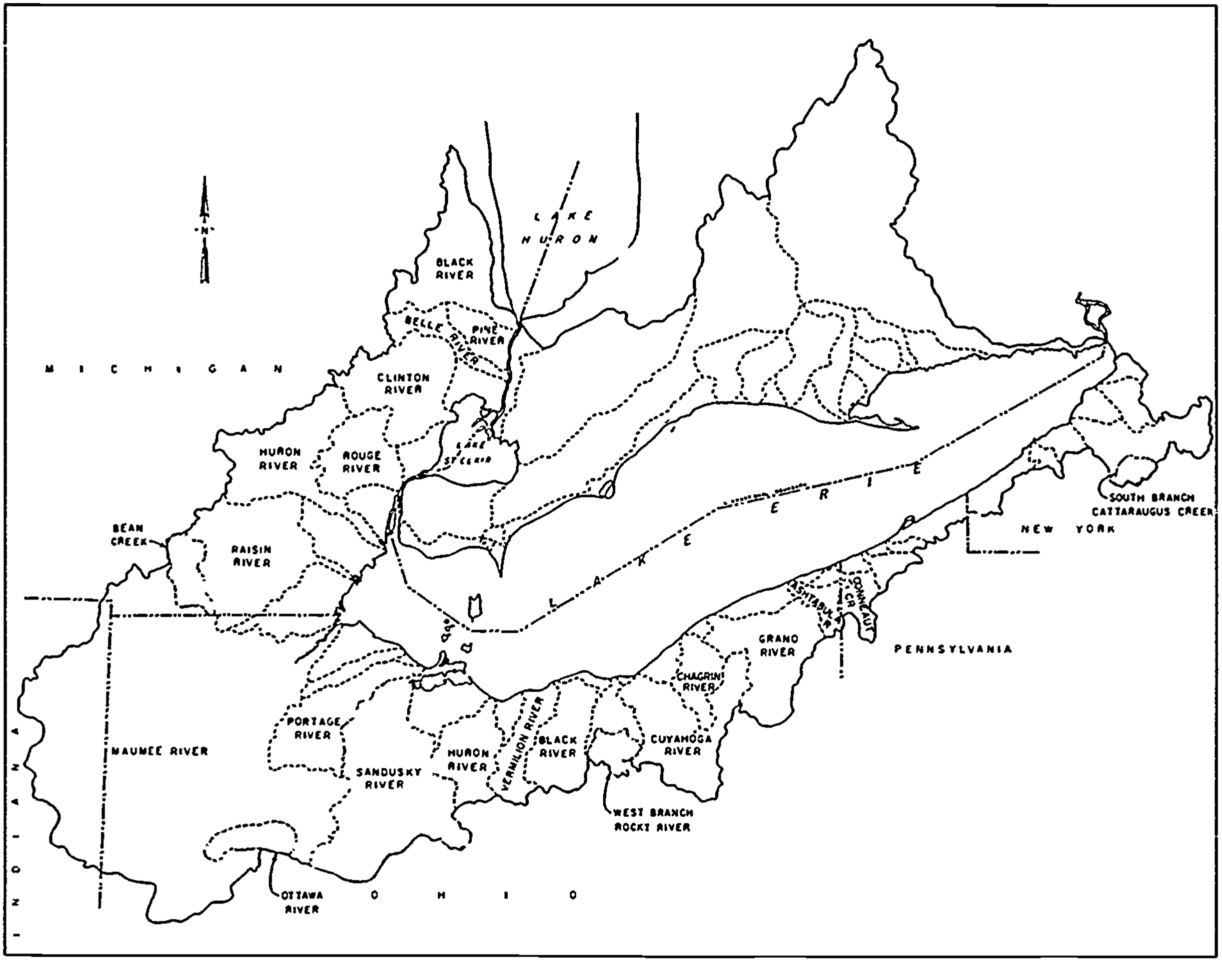

Figure 1.2. Lake Erie drainage detail. *(U.S. Army Corps. of Engineers, 1983)*

they exchange with the atmosphere affect the climate. It is cooler in summer and warmer in winter near a Great Lake. Retention of heat lengthens the frost-free season and is the reason fruit is grown near Lakes Michigan, Ontario and Erie.

In winter and summer, the weather is more changeable because cold fronts from the Arctic and warm fronts from the Pacific and the Gulf confront each other often in the moisture-laden atmosphere over the lakes. The moisture in the atmosphere provides many humid days in summer and heavy snowfalls in the lee of the lakes.

The long term average annual precipitation is about 31 inches (77 cm.), less at the western edge of the basin and more on the east. Variations in precipitation and temperature are the chief reasons for fluctuations in lake levels, with more water supply and less evaporation during the wetter, colder periods when lake levels rise. While changes in lake levels affect shoreline development severely, the fluctuations of several feet are small in relation to the volume of water.

Changes in the Great Lakes Ecosystem

When the first European explorers found the lakes in the 16th century, it is estimated that about 120 thousand people lived in the watershed that is now home to more than 40 million Canadians and Americans. Many of the native peoples depended on hunting and fishing. Those who planted crops moved on to a new location every few years, leaving the land to recover and waterways unchanged.

Most of the region was heavily forested, with deep grasslands in the few open areas, and travel was very difficult except by water. Streams ran clear and cold year round and seldom flooded because wetlands filtered the nutrients in slow runoff from the wooded land. Elk were the largest mammals, with bear, deer, wolves, beaver and large members of the cat family common throughout the region.

There were several hundred species of birds in great abundance. The Great Lakes, especially the north/south shores of Lake Michigan, are a continental flyway for migratory birds, with wetlands providing essential habitat for many species of waterfowl.

The Europeans also made little difference for the lakes in the first 200 years after their arrival. They lived in small settlements around the forts that protected the fur trade, and the voyageur traders traveled mainly on the natural waterways. Permanent changes began first in the east in the 18th Century with removal of the forests for settlement and fields and damming of the streams to power grist mills.

The Great Lakes fishery

Radisson, LaSalle and other early French explorers were amazed by the size, abundance and number of species of fish in the Great Lakes. It is thought there were about 180 native species of fish, some now extinct, and many subspecies adapted to particular locations. Still, the lakes were relatively unproductive for their size, because of the low level of nutrients in the water, and the fishery was quite different than it is now.

It is believed there were many fewer individual fish in the lakes but that the average individual fish probably weighed 4 or 5 pounds (1.7 to 2.2 kg). Radisson marveled at six foot long pike. Century-old sturgeon that weighed up to 400 or 500 pounds (171 to 227 kg) may explain the old drawings of so-called sea monsters in the lakes. Several kinds of herring, whitefish and lake trout were abundant in open waters. Yellow perch were found mainly in shallow bays where nutrient levels were higher.

But there were no carp, smelt, brown or rainbow trout, white perch, alewives, pink salmon, splake, or the Pacific salmon now so prized by sports fishermen, the coho and chinook. Nor was there any sea lamprey, at least not above Niagara Falls. None of these fish so common today are native to the lakes, while a number of native species, like the blue pike and the long-jawed cisco, are extinct.

The lamprey and the alewife, a small ocean herring, are believed to have invaded the lakes from the Atlantic through canals. The smelt and pink salmon accidentally reached the lakes after being stocked elsewhere. The others, including carp, were deliberately introduced.

Human impacts on the fishery

The temperature was raised and the character of streams changed as forests were removed from the banks and flows were slowed by dams. Fishery biologists speculate that the warmer water gave an advantage over native species to the parasitic sea lamprey in streams where they spawn. The lamprey attacks large fish by attaching itself by its large mouth ringed with sharp teeth and feeding on the body fluids.

After the Northwest Ordinance opened the Great Lakes region to permanent settlement following the Revolutionary War, canals were built to improve transportation into the interior of the continent. It is believed the alewife and lamprey entered the Great Lakes through the Erie Canal and reached the upper lakes through the Welland Canal that was built to bypass Niagara Falls for navigation.

Both were present in Lake Erie by the mid-19th century but were not recognized as a threat until much later. The Great Lakes fishery was a major food source for the expanding cities through the century. Little notice was taken initially of fluctuating catches and decline of some species, because other desirable species always seemed to be available.

The peak commercial fishing years on the Great Lakes were from the 1860s to the turn of the century as lack of regulation, increasing markets and more efficient fishing equipment encouraged heedless harvesting. Sturgeon had become rare by 1900 because fishermen, who disliked the way the sturgeon's bony snouts tore their nets, piled them up like logs and burned them. By the time the value of sturgeon caviar was recognized, it was too late. Today, sturgeon in the lakes are rare and small.

Commercial fishing remained a major Great Lakes industry through World War II, but by the 1950s the lamprey had almost destroyed the lake trout in Michigan and Huron, and other catches had declined drastically. Now the largest commercial catch in Lake Michigan is alewives for animal and chicken feed. It is difficult to weigh the relative role of several factors in the decline of the value of the commercial fishery. In the United States, some species cannot be sold in interstate commerce because the concentrations of PCBs and certain other chemicals exceed levels considered safe by the Food and Drug Administration. The populations of other species are too small and increasingly state governments favor sport fishing over commercial fishing because they believe the economic return is higher.

Controlling invading species

In 1955, Canada and the United States established the Great Lakes Fishery Commission to find a way to control the lamprey. Since the early 1960s, two chemicals have been used to kill lamprey spawn in streams. The lamprey population has been reduced up to 90 per cent, but total eradication is unlikely. One concern is that the lamprey may be developing resistance to the lampricides.

Another is that deliberate introduction of chemicals into the aquatic ecosystem should not be continued. A third is that, ironically, pollution control has extended the lamprey's intrusion into cleaned up rivers. The sea lampreys need clear water for spawning. Since water quality improved in the St. Louis River near Duluth in the 1970s, the walleye have returned but the dreaded lamprey has also begun spawning there in the farthest reach of the Great Lakes system.

The intrusion of the alewife and smelt also contributed to permanent change. The alewife is not well adapted to the Great Lakes and dies off in the spring. In Lake Michigan, the alewife population grew as the lamprey destroyed the top predator, the lake trout, leading to one of the best-remembered Great Lakes disasters. In 1967, thousands of tons of dead alewives clogged Chicago's drinking water intakes and made beaches all around the lake unusable all summer. The smell will never be forgotten. Public horror increased because of massive waterbird dieoff at the same time. The birds had contracted botulism by eating the rotting fish.

The depredations of even the tiny smelt were first recognized by commercial fishermen who observed that the smelt eat eggs and fry of other, more desirable fish. Debate continues over the relationship between species changes and degradation of water quality as factors in ecosystem change. Sport fishermen do not question the value of the deliberate introduction of salmon from the Pacific Northwest into the Great Lakes.

Promoting desirable species

The coho and chinook salmon were introduced in the mid-1960s by fishery experts who reasoned that the alewife population could be reduced by new predators and the lake trout restored as the lamprey declined. The salmon thrived so well that by 1970 the enthusiasm felt by fishermen for the big fish was called coho fever. With return of the walleye to Lake Erie and salmon stocking in all the other lakes, sport fishing has developed as a major new industry in a region that has been losing others.

The State of Michigan officially promotes sport fishing over commercial fishing. Other states seek to promote both, but competition between sport and commercial fishing interests is growing. Some sport fishing organizations are using their political power to advocate that efforts to restore the native lake trout be abandoned so that more money can be devoted to stocking the exotic salmon. With new appreciation for the many ways the Great Lakes ecosystem has been disturbed, biologists consider the future of all Great Lakes fisheries to be uncertain.

Although massive stocking of the lake trout has continued since the mid-1960s, the trout does not yet reproduce enough to sustain itself except in Lake Superior. The problem may be partly genetic, since many subspecies adapted to specific locations were lost. Research has shown that both reproduction and survival are affected by the presence of toxic contaminants such as PCBs and toxaphene. In any case, bioconcentration of persistent organic hydrocarbons makes the trout, as well as the large salmon, unsafe for human consumption in most places.

Furthermore, the alewife population has now been reduced so much that it no longer provides a sufficient forage base for the Pacific salmon, which, to the dismay of sport fishermen, are not growing as large now as they did in the early 1970s. Now the salmon seem to be turning to the smelt and to native herring and perch for food. Fishery management agencies are being urged to limit commercial fishing of native species to protect a forage base for the put-and-take salmon fishery. Lake Michigan, the sixth largest lake in the world, is so dependent on stocking that it is called the world's largest fishbowl. Public health advisories against consumption of various species are issued by every state and province. Toxic contamination is now considered a potential threat to future use of the lakes for drinking water as well as for the Great Lakes fishery.

Great Lakes water quality: Degradation and Remediation

The first pollution problems in the lakes were also observed by 1900, but they seemed to be localized and caused no general concern. As lumbering spread across the Great Lakes region, sawdust clogged the mouths of tributaries, destroying habitat and increasing biochemical oxygen demand (BOD) as it decomposed. Increased soil erosion and runoff, as the land was stripped of vegetation and plowed, added silt to the pollution load that tributaries delivered to the lakes. Today, agricultural runoff is a source of pesticides as well as nutrients.

Near the rapidly growing cities, industrial wastes and untreated sewage caused fouled harbors and nearshore waters, adding disease-causing bacteria to high BOD problems. Chicago was the first city to act to protect its Great Lake water supply. After an estimated 15 per cent of the city's population died in epidemics of cholera and typhoid from 1885 to 1887, the flow of the Chicago River was reversed to carry sewage effluent away from Lake Michigan into the Illinois and Mississippi rivers. The action protected the lake but was an early example of displacement rather than elimination of wastes. Congress passed the 1899 Refuse Act to stop discharge of industrial wastes but vigorous enforcement of this law did not begin until 1969 and localized pollution continued to grow in the Great Lakes.

Eutrophication and the Great Lakes

The trophic status of a lake is a measure of its biological productivity. Nutrients and light are necessary to sustain life in water as they are for growth on land. Eutrophic waters, those receiving a large amount of nutrients, are most productive, and oligotrophic, those receiving few nutrients, least productive, with mesotrophic somewhere between. Accelerated eutrophication in Lake Erie actually meant more life rather than less, with more pollution-tolerant species becoming dominant.

The most obvious signs to the public were fewer walleye and many more yellow perch, and turbid or cloudy water. Excessive growth of the green algae, *Cladophora*, overshaded other plants and became exceeding unpleasant for beach recreationists. The Great Lakes agreement stressed reduction of phosphorus loadings and called for a binational cleanup process to be carried out through the new Great Lakes Regional Office of the IJC, located in Windsor, Ontario, just across the river from Detroit. Scientists agreed that phosphorus is the limiting nutrient for the Great Lakes; that is, if phosphorus loadings into the lakes were controlled, decreased algal growth would result.

The Boundary Waters Treaty of 1909 and the IJC

In 1909 Canada and the United States negotiated the Boundary Waters Treaty to provide a peaceful system for resolving disputes and for making cooperative decisions for all the waterways that cross their common border. The treaty established the International Joint Commission (IJC) as a uniquely independent agency that advises the governments.

Three members of the IJC are appointed for each side and they are directed to carry out their duties as individuals without regard for national concerns. The duties of the IJC include studies on problems by reference, or request, from the governments. The IJC also informs the governments about problems that need attention, but it has limited authority to initiate a study on its own. Nor can the IJC initiate actions to solve problems unless directed to do so by the governments.

By 1919, the IJC reported to the governments that serious degradation of water quality was occurring in more and more locations in the Great Lakes but no action was taken. By 1929, the first scientific report was made that decay of massive algae growths was causing depletion of oxygen in the western basin of Lake Erie. Over the next decades oxygen depletion was observed in a larger area in Lake Erie every summer. About 1960, scientists reported that for the first time accelerated eutrophication threatened the future of a whole Great Lake. A reporter's interpretation that "Lake Erie is dying" alarmed a public that was growing increasingly concerned about air and water pollution.

The public concern provoked both governments to sign the Great Lakes Water Quality Agreement in 1972, with the IJC directed to oversee its implementation. Initially, the binational Great Lakes agreement emphasized reduction of phosphorus loadings to control eutrophication.

The Great Lakes Water Quality Agreement

In the Great Lakes agreement, the governments of Canada and the United States agreed to work together and separately to achieve specified water quality objectives. The aim is to clean up existing pollution and to prevent continuing degradation. The process established by the agreement calls for remedial programs, research and monitoring. It also provides for accountability and flexibility to modify the objectives as conditions change or as new information is developed.

Two binational boards of experts were established, the Water Quality Board and the Science Advisory Board. Members of the Water Quality Board represent environmental management agencies while members of the Science Advisory Board include academic experts as well as staff of research agencies. Both assist accountability by making annual reports to the IJC on progress toward meeting agreement objectives.

The agreement recognizes differences in the two countries by allowing remedial programs to be carried out under their own laws. In Canada, the province has primary responsibility for environmental management. Thus there is a Canada-Ontario Agreement that the province uses to apply the Great Lakes water quality objectives in its pollution control programs. In the United States, the federal government set minimum national standards under the Clean Water Act, and the Environmental Protection Agency has the lead responsibility for meeting Great Lakes water quality objectives.

Both countries established new Great Lakes research programs to meet commitments under the agreement. Canada has its Centre of Inland Waters and the United States has special Great Lakes programs and laboratories under EPA, the National Oceanic and Atmospheric Administration (NOAA), and the Army Corps of Engineers, with other agencies participating as needed. A reference from the governments called for a cooperative Pollution from Land Use Activities Reference Group study (PLUARG) as the first major effort.

The study conducted from 1973 to 1976 was designed to answer three questions: How much Great Lakes pollution is caused by land runoff? Where is it occurring? What should be done about it? The PLUARG report identified agricultural runoff as the source for about half the phosphorus loading of Lake Erie and led to demonstration projects for conservation tillage. What is now a national movement for conservation tillage to reduce soil erosion was begun to improve Great Lakes water quality. The study also identified the atmosphere as another major diffuse source of pollution to the lakes, particularly toxic substances.

Toxic contamination

By 1976, the monitoring reports and results of research had confirmed high levels of many toxic chemicals and heavy metals in the lakes as well as long range transport through the atmosphere. Great Lakes states had banned DDT after scientists demonstrated in 1968 how the pesticide bioaccumulated in the food chain of Lake Michigan. In 1971, fishery biologists who were monitoring decline of DDT levels in fish discovered high levels of polychlorinated biphenyls (PCBs), a discovery that led to a ban on manufacture of PCBs in the Toxic Substances Control Act. In 1975, high concentrations of PCBs were found in lake trout in a small lake on Isle Royale, a wilderness national park in northern Lake Superior far from any possible direct source.

When results of the 1972 agreement were reviewed after five years by the governments, a second agreement was developed and signed in 1978. The new agreement added a call for an ecosystem approach to management and a virtual zero discharge of toxic substances as objectives.

For phosphorus, the 1978 agreement introduced the concept of mass balance as a basis for control by calling for individual target loadings for each lake. The target loading is set to reverse eutrophication. Today, reduced algae growths in most Great Lakes locations and return of the walleye to Lake Erie, to the St. Louis River near Duluth and to the Fox River that flows into Green Bay, are considered by many to be signs of reduced eutrophication. The signs continue to improve in the lakes themselves.

Comparable progress has not been made in control of toxic contamination, but experience with the Great Lakes is again showing the way for addressing a serious, complex and most difficult environmental problem. The National Academy of Sciences in the United States and the Royal Academy of Canada recently endorsed the need for an ecosystem approach to management in their joint review of progress toward meeting the objectives of the 1978 Great Lakes agreement. Better understanding of the sources and fates of toxic contaminants in the Great Lakes has set the stage for an ecosystem approach in remedial programs, with ecological integrity rather than only reduced levels of specific pollutants as the goal.

A new Great Lakes strategy

The new strategy for control of toxic contamination that is emerging for the Great Lakes is based on a mass balance approach, which seeks to identify all sources of toxic substances, control and prevent them from entering the Great Lakes systems. The IJC defines toxic substances as those chemicals which, when released into the environment, or if changed by chemical, physical and biochemical processes after release, could be detrimental to natural ecosystems or to human health. Many such substances are considered hazardous because of bioconcentration, the process by which contaminants present in very low levels in the water bioaccumulate to dangerous levels that affect both life in the lake and other organisms, including humans, at the top of the food chain.

To date, over 1,000 chemicals and heavy metals have been identified in the Great Lakes ecosystem, in the water, in sediments, or in fish. Persistent organic chemicals such as PCBs can concentrate up to levels a million times greater in large salmon and trout than in the water. High rates of tumors in fish and birth defects in herring gulls and cormorants demonstrate consequences of toxic contamination. Long term epidemiological studies of humans with high levels of PCBs in their bodies because they eat Great Lakes fish are showing potential consequences for human exposure. Babies born to and breast fed by mothers with high concentrations of PCBs in their fat and blood are smaller on the average at birth and show subtle neurological signs of developmental disturbance.

We now know that sources of toxic contaminants into the lakes include the atmosphere and sediments as well as direct discharges and land runoff. Four-fifths of the loading of toxic substances to Lake Superior and half to Lake Michigan is by atmospheric deposition. Sources to the atmosphere include incineration, evaporation from industrial and sewage treatment systems, and evaporation from agricultural operations. In recent years scientists have learned that PCBs and other volatile organic chemicals evaporate from the surface of the water and are passed through the water column back into the atmosphere in gases excreted by bottom feeding organisms.

Chemicals are reaching the lakes through groundwater from hazardous waste landfills in connecting channels such as the Niagara and St. Clair rivers. They do not permanently remain in bottom sediments but can be resuspended by wave action due to passing ships or storms, or by ingestion and excretion. The size and closed nature of the Great Lakes make them a sink for toxic substances. The lesson of the Lakes is that, if it is happening in the Great Lakes, it is happening in the biosphere.

Conclusion

The story of the Great Lakes is complex. In this general discussion, many details of how the Great Lakes community is learning to apply an ecosystem approach to management of this huge resource have been omitted. Whether we will succeed as well with the more difficult problem of toxic contamination as we have with eutrophication remains to be seen.

Still, scientists observe that the Great Lakes achievement with phosphorus control in such a large system in so many jurisdictions by so many different measures is unmatched anywhere in the world. Surely we should learn from this success and continue the Great Lakes Water Quality Agreement to carry out remedial programs, research and monitoring bilaterally.

Scientists agree that restoration to the conditions that existed before the landscape and the lakes were changed by settlement and industrialization would be impossible. Yet protection of the integrity of the ecosystem for the future requires attention to how much rehabilitation and restoration can be accomplished and to whether there is agreement on what would be desirable. With sufficient understanding, the public will support whatever is necessary for control of toxic contamination. We look to educators and communicators to join in fostering the understanding on which the future of the sweetwater seas, and the biosphere, depends.

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2/ The Geological Setting of the Great Lakes

by Jane L. Forsyth

The Great Lakes are some of the largest and most beautiful freshwater bodies in the world. They are also scientifically very interesting, and geologically very young, for they did not even exist during preglacial time, a million years ago. The foundations for the lakes were being prepared, however, almost from the beginnings of our planet earth.

During the many hundreds of millions of years that preceded the Pleistocene Ice Ages, the present locations of the lakes were occupied by a major river system, the Laurentian River, that drained toward the northeast, with a tributary in each of what would become one of the Great Lakes. In the Lake Erie basin this tributary has been called the Erigan River. These rivers followed low valleys they had made by eroding deeply down into belts of weaker rocks. When the Pleistocene glaciers advanced southward out of Canada, they blocked and destroyed these ancient rivers, and gouged their valleys deeper and wider, thus creating the basins of the modern Great Lakes. The ice cut deepest where it was thickest, farther to the north. As a result, the basins of the northern Great Lakes are especially deep, with their bottoms far below modern sea level, while the southernmost lake, Lake Erie, averages only about 100 feet deep overall, and less than 30 feet deep in its shallow southwestern basin.

Bedrock

Pre-Cambrian formations

The geologic setting of these lake/river basins began far earlier, with the formation of the bedrock in which these basins occur. In most cases this bedrock is sedimentary rock of Paleozoic age (roughly 200 to 600 million years old), but the rock surrounding Lake Superior, the northernmost and deepest of the Great Lakes, is much older igneous and metamorphic rock, Pre-Cambrian in age (one to two billion years old). These very old rocks actually occur down below the younger, Paleozoic sedimentary rock in the south, forming the so-called Pre-Cambrian "basement" rocks there. Northwards they rise nearer the surface until they occur at the surface, forming a broad Pre-Cambrian upland around the Lake Superior basin and throughout much of Canada, called the "Canadian Shield."

These igneous and metamorphic rocks were formed by mountain-making processes—volcanoes, intrusions and metamorphism—that were active through much of Pre-Cambrian time. Ancient sediments, buried by younger sediments and subjected to intense mountain making pressures, became the metamorphic rocks, while molten material in deep batholithic intrusives and in volcanoes at the surface contributed magma and lava that hardened into igneous rock. Great flows of basalt also emanated from giant rifts in the earth's crust and spread over the land, accumulating to a thickness of as much as 40,000 feet of hardened lava. Subsequently, forces within the earth bent all of these rocks in the Lake Superior region down into a giant syncline which, though the rocks have since been greatly eroded, still exists to help create the Lake Superior basin.

Igneous and metamorphic rocks are the most resistant rocks of all in the Great Lakes region, so the land around the Lake Superior basin is especially high and hilly. Even so, some

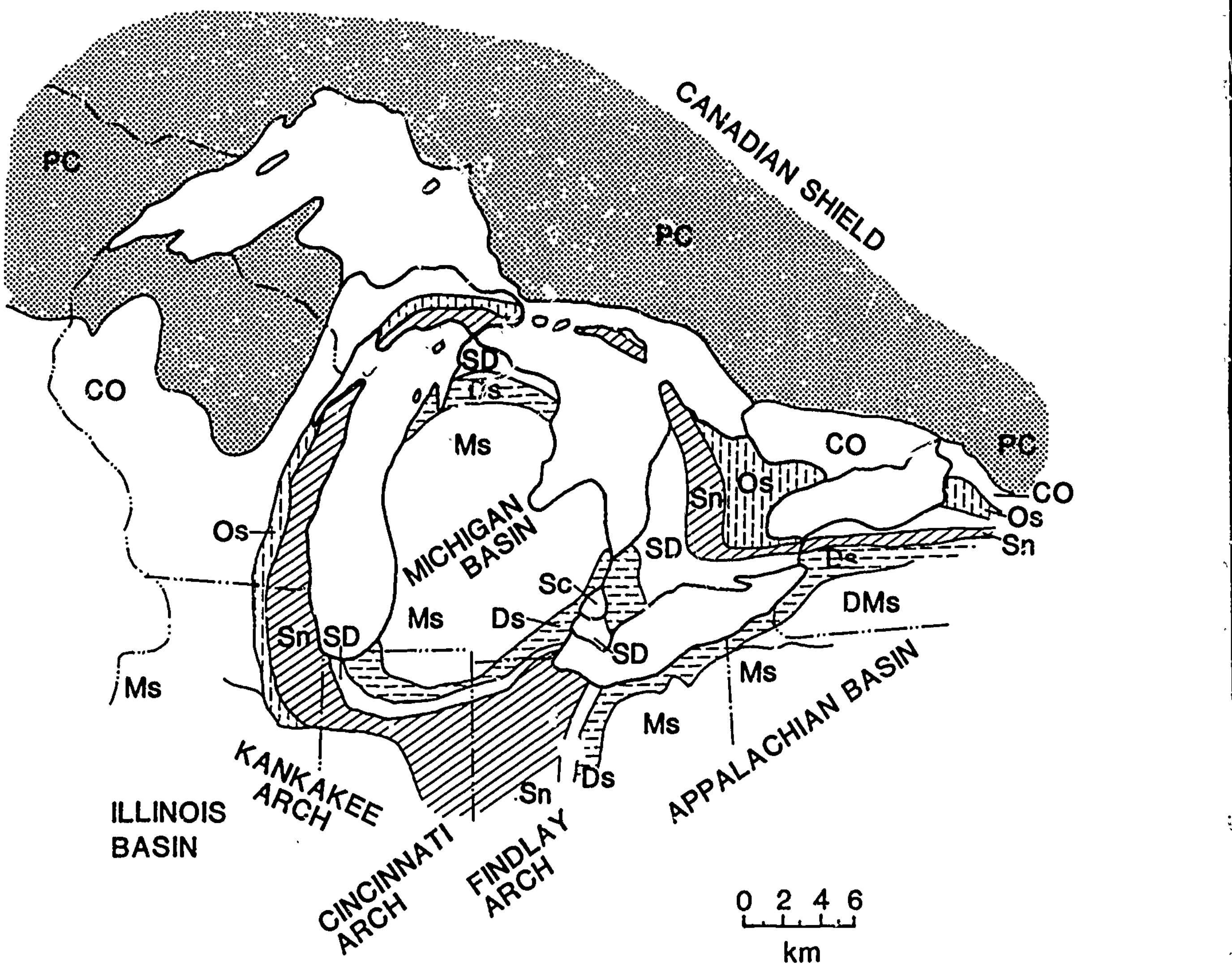


Figure 2.1. Geologic formations of the Great Lakes Basin

of these rocks are somewhat less resistant, allowing erosion, first by streams and later by glaciers, to cut a little deeper where they occur, also helping to create the basin of the largest of the Great Lakes.

Paleozoic sedimentation

Following the long Pre-Cambrian history came the accumulation of extensive Paleozoic sediments that developed into the bedrock surrounding the other Great Lakes, sediments that never covered the Pre-Cambrian rock in the Lake Superior region. These Paleozoic sediments began with a deposit of sand, weathered from the older igneous and metamorphic rocks and washed into the shallow intermittent sea that had spread across the entire lower Great Lakes and midwestern region. This sand became the Mt. Simon Sandstone, the "basal sandstone" of the Cambrian (lowermost Paleozoic). Limy sediments precipitated next from clear sea water, and the lime was subsequently recrystallized into layers of limestone and dolomite (the magnesium-bearing form of limestone).

During Silurian time, while the limestone (dolomite) was being deposited in the shallow open ocean, great reefs or other shallow marine bars developed, cutting off broad segments of the sea and allowing very little inflow of new sea water. In these closed basins, intense evaporation took place, causing precipitation of salts, mostly lime (both $CaCO_3$ and $(CaMg)CO_3$), but also gypsum ($CaSO_4.nH_2O$) and salt ($NaCl$). These precipitates, mined near Lake Erie, are important natural resources today. The gypsum is used to make Plaster of Paris and wallboard for building construction. The salt is used primarily as road salt in winter and in the chemical industry, though some also reaches the table. The limestone is used for flux in blast furnaces, for concrete construction and for agricultural lime. Oil and natural gas are also obtained from rocks of this age, as well as from older (Ordovician and Cambrian) limestones, where these rocks lie deeply buried.

About midway through the Paleozoic Era, the nature of the sediments changed. Mud, and later sand, began washing into the sea. The mud represented fine-grained sediments eroded from a rising land mass on the eastern shore of this ocean, and the change from mud to sand reflected the increase in height and steepness of this rising land. These muds formed the rocks known as the Ohio (or Cleveland) Shale, of Devonian age, and the sands formed the Berea and Black Hand Sandstones of Mississippian age. Evidence for the location of this rising land east of the Great Lakes is the increasing coarseness of all marine sediments in that direction.

Uplift and erosion

As uplift of this land mass continued, it apparently also raised up adjacent lands, including Ohio and its neighboring states and provinces, allowing the sea waters to drain away. River sands replaced the marine deposits, and fallen trees and other organic materials accumulated in low swampy areas, deposits which changed through time into sandstone and coal. This sandstone and coal, together with shales and clays, created an alternating pattern of sediments called the Coal Measures, found in Ohio's Pennsylvanian coal deposits. Ultimately all the adjacent land was raised above sea level, so sediments were no longer deposited and erosion dominated everywhere. The rising land to the east culminated in the formation of the original Appalachian Mountains, which towered impressively high like the modern Himalayas. The present Appalachians are just the eroded roots of those ancient mountains!

Preglacial rivers

As the mountains rose, many rivers developed on their slopes. Of these rivers, the main one flowing westward was the Teays, which followed a northwestward course across West Virginia, Ohio, Indiana and Illinois to join a very small preglacial Mississippi River. Though this river no longer exists, and its valleys are now deeply buried by glacial deposits everywhere north of the glacial boundary, the locations of these valleys can be determined from well records so that, together with the abandoned valleys still visible south of the glacial limit, a good picture of that ancient drainage system can be drawn. Contemporary drainage also came southeastward from some moderately high land to the northwest, drainage in the form of the Laurentian/Erigan River system, whose valleys represented the lowlands destined to become the basins of the future Great Lakes. Together the erosion of these preglacial rivers formed the modern bedrock landscape of this entire area.

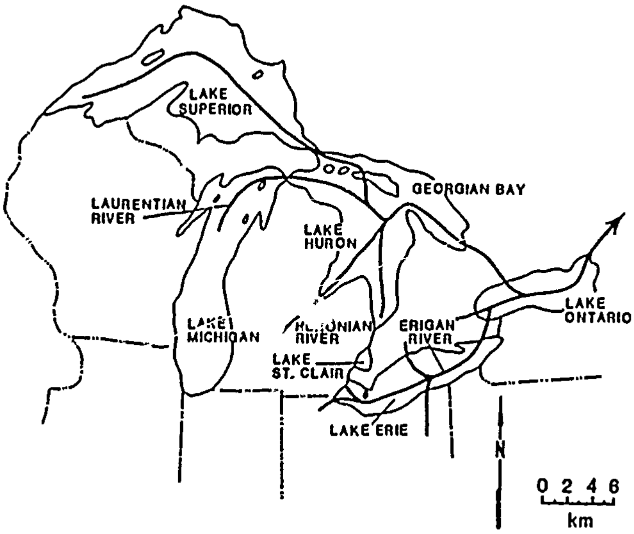


Figure 2.2. Preglacial river systems in the Great Lakes region

Extensive patterns of ridges and lowlands were formed by the erosion of these streams, because the sedimentary rocks here were not entirely flat-lying. They had been bent into a series of very shallow, broad structural basins separated by very low, elongate structural arches (note that these terms, "basins" and "arches" (anticlines) relate to internal patterns of the rock layers and not to landscape features). The main structural basins in this area are the Michigan Basin (which created circular patterns of eroded bedrock in lower Michigan), the (southern) Illinois Basin, and the Appalachian Basin (in southeastern Ohio, western Pennsylvania and West Virginia). In these areas where the rock layers were bent gently downward, erosion cut much less deeply down through the sequence of Paleozoic rock layers, so that the younger, coal-bearing Pennsylvanian rocks were generally preserved at the surface in the central parts of the basins.

In contrast, the low arches bent the rock layers upwards (though very gently, with slopes of less than one degree), so that erosion cut deeper into the sequence of rock layers, completely removing the younger layers and exposing the older (Ordovician and Silurian) rocks. The main arch here is the Cincinnati Arch, with a crest extending north-northeastward through Cincinnati. In west-central Ohio this arch divides, forming the northeast-trending Findlay Arch in northern Ohio and the northwest-trending Kankakee Arch in northern Indiana and Illinois.

Areas of resistance

The depth of the erosion accomplished by the Teays and Laurentian/Erigan River systems was affected not only by the location of the rocks relative to these structural basins and arches, but also by the erodibility of the rocks themselves. Some of the sedimentary rocks, like sandstone or solid limestone or dolomite, are more resistant to erosion than other rocks, and when erosion takes place they tend to make ridges or hills. Where weak, nonresistant rocks like shale occur at the surface, on the other hand, lowlands are created, such as the low river valleys that would ultimately become the basins of the Great Lakes.

Most famous of the resistant Paleozoic sedimentary rocks in the lower Great Lakes area is a Silurian dolomite of Niagaran age (about 400 million years old) called the Lockport Dolomite. It is this resistant rock that creates Niagara Falls in New York, the Bruce Peninsula and line of rocky islands separating Georgian Bay from Lake Huron, an east-west ridge on the Upper Peninsula of Michigan, and the Garden and Door-Green Bay Peninsulas on the west side of Lake Michigan.

Other somewhat less resistant rock layers in Ohio, the later Silurian Put-in-Bay Dolomite and the Devonian Columbus Limestone, form very low, asymmetrical ridges (or "cuestas") that extend out into Lake Erie and form belts of islands and peninsulas there, the Bass and Sister Islands and Catawba peninsula on the Put-in-Bay Dolomite, and Kelleys, Middle and Pelee Islands and Marblehead and Pelee Point peninsulas on the Columbus Limestone. Farther south in Ohio, Pennsylvania and New York, the very resistant Mississippian sandstones form the high impressive edge of the Appalachian Plateau.

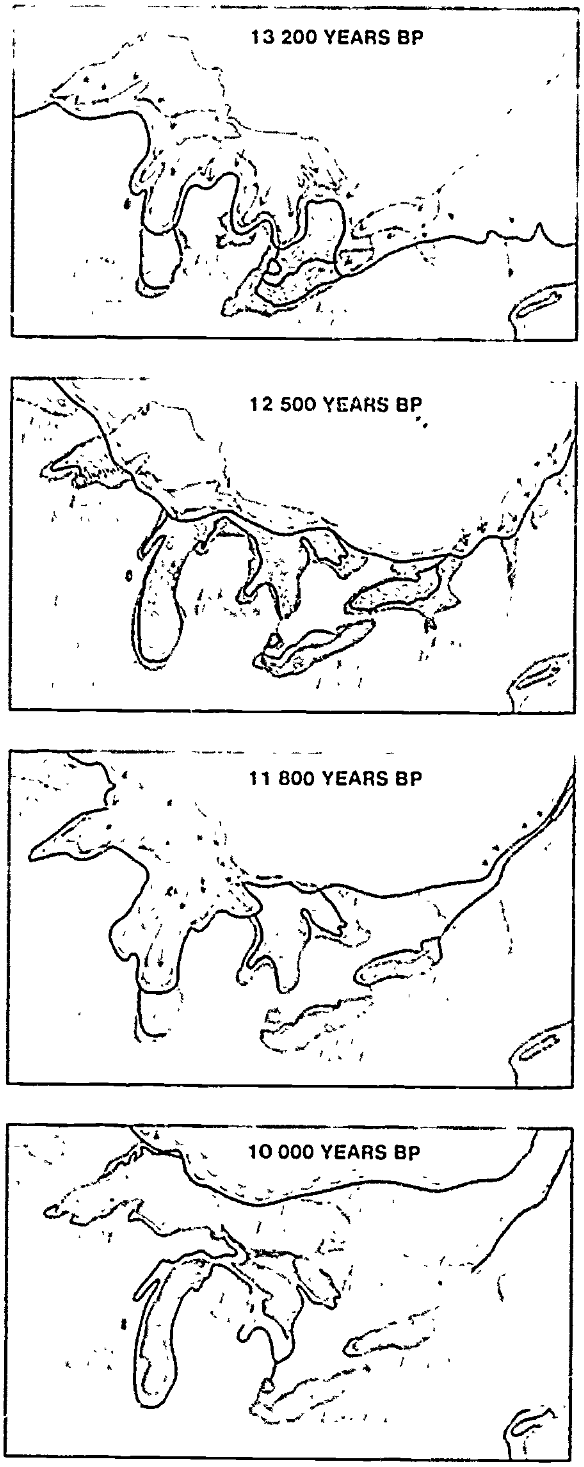
Lowlands on either side of the Niagaran Dolomite ridge were created by the deeper erosion of adjacent nonresistant sedimentary rocks. Most extensive of these lowlands are those that were occupied by the Laurentian/Erigan River system, lowlands cut generally into weak Devonian shales and destined to become, following glacial erosion, the basins of some of the Great Lakes. Lowlands also occur along the outcrops of weak Ordovician shales, lowlands that now contain Lake Ontario, Georgian Bay, Green Bay, and the bay west of the Door Peninsula (Big Bay de Noc).

Glaciation

With the advance of the earliest of the several Pleistocene glaciers, about a million years ago, the preglacial rivers in the Great Lakes area were blocked by the ice and in many cases were destroyed. Glacial erosion widened and deepened their valleys, with the deepest erosion done by the last (Wisconsinan) glacier because of its greater thickness in basins already deepened by earlier advances. The ice of all the glacial advances was of course thinner, and therefore did less erosion, farther south, where the shallowest of the Great Lakes, Lake Erie, occurs.

STAGES IN THE EVOLUTION OF THE GREAT LAKES

SCALE 1: 20 000 000



NOTE:
The maps on left are "snapshots" of a continuously changing situation during the retreat of the Wisconsin icesheet. They should not be viewed as a simple sequence, since many intermediate stages are omitted. The letters BP denote before present.

Figure 2.3. Formation of the Great Lakes. (from Botts and Krushelnicki, 1987, p. 6)

Ice-dammed lakes

As the ice retreated back toward the north, a whole series of ice-dammed lakes was formed in each of the Great Lakes basins. Each lake left deposits: sand beaches and sand bars along the old shorelines, clay settled out on the deeper lake bottoms and deltas wherever major rivers entered these lakes. Sandy beach ridges dramatically mark the shorelines of each ancient lake in the Great Lakes region. In prehistoric and early historic times, the ridges served as animal paths and Indian trails, and today they provide the location of many modern highways. Composed of well-drained sand, the ridges also support orchards and vineyards along the Lake Erie shore.

Like all lakes, it was the elevation of the outlet that controlled the level of each of the ice-dammed lakes. As the retreating ice exposed new, lower outlets, water levels dropped abruptly to new lower levels. If the ice readvanced, water levels rose to the elevation of the next higher ice-free outlets. Glacial retreat was more common than advance, so generally lake levels in each of the Great Lakes basins lowered through time.

The history of the lake levels in each of the Great Lakes basins is different, because each basin lay in a different position relative to the irregular retreating ice edge and to the available drainage systems. As a result, both the sequence of lake levels in each basin and the interrelationships of all these different lakes are most complex and have been a subject of study for many years. These histories are summarized here in only the most general way. (For more detailed interpretations see Karrow and Calkin, 1985.)

Formation of Lake Erie

Initially only the southernmost tips of the Erie and Michigan basins were ice-free, though the early lake histories in these two basins went on almost independently. Most complicated of the histories was that of the Erie basin, where more than a dozen different lake levels are recognized. There were three major levels, each marked by well-developed sand beaches. Highest was Lake Maumee at an elevation of 780', which drained westward by Fort Wayne, Indiana. Next was Lake Whittlesey at 735', draining north across the "thumb" of Michigan into a small ice-dammed lake in Saginaw Bay, which in turn drained westward across Michigan via the Grand River. The third lake was Lake Warren at elevations varying from 690' to 675' as its outlet was lowered by erosion. Lake Warren flooded into the southern end of the Huron basin and around the "thumb" of Michigan, forming a single extensive lake that also drained westward across central Michigan.

All these Erie-basin lakes drained westward. When the glacier finally retreated far enough north to allow the impounded waters from the Erie basin to flow eastward through a much lower outlet near Buffalo, a tremendous flood resulted. The Buffalo outlet was especially low then, because it had been weighted down more than 150 feet by the heavy glacial ice, so that Lake Erie, which today averages only about 150 feet deep, was almost entirely drained away in what must have been a truly catastrophic flood. The lower end of the Mohawk valley is filled with the kind of thick, coarse, poorly sorted deposits that such floods would generate.

With the lake water virtually gone, rivers became extended out onto the exposed lake bottom. Only a few small ponds were left in the deep eastern part of the lake and upstream of several end moraines that cut across the lake bottom, ponds collectively called "Early Lake Erie." As the Buffalo outlet subsequently raised slowly back up, rebounding isostatically from the weight of the glaciers, the level of Lake Erie rose too. The lake attained its present level only very recently. High lake levels in the 1980s are a result of increased precipitation and reduced evaporation, not the ancient process of isostatic rebound.

Figure 2.4. Niagara Falls outlet of Lake Erie.

Formation of the other Great Lakes

Similar complex histories are known for the ice-dammed lakes occurring in the other Great Lakes basins. The sequence of lakes in the Huron basin began slightly later than that in the Erie basin, but was closely related to it. Huron began with a small ice-dammed lake that drained westward across Michigan and later, with continued ice retreat, merged with the waters of the Erie basin into a larger lake that drained first westward and then eastward. Lakes in the Ontario basin also started later, beginning with Lake Iroquois, which drained eastward down the Mohawk valley, at times also by catastrophic floods, and then Lake Belleville, which drained northeastward through the St. Lawrence valley, followed by a low-level Early Lake Ontario. In the Michigan basin, there was one main ice-dammed lake, called Lake Chicago, which occurred at different levels as its outlet to the west became lowered by erosion and inflow from the Erie and Huron basins varied. The Lake Superior basin, the northernmost of the Great Lakes basins, remained ice-covered the longest, then ultimately contained several different lakes located in both the western (Lake Duluth) and eastern (Lake Minong) ends of the basin.

Once the glacial margin had retreated north of the tip of Michigan's lower peninsula, waters from the Michigan and Huron (and briefly the Superior) basins merged into one single broad, extensive lake, Lake Algonquin, with an outlet eastward across central Ontario, which had not yet rebounded from the weight of the glacier. Drainage from this large lake therefore completely bypassed the Erie basin. Continued ice recession opened up a still lower (isostatically) outlet across northern Ontario and Quebec, creating Lake Nipissing. With full recession of the glacier from the Great Lakes area, the isostatically low land in Ontario rose, tilting the old shoreline beaches around almost all the Great Lakes basins upward to the north. This isostatic uplift of land in Canada also raised the Ontario and Quebec outlets so high that both became abandoned, shifting the drainage from the upper lakes back southward through the Erie and Ontario basins and creating the modern Great Lakes.

Thus the Great Lakes are seen to be recent additions to the landscape of middle America, but with their origins going far back to the Pre-Cambrian and Paleozoic, when the rocks making up their landscape were formed, and to the subsequent erosion, by rivers and by glaciers, that molded that landscape. Without this long and complicated geologic history, we would not have our economically important, recreationally enjoyable and aesthetically satisfying Great Lakes of today.

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3/ Vegetation and Plant Geography of Lake Erie

by John J. Furlow

The traveler is impressed by the dramatic contrasts of the landscape around Lake Erie. Stretching along great lengths of its shores are some of the largest urban areas of the upper Midwest. And yet, within a few miles of these teeming population and industrial centers are lands so wild that America's rarest living things continue to thrive there. The Lake Erie region abounds with wild plant and animal life in an extraordinarily diverse natural setting. Such a wide variety of communities exists here because this region is a great meeting place for several distinct physiographic, climatic, vegetational and floristic elements. To the southeast rise the Appalachian Highlands; to the west stretch the vast plains of the continental interior. Not far north is the boreal forest, and just to the east, via Lake Ontario and the St. Lawrence River, is the Atlantic Coastal Plain. Each of these places has its own unique plant forms, and here the edges of the ranges of these plants come together in the varied habitats provided.

The flora and vegetation of the Lake Erie basin

Lake Erie lies within the deciduous forest biome of eastern North America. The most obvious component of this vegetation consists of broadleafed trees and shrubs. Some conifers are also present, but the great majority are flowering plants. With few exceptions, the woody plants lose their leaves during the cold winter season. The leaves become brightly-colored just before falling, painting the forest in a patchwork of reds, yellows, oranges and brown, a phenomenon which does not occur in most other deciduous forests of the world.

Around Lake Erie, including the islands, shores, and surrounding forests, about thirty-five percent of the plant species are trees and shrubs, sixty percent are perennial herbs, and five percent are annuals that complete their life cycles in one season. The flora of the shoreline and islands alone consists of over 1,000 species, and there are many more than this when adjacent areas are included. However, because of widely varying climatic, substrate, and topographic features, the plant life is far from uniformly distributed. Maps showing the general distribution of the vegetation types in the Great Lakes region have been prepared for the United States and for Canada, and a detailed map, based on the "bearing" or "witness" trees of the original land surveys, plus information taken from published accounts, old photographs, and other sources, has been drawn up for Ohio. At least six major vegetation types may be identified on the lands surrounding the lake, and several additional types occur sporadically throughout the region.

Within these "formations" are found plants related to the floras of the boreal region to the north, the prairies to the west, the Appalachian Mountains and the Atlantic Coastal Plain to the east, and the Gulf Coastal Plain to the south. Although it has often been suggested that the members of each of these floras entered the region as a unit following the Pleistocene glaciations, this view probably represents an oversimplification in many cases.

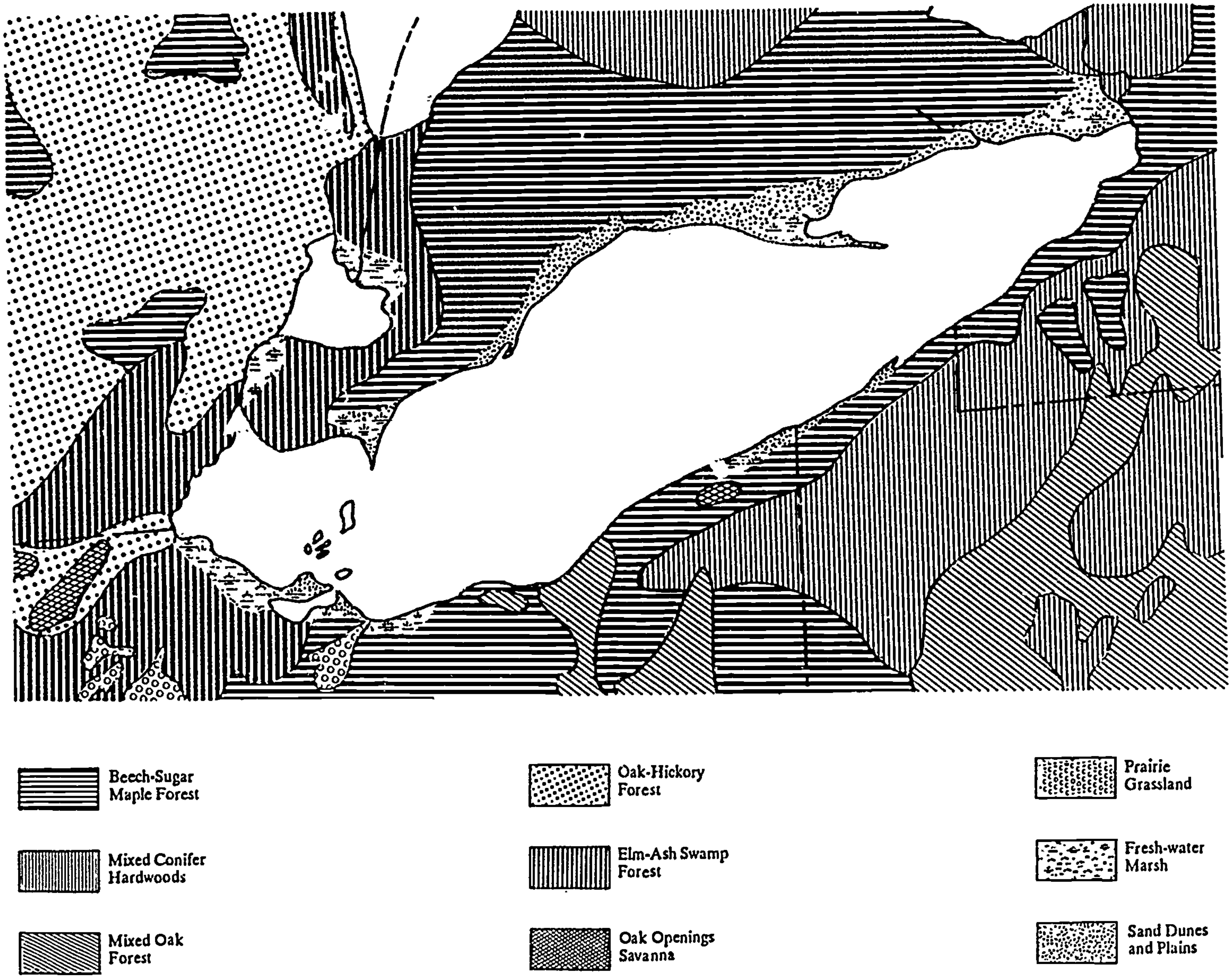

Figure 3.1. **Map of original natural vegetation patterns around Lake Erie.** *(John J. Furlow)*

The paleoecology of Lake Erie plant communities

The region today occupied by Lake Erie has been vegetated by deciduous forest at least since the Eocene Epoch (60 million years ago), but it has undergone considerable climatic alteration since then, both in terms of temperature and moisture. The vegetation has continually changed in response to the constantly varying climate. The most drastic of these changes in recent geological time were the Pleistocene glacial advances, beginning about one million years ago. Since then, there have been four major ice advances lasting from 3,000 to 10,000 years each and separated by interglacial periods which lasted between 25,000 and 200,000 years. It is possible that we are now in one of these interglacial periods.

During each of the Pleistocene glacial periods, the Lake Erie basin was completely covered by a thick cap of ice. Thus all of the plant and animal life of the region, as well as the physical lake itself, is of relatively recent origin. It has been shown by analysis of fossil pollen samples taken from cores drilled into the bottoms of old lake beds that revegetation following the most recent glaciation passed through a series of stages. The first vegetation to appear resembled arctic tundra in species composition, then this was replaced by a type dominated by spruce, and finally by deciduous forest vegetation of the general kind seen today. (For general reviews of this work, see Watts, 1979, 1980; Whitehead, 1973; and Wright, 1970).

The revegetation process appears to have occurred very rapidly, indicating that at least some of the species involved survived the most recent (Wisconsin) glacial advances not far south of the ice. By 11,000 years ago, deciduous trees, including ashes, oaks and hickories began to move back into the lower Great Lakes area from areas to the south. Certain tree species, including chestnut and American beech, migrated north following the Wisconsin glacial period from sites along the southern Atlantic Coastal Plain, while others, including hickories, re-entered the area from a southwesterly direction. A similar pattern apparently occurred for the aquatic vascular plants of the Great Lakes, certain species migrating northward along the Atlantic Coastal Plain and then westward through the St. Lawrence valley, and others migrating northward along river systems in the Mississippi Embayment region. The conclusion of a number of authors on the subject is that the pre-Pleistocene vegetation of northeastern North America, including the Great Lakes, did not survive intact throughout the glacial period. The present vegetation and flora instead represent a mixture of species, assembled following the glacial retreat, which was capable of surviving in the local conditions.

Shoreline vegetation

Sand beaches and dunes occur along extensive parts of the Lake Erie shoreline, depending on lake currents and wind patterns. In general, the northern shore is much sandier than the southern, with extensive sand plains occurring near the mouths of old rivers. However, beaches and dunes, sometimes of considerable magnitude, also occur at Cedar Point, Ashtabula, Presque Isle and other isolated sites along the southern shore. The dunes and their communities are similar to those of the southern and eastern shores of Lake Michigan, although they are much more limited in size. The most extensive dunes of Lake Erie have developed along the north shore of the eastern section of the lake in response to currents and prevailing southwesterly winds. These are found near Long Point and Point Albino on the Ontario shore.

Figure 3.2. Sand dune plant community. *(John J. Furlow)*

The vegetation of the sandy areas is very distinctive, and it contains many interesting and unusual plants. These plants are adapted by means of water-retaining tissues, waxy coatings or layers of hairs over the leaves, and extensive root systems to survive in very dry soil and where the ground is not very stable. Some examples include sand cherry, spreading juniper and prickly pear cactus. Many of the dune plants, such as white pine, are characteristic of northern regions. Others, including marram grass, an important sand-stabilizing plant, and bayberry are Atlantic Coastal species, which are thought to have migrated westward along the Saint Lawrence river system. Still others, including blazing star, false indigo and many grasses are prairie "outliers." Also present are species found only in the Great Lakes region, including lake iris and Pitcher's thistle.

Along the southwestern quarter of the shore of the lake, especially near the mouths of the Ottawa, Maumee and Portage Rivers, lie extensive freshwater wetlands, including vast cattail and reed marshes, dense shrub thickets, shady swamp forest remnants and wide expanses of open water. The vegetation here is of many types. Some common plants in the open marshes, besides cattails and reeds, include bluejoint grass, cord grass, curly pondweed, pickerel weed, arrowhead, swamp mallow, white water lily and American (yellow) lotus. Formerly present were such currently rare forms as wild rice, the flexed naiad, and water marigold, species which require clear, well-oxygenated water.

Figure 3.3. A wetland plant community. ***(photo by Siobhan Fennessy)***

The adjacent forests

The land surrounding Lake Erie itself was completely tree-covered in pre-settlement times, although little of this forest remains today, especially on level areas. The flat glacial till plains to the north and southeast were covered with a moist forest dominated primarily by American beech and sugar maple. East of Cedar Point, this beech-maple forest continued along a narrow strip of low-lying land which follows the southern margins of both Lake Erie and Lake Ontario. To the south of this strip rises the hilly (and still mostly forested) country of the Allegheny Plateau. Here the vegetation consists mainly of a mixed conifer-hardwoods (sometimes called hemlock-white pine-northern hardwoods) forest, the characteristic vegetation of the northern Appalachians and adjacent northeastern Canada. In northeastern Ohio, at the western edge of the Allegheny Plateau, the mixed conifer-hardwoods vegetation meets and intermingles with the mixed oak forest of the central and southern Appalachians, forming a mosaic of vegetation types, the mixed oak association often occurring near the tops of ridges and the mixed conifer-hardwoods type being more restricted to the cooler, moister ravines and gorges.

The beech-sugar maple forests, which today occur as isolated patches on the rich, moist soils of the glaciated till plains, have dense canopies and produce deep shade in the summer, allowing very little ground cover to develop. However, in the spring before the canopy closes, a profusion of herbaceous wildflowers covers the forest floor. Familiar examples include spring beauty, mayapple and wild ginger. The woody species present, in addition to beech and sugar maple trees, include tulip tree, white oak, black cherry and white ash.

The mixed conifer-hardwoods forest is similar to the beech-maple in its dominant tree species composition, but it also includes hemlock and/or white pine, plus yellow birch. This vegetation is mostly restricted to regions of cool climate. South of Lake Erie near its southern limit, it mostly occurs in the moist regions of the Allegheny Plateau. A large number of herbs of northern affinity are present, including wild calla, northern monkshood, wintergreen and bunchberry.

Figure 3.4. **A beech-maple forest community.** ***(John J. Furlow)***

The mixed-oak forest, the characteristic vegetation of the southern Appalachians, also occurs in the Allegheny Plateau, but in much drier and less fertile habitats than the mixed conifer hardwood forest. It is characterized by a more open canopy, which permits the existence of many summer-blooming understory plants, including partridgeberry and foamflower. Here the dominant trees are various species of oaks, with hickories and, formerly, American chestnut being frequent associates.

Along the floodplains of the larger streams occurs a somewhat different forest type, made up primarily of ashes, elms, silver maple, willows, box elder and sycamore. Here the environment differs dramatically from that of upland sites in relief, climate, soil characteristics and periodic flooding. The plants which grow here must tolerate the extreme shifts in soil moisture which occur seasonally. The understory is frequently "brushy" and includes plants such as spicebush, honeysuckle, wild grapes and poison ivy. Common understory herbs include the familiar touch-me-not and stinging nettle.

The major islands of the 22-island Lake Erie Archipelago have mostly rocky or cliffbound shores and thin soils. These islands have a generally warmer and drier climate than that of the adjacent mainland. The vegetation of the upland areas of the islands consists of a forest similar to the mixed conifer-hardwoods type, but it is distinctive in that it lacks beech and conifers and contains very few oaks, probably mostly due to the lack of suitable soils. The dominant species consist of sugar maple and hackberry with other common trees, including American basswood, red elm, green ash and black cherry.

The vegetation north of Lake Erie, in Ontario's Niagara Peninsula, is primarily of the beech-sugar maple type. Here both the dominant tree species and the flora in general have a decidedly southern character in comparison to the forests southeast of the lake. The trees include not only beech and sugar maple, but also tulip tree, cucumber tree, pawpaw, black gum, sassafras, Kentucky coffeetree and other species characteristic of the Appalachian and interior forests far to the south. The herbaceous flora, as well as the trees of this region, contains an extensive "Carolinian" element, and one finds such plants as wild senna, trumpet creeper, wild indigo, and twinleaf. Today most of these plants are rare in Ontario, although most are fairly common in the central eastern United States.

Other communities

The area west and south of the western end of the lake, east to about Cedar Point, is of very flat topography marked by occasional scattered sand ridges and weathered dunes, remnants of the shorelines of several older lakes which preceded Lake Erie during interglacial periods prior to the Wisconsin ice advance. The vegetation of this region is diverse in nature and origin, and it includes the largest array of rare plants in Ohio. The original forests were primarily swamp forests dominated by American elm, white and black ash and red maple, although on higher and sandier sites, they were of a mixed oak forest, and where more fertile soils existed, a forest dominated by oak and sugar maple.

Before 1900, this region, which stretched over 100 miles from the present western end of the lake across northern Ohio and southeastern Michigan to Fort Wayne, Indiana, and covered about 1,500 square miles, was an impenetrable tangle known as the Great Black Swamp. For nearly one hundred years, the swamp presented a great obstacle to transportation and development in northwestern Ohio, but during the late 1800s, it was gradually drained and cleared. Today only small portions of the original vegetation remain, the area being one of the most fertile farming areas in Ohio and southeastern Michigan. A remnant of the original forest may be seen at

Goll Woods State Nature Preserve in Fulton County, Ohio.

Of special interest in this region, in Lucas and Fulton Counties of Ohio, are large tracts of oak savanna known as "Oak Openings." Here low, eroded sand dunes, formed on the southern shore of the glacial lakes which preceded Lake Erie, stand out from the surrounding flat countryside. These sand hills are covered with scattered oak trees. Open areas are vegetated with such plants as bracken fern and lowbush blueberry, plus numerous prairie species, including big bluestem grass, blazing star and yellow fringed orchid. The swales and hollows lying between the ridges contain swamp forest remnants of pin oak, red maple, black gum and ash.

South of the western end of the lake, and south of Cedar Point, are extensive areas formerly vegetated by tallgrass prairie. These tracts represent vestiges of a large eastern lobe of the prairies of the northern mid-Continent which extended eastward across Indiana and Ohio following the Wisconsin ice retreat. This "Prairie Peninsula" extends into western New York state, but the frequency of occurrences of prairie species diminishes rapidly east of central Ohio. Controversy has long surrounded the origin of the prairie peninsula, but the predominant view has been that the element entered the Great Lakes region during a dry *(Xerothermic)* period which occurred between 3,000 and 5,000 years ago. Others have maintained that the prairie species present are in reality as much eastern as western in nature, and that these have existed in the forest region since it was revegetated just after the Wisconsin glacial retreat.

Over 300 separate patches of prairie may have existed in northern Ohio before it was settled. Today this prairie vegetation occurs mostly along roadsides, on railroad embankments, in old cemeteries, and in a few preserves. The remnants include big and little bluestem grasses, prairie dock, purple coneflower, royal catchfly, blazing star and many other species.

Finally, scattered throughout the flat till plains surrounding the lake are numerous isolated bogs and fens, these populated largely by species of northern affinity. The acid bogs, usually formed in Pleistocene "kettlehole" lakes, contain mats of sphagnum moss, often floating on the surface of open water. The dominant trees of these bogs include tamarack and, to the north, black spruce and balsam fir. The shrubs include blueberries, cranberries and leatherleaf. Some common herbs in these habitats are northern pitcher plant, roundleaf sundew, moccasin flower, cotton sedge and buckbean. The fens, in contrast to the bogs, are found around springs of flowing water, which is alkaline. There are frequently extensive deposits of marl (crumbly soil rich in calcium carbonate) around these springs, and one finds such calcium dependent plants as shrubby cinquefoil, spreading globe flower and royal lady slipper.

Lake Erie's wildlife

Wild animals are always closely associated with the vegetation of a region, which provides them with the necessities of food, shelter, and breeding grounds. The freshwater marshes and estuaries of Lake Erie provide important spawning and nursery grounds for many species of fish, including yellow perch, smallmouth and white bass, channel catfish and smelt. These marshes were also formerly inhabited by species such as lake sturgeon, cisco, whitefish, blue pike and walleye, though these largely disappeared long ago. Nevertheless, the Lake Erie commercial fishery remains ahead of that of all the other Great Lakes combined in terms of its fish harvest, largely as a result of the higher nutrient level and warmer temperatures of its waters.

Perhaps the most spectacular animal resource of the Lake Erie region is its bird population. On the islands are important rookeries for great egrets, great blue and green herons, several species of gulls, common terns and cormorants. But the marshes contain the widest variety of birds. Here are found the nesting sites of many unusual types, including the northern bald eagle. Also found are bitterns, coots, rails, terns, Canada geese and many species of ducks, including mallards, black ducks, redheads, canvasbacks and mergansers. Over 300 species of birds have been identified in the western Lake Erie marshes, which lie within branches of both the Mississippi and Atlantic flyways. In the forested and agricultural region around the lake are seen the common birds of northeastern North America.

The mammals of the area are also the ones familiar throughout the deciduous forest region and include the whitetail deer, cottontail rabbit, woodchuck, racoon, opossum, skunk, fox squirrel, and various mice, voles and shrews. In the marshes of western Lake Erie, the muskrat is a common and economically important resident, providing fur trappers with an income of over $1.5 million per year. Only a few mammals live on the islands because of the limited habitats there. Carnivores, other than the red and gray foxes, are largely absent today, except in the adjacent mountainous regions of western New York and northwestern Pennsylvania, where black bears remain. These have recently been noted to be moving into northeastern Ohio from Pennsylvania. In other areas around the lake, animals such as bears, wildcats and wolves were eliminated long ago.

The human impact

The present plant life of the lower Great Lakes region does not closely resemble that of presettlement times. Nearly three hundred years of clearing, draining and leveling, as well as extensive residential, commercial and industrial development, have created a landscape radically different from that which the original settlers saw. Today, natural plant communities exist on a small percentage of the land, mostly in areas of secondary value for agricultural or industrial purposes. The maximum clearing of the land occurred before 1900. Since then, in response to technological advances and changing demographic patterns, much of the formerly cleared land has been abandoned for agricultural purposes and allowed to return to a forested condition. However, the demand for space has increased greatly since 1950. If current urbanization trends continue at their present rate, there will be almost no wild land left in another hundred years.

Most of the remaining vegetated areas consist of farm woodlots, forested ravines or streambanks, regions of relatively severe relief, and park land. On the flat, fertile plains bordering the northern and southwestern shores of the lake, virtually nothing of the original forest remains, all of it having been converted to farmland. In densely populated urban areas, such as Cleveland, Detroit and Buffalo, suburban growth is rapidly depleting thousands of additional acres.

The natural vegetation has not only been greatly diminished in size in the Lake Erie region; it has also significantly changed in composition. A growing number of plant species have been eliminated altogether, and hundreds of alien species have been introduced and become naturalized. Virtually all of the important weeds of the Great Lakes region, including giant ragweed, Canada thistle, bull thistle, burdock, jimson weed, pigweed, velvet leaf, foxtail grass, wild carrot, chicory, buckhorn plantain, lamb's quarters, corn cockle and dandelion fit into this category. It has been estimated that one fourth of the flora around Buffalo, New York, is introduced, while about one third of the wild plants growing in Ohio are naturalized aliens. Many of these species are of serious economic significance to agriculture, and a number (such as purple loosestrife) have been shown to have a very negative effect on the natural vegetation, outcompeting and eliminating the natural species in some cases.

The invading aliens are not restricted to herbaceous weeds. Many trees and shrubs of European origin have also become quite widely distributed in the wild areas of northeastern North America. These include white willow, Chinese elm, black alder, tree of heaven and buckthorn. These species have sometimes become parts of the permanent forest vegetation itself, changing its composition and overall ecology. And at the same time, the forests have changed in response to other factors. For example, the mixed conifer-hardwoods forest of western New York State, northwestern Pennsylvania and northwestern Ohio today varies in composition from that known to have existed in presettlement times. This may be a result of changing climates, atmospheric pollution, the nearly complete removal of the forests in the 1800s, or other factors.

A series of studies by Stuckey has demonstrated a way some weedy aquatic plants have migrated into the Lake Erie basin. In these studies, the earliest known occurrence in a particular county of a plant species has been mapped, based on existing specimens in major herbarium collections. The resulting maps show that within the past 200 years, these species have migrated from the Atlantic Coast westward through the Great Lakes along human transportation routes, especially railways and canals.

However, at the same time the vegetation is becoming increasingly scarce and changing dramatically in character, there has developed an intense and widespread effort to identify, monitor, and preserve the best of the remaining wild areas, as well as to increase the general awareness of and appreciation for wild plants in general. All of the states and provinces surrounding Lake Erie have recently undertaken surveys of their rare and endangered plant species. All of the states and provinces are also currently involved in producing up-to-date comprehensive floras of their regions, and many have developed permanent Natural Heritage Programs or otherwise increased their efforts to enlarge and improve their systems of natural parks and nature preserves, both to save unique geological and scenic features and to preserve essential habitats needed by rare plant and animal species to survive.

Whether the extraordinary diversity of wild plants and animals seen today around Lake Erie will continue to exist in the future, only time will tell. The present efforts to conserve these striking and important features of our environment represent a good beginning. Hopefully, today's conservation programs will be continued and expanded in the years ahead, and new ones will be instituted where they are needed. Without such a concerted effort, future generations will be denied a remarkable and important part of their heritage.

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4/ The Effect of Lake Erie on Climate

by Val L. Eichenlaub

Introduction

The Great Lakes modify the climates of their surrounding shores and cause some twists of weather that occur in few other places. About 40 million people live in the Great Lakes basin and experience, in varying degrees, an array of weather quirks known collectively as "lake effects." Lake effects occur around all of the Great Lakes, but each of the lakes affects climate and weather somewhat differently.

Lake Erie is no exception. It shares most of the lake effects common to the other lakes but also creates its own individual imprint on climate. This is because Lake Erie differs from the other lakes in size, shape, depth, alignment, latitude and in the topography of its bordering land area.

Obviously, not all of the climatic features of the areas around Lake Erie and the other Great Lakes are directly caused by the Lakes themselves. Many are due to broad-scale locational and atmospheric controls and would occur whether or not the Lakes were present. An example is the fact that the Lakes are situated in the belt of the westerly winds and are located inland, many miles from the nearest ocean. These provide major controls on climate. The Lakes modify these controls in various ways and that is what creates the lake effects.

This chapter overviews the locational and atmospheric controls which establish the broad framework of Great Lakes' climate. It then reviews the processes by which the Great Lakes modify these controls and, consequently, change the weather and climate of their surrounding shores. Within this context then the specific lake effects themselves are explained.

General climatic controls of the Great Lakes Basin

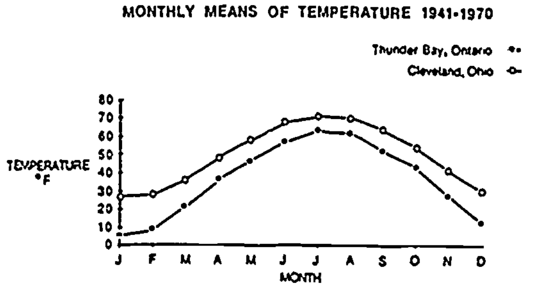
Locational controls

The Great Lakes are located halfway between the equator and the North Pole. This is the most important locational control of climate. The Lakes' middle latitude location insures large seasonal differences in the amount of energy received from the sun. These differences in energy account for the great seasonal temperature variations that occur in the region (Figure 4.1).

The Lakes' location near the center of the North American continent complements the latitudinal control described above by minimizing the tempering effects of the oceans. Thus the fact that large land areas rather than oceans are the primary influence on the area's climate (an effect called continentality) is also a key to the nature of the climate of the Great Lakes Basin. This means that the basin as a whole responds quickly to increasing amounts of solar energy in the spring and warms up rather rapidly. This occurs because land areas heat up quickly as compared to water areas. In the fall, when the daily amount of solar energy received is decreasing, the cooling in temperature is also rapid. Marked seasonal temperature differences because of the area's middle latitude location are thus amplified by its continentality, and the region experiences warm summers and cold winters. Actually, because of continentality, for much of the year the Great Lakes region is colder than other areas located at its same latitude. Only in the summer months are parts of the region warmer than other areas at its latitude.

There are, of course, differences in latitude and continentality within the Great Lakes Basin itself. The latitudinal spread of the Lakes, nearly 7 1/2 degrees, is substantial and insures that contrasts in solar energy reception will be sufficient to cause significant temperature differences. In the winter there is a rapid decrease in mean temperature from south to north. Thus, winters are considerably colder in the northern portions of the basin than the southern portions (Figure 4.1). In the summer, northern areas are cooler than southern areas, but the temperature differences are not as extreme.

Continentality also varies because of the great east to west extent of the Lakes. A general pattern of increasing continentality occurs toward the west, nearer the heart of North America. This pattern, however, is modified along the immediate shores of the Lakes because of the effect of the large bodies of water, which produce a semi-marine climate. The lake effects are the result of this modification of continentality.



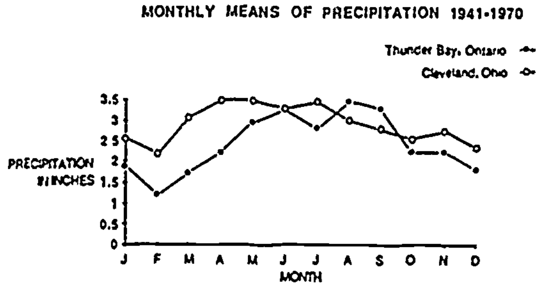


Figure 4.1. Temperature and precipitation differences within the Great Lakes Basin. *(Data sources: Ontario Atmospheric Environment Service and NOAA Environmental Data and Information Service)*

Location also determines the major source of moisture for the area, which is the Gulf of Mexico. The eastern portion of the Great Lakes is more easily accessible to moisture bearing winds from the Gulf. Consequently, precipitation totals are larger and more evenly distributed there than in the west.

Atmospheric controls

The locational factors described above interact with certain atmospheric controls which prevail over the area. The major atmospheric control is the westerlies which blow across the Great Lakes. These winds prevail at the surface, although there can be considerable variation from day to day. Aloft, the westerlies are much more persistent, and it is unusual for the winds at the higher levels to blow other than from southwest to northeast.

With westerly winds at the surface and aloft, most weather systems move west to east through the Great Lakes. Thus the weather of today in Milwaukee may be tomorrow's weather in Buffalo. In addition, with westerly winds, the modifications imposed by the lakes are likely to be more strongly felt on the eastern shores of the lakes and the temperature differences caused by the lakes are more prominent at their eastern ends.

The middle latitude location of the Lakes also means that the polar jet stream is a weather factor during much of the year. This is a high altitude current of air flowing generally from west to east, with velocities which may reach 150 knots during the winter. The mean location of the polar jet stream in summer is north of the Lakes, in Canada. At that time of year the velocities are generally weak. In winter, the polar jet intensifies and shifts equatorward. Its mean position by late winter is south of the Lakes, and velocities are normally much higher.

Although these winds occur five or six miles above the surface, they may have an indirect but very important effect on the surface weather. As the polar jet separates warm tropical air from cold polar air, its position in relation to the Great Lakes may determine the occurrence of the warm and cold "spells." With the polar jet north of the Great Lakes warm air is drawn northward and a spell of warm weather may occur. When the jet alignment changes, and the core of the jet moves south of the Great Lakes, cold air from Canada spills across the border and the region may experience a cold spell.

The jet stream also controls the formation, movement and dissipation of the large low pressure areas (extratropical cyclones) which are so common in this region during the winter. These weather systems are instrumental in causing day-to-day variations in weather. Normally clouds and precipitation are associated with them while clear weather is associated with their counterparts, the anticyclones or high pressure systems.

Note that the mean tracks of cyclones moving through the United States and southern Canada seem to coalesce over the Great Lakes Basin (Figure 4.2). This insures much vigorous weather activity within the area with abundant clouds and precipitation. As cyclones are frequently accompanied by sharply defined fronts along which quick changes of temperature occur, unstable weather with sudden changes of temperature are not uncommon, particularly in winter when cyclonic activity is more frequent.

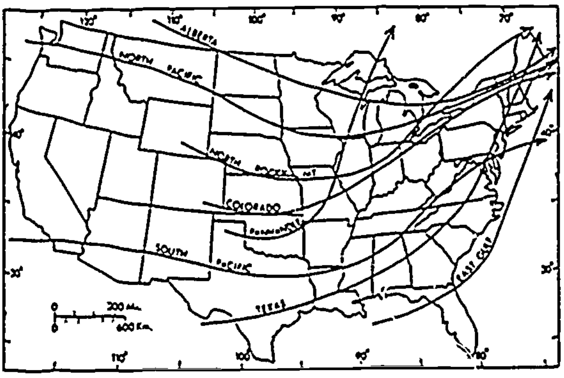


Figure 4.2. Main tracks of cyclones in the United States *(Redrawn from Glenn T. Trewartha, An introduction to climate, Fig. 6.23, p. 219. New York: McGraw-Hill, 1968.)*

Locational factors also determine the types of air masses which the Great Lakes region experiences. These are larger homogeneous portions of the atmosphere which form over certain parts of the earth's surface called *source regions* by meteorologists. The air masses are guided into the Great Lakes by the location and movement of the jet stream aloft. They can dominate the weather for days and weeks at a time. Figure 4.3 shows the three air mass types which affect the Great Lakes, along with their source regions.

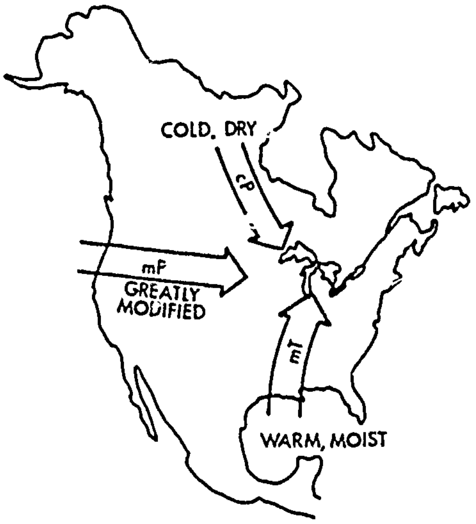


Figure 4.3. Air masses affecting the Great Lakes: cP = continental polar; mT = maritime tropical air; mP = maritime polar. *(From Val L. Eichenlaub, Weather and climate of the Great Lakes. University of Notre Dame Press, 1979)*

The source region for continental polar air masses (cP) lies north of the Great Lakes over the vast northern expanse of Canada. In winter, this source region is very cold and snow covered, and the air mass which forms within may be very cold and dry. It may then be referred to as "arctic" air. It will move southward very rapidly forming the famous Siberian Express. It may cause cold, clear weather over the Great Lakes when it arrives in the form of a polar anticyclone, but also may be sharply modified by the Lakes. In summer, the air mass brings delightfully cool, clear weather with low humidities, and is less modified by passage over the Lakes.

Far to the south of the Great Lakes, over the Gulf of Mexico, is the source region of maritime tropical air (mT). This air mass, forming over a warm water surface, is warm and humid. It seldom moves into the Great Lakes region in winter but it may cause winter thaws on the rare occasions that it does. In summer, the mT air mass is much more common. It causes the hot and sticky weather which is inevitable in the southern part of the basin, but occurs less frequently in the northern part.

Air masses of Pacific origin dominate the weather in the winter, when they occur over 75% of the time. These air masses are called maritime polar (mP) and are usually highly modified by the time they reach the Great Lakes. In the winter they are warmer and more humid than the cP or arctic air masses and in summer are cooler and drier than the mT air mass. They occur less frequently in the summer, but when they do they give welcome relief from the heat and humidity of the maritime tropical air.

Modifications by the Great Lakes

Essentially all of the climatic modifications imposed by the Great Lakes arise from three fundamental differences between the surfaces formed by the atmosphere and the Lakes and those formed by the atmosphere and the land surrounding the Lakes: 1) the "lag" of the changes in water temperature of the Lakes behind that of the surrounding land as the seasonal change of temperature occurs; 2) the greater amount of water available to be evaporated into the air from the Lakes as compared to the land, and 3) the smoother surfaces of the Lakes compared to those of the surrounding land.

The thermal lag of the Lakes

The Great Lakes, including Lake Erie, warm more slowly than the surrounding land in the spring and cool more slowly in the fall. This "lag" in temperature change means that average water temperatures may be significantly different than those of the nearby land area at certain times of the year. With individual weather situations these thermal contrasts can be very large.

In the spring, when land surfaces begin to warm rather rapidly, the lake temperatures warm much more slowly. There are a number of reasons for this. First, the solar energy received on a water surface can penetrate to a considerable depth. Consequently, warming is not confined to the surface, as is the case with the land, which is opaque to incoming solar energy. In addition some of the energy received from the sun is used to evaporate the water and thus it is stored in the atmosphere as latent heat.

More importantly, the *heat capacity* and *thermal conductivity* of water differ from those of land surface materials. The heat capacity is a measure of the amount of energy a substance can absorb. It is expressed as the number of calories of energy needed to increase the temperature of one cubic centimeter of the substance by one degree Celsius. The heat capacity of water is greater than that of land and consequently, with equal amounts of energy absorbed, land heats more rapidly than water. The thermal conductivity of a substance is its ability to transmit energy. It is very small for land surface materials, where the downward transfer of energy occurs only by conduction, but very large for stirred water, where downward transfer can occur by mixing. Consequently, water bodies heat more slowly than land surfaces because of water's high heat capacity and high rate of thermal conductivity.

In addition, density differences within the lakes due to temperature stratification play a role in slowing the spring warm-up of water bodies. Water is most dense at 4° Celsius (39.2°F). In winter, the Great Lakes cool below this temperature in their upper portions. Thus, as spring warming occurs in the upper layers, the density of the water increases and the colder, less dense waters from below rise to replace the warmed surface waters. The entire column of water must be warmed to the temperature at which maximum density occurs (39.2°F) before further warming can continue.

In the fall, as the lakes cool, the surface water becomes more dense, sinks and is replaced by warmer, less dense water from below. This retards the cooling of surface waters and the temperatures of the Lakes lag behind (are warmer than) those of the land. The immense storage of heat by lakes compared to land keeps the water warmer than the land for many months during the autumn and winter.

The lag of temperatures of water compared to the land is accentuated if the lake is large and deep. Thus the mean water temperature of Lake Superior, with a surface area of 31,700 square miles, an average depth of 489 feet, and a volume of 2,935 cubic miles, exhibits a marked thermal lag compared to surrounding shore areas (Figure

4.4). Lake Erie, on the other hand, has a surface area of only 9,910 square miles, an average depth of 62 feet, and a volume of 116 sqare miles. Thus the surface temperatures of Lake Erie respond more quickly to seasonal energy fluctuations, and the lag behind the change of surrounding land temperature is smaller. Nevertheless, substantial differences between mean water and land temperatures can occur at times, particularly in the spring and fall.

The shallowness of Lake Erie compared to the other Great Lakes lessens the thermal lag because of another rather surprising fact. In spite of its southerly location, large portions, if not all, of Lake Erie are likely to be covered with ice during normal winters (Figure 4.5). Other Great Lakes, larger and/or deeper (as is the case of Lake Ontario) remain ice free over large portions of their surfaces, at least during normal winters. Once an ice cover forms, a lake behaves much like a land surface.

Moisture exchange from the Great Lakes

When the temperatures of the open water surfaces of the Great Lakes are very different than those of the land surfaces of surrounding areas, evaporation from the lakes may be large relative to that occurring from the land. The Great Lakes have large fall and winter evaporation rates and may become important sources of moisture during those months. In the spring, when the lakes are cooler than the land, evaporation rates are low. In fact condensation will often occur over the Lakes instead of evaporation. Over Lake Erie, evaporation rates reach a peak in October and November, when the Lake is warm relative to the air.

Alterations of wind fields by the Lakes

The surfaces of the Lakes are smoother than the surrounding land areas. The amount of turbulence in the lower layers of the atmosphere, which is caused by air moving over rough surfaces, is lessened when the air passes from over the land to over the water surface of a lake. This turbulence, when present, slows down the wind. Consequently, wind velocities over the Lakes are higher. In addition, winds may change direction as they blow from the Lakes to the land or vice versa. This is because wind direction is in part controlled by the Coriolis Effect, a deflection of the path of the wind to the right in the Northern Hemisphere because of the rotation of the earth. The amount of deflection will be greater the higher the velocity of the wind. This change in amount of deflection may be experienced as a change in wind direction. As the wind moves from the rougher land surface to the smooth surface of the lake, its velocity will increase. The wind will spread out or diverge and sink. As a result there will be little cloud formation or precipitation. This helps to account for the relatively dry climate of the Lake Erie islands for example, all of which are found in the western end of the Lake. When the wind is blowing from the lake to the land, the wind becomes more concentrated (converges) and rises as its speed decreases on encountering the rougher land surface. This increases the likelihood of cloud development and precipitation, and helps to account for the higher levels of precipitation at Buffalo.

The climate of Lake Erie

Thermal modifications—seasonal temperatures

When water temperatures differ markedly from land temperatures, the Great Lakes have a great impact on temperatures of the surrounding land (thermal modifications). The area of land affected is largest in the winter, less in the summer, and may be least at the time of the equinoxes, when there is little difference between lake and air temperatures. The mean daily range of temperatures over the lakes and on surrounding shores is reduced throughout the year, while mean daily temperatures are increased during the cool season and decreased during the warm season. In summer, the thermal effects have the most influence on the daily maximum temperatures, while in the winter the effect is strongest on the daily minimum temperatures. Fall modifications include increases of minimum temperatures, while in spring, large decreases of maximum temperature due to the influence of the lakes occur with little effect on minimum temperatures.

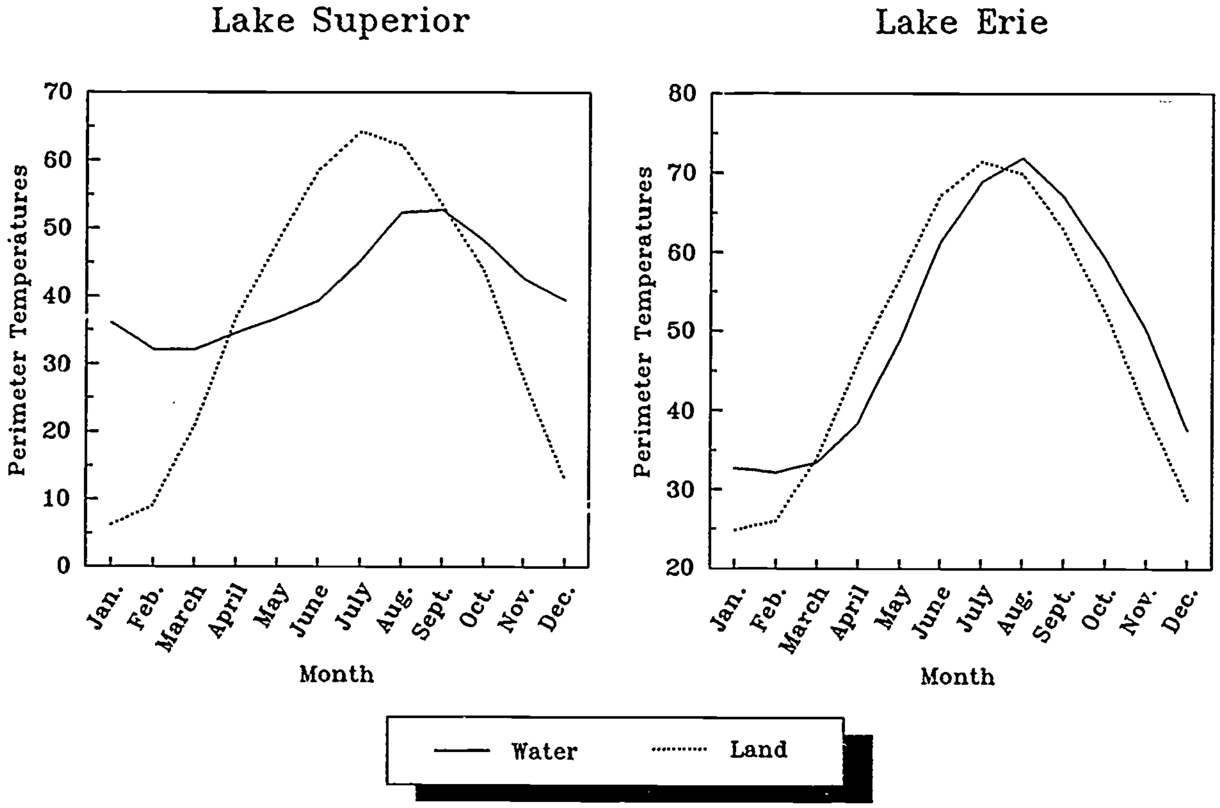


Figure 4.4. Mean water and land perimeter temperatures: Comparison of Lakes Erie and Superior. *(from NOAA Technical Report ERL 342-GLERL3, 1985, and Journal of Great Lakes Research. 4(3-4):291, December 1978)*

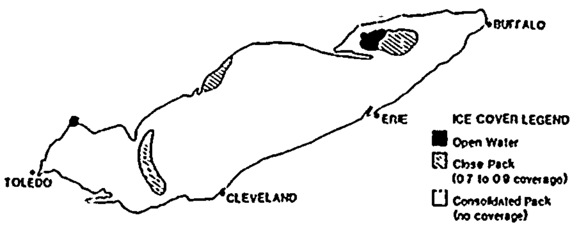


Figure 4.5. Normal winter maximum ice cover, Feb. 20-28. *(Redrawn from Donald R. Rondy, Great Lakes Ice Atlas. NOAA Technical Memorandum LSCR 1, Sept., 1971, Plate 26.)*

The thermal modifications exhibited by Lake Erie are less marked than those of the other Great Lakes because of the shallowness of Lake Erie and its relatively small size and volume. Nevertheless, at times they are well-defined. Figure 4.6 shows the mean daily temperature range over the Lake Erie basin for the winter, spring, summer and fall months of January, April, July and October. During all months the daily temperature range is reduced more on the southern and eastern shores than on the northern and western shores. In January, the role of Lake Erie in suppressing the daily temperature range is small compared to that of the other Lakes because of the build-up of ice cover on Lake Erie.

The effect of the lake is more noticeable in April and October, and greatest in July. During these months, Lake Erie's effect on daily temperature range is comparable to that of the other Great Lakes. The effect on mean daily temperature (Figure 4.7) is small in January and nearly absent in July. During these peak winter and summer months, Lake Erie's effect is less than that of the other Great Lakes. This is due to the ice build-up in January, and the more rapid spring warm-up of Lake Erie's surface waters due to its shallowness. Its effect on mean daily temperature, however, is substantial from April

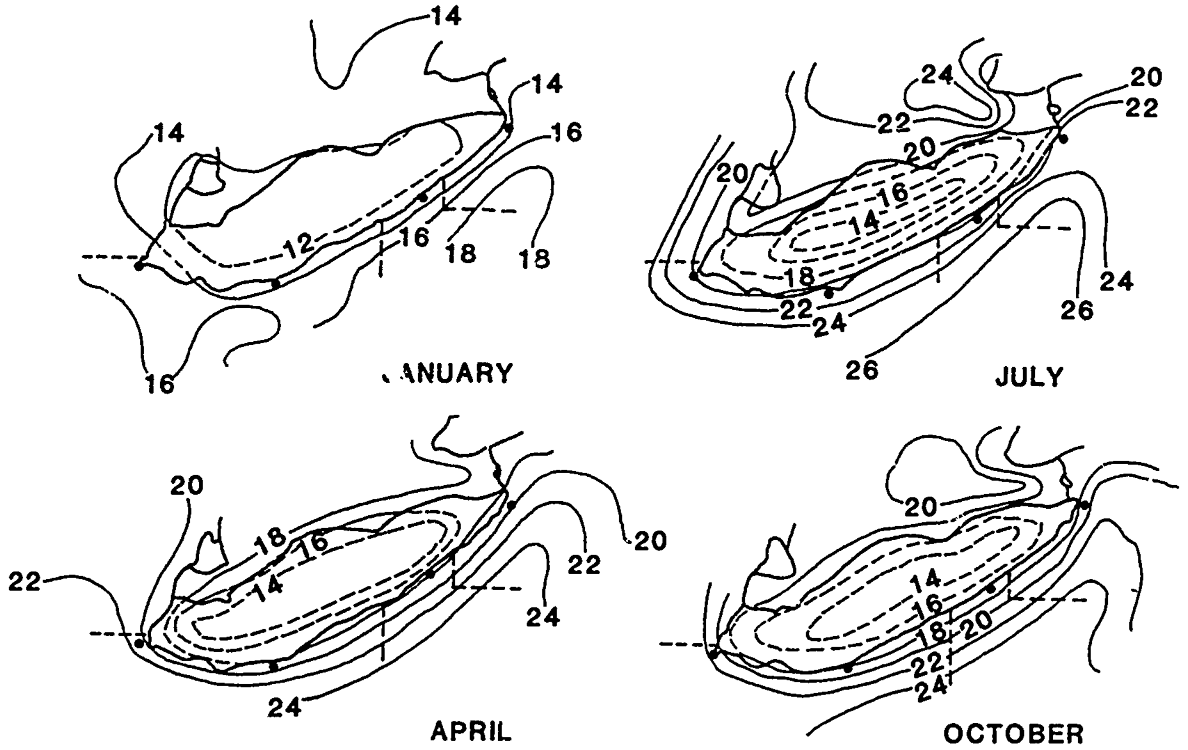


Figure 4.6. Mean daily range of temperature (°F). *(Redrawn from D.W. Phillips and J.A.W. McCulloch, The climate of the Great Lakes basin. Environment Canada, Atmospheric Environment Climatological Studies No. 20. 1972)*

through the summer and comparable to that of the other lakes. By October its effect once again is rather small.

Thermal modifications—growing season

The frost-free season is also extended along the shores of the Great Lakes, especially on downwind sides. This is chiefly due to the delay in the occurrence of the first autumn frost because of the thermal effects of the lake water. The earlier occurrences of the last spring frosts, however, also have an influence. In northern portions of the Great Lakes Basin, the difference in the frost-free season between interior and lake shore areas may be as much as two or three months.

The frost-free season is extended to over two hundred days on the south and east shores of Lake Erie. This constitutes the longest growing season within the Great Lakes Basin. Within about 50 miles of the shoreline, in the hills of northeastern Ohio, northwestern Pennsylvania and southwestern New York, the growing season is less than 140 days (Figure 4.8).

Effects of Lake Erie on precipitation

The effect of the Great Lakes on precipitation is to increase, in general, the amounts occurring on the downwind or lee shores. This occurs primarily because of large increases of winter snowfall in the form of lake effect snow which results from moisture added to air masses as they pass over the Lake. Around Lake Erie mean annual precipitation exceeds 40 inches at the eastern end of the lake in the highland areas of northwestern Pennsylvania and southwestern New York (Figure 4.9), whereas at the western end of Lake Erie, mean annual precipitation is less than 32 inches.

While the effects of the Great Lakes and Lake Erie are fairly straight-forward in regard to snowfall, the modifications imposed on rainfall

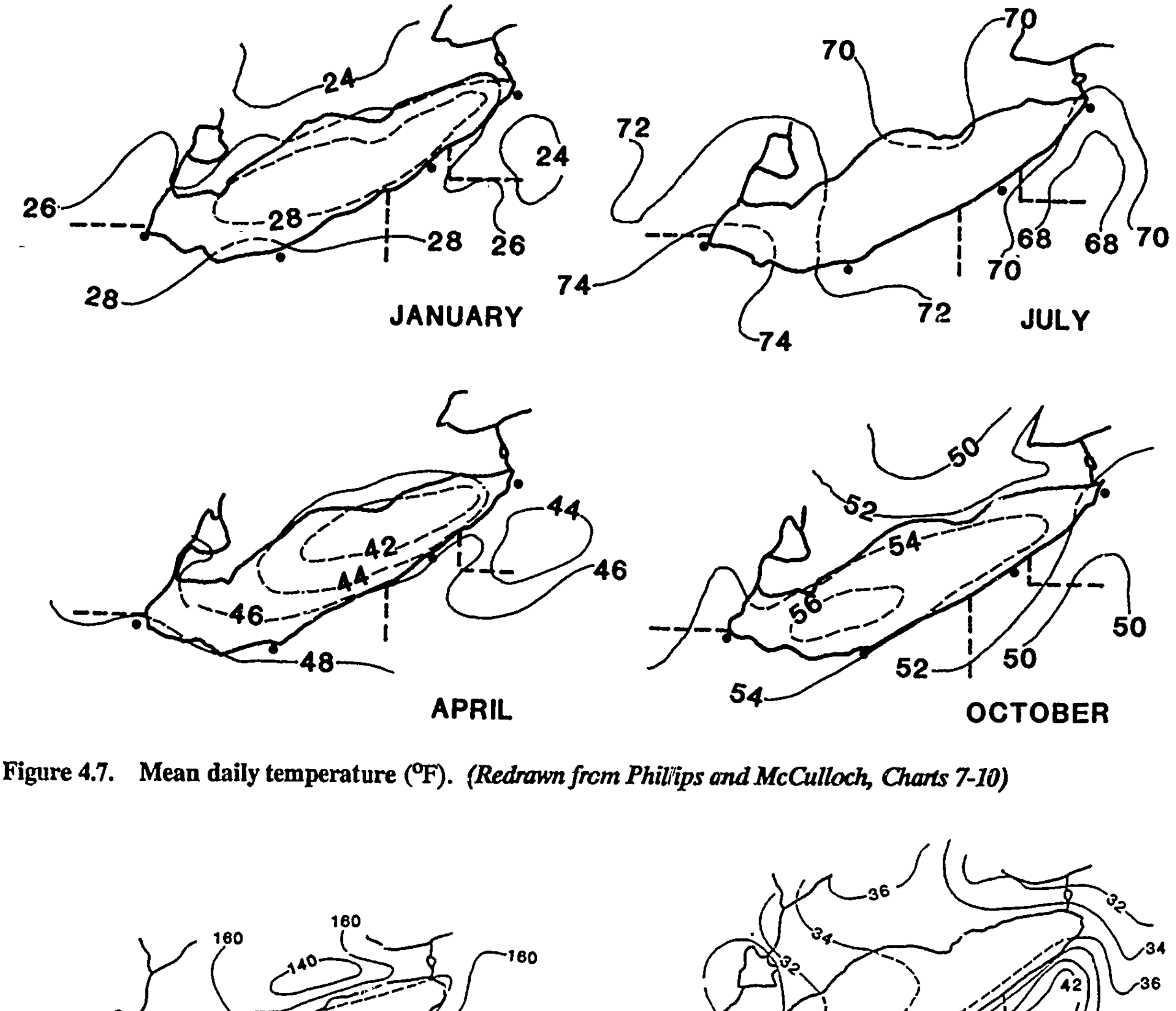


Figure 4.7. Mean daily temperature (°F). *(Redrawn from Phillips and McCulloch, Charts 7-10)*

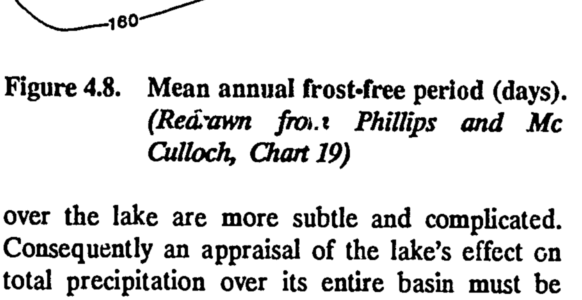


Figure 4.8. Mean annual frost-free period (days). *(Redrawn from Phillips and Mc Culloch, Chart 19)*

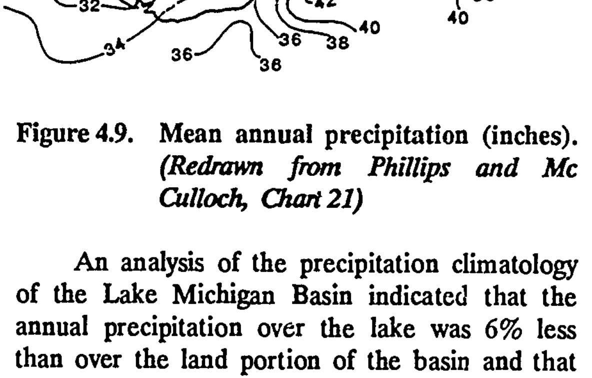


Figure 4.9. Mean annual precipitation (inches). *(Redrawn from Phillips and Mc Culloch, Chart 21)*

over the lake are more subtle and complicated. Consequently an appraisal of the lake's effect on total precipitation over its entire basin must be approached with some caution. In addition, regional differences within the basin occur, with eastern portions in general receiving more precipitation than western portions.

An analysis of the precipitation climatology of the Lake Michigan Basin indicated that the annual precipitation over the lake was 6% less than over the land portion of the basin and that the lake suppressed thunderstorm activity by 20% in summer (since its colder waters curtail the upward movement of air), while in the fall thunderstorms were increased by 50%. Lake effects were found to cause 25% to 100% more snowfall along the eastern shore of Lake Michigan than on the western shore. Overall Lake Michigan had 4% more precipitation in winter, 75% less in spring and 14% less in summer than the surrounding land areas. Amounts were equal in fall.

Lacking detailed studies for the Lake Erie basin, it is difficult to determine the role of the lake in terms of its effect on total precipitation, although it is likely that the lake, as does Lake Michigan, has a net effect of suppressing precipitation over its surface.

Effect on snowfall—lake effect snow

There are large differences in snowfall within the Lake Erie Basin. Snowbelts occur on the lee shores of the Lakes (Figure 4.10) and a well defined snowbelt exists on the eastern and southeastern shores of Lake Erie and within adjacent upland areas of northwestern Pennsylvania and southwestern New York State. Amounts of snowfall in the heart of the Lake Erie snowbelt range upwards of 100 inches, while totals at the western end of the basin are less than 40 inches. Comparing two large cities on the shore of Lake Erie, snowfall at Buffalo at the eastern end averages 93 inches seasonally, while amounts at Toledo at the western end average only 39 inches. Amounts in the eastern part of the lake basin along the Ontario shore are less than half of those across the lake on the south shore. In addition to increased snowfall, the duration of snow cover in the snowbelt areas of eastern Lake Erie is twice that of the western Lake Erie Basin.

This large difference in snowfall is probably the most prominent modification exerted by Lake Erie on the climate of its surrounding shores. It is the result of lake effect snowfall, a familiar phenomenon to all residents residing along the downwind (usually east) shores of the Great Lakes. Lake effect snowfall occurs when cold Arctic air flowing across the lakes acquires heat and moisture from the warmer lake waters. Lake effect snows may occur when weather maps show no apparent cause for snowfall. They may be extremely heavy, and often are highly localized, escaping detection by conventional data gathering networks. The snowfall pattern from individual storms may be extremely erratic. As much as 40 inches can occur with some snowbursts, while in areas 10 or 15 miles away very little snow will fall.

These storms normally extend only 20-30 miles inland but may account for from 30-50% of the seasonal snowfall in snowbelts. These regions experience larger annual totals, more snowfall days, larger frequencies of heavy snows, greater snowdepths and a longer duration of snowcover than inland or upwind areas. The economic consequences of the heavier snow within snowbelts can be considerable. Heavy snow in New York state snowbelts can be either an economic gain or loss. They are welcomed by ski resort owners. However, lost work days, transportation tie-ups, business closings and school closings may all occur more often in snowbelt areas. On January 26-31, 1977, a series of lake effect snowstorms paralyzed Buffalo, NY, and caused economic losses of over $150 million.

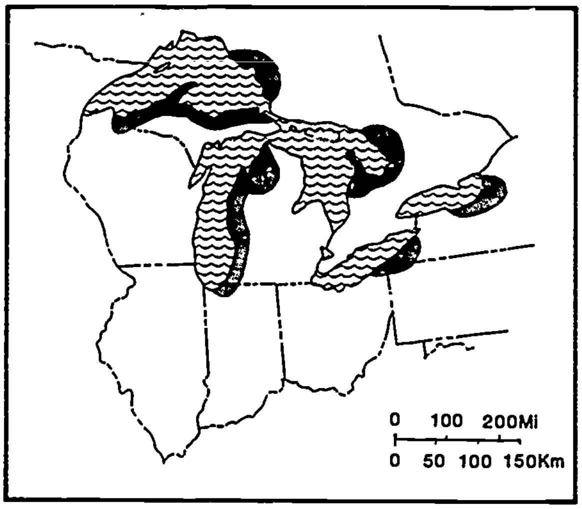


Figure 4.10. **Snowbelts of the Great Lakes.** *(Redrawn from Eichenlaub, p. 165)*

There are a number of variables that determine whether lake effect storms will form, where they will strike, and how intense they will be. Basically, the larger the temperature contrast between the air passing over the water and the water itself, the greater the potential for lake effect snow. Lake effect snowfall diminishes in late winter as lake temperatures cool and ice becomes more extensive. Lake Erie lake effect snows are much more common in the late fall and early winter before the lake is covered with ice. By late winter, with much ice and with water temperatures at a yearly minimum, the dynamic interactions between warm water and cold overpassing air are weaker and the lake effect snow mechanisms are suppressed.

The *fetch*, or length of travel of air over the lake surface, is also extremely important. Here the east-west alignment of the long axis of Lake Erie makes the fetch greatest with west or west-southwest winds and small with north or northwest winds. Lake effect snowstorms over Lake Erie usually occur in bands. These can form over the lakes or along the shorelines. The "overlake" bands may be 2-20 miles wide and 50-100 miles long and may form when the winds parallel the long axis of the lake (winds from southwest or west). The "shoreline" bands form along the downwind shore and extend inland as narrow, short bands 1-5 miles wide and 25-50 miles long.

The heaviest lake effect snowstorms to the lee of Lake Erie are associated with southwest to west winds and a single intense overlake snowband. This assures a lengthy fetch over Lake Erie. A secondary role is played by the higher terrain to the south and east of the eastern end of Lake Erie, which causes the winds to rise. Thus the air which has accumulated moisture over the long fetch cools and releases this moisture in the form of snow.

Other climatic effects of Lake Erie—lake breezes

Lake breezes are warm season phenomena, occurring when lake waters are cold relative to the land. They are breezes which flow from lake to land, penetrating anywhere from several blocks to as much as 40 km inland. They bring cooler temperatures to the surrounding shores, and higher humidities. They are daily features, beginning some hours after sunrise and dissipating in late afternoon or early evening. The leading edge of the lake breeze is called the "lake breeze front" and is often marked by increased cloud build-up.

Lake breezes are caused by differential pressures over the lake relative to the land. During the day, when land surfaces warm, air over the lakes remains cold due to lower water temperatures. As cold air is more dense than warm air, the pressure over the lake becomes slightly higher. The air is thus set in motion moving from the higher pressure of the lake to the lower pressure of the land. True lake breezes blow in opposition to the regional winds.

The occurrence of a lake breeze is dependent on temperature contrasts between lake and land and the regional weather pattern. As Lake Erie warms more rapidly than other Great Lakes because of its shallowness, temperature contrasts between lake and land are less marked during the summer and lake breezes may be less frequent than around the other Lakes. However, in the spring, temperature contrasts between Lake Erie and surrounding land are larger and lake breezes more common.

Sunshine and cloudiness

The Great Lakes exhibit contrasts in sunshine and cloudiness on upwind and downwind shores during the fall and winter. Increased winter cloudiness on downwind shores occurs because of acquisition of heat and moisture when cold air flows over warmer water. Increased winter cloudiness is not confined to narrow shoreline zones, but can extend far inland.

During the warm season, the lakes tend to suppress the development of clouds. Air rising above the warmer land carries with it moisture. As the air reaches a certain elevation it is cooled sufficiently for the moisture to condense, forming clouds. Over the lake, however, the surface is cooler, thus there is less of this convective activity. The immediate shore areas, therefore, enjoy slightly more sunshine in the summer, a factor making them more attractive for the summer visitor. This added sunshine is also one of the factors that make the downwind shores favorable locations for orchards and vinyards.

Fogs

Fogs may form over the lakes when warm air is chilled causing condensation. Fogs are most common during spring and summer, particularly in May and June when lake-land temperature contrasts are large. Lake breezes may move the fogs onshore a short distance before the increasing warmth of the land surface causes them to dissipate.

During the cool season, the lakes tend to decrease the occurrence of fog on their downwind shores. However, when strong incursions of Arctic air cross much warmer surface waters of the lakes, "steam fog" may result because of rapid evaporation from the warm lake into the overpassing cold air. This fog is likely to dissipate downwind, giving way to cloudiness and snow shower activity.

Summary

The Great Lakes are weather factories producing a surprisingly broad spectrum of weather effects. Some of these (lake effect snow, for example) occur in few other areas of the world. The weather modifications caused by the lakes are superimposed on the regional climatic patern, sometimes in dramatic ways, but often in very subtle ways.

Temperature differences between lake and land are most important in causing lake effects, and the magnitude of lake-caused modifications waxes and wanes seasonally as the water temperatures "lag" behind those of surrounding shores.

From about September until March, the Lakes are generally warmer than the land, and are then a source of heat and moisture, warming the surrounding land, forming clouds over the Lakes and on the downwind shores, and causing lake effect snows.

From March through August, the Lakes play the opposite role. Lake temperatures are generally cooler than the land, and the surrounding shores are chilled. Clouds and precipitation are suppressed and lake breezes and fogs occur.

The climatic patterns within the Great Lakes basin reflect the individual impact of each lake. Lake Erie, the shallowest and most southerly of the Great Lakes, generally has a smaller impact on climate than the other Lakes. Nevertheless, the effects are prominent at certain times of the year and play an important role in the life styles of those individuals living along the lake and utilizing its resources. Sometimes dangerous, but often benign, the lake effects afford a continuing challenge for the forecaster and researcher.

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5/ Coastal Processes on the Great Lakes

by Charles Carter

The coastal zone, on both the Great Lakes and the oceans, is the dynamic interface between the waves and the land. On the Great Lakes this is the zone that can change from tranquil to turbulent in a matter of hours (if not minutes), and the zone for which major historic changes can be documented. Moreover this is a zone of crucial importance to electrical power, commercial navigation, recreation, shoreline development and environmental interests. Almost without exception, the naturally occurring physical processes that take place in this zone have a profound effect on these activities and systems.

Physical setting

The lakeshore deposits consist largely of rock, clay, sand, and wetlands (Figure 5.1). The rock is exposed along the north shores of Lake Superior and Lake Huron (Georgian Bay and North Channel) and at scattered locations on the other lakes. The rock along Superior and Huron is part of a vast complex of erosion-resistant igneous and metamorphic rocks known as the Canadian shield, whereas the rocks exposed along Lakes Erie and Ontario to the south consist of less resistant Paleozoic sedimentary rocks.

The clay, with intervening stretches of rock, sand, and wetlands, is exposed along most of the remainder of the shore. For the most part it was deposited by or in association with the Pleistocene glaciers and glacier-dammed lakes. The rock is most resistant to erosion, followed by clay and then sand as the least resistant.

The wetlands occur commonly along Green Bay off Lake Michigan, along Saginaw Bay off Lake Huron, and at the west end of Lake Erie. The wetlands may be associated with narrow strips of sand known as barrier beaches. The relief (the elevation of the shore deposits above the lake) of the lakeshore ranges from essentially zero along the wetland shores to nearly 800 feet along Lake Superior's north shore.

The beaches, which are so important as a barrier to wave erosion, are as variable as the relief and the nature of the shore deposits. For example, wide, sandy beaches characterize the eastern shore of Lake Michigan; narrow, discontinuous beaches characterize the south shore of Lake Erie; and pocket, cobble beaches characterize the north shore of Lake Superior. In general, the nearshore slopes (the submerged surface lakeward of the beaches) are gentle with slopes of no more than a few degrees.

Physical processes

Water levels

Water levels are of singular importance on the Great Lakes for almost all coastal zone processes. However, in contrast to oceanic water levels, the mean annual levels (long term fluctuations) of the lakes show marked fluctuations that have major effects on the coastal zone and on coastal zone interests and environments. Moreover, in contrast to oceanic coasts that commonly experience predictable daily tides of a few feet in amplitude, the long term fluctuations on the Great Lakes take place over a period of a few to several years. These fluctuations are no more predictable than the weather which causes them. In addition to the long term fl

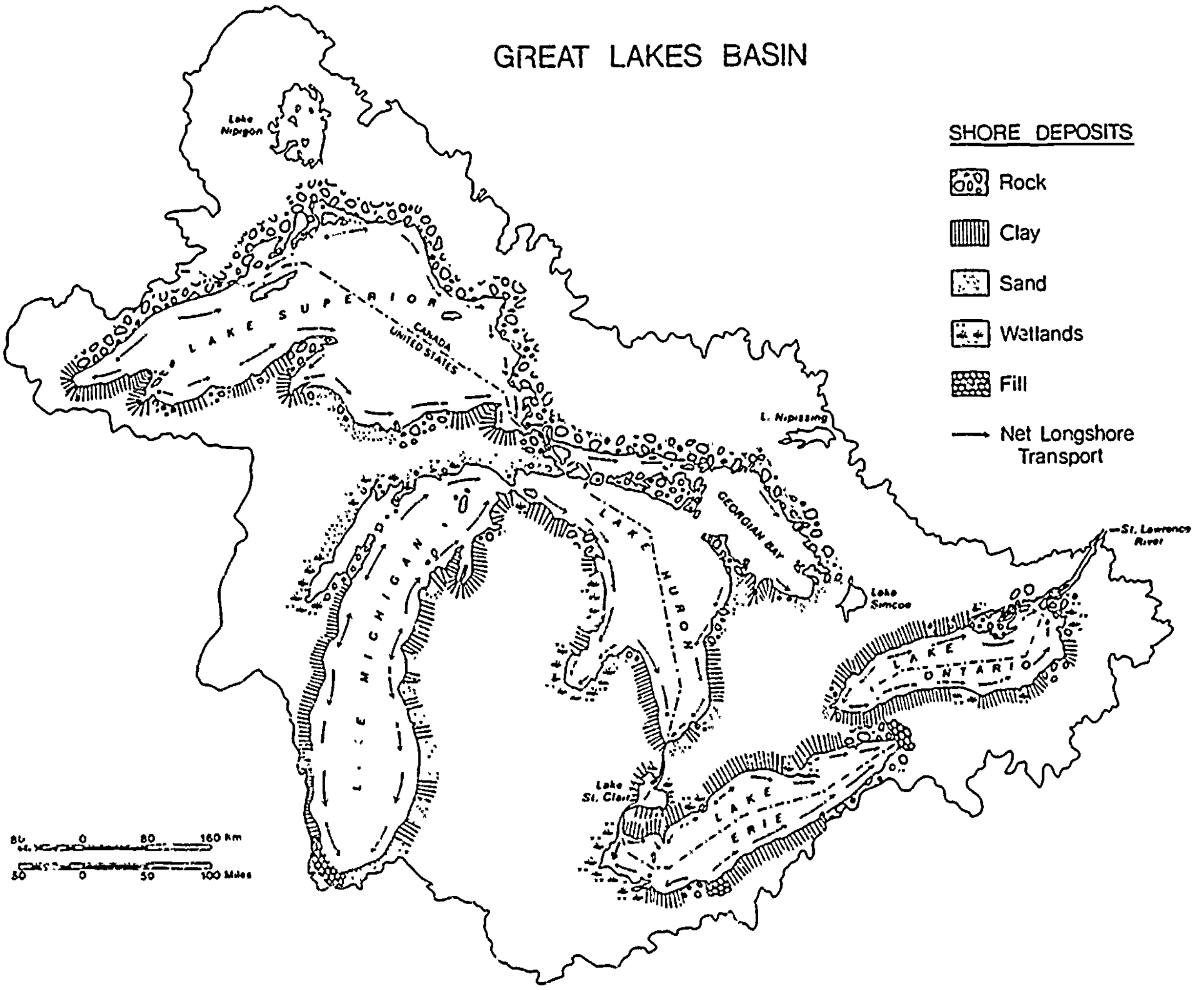

Figure 5.1. The Great Lakes Basin, with lakeshore deposits and net longshore transport directions. *(Bird and Schwartz, 1985)*

tuations are the seasonal fluctuations that have a yearly range of about one foot, and the short term, storm related fluctuations that can cause a rise in lake level of a few feet in several hours.

Long term and seasonal variations in lake levels are discussed more thoroughly in Thomas Croley's chapter. The short term fluctuations are due to storm surges, atmospheric pressure changes ("jumps"), and seiches. Surges are the most significant in terms of coastal processes because of their height, duration, and association with large, wind-driven waves. In essence, wind stress across the lake surface causes mass transport of the lake water; this transport causes a rise in lake level along the lake shore. The lake level rise is eventually compensated by a return flow to the other side of the lake basin that constitutes a seiche, a free oscillation of the lake's surface. Storm surges are much greater on Lake Erie in comparison to the other lakes because of Lake Erie's orientation and shallow depth. A Lake Erie storm surge and subsequent seiche are shown in Figure 5.2.

Waves and sediment transport

Wind-driven waves, not to be confused with the swell, characteristic of certain ocean coasts, provide the dynamic element to Great Lakes coasts. The winds are generated by both high and low pressure systems traversing the Great Lakes region in a roughly west to east direction. Deep water waves on the lakes have been

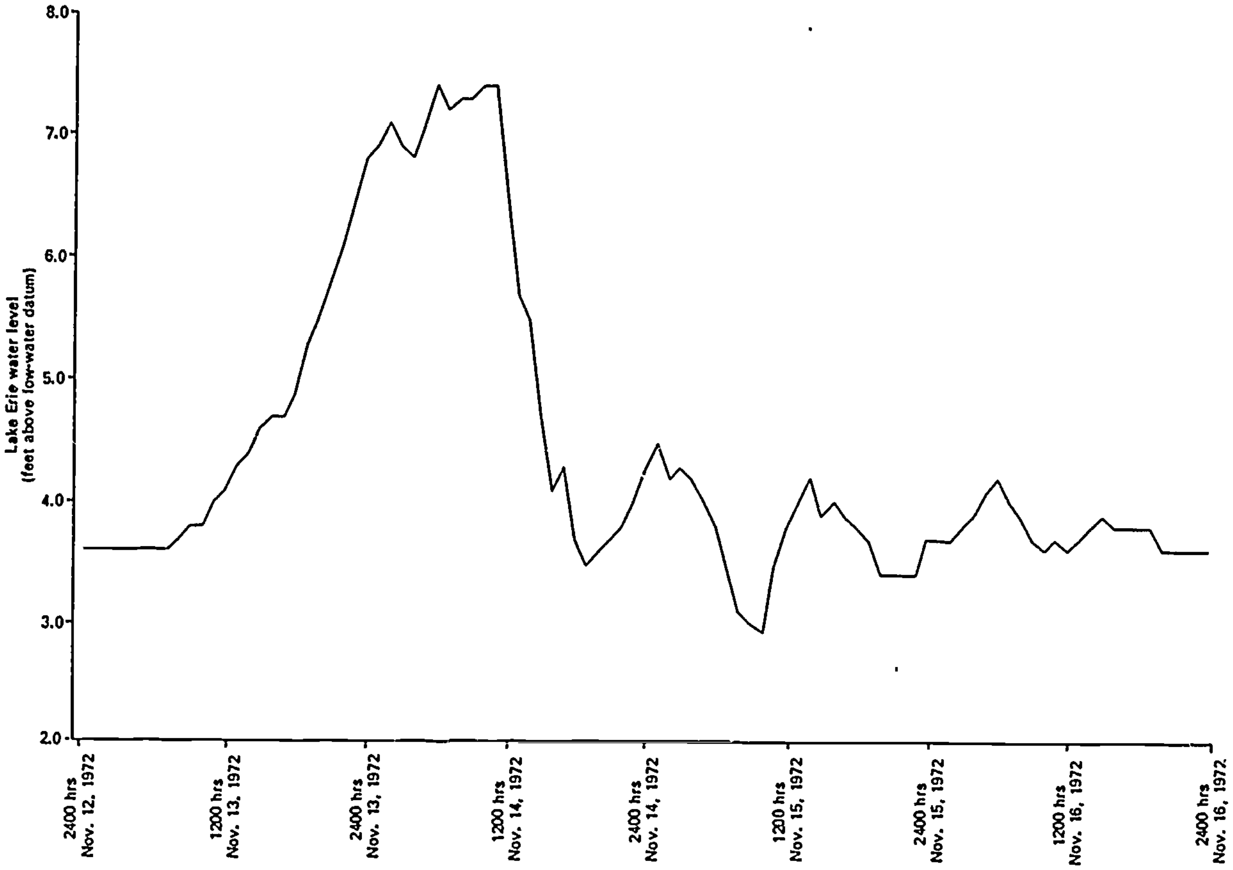

Figure 5.2. Lake Erie storm surge and subsequent seiche from the 13-14 November 1972 storm, recorded at Toledo, OH. ***(from C. Carter, Ohio Geological Survey Information Circular 39)***

estimated to reach about 20 feet high. However, once these waves reach the shallow coastal slopes their energy is lost to friction and breaking, and for the most part the storm waves that reach the shore are no more than three to six feet high. Fortunately for the people that live along the shore most of the Great Lakes wind storms occur from the late fall to the early spring when lake levels are lowest and when lake and/or shore fast ice (ice in contact with the beach and nearshore) are present to restrict the formation of waves or keep the waves from reaching the shore (Figure 5.3).

The waves, aside from shore erosion, transport appreciable quantities of sand along the shore. Sand accumulation measurements made at harbor jetties indicate up to 100,000 cubic yards of sand per year can be transported and deposited adjacent to harbor structures on the Great Lakes. Naturally the sand is not in continual motion because winds are not constantly blowing onshore; nor is the sand moved in just one direction, because the winds blow onshore from different directions. For example, on Lake Erie, even at exposed locations such as Cleveland, and Erie, Pennsylvania, the lake surface is characterized by calm conditions or by waves less than a half a foot high about 80% of the time.

Nonetheless, there is usually a preferred (net) direction toward which sand is episodically moved. For example, along the south shore of Lake Erie the net sand transport direction is to the east on the east side of Cleveland, and to the west, west of Cleveland (Figure 5.1). In this case the more frequent and stronger winds from the west are the principal cause of the dominant west to east transport of sand. Furthermore, because sand is important as a recreational

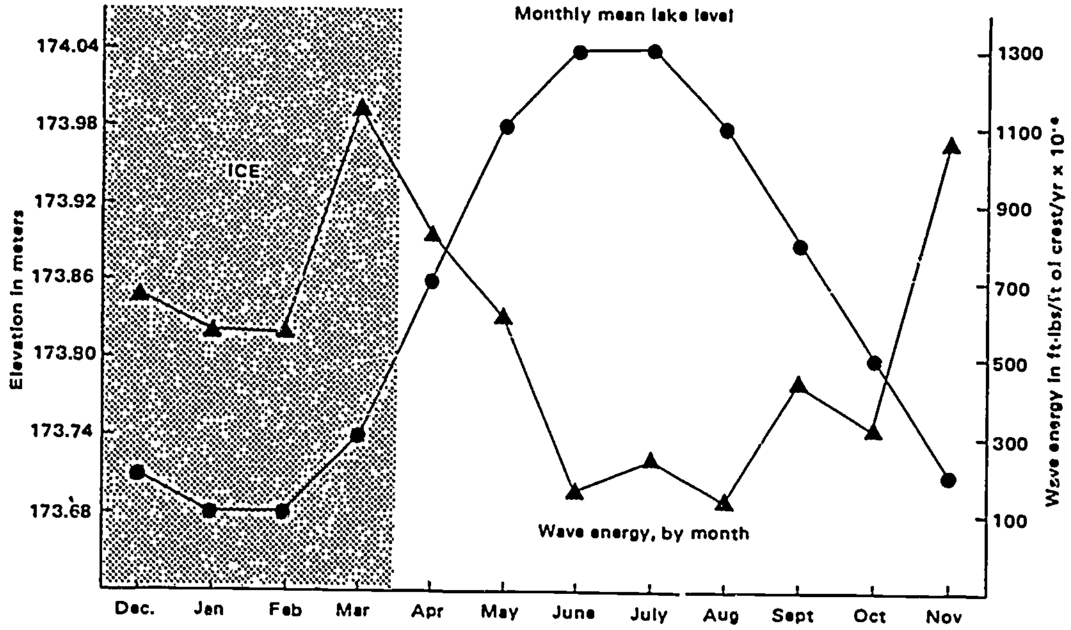

Figure 5.3. Wave energy, lake level and ice on Lake Erie. ***(Carter, et al., 1981)***

resource and as a buffer between lake waves and the land, a knowledge of the direction and quantity of sand being transported (longshore drift) is essential.

Shore erosion

The waves that reach the shore erode the shore. The higher the lake level, the closer waves break to the shore, and the greater the amount of wave energy that reaches the shore (Figure 5.4). Naturally, the greater the wave energy reaching the shore, the greater the shore erosion.

Waves erode the shore in different ways. They erode by the force created by impact, by the force created by the compression of air and/or water into cavities and fractures, and by simply abrading (sand blasting) the shore with sand picked up by the waves on the beach.

The nature of the shore material, like the amount of wave energy reaching the shore, has a major effect on erosion. Rock for the most part is quite resistant to erosion and usually erodes at less than one foot per year. However, if the rock is highly fractured it may erode at 2-3 ft/yr because the waves can easily quarry the broken rock. Clay-rich glacial drift (debris transported by or away from a glacier) on the other hand usually erodes at 2-3 ft/yr but may erode much more rapidly. This is happening along the north central shore of Lake Erie where erosion rates are as high as 18 ft/yr. Sand is the least resistant to erosion. Unlike rock or glacial drift, sand can also accumulate and build out from the shore. This circumstance is unusual on Lake Erie, where major sand spits such as Point Pelee, Long Point and Presque Isle are all eroding because of the high lake level and scarcity of sand.

Erosion rates on the Great Lakes are decidedly nonuniform. Although the nature of the shore material is constant, the amount of wave energy reaching the shore is quite variable because of fluctuations in lake level and in the frequency and intensity of the storms that create the waves. For example, at a low lake level there may be little if any shore erosion because the storm waves break far offshore. Whatever wave energy is available is easily damped before it reaches the shore. On the other hand, at a high lake level even small waves can reach a shore with a narrow (probably submerged) beach. At high lake levels erosion rates can be several times the long term rate; in fact, there may well

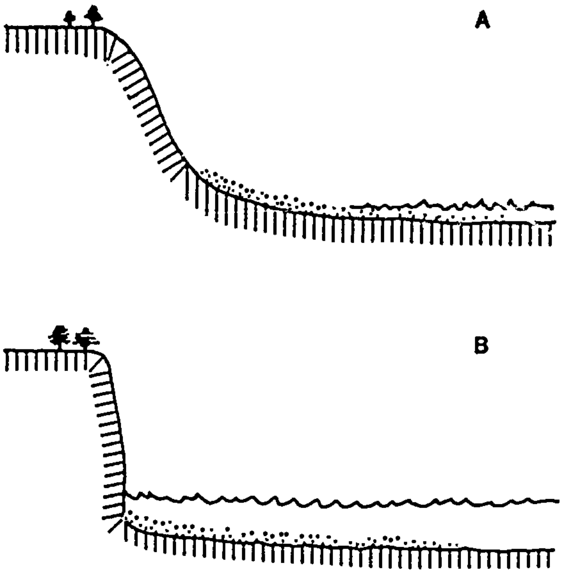

Figure 5.4. **Effect of lake level on wave erosion. Wave energy lost to the beach at a low lake level (A), and wave energy expended on the shore at a high lake level (B).**

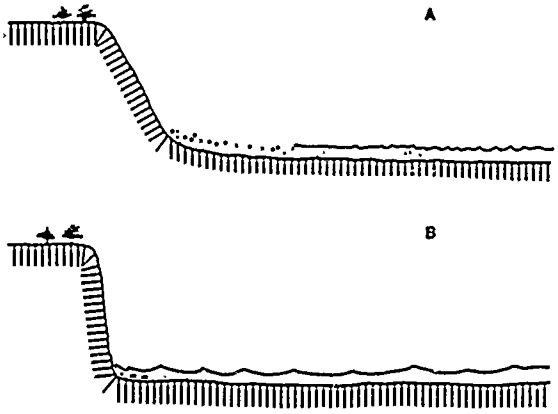

Figure 5.5. **Effect of a beach on wave erosion. Wave energy is lost to the wide beach that protects the shore (A) whereas at the same lake level, wave energy reaches the shore because of the lack of a wide beach (B).**

be a threshold level at which erosion will take place practically everywhere along a lakeshore if there is insufficient beach width to protect the shore from waves (Figure 5.5).

The base of the lakeshore slope or bluff plays a major role in the erosion process. The crucial nature of this area can be illustrated in terms of an erosion cycle that is generally applicable to the Great Lakes shores with the exception of the shore made up of barrier islands and wetlands (Figure 5.6). The cycle can take place in a year or over a period of several years. The principle is this: (1) during a high lake level waves erode the base creating an unstable slope (this process may take place over a few weeks); (2) slope failure (mass wasting) occurs in the form of rock/clay falls, slumps, slides, or debris flows, and (3) subsequent erosion (usually at a high lake level) of the base of the slope allows the waves once again to create another unstable slope.

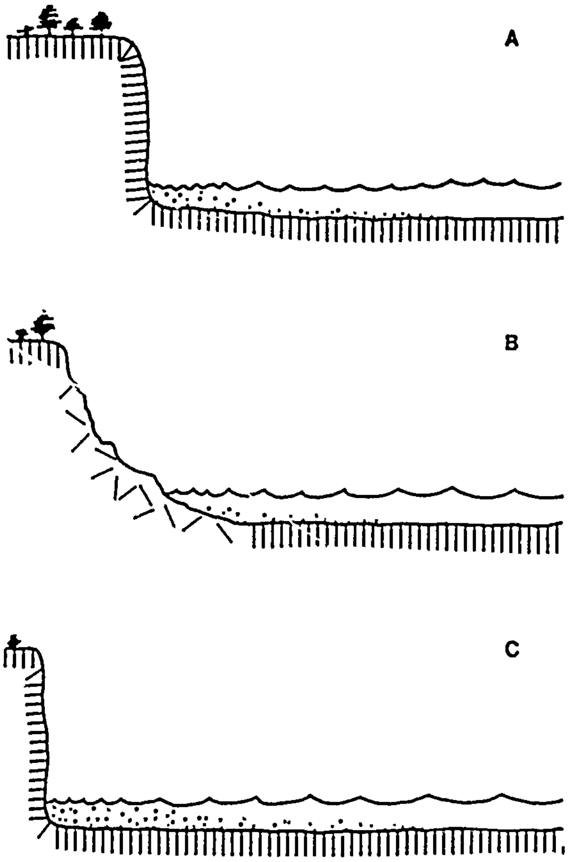

Figure 5.6. **The erosional cycle. (A) Erosion at the slope toe during high lake level. (B) Slope failure. (C) Erosion of the debris deposited by slope failure and renewed erosion at the slope toe.**

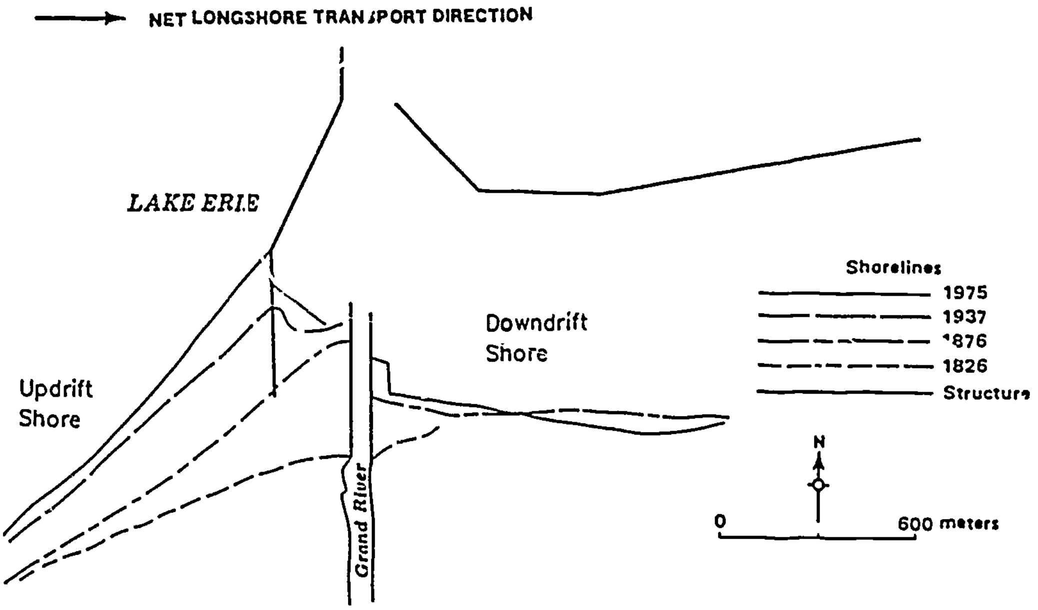

Figure 5.7. **The Fairport Harbor (Grand River) area with shore-lines and harbor structures** *(Carter, et al., 1981)*

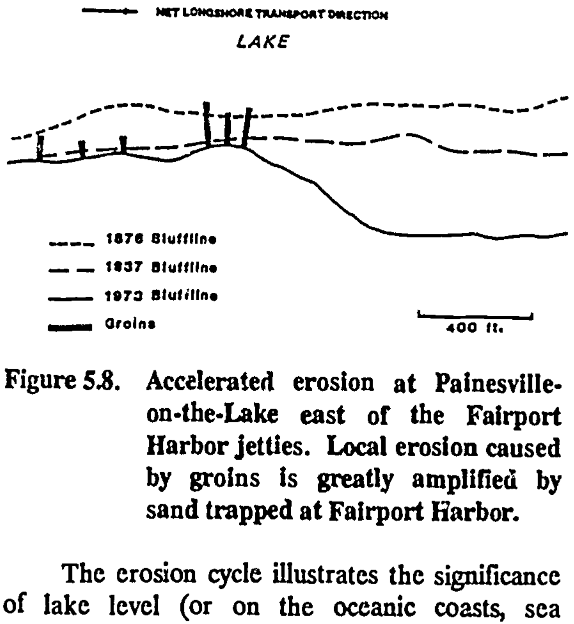

Figure 5.8. Accelerated erosion at Painesville-on-the-Lake east of the Fairport Harbor jetties. Local erosion caused by groins is greatly amplified by sand trapped at Fairport Harbor.

The erosion cycle illustrates the significance of lake level (or on the oceanic coasts, sea level) to shore erosion. If the mass wasted debris at the base of the slope were allowed to accumulate, the slope would eventually reach a stable angle of repose. Downslope movement would then be restricted to the relatively slow slope process of creep. However, if there is wave erosion of the mass wasted debris by high lake levels, as there is along much of the Great Lakes shores, the slope never reaches equilibrium and erosion persists.

In human terms the overall shore erosion problem is harder to comprehend because of the long term fluctuations in lake level. For example, a person may buy a house along the lakeshore at a low lake level, i.e. at a time when there is a relatively wide beach and when mass wasted debris commonly covered by vegetation has accumulated at the base of the slope, giving a semblance of stability. But with the return of a high lake level, the beach is partially (if not wholly) submerged and waves then erode the mass wasted debris to the surprise of the shoreland owner.

Human impacts

People, as they have done in so many other natural systems, have had a major impact on shore processes, particularly shore erosion. Human effects on erosion along the Great Lakes shore are caused in two ways: by harbor structures, and by shore protection structures. The harbor structures that have had the most effect are the jetties that were built to keep the river mouth harbors free of sediment. These structures

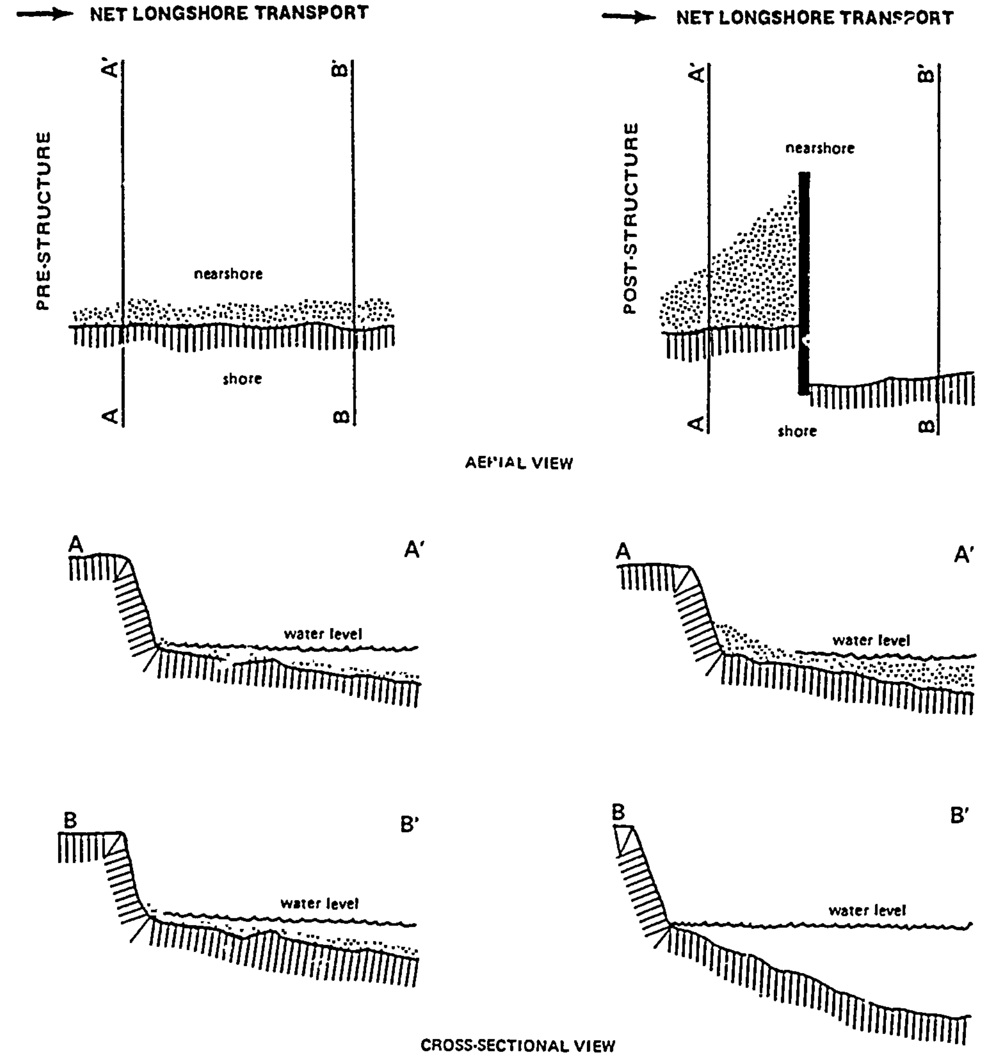

Figure 5.9. Changes caused by a groin. *(from Carter and Guy, Ohio Geological Survey Report Inv. 115)*

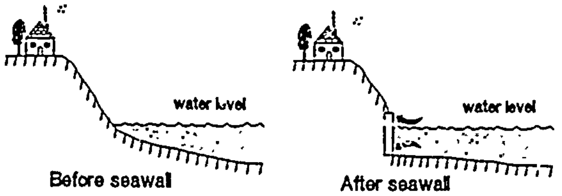

Figure 5.10. Changes caused by a seawall.

block and/or divert the longshore transport of sand and in so doing usually deprive the downdrift beach of sand. Naturally, this leads to a wider beach (and thus more protected shore) along the updrift shore, but a narrower beach (and thus a less protected shore) along the downdrift shore.

Unfortunately the length of shore affected by the loss of sand is generally several times the length of the shore affected by the gain of sand. The Fairport Harbor area (Grand River) along the south shore of Lake Erie is an excellent example of the effect of the harbor structures. The jetties that were first constructed in the mid-1820s, and subsequently lengthened, have trapped appreciable quantities of sand from the net west to east longshore transport system. This has resulted in a build-up of sand into the lake adjacent to the west jetties of more than 2000 feet and shore protection in the form of a wide beach for about one mile to the west (Figure 5.7). On the other hand, there has been a tremendous loss of sand in the beaches at least for 4 miles to the east of the jetties that has led to accelerated erosion along this shore (Figure 5.8).

Naturally if the setting and processes are different, the effects will be different. Overall, however, the jetties have had a major effect on sand transport and thus on the distribution of sand along the Great Lakes shores, thereby a major effect on erosion rates.

The shore protection structures that have had the most effect are groins and seawalls. Groins act as small jetties in that they block and/or divert the longshore transport of sand. In so doing they lead to the formation of a wider beach on one side of the structure, which is the basic purpose of a groin, but again, a narrower beach on the other side of the structure (Figure 5.9). Frequently, the apparent necessity for the construction of the groins has been created by the jetties built updrift. These have contributed to narrower beaches and thus the need for shore protection.

Seawalls, on the other hand, armor the shore and thus make it more resistant to wave attack. However, erosion takes place at the base of the structures by the downward deflection of wave energy. This leads to greater energy reaching the shore (deeper water) as well as accelerated sand transport along the shore (Figure 5.10). And, by armoring the shore and reducing erosion rates, seawalls also reduce the amount of sand entering the system. This is probably the most important effect of seawalls, because the shore is the principal source of beach sand. This leads to narrower beaches and consequently higher erosion rates. Moreover, with both groins and seawalls the distribution of sand along the shore is becoming increasingly nonuniform, and with larger numbers of structures the distribution will become even more sporadic.

What about the future of the Great Lakes coastal zones in terms of human development? The stretches fronted mostly by shore protection structures will lose their beaches, as a diminished sand supply coupled with accelerated longshore sand transport will erode sand. On the other hand, the stretches that lack such structures will continue to have beaches, as shore erosion will provide sand to replenish what is moved by longshore currents. However, if structures are built along the shore there will be less sand entering the system from erosion and the beaches will narrow.

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6/ Early Struggles for Peace on Lake Erie

by Gerard Altoff

In traveling to their destinations it has always been the tendency of creatures to choose the easiest path. The human need to explore epitomized this precept, and it was early discovered that travel across water proved one of the easiest modes of transit from one location to another. Thus it was when North America was discovered—the waterways yielded easy access to the interior. Near the center of the North American continent lies a series of these waterways traversing almost forty percent of its width. The five Great Lakes and the St. Lawrence River conferred upon early travelers a natural route for exploration, settlement, and exploitation of the resources of the continent. As time passed the political, military, and economic significance of the Great Lakes grew, and nations found themselves contesting each other for their control. So it was that Lake Erie, being second and southernmost in the chain of Great Lakes, would play a vital and strategic role in the development of North America.

The discovery and early exploration of Lake Erie

Oddly enough Lake Erie was the last of the Great Lakes discovered by European explorers. In the early 17th century Jesuits and voyageurs followed the Indian route to the interior via the Ottawa and Mattawa Rivers into Lake Nipissing, and then along the French River to Georgian Bay. Hence the three upper lakes received the earliest attention, and it was thus from the "back door" that Lake Erie was first glimpsed.

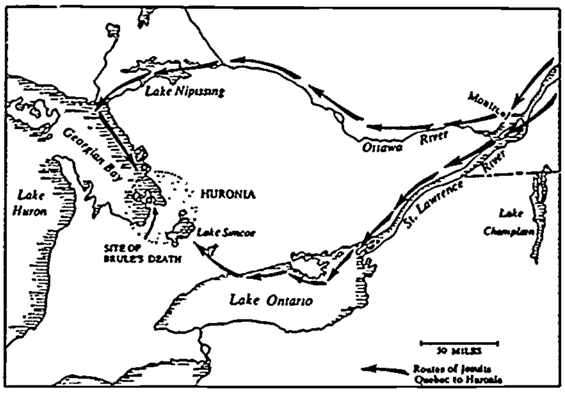

Figure 6.1. Route of the Jesuits. *(McKee, 1966, p. 104)*

Though still a matter of dispute, Louis Joliet is most often credited as being the first white man to see Lake Erie, in 1669. After an unsuccessful search for a copper mine on Lake Superior, Joliet paused at Sault Ste. Marie on his return to Montreal. There he acquired an Iroquois guide who convinced him to return via a southern route, and Joliet traveled south into Lake Erie via the St. Clair River, Lake St. Clair, and the Detroit River. By an amazing stroke of luck and a hair's-breadth Joliet managed to discover Lake Erie only days before one of his major rivals of the period, Rene Robert Cavelier, Sieur de la Salle.

An ambitious man with a dream of discovering a trade route to the far east, La Salle led an expedition up the St. Lawrence River in the summer of 1669. Following the south shore of Lake Ontario he reached the vicinity of Hamilton, Ontario, on September 4th, where he learned from Indians that another European, Joliet, was nearby. La Salle had been fighting an illness for two months, so after meeting Joliet he decided not to continue with his original plan. However, a Sulpician priest and a deacon who accompanied La Salle did press on, and these two men, Francois Dollier de Casson and Rene Brehant de Galinee, completed the first east-west transit of Lake Erie by white men. After wintering near present Port Dover, Ontario, they continued their journey by water to Sault Ste. Marie, there to proselytize among the Indians.

La Salle was somewhat daunted after encountering Joliet but did not abandon his dream of exploring the great rivers to the southwest spoken of by the Indians. His movements over the next two years are uncertain. It is speculated that La Salle, accompanied by a Seneca guide, traveled south to the Ohio River, following it westward to the site of Louisville, Kentucky, where he veered northward and returned by way of Lake Erie. His subsequent actions tend to support this supposition. Returning to France, La Salle obtained a grant from Louis XIV to explore his supposed new route and establish trade with the Indians. Compiling another expedition, this one including men and material for ship construction, La Salle again set out. Crossing Lake Ontario and sailing up the Niagara River, he portaged the falls and began building this ship. After incredible toil the *Griffin*, a two-masted vessel of approximately 45 tons, was launched, and on August 7, 1679, she sailed into Lake Erie. After three days La Salle, the first known white man to navigate the length of Lake Erie, reached the Detroit River. The *Griffin*, minus La Salle, was soon afterward lost without a trace on the upper lakes, and La Salle himself, in search of his dream, was killed in Louisiana in 1682. Although their sojourn on the lake was short-lived, La Salle and the *Griffin* will forever be part of Lake Erie's mystique.

The fur trade: Conflict between France and Great Britain

The next eighty years would see a continual tug of war between France and England for control of the Great Lakes, and one overriding economic factor was the root cause of this struggle for empire—the fur trade. Through their initial explorations and contacts with the Indians the French had established a system of trade which stretched from the St. Lawrence to the mouth of the Mississippi. Several routes connected the Great Lakes to the Mother of all Rivers, one of the major ones via Lake Erie and the Maumee, Wabash, and Ohio Rivers. But the French were not to have a monopoly. Inroads were made when England established the Hudson Bay Company in the latter half of the 17th century. The economic war was on. On Lake Erie trading posts were established on the Cuyahoga, Sandusky, and Maumee Rivers, and for a time both English and French traders worked the area in uneasy harmony. The dominant French were little bothered initially as few Englishmen were able to penetrate the wilderness; voyageurs only had to paddle down the French controlled waterways, whereas English efforts were hampered by the natural barrier of the Allegheny mountains. The French, however, were not unaware of the insidious nature of English pressure.

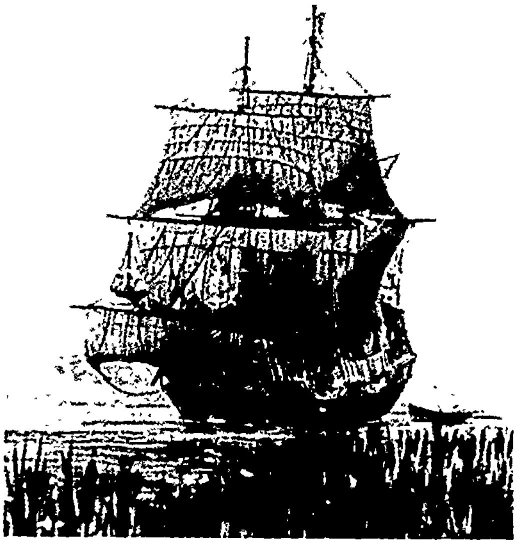

Figure 6.2. The *Griffin*. (*G.A. Cuthbertson, Freshwater*)

East of the mountains King William's War erupted in 1689, followed shortly thereafter by Queen Anne's War in 1701. While the Alleghenies and the Iroquois League provided a buffer to the fighting, English influence exerted itself, compelling France to take steps to strengthen its grip on the lakes. In 1701 Antoine Laumet, Sieur de

Lamothe Cadillac established Fort Pontchartrain—soon to be referred to simply as Detroit—to protect the vital strait between Lakes Erie and Huron, just one of the chain of forts France constructed to consolidate its hold on the fur trade.

Struggle for control of the Indians

One of the keys to mastering the fur trade was controlling the Indians. With most of the tribes the French enjoyed preeminence, but there was one group of Indians they never could seem to sway—the Iroquois, mightiest Indian confederacy in North America. The Treaty of Utrecht, concluding Queen Anne's War in 1713, formally prohibited any French meddling with Britain's trade and influence with the Five Nations, as the Iroquois confederacy was called. England used this edict to lay claim to Lake Erie on the premise that since the Iroquois destroyed the Erie Indian tribe in 1655, Lake Erie should rightfully belong to the English. The problem with this claim, however was that it was obviously unenforceable and heightened tensions in the Lakes region.

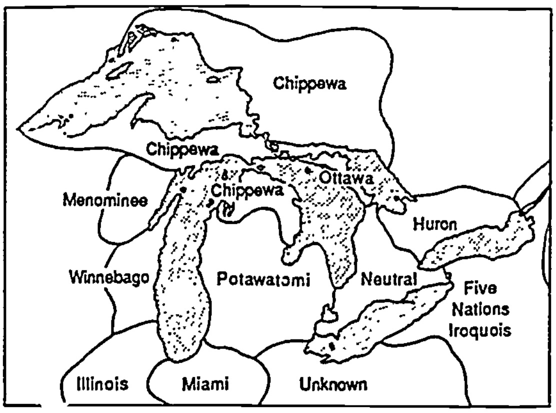

Figure 6.3. Approximate locations of Great Lakes tribal groups in the early 1600s. *(Adapted from Tomboulian, Michigan Natural Resources, 1986)*

By this time France, with Forts Niagara and Detroit, controlled their namesake rivers. Both ends were effectively plugged, but the French still couldn't prevent the English from penetrating Lake Erie's midsection. Frontiersmen from the colonies had by this time conquered the Alleghenies further south, and English fur traders were now moving north through the Ohio country. Many tribes, especially those along western Lake Erie, were becoming disgruntled with seemingly shady French trade practices, and the English exacerbated the situation by agitating amongst the tribes and undercutting French prices, thereby sowing discontent. The outbreak of yet another Franco-English conflict, King George's War (1744-48), instigated several minor skirmishes along Lake Erie, but the Treaty of Aix la Chapelle restored order.

In 1749 the French attempted to cement their claim on Lake Erie. Realizing that the English were in North America to stay, they tried to forestall further westward expansion by dispatching Celeron de Bainville on a 3,000 mile trek, during which he nailed tin plaques to trees and buried lead plates at strategic locations to once and forever delineate French territory. Part of his route took Celeron down the eastern shore of Lake Erie, then south to the Ohio River, down the Ohio to the Great Miami, from whence he headed north, crossed over to the Maumee, and reentered Lake Erie. It was a historic journey, and caused the English to take aggressive action to counteract Celeron's move. The Ohio Land Company, formed by several prominent colonists from Virginia and Maryland in 1748, sent Christopher Gist across the mountains, where he traversed much the same territory as Celeron. Gist wooed the Indians, winning over several influential chiefs. It was a masterpiece of deception. Gist turned the Indians against the French, all the while concealing the fact he was scouting the area for English settlement. Unlike the French, who limited their intrusions to trading posts and forts, the English planned to take it all.

Gist's overtures to the Indians were not ignored by the French. Charles Langlade, a Canadian with half Indian blood, led a punitive campaign on his own initiative from Detroit in 1752 against those who befriended Gist. Langlade attacked and destroyed the village of Pickawillany, and Old Britain, a Miami chief and Gist convert, was boiled and eaten by the victors. Another French expedition was sent south from Montreal in 1753 to secure the upper Ohio valley, and yet another series of military posts were built, the first of which was Fort Presqu'Ile (now Erie, PA). The Indians were thoroughly cowed by these tactics and returned once more to the French fold.

One of the new French installations, Fort Duquesne (Pittsburgh, PA), was cavalierly located on land steadfastly claimed by the English, who were quick to react. In 1755 a young colonel in the Virginia militia, none other than George Washington, guided by Christopher Gist, was sent to cope with the French incursion. Nearing Fort Duquesne, Washington was forewarned by his scouts of an advancing French party, and with 40 of his own men ambushed 33 French soldiers, killing 10. Washington had just single-handedly launched a war that would determine once and for all the dominant culture of North America.

The French and Indian War and its aftermath

Lake Erie, still part of the western wilderness, was spared the horrors of the Seven Years War, dubbed the French and Indian War in American history. Some Ohio Indians did assist the French during the early stages of the war, participating in the overwhelming rout of British General Edward Braddock's force near Fort Duquesne on July 9, 1755. But the British, undaunted after numerous blunders and setbacks, recouped their early losses, and in 1758 General John Forbes enlisted Christian Frederick Post, a Moravian missionary, to roam among the Indians of the Ohio country and counsel peace. Post succeeded, and without Indian support Fort Duquesne, at the extremity of a tenous supply line from Montreal, withered on the vine. Abandoned by the French in late December, 1758, Fort Duquesne was occupied by the British and renamed Fort Pitt. Duquesne was soon followed by Forts Le Boeuf, Venango, and Presqu'Ile, their garrisons retreating to Detroit. Even the citadel of Fort Niagara, at the mouth of the Niagara River, fell to the British onslaught. Although peace was not declared until 1763, the fighting was virtually over after Quebec fell in 1760; the rich lakes country was now ripe for the picking.

Assigned this task was the redoubtable Major Robert Rogers and 200 of his now famous Rangers. Rogers departed Montreal on September 13, 1760, and proceeded to the now British Fort Presque Isle. Pushing on to the Cuyahoga River, Rogers was intercepted by the prestigious and powerful chief of the Ottawa nation, Pontiac. Their encounter was strained; the Indians of the Detroit region were still favorably disposed towards the French. Not until Rogers convinced Pontiac that the Indians would benefit from British trade was he allowed to continue. Detroit capitulated without a fight, and Lake Erie, together with all French bastions north and west of Detroit, reverted to British rule.

Detroit was one of the few posts west of the St. Lawrence to blossom under French control. By 1760 it was a boomtown of 500 people, and now British traders flocked to the area. The Indians, looking forward to a new prosperity, were soon disillusioned and dismayed by unscrupulous traders who, now that the British sustained a monopoly, swindled the Indians regularly. Taking advantage of this the French, from their location in the Illinois country, stirred unrest among the tribes. The pressure built until 1763, when Lake Erie experienced its first serious bloodletting since the Iroquois wiped out the Erie nation almost 110 years before.

The Indians fight back

One of the great Indian leaders of all time, Pontiac possessed a magnetic personality, his oratory easily able to sway and galvanize others. He seduced the Chippewa, Delaware, Shawnee, Huron, Potawatomi, his own Ottawa, and others to help him expel the English. Pontiac struck in early May, 1763. Endeavoring to capture Fort Detroit by a ruse, Pontiac was frustrated when Major Henry Gladwin, now in command, received advanced warning and evaded the trap. Detroit, however, was one of Pontiac's few setbacks. Within two months almost every fort from western Pennsylvania to Lake Superior fell, including Forts Miami, Sandusky, and Presque Isle, and in most cases their garrisons wiped out. Only Forts Pitt and Detroit stayed the tide, but both were isolated and under siege.

Gladwin stubbornly defended his beleaguered outpost, ably assisted by two newcomers to Lake Erie, the 80 ton schooners *Michigan* and *Huron*. Built above Niagara Falls at what was later named Navy Island—the first ships built on the lake since the *Griffin*—they were ready just in time. Assailed time and again while running the Detroit River gauntlet, the little vessels still managed to keep Gladwin's supply line open and were instrumental in preventing Detroit from falling.

Dozens of battles and skirmishes marked the bloody uprising and few vessels were as fortunate as the *Michigan* and *Huron*. A large number of *bateaux* trying to supply Detroit were ambushed at Point Pelee; 61 men were killed or captured and most of the bateaux lost. Another 75 men were killed in ambush on the portage road just below Niagara Falls, known as the Devil's Hole Massacre. And at one point after 280 reinforcements finally arrived at Detroit, Captain James Dalyell led 247 of them in an attack against Pontiac, who ambushed this venture, killing Dalyell and 22 of his men. The lake itself quashed one effort to relieve Detroit; high winds caught 600 men in boats off the north shore and all the supplies along with 70 men were lost.

Despite such setbacks, Detroit and Fort Pitt continued to hold out, providing the English time to regroup and strike back. Helping the British were Pontiac's own mercurial allies. The Indians possessed neither the temperament nor the patience to sustain a long, drawn out conflict; the rebellion was eroding from within. But the mortal blow was administered by a Swedish born British officer named Henry Bouquet. Leading a relief force of 400 men toward Fort Pitt, Bouquet was ambushed by an equal number of Delaware and Shawnee on August 5th, 1763. The Battle of Bushy Run lasted two days; Bouquet, with 25% casualties and his men exhausted and near defeat, desperately laid a counter ambush, into which the Indians impetuously pounced. Surprised and defeated, the Indians withdrew, and on reaching Fort Pitt just kept on going. The siege at the easternmost fort was lifted.

It was another 11 weeks though before Detroit could breathe easier. Through the force of his personality alone Pontiac was able to keep enough of the wavering warriors with him to maintain Detroit's siege. When finally a French representative from the Illinois country arrived and made it plain that French assistance, the last hope keeping Pontiac's dream alive, would not be forthcoming, his rebellion at last petered out. Six months of blood and horror on Lake Erie came to an end. Pontiac himself lasted six more years, and died ignominiously, killed by a Peoria Indian at Cahokia, Illinois.

Relative calm characterized Lake Erie over the next 13 years. Another brief uprising by Ohio Indians in 1764 was quelled by the intrepid Colonel Bouquet. Marching into Ohio as far as the Muskingum River he cowed the Indians, forcing them to release 200 white prisoners captured during Pontiac's War. After these last recalcitrant Indians were subjugated, and a number of the Indian grievances redressed, the fur trade once again flourished, both Indian and trader alike profiting.

White settlement of the Great Lakes area

Like the French before them the British realized that to protect the fur trade they would need to maintain good relations with the Indians and prevent expansion and settlement from the colonies. A Royal Proclamation Line, circumscribed in 1763, limited settlement to east of the Alleghenies; however, colonies such as Connecticut, Pennsylvania, and Virginia had extended their boundaries westward, in some cases from ocean to ocean, and development could not be long forestalled. The Iroquois League was still a powerful faction and precluded any movement along the shores of Lake Erie, but farther south settlers were pushing down the Ohio River. In 1774 Lord Dunmore's War erupted along the Ohio, but Lake Erie was spared from this local outbreak. Also in 1774 the British passed the Quebec Act, which in addition to protecting the fur trade also extended Canada's boundary along the Ohio River to the Mississippi; what it didn't take into consideration were the lands claimed by the colonies, who by this time were paying scant heed to British bombast anyway.

As yet there were no settlers per se in Ohio, but white men were living there. In 1772 Moravian missionaries David Zeisberger and John Heckewelder had established a mission at Schoenbrun, and before long several missionary families were working with the Tuscarawa and Delaware Indians in eastern Ohio. These innocuous philanthropists and their flock were soon to be caught up in events far beyond their control.

The American Revolution

It took very little to fan the long smoldering resentment between Great Britain and her American colonies into the flame of open war. The outbreak of the Revolution brought no large armies into the Lake Erie wilderness; primarily it was just a continuation of a steadily increasing animosity between Red inhabitant and Colonial expansionist. Seemingly always caught in the middle of the white man's wars, the Indians in this instance opted to seek shelter under the British umbrella since the Americans were trying to appropriate and settle Indian lands, and the British were endeavoring to prevent just that, albeit for ulterior motives. Americans pushed north and west from Fort Pitt, British and Indians pushed south and east from Fort Detroit; bloody skirmishes were fought and nothing was gained. Fort Laurens, the first fort established in Ohio, was constructed along the Tuscarawas River in September, 1778, during one American foray against Detroit. For two months in the beginning of 1779, 150 defenders were besieged by British and Indians; the British, unable to crack the fort's walls, retreated, and the Americans, after successfully foiling the British, felt the fort was untenable and abandoned it. To the northeast General John Sullivan marched a U.S. Army into western New York in the fall of 1779, and in a campaign of destruction devastated the villages and crops of the Iroquois. Though few Indians were killed, their homes and livelihoods were destroyed, and the once all-powerful nation that controlled the shores of eastern Lake Erie for two centuries was in weeks reduced to a virtual nonentity.

As the war progressed columns of soldiers intermittently continued to move westward from Fort Pitt. Indians were killed and villages razed. One particularly brutal episode occurred in March, 1782. Moravian converts refused to compromise their new beliefs and fight for the British, consequently other Ohio Indians capriciously forced these peaceful Indians to move to the Sandusky area with nothing but the clothes on their backs. Faced with starvation a portion of the Moravian Indians were permitted to return to Gnadenhutten to gather crops left in the fields. There they were set upon by ninety American militiamen commanded by Captain David Williamson. Try as they might the Indians simply couldn't convince the incredulous Williamson that they were noncombatants. After all, they were Indians. Unable to think of anything else to do, Williamson and his men murdered them. Killed were 96 men, women, and children, their skulls crushed with wooden mallets. Only 2 young boys managed to escape.

Later that same year another American column was routed at the Battle of Olentangy in north central Ohio. The captured American commander, Colonel William Crawford, was tortured and burned at the stake in retribution for Gnadenhutten. Only the end of hostilities in 1783 brought a halt to the brutalities which were of late becoming commonplace in the Ohio country.

Figure 6.4. **Burning Crawford at the stake.** *(Print from The Ohio Historical Society)*

Even though Lake Erie's role in the Revolutionary War was extraneous, the Treaty of Paris, which brought about its end, held long-term significance for the region. The treaty stipulated the lake be part of the demarcation line between U.S. territory and Canada, running from the centerline of the Niagara River through the center of Lake Erie and continuing through the centerline of the Detroit River. Islands in the lake and rivers were not specifically considered, meaning there would be later arguments and adjustments, but for all intents and purposes the border between the two countries was firmly established.

Another important consequence of the war was that much of the lake region could be opened for white settlement—it was still Indian land, but why worry about such trivial matters. The main difference between the north and south shores of the lake was that the Canadians co-habited with the Indians in peace. During the war tens of thousands of people in the colonies remained loyal to the crown, and with America gaining its independence many loyalists chose to emigrate. Fort Niagara, a British stronghold, was a natural gathering place for displaced loyalists while the war was in progress, and when it ended many simply crossed the river and settled the Niagara region of Ontario and the north shore of Lake Erie.

Early Indian treaties

On the south shore the Iroquois still claimed the land that once belonged to the Erie Indians, so the U.S. negotiated and acquired the land from the remnants of the league in a treaty signed at Fort Stanwix, NY, in 1784. The treaty, however, failed to take into account the de facto occupants: the Wyandots, Ottawas, Chippewas, and Delawares. Further negotiations were therefore necessary, and in 1785 another treaty was signed with these tribes at Fort McIntosh, Pa. The boundary for Indian territory was then delineated by the Cuyahoga and Tuscarawas Rivers, thereby opening up the Connecticut Western Reserve for settlement. However, the treaty didn't include the Firelands, that section of the Western Reserve stretching westward from the Cuyahoga to Sandusky Bay—including the Lake Erie Islands—claimed by Connecticut for her residents whose homes were razed by the British during the war.

The Northwest Ordinance

Ohio at this time was partitioned into a crazy quilt pattern of tracts divided among diverse ownership. Three of these tracts were reserved as bounty lands for Revolutionary War veterans, or those who suffered in the war, and were claimed respectively by the U.S. Government and the states of Virginia and Connecticut—hence the Connecticut Western Reserve. Some land was public, some was private, and with some one just couldn't tell. Such an amorphous system could easily lead to chaos; in all the lands north and west of the Ohio River there was no rhyme nor reason, no system for buying or selling, and no laws for government.

Attempts were made to institute guidelines when Congress enacted the Ordinance of 1784. The provisions of the ordinance were unusually broad and nebulous. In the governing of a prospective state it bestowed almost unlimited power to a governor and only very limited participation to the people. As a result the ordinance was never really accepted. A year later came the Land Ordinance of 1785, organizing a system for surveying and selling public lands or distributing them in a manner to benefit all, but it still made no provision for government. Congress rectified this omission when it finally passed the Ordinance of 1787, sometimes known as the Northwest Ordinance. The Ordinance of 1787, its provisions still in effect to this day, established the territorial system, fabricated policies for governing the Northwest Territory, created procedures for carving individual territories out of the whole, and specified requirements for new territories to become states. Slavery was one of the more significant aspects of the ordinance: none would be allowed in the Old Northwest. Essentially the Northwest Ordinance was a constitution for the newly formed Northwest Territory, and more than any document in the nation's history molded the five states of the Old Northwest into what they are today. Ohio was confederated shortly afterward, and within the Northwest Territory was the first individual territory, eventually becoming the first state.

The Northwest Territory was now officially part of the new nation, and its first Governor, Arthur St. Clair, was elected by Congress on October 5th of that same year. There was little to govern as yet since the territory was sparsely populated, but this didn't relieve it of problems, almost all of which were caused by the British and Indians.

Continuing problems with the Indians and British

When the Treaty of Paris ended the American Revolution, its fifth article stipulated that Congress would recommend to all state legislatures that properties confiscated from British subjects during the war would be returned to their rightful owners. The new owners were naturally loathe to do this, and didn't. The British used what was to them an obvious treaty breach to remain in possession of the lands they were obligated to abandon, including Forts Niagara, Detroit, and Miami. At least this was the ostensible reason because in actuality Britain was vying to retain control of the lucrative fur trade, and secretly hoped the established boundary line would soon be realigned in its favor.

The Indians, even though many of their lands were signed away by treaty, did not consider binding on Indian nations what was signed by a relative few of each tribe. Their philosophy of land ownership simply didn't abide that principle. The British thus manipulated the Indians to prevent U.S. expansion into the Old Northwest, providing them with weapons, ammunition, supplies, and occasionally military advisers, encouraging them to raid American settlements and discourage prospective settlers. Since the British controlled the forts on the lakes and were agitating amongst the tribes, any attempts by Americans to exercise their rights on Lake Erie or settle its shores proved hazardous in the extreme. Neither Great Britain nor the U.S. were willing to go to war over what was considered a relatively minor issue, so America attempted different solutions on the different factions: one military and one diplomatic.

A military solution obviously could not work against the British without inciting another war—that left the Indians. In late 1790, General Josiah Harmar, with an army of approximately 1,500 men, marched north from Cincinnati. After burning some villages and crops unopposed, Harmar injudiciously divided his force to facilitate the task at hand. Awaiting just such an opportunity, and taking advantage of Harmar's ineptitude, a loose Indian confederacy, led by Little Turtle of the Miami and Blue Jacket of the Shawnee, attacked and routed the isolated detachment; outwitted, Harmar limped back to Cincinnati in humiliation. Chagrined by the defeat President George Washington appointed his old friend, General Arthur St. Clair, to assume command, and in the fall of 1791 St. Clair marched north to avenge Harmar's defeat. With almost 1,400 men St. Clair was surprised one frosty morning by the same Indians, who once again prevailed; in fact St. Clair's defeat remains to this day one of the worst disasters ever suffered by a United States Army. It was not until 1794 that the Indians were ultimately defeated at the Battle of Fallen Timbers (south of present Perrysburg, Ohio) by General "Mad Anthony" Wayne. The upshot of Wayne's victory was the Greenville Treaty, signed by the Indians in August, 1795. Besides the obvious cessation of hostilities, the treaty stipulated a boundary line remarkably similar to that of the Fort McIntosh Treaty, the only difference being that all Indian claims on the area were not totally eliminated.

Figure 6.5. "Signing the Treaty of Greene Ville." *(Painting by Howard C. Cristy)*

The problems with both Indians and British were fortuitously rectified almost simultaneously: Jay's Treaty with Great Britain was ratified the same month the Greenville Treaty was signed. Containing 28 articles altogether, it was the second article of Jay's Treaty that concerned the Northwest Territory: British troops and garrisons from all posts within the boundary lines of the Treaty of Paris were to be withdrawn by June 1, 1796. Free of constraint at last, all of Lake Erie's south shore was now open for settlement except a portion of northwest Ohio west of the Cuyahoga River. Subsequent negotiations with the Indians resulted in the Treaty of Fort Industry in 1805—which gave up the Firelands—the Treaty of Detroit in 1807, and the Treaty of Brownstown in 1808. Only a few very small reservations along western Lake Erie could afterwards be claimed by the Indians.

The founding of the first villages along the Lake

With the fear of Indian depredations removed settlers began wandering into the eastern lake region. Connecticut had been unable to dispose of this land in the Western Reserve, so in 1795 it sold the remaining 4,000,000 acres to a group of speculators who formed the Connecticut Land Company. To survey its new holdings the company dispatched a party of 50 people westward in 1796. Stopping at the Conneaut River on July 4th a few hardy people were impressed and decided to remain, founding the first community in the Western Reserve. The remainder pushed forward, reaching the mouth of the Cuyahoga River on July 22nd, where the party's leader, a land company director named Moses Cleaveland, began surveying the site for a city—the city would of course bear his name, minus one letter. Future towns in the Western Reserve were named for two other directors of the land company, Moses Warren and John Young.

Cleveland and Conneaut were only two of several villages to be founded during this period. Erie, Pennsylvania, once the site of Fort Presque Isle, was laid out by Andrew Ellicott in 1795 and settled shortly thereafter. The east bank of the Niagara River, recently the home of the Seneca Tribe of the Iroquois League, was next to receive attention. The Holland Land Company of New York acquired a piece of land along the east bank of the river, and the site of Buffalo was surveyed in 1798. Civilization was ever so slowly creeping westward.

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7/ Opening the Region to Prosperity

by Gerard Altoff

After the British evacuated their forts in U.S. territory following Jay's Treaty, they built new forts in Canada to protect their interests in the Great Lakes region. Fort Erie was constructed just across the Niagara River from Buffalo, and Fort Malden was raised at the southeast end of the Detroit River. When Detroit was evacuated many of its residents remained loyal to the Crown, so the civilians accordingly followed the military and established Sandwich and Amherstburg on the east bank of the Detroit River. No major settlements were yet located between Fort Erie and Malden, but small farms and mills were already springing up to work this rich agricultural area.

Under the provisions of the Northwest Ordinance Michigan became a territory on June 30, 1805, with William Hull as its first governor and Detroit the seat of government. Most of the territory was still Indian land. only a few scattered settlements dotting its lakeshores and riverways; in the southeastern corner of the territory only Detroit and Frenchtown could by any stretch of the imagination be called towns. A dispute arose between Michigan and Ohio over their respective borders along western Lake Erie, but little was done for the time being.

In the years prior to the War of 1812 the sparsity of population precluded heavy commercial use of Lake Erie. The fur trade was a still a viable industry, but as civilization encroached and the Indians were forced out, the trade moved to the upper lakes. The military accounted for a fair percentage of the limited traffic, not necessarily war vessels, but ships contracted to supply the numerous posts on Lake Erie and the upper lakes; in fact the first vessel to fly the American flag on Lake Erie was hired by the army to transport troops to Fort Detroit in 1796. Peter B. Porter, future general in the War of 1812, helped form a transportation company in 1805 and acquired several parcels of land along the east bank of the Niagara River. Porter, Barton & Company built several warehouses near the river, and by transporting salt from Black Rock to Fort Erie they established the first commercial link between the U.S. and Canada on Lake Erie.

The fastest growing industry on the lake was shipbuilding. Portaging large vessels around the Niagara's cataract just wasn't possible, and goods on Lake Erie were awaiting transport; shipbuilding perforce became the logical alternative. The Canadian Provincial Government established a shipyard at Amherstburg, adjacent to Fort Malden, building merchant and military vessels alike. Likewise the U.S. Government was operating from the River Rouge shipyard in Detroit. Shipyards at Cleveland, Erie, Buffalo, Black Rock, and Fort Erie were adding their tonnage. The vast majority of these vessels were sloops, schooners, or small brigs, averaging anywhere from 25 to 100 tons. Cargoes at this time comprised mostly furs, Indian annuities and trade goods, military stores, and salt. Lake Erie's potential as a major commercial route was just beginning to be realized when all of a sudden progress came to an abrupt halt—America declared war on Great Britain on June 18, 1812.

The causes of the War

It is stretching the bounds of credulity to state that the war could have been averted via implementation of judicious diplomatic measures. The affronts for which America went to war in

1812 were serious, but not unsolvable. Fighting the Napoleonic Wars, Britain at this time was endeavoring to blockade Europe. America, as a maritime nation, conducted most of its trade with Europe and hence ignored a series of economic sanctions issued by the British against Napoleon. Under the guise of these sanctions Britain confiscated over 400 American merchant ships. Another problem was the British Navy. Desperately short of sailors for its more than 600 warships, the British were stopping American ships on the high seas and abducting American sailors to fight for the British navy. Supposedly searching for deserters, the British didn't bother looking at citizenship papers and impressed over 5,000 seaman from American vessels.

Figure 7.1. **Old shipyard at Ninth Street, Cleveland.** ***(Roseboom and Weisenbergen, The Ohio Historical Society, 1986)***

In the Old Northwest the problem was, as usual, the Indians. Wayne's victory at Fallen Timbers alleviated temporarily but did not eliminate Indian confrontations. As the new symbol of Indian leadership Tecumseh, by peaceful means if at all possible, ventured to regain Indian lands. Tecumseh's dream ran contrary to American governmental policies, which were to procure more land for white settlement. With inherently conflicting viewpoints Tecumseh and William Henry Harrison, Governor of the new Indiana Territory, were frequently at loggerheads, and each new American grab for land induced bitter acrimony. In the Spring of 1811 Tecumseh, on one of his periodic travels to recruit converts for his Indian confederacy, journeyed south. In his absence Harrison decided to force a showdown. Marching a small army to Tecumseh's village along the Tippecanoe River in western Indiana, Harrison confronted Tecumseh's brother, the Prophet, whom Tecumseh had left in charge. The Prophet, ambitious in his own right, attacked Harrison's army on the morning of November 7, 1811, despite Tecumseh's implicit instructions to the contrary. The Indians were defeated, and found in their village afterwards were numerous weapons supplied by the British.

Herein lay the heart of the problems. Settlers had been plagued by Indians, and vice versa, from the beginning of the westward movement; there was mutual hatred. The consensus was that the British were doing all in their power to assist the Indians to kill and scalp "helpless" settlers. The weapons found at Tippecanoe proved this. Whether it did or didn't prove British conspiracy is irrelevant; westerners firmly believed it. It was also young westerners, with a few southerners, who were the driving influence in Congress at this time, and men like Henry Clay, Richard M. Johnson, and John Calhoun, dubbed the "War Hawks," pushed for a second war with Great Britain. Diplomacy might have avoided war, but the temperament of the times wouldn't permit it. Too many people wanted war, and when they achieved it westerners just considered it a continuation of the war already begun at Tippecanoe.

Lake Erie in the War of 1812

Strategically located Lake Erie naturally became one of the major theatres of operation in the War of 1812. With so few roads along its undeveloped shoreline, the lake was necessarily a major transportation route and lifeline to the western forts and garrisons of both sides. Lake Erie was also a ready made invasion route which could cut into the soft underbelly of either Canada or the U.S. Therefore whoever controlled Lake Erie possessed a tremendous strategic advantage. At the outset the British maintained a small fleet of warships on the lake, whereas the U.S. had but one small armed vessel.

Prior to the war many Americans erroneously believed Canada secretly desired assimilation by the U.S., and since most of Britain's armed forces were involved in Europe, Canada was deemed ready to be plucked. Of the four routes chosen to invade Canada two were located

Figure 7.2. One cause of the war was impressment of American sailors. ***(Ohio Historical Society)***

on Lake Erie, one at either end. The dual invasions of Upper Canada were designed to capture the British forts, Malden and Erie, which controlled lake access, and also render southern Upper Canada defenseless. With Fort Malden and the Amherstburg Navy Yard as an objective, General William Hull's army of 2,500 men, largely Ohio Militia, marched north from Cincinnati and up the western shore of the Lake to Detroit. After a short campaign characterized by incredible ineptitude and unbelievable blunders, Hull surrendered his entire army at Detroit to an inferior British force on August 16, 1812.

Operations at the eastern end of the lake fared no better. An army commanded by General Stephen Van Rennselaer began crossing the Niagara River below Queenston Heights on October 13, but after the fight was raging most of the New York Militia, citizen soldiers as opposed to army regulars, refused to cross the river, leaving their comrades stranded on the opposite bank. Of the roughly 1,000 regulars and militia that did cross almost all were killed or captured. General Alexander Smyth, with a brigade of 1,650 regulars at Buffalo, arbitrarily refused to cooperate with Van Rennselear. At the end of November, however, Smyth finally stirred, making a move to capture Fort Erie by crossing the Niagara with his regulars and more New York Militia; complete mismanagement and confusion compelled the landing to be aborted. The only bright spots for America on Lake Erie in 1812 were the capture of two British ships at Fort Erie on October 8th by naval lieutenant Jesse Elliott, and the fact that a man named Daniel Dobbins commenced building a fleet of gunboats at Erie, Pennsylvania, to contest British naval supremacy of the lake.

On the opposite side of the lake the small force of British regulars and Canadian militia, under better leadership, acquitted themselves creditably. Canada's greatest disaster was the death of Isaac Brock, Britain's most enterprising general officer in Canada. Killed leading a charge at Queenston Heights, the loss of Brock's indomitable leadership undeniably altered the course of the war along the northern frontier.

Seeming to make an inhuman war even more brutal, the conflict along Lake Erie's north shore took on all the aspects of virulent civil war. In the years before the war large numbers of people from the states emigrated to Canada, consequently loyalties were uncertain. Both sides recruited in the region with varied success, and quasi-military units claiming allegiance to either or neither side raided freely. In many cases guerilla raids were simply excuses to settle old grudges under the guise of military expedience. Fear ran rampant and atrocities engendered further bitterness, precipitating even more senseless violence. It was a problem unsettled during the course of the war, and deep scars remained for decades thereafter.

The year 1813 began for the Americans the way 1812 ended, inauspiciously. Another invasion attempt along western Lake Erie resulted in yet another disastrous defeat. General James Winchester was caught unaware at the River Raisin (Monroe, Michigan) on January 22nd, and only 33 men of an army of approximately 950 escaped. Amplifying hatred between Indian and American was the massacre of 65 wounded prisoners by Potawatomies the day after the battle. Perpetrated as retribution for the burning of Indian villages by American cavalry in late 1812, few Americans cared about the reason, only the dead.

After the River Raisin episode General William Henry Harrison constructed Fort Meigs at the rapids of the Maumee as an advanced base. Recognizing the fort as out on a limb the British elected to invade the U.S.; in late April the British fleet debarked the army and artillery on the banks of the Maumee and seige operations were initiated. After holding out for a week American reinforcements arrived, and despite more than half being killed or captured in a pitched battle, enough managed to reach Fort Meigs to stave off capitulation; the British retired back to Fort Malden.

The fighting was not limited to the west end of the lake. On May 27, 1813, a joint American army and navy operation captured Fort George at the mouth of the Niagara River. The fall of Fort George severed Fort Erie's supply line, necessitating the abandonment of the latter fort, so that for awhile at least both banks of the Niagara were in American hands. The fall of Fort Erie also enabled Oliver Hazard Perry, newly appointed commander of the infant Lake Erie fleet, to transfer several small converted merchant ships from the previously blockaded Black Rock Naval Yard to Erie, Pennsylvania. Added to the six vessels constructed at Erie between November, 1812, and July, 1813, they combined to furnish Perry a formidable fleet of warships. In mid-August Perry sailed for Western Lake Erie, choosing Put-In-Bay on South Bass Island as his base of operations. There was little for Perry to do afterwards except wait. The next move was up to the British.

Figure 7.3. Massacre of captured Kentuckians at Frenchtown following the battle at the River Raisin. ***(Clements Library, University of Michigan)***

The British in the meantime had mounted a second invasion of northwestern Ohio in late July. A second attempt to capture Fort Meigs was no more successful than the first, and feeling their Indian allies would abandon their cause without some sort of victory, the British moved on to what they felt was a more tractable target. On August 1st the British forces surrounded Fort Stephenson (Fremont, Ohio). There the obstinate 21-year-old Major George Croghan and his small, heavily outnumbered garrison of U.S. infantry bloodily repulsed a determined bayonet charge, forcing the British to once again retreat to Fort Malden.

Perry's appearance at Put-In-Bay created a dilemma for the British. With their fleet out-

Figure 7.4. Perry's Victory on Lake Erie. *(from an engraving by A. Lawson, after T. Birch)*

numbered and supply line along the lake cut off, they were left the option of either to fight, or abandon Fort Malden and the entire Detroit region. There was really no choice; the British fleet appeared northwest of Put-In-Bay, and in a three hour duel Perry's fleet of nine vessels overwhelmed and captured Robert Heriot Barclay's entire force of six ships. It was a signal victory with fortunate timing. Besides being a turning point of the War of 1812 in the Old Northwest, the victory occurred at a time when America was becoming frustrated and disenchanted with the war. Perry's decisive victory bolstered American morale and provided the necessary impetus to finish the struggle.

For the first time in the war the lake was undisputedly American. Perry's ships, combined with a fleet of small invasion craft built at Cleveland by Major Thomas Jessup, ferried Harrison's army from Camp Portage (Port Clinton, Ohio) to the Canadian mainland. Having no hope of a successful defense the British burned Fort Malden and the navy yard, and with their Indian allies retreated up the Thames River. Harrison followed and brought the British to bay just west of Moravian Town (near Thamesville, Ontario)—ironically occupied by the same peaceful Indians who had fled the U.S. seeking a place of safety after Gnadenhutten. Harrison attacked. Demoralized after Fort Stephenson and Lake Erie, the British regulars surrendered after only a short fight. The Indians, however, stoutly resisted, fighting for their homeland and very existence, until Tecumseh, physical and spiritual leader of the Indian movement, was killed. After Tecumseh's death the Indians melted into the woods, and for all intents and purposes, as far as Lake Erie was concerned, faded into the oblivion of the history books. The Battle of the Thames was another decisive American victory, and together with the Battle of Lake Erie virtually ended the War 1812 in the Old Northwest.

But eastern Lake Erie was still embroiled in conflict, and scorched earth became the unfortunate policy. After capturing Fort George in May the Americans met with several reverses and the tempo stabilized, much of the fighting and most of their troops eventually moving up the St. Lawrence. Fort George was left garrisoned by New York Militia, many of whose enlistments expired in early December, so naturally they went home. With few men and fearing a British attack, General George McClure chose to abandon the fort and retreat across the Niagara. In the early hours of December 10th he moved, but instead of burning Fort George and its supplies, McClure unaccountably set fire to the adjacent town of Newark, throwing the inhabitants, mostly women and children, out in the snow.

The British, of course, retaliated. In the pre-dawn hours of December 18th British soldiers crossed the Niagara River, and in a surprise bayonet attack captured Fort Niagara. British and Indians moved quickly south behind a hasty and rapid retreat of the American militia. Lewiston, Youngstown, Manchester, and Fort Schlosser were burned by the British; Black Rock and the navy yard, including two vessels from the Battle of Lake Erie, were burned; Buffalo was burned. Little remained of the east bank of the Niagara frontier except foundations and chimneys.

There was no improvement in 1814. In mid-May a force of regulars and Pennsylvania militia boarded ships at Erie and sailed for Port Dover. Sent to destroy military supplies, matters somehow got out of hand; old scores and grudges needed to be se ·d, so private homes from Port Dover to Long Point were looted and put to the torch. To avoid inevitable British retaliation the Americans denounced the atrocities and court martialed the American commander of the expedition. It was too late; the British were palpably outraged, and the Port Dover debacle culminated in August with the burning of all public property in Washington, D.C.

The regular war on the Niagara frontier resumed in July, 1814. On the third of that month General Winfield Scott led a strong American army across the Niagara, this time well trained and disciplined regulars. Two days later they defeated a British force of regulars at the Battle of Chippewa, and on July 25th the armies fought each other to a bloody standstill in the Battle of Lundy's Lane, near Niagara Falls. An American retreat to Fort Erie was followed up by the British, who laid seige to the fort. For six weeks the British doggedly maintained their seige; one determined British assault was repulsed with heavy losses, an American counter-attack met with like results. On September 21st the stultified British finally gave up and withdrew. The Americans, after spending many lives to hold Fort Erie, decided they didn't want it after all, and on November 5th they mined the fort and retreated across the Niagara. The War of 1812 on Lake Erie ended with a big bang, the final act making about as much sense as the whole war.

The aftermath of the War

The Treaty of Ghent was signed on Christmas Eve, 1814, bringing the Canadian-American tragedy to an end. Ironically the major causes for the war weren't even addressed in the treaty—the fall of Napoleon had eliminated the economic sanctions and impressment problems, and the Indian question was glossed over. As to the boundary, the treaty called for "status ante bellum," everything was to remain the same as before the war and all captured territory was to be returned. Over two years of bloodshed and absolutely nothing was materially gained by either side. Typically, the only real losers were the Indians.

Both sides also won. Canada emerged from the war with a newly discovered national pride, having rebuffed annexation attempts by a country with vastly superior material and population. America displayed a newly won pride in its military—despite its early humiliations-after defeating the cream of the British army at Chippewa and New Orleans, and also evinced a renewed confidence in its independence. For Lake Erie the War of 1812 was the single most dramatic episode in its human history. This war reached all the lake's nooks and crannies, impacted its future development, left monuments to blood and heroism along its shorelines, implanted bitterness over the brutalities and atrocities, and saw the birth of a peace that remains to this day.

Once begun the peace movement flourished. On April 16, 1818, the U.S. ratified the Rush-Bagot Agreement, a treaty between the U.S. and Great Britain that limited naval vessels and armaments on the Great Lakes. For the upper lakes, including Lake Erie, it dictated no more than two vessels for each country, not exceeding 100 tons and one 18-pound cannon. Although the terminology is archaic, the provisions of the treaty are still in effect. Many first had to die, but a lesson was learned, the hard way. Ever since the War of 1812 the U.S., Canada, and Great Britain have settled their differences peacefully through a process of disarmament, arbitration, and negotiation.

Opening the region to prosperity

The end of the war also marked a new era of prosperity on Lake Erie. With the threat of violence removed settlers flowed into all corners of the lakeshore, isolated cabins became villages, villages became towns, and towns became cities. Industries developed, the land was worked, and the bounty of the lake was harvested; commerce thrived and Lake Erie became one of the hubs of that commerce.

Helping to mark the beginning of this new era was the appearance on Lake Erie of a completely new type of vessel, the steamboat. Built at Black Rock, N.Y., the *Walk-in-the-Water* sailed on her maiden voyage on August 23, 1818, creating a sensation wherever she put in. Lost in a storm only three years later, the *Walk-in-the-Water* was nevertheless a precursor of the tremendous volume of commercial traffic that would appear in just a few short years.

New technology was appearing, the economy of the lake region was growing and exports were increasing. The only problem now was getting these goods to their destination. No easy transportation route existed once the eastern end of Lake Erie was reached; either a laborious and time consuming land route was involved, or, if something needed to be shipped east from say central Ohio, it was sometimes easier and faster to ship it by the unbelievably roundabout route of the Ohio and Mississippi Rivers, and then around via the Atlantic Ocean. If the situation remained static Americans of the western lakes region would lose the competitive race because the St. Lawrence was available to their northern neighbors. The solution was well known, it had been bandied about for almost 100 years, but was just never tried. Canals!

The Erie Canal

As early as 1724 Cadwallader Colden of New York City espoused the feasibility of a water route to Lake Erie via the rivers of central New York state. George Washington brooked the subject in 1783, as did George Clinton in 1791 and General Philip Schuyler in 1797. New York even passed a resolution in 1810 to examine a route from the Hudson River to Lake Erie, but action was interrupted by the War of 1812. Difficulty in moving supplies during the war only reinforced the need for an easier route, and at war's end enthusiasm for the project grew.

Due in no small part to the efforts of DeWitt Clinton, New York finally appointed a canal commission and appropriated funds. Work began on July 4, 1817, in Rome, New York, and over the next eight years a canal was built in three major sections. During construction of the western section a controversy arose over where the terminus should be located. Black Rock argued it already had the necessary facilities and established trade, but Black Rock was three miles down the Niagara River from Lake Erie, and manually dragging vessels against the current was an onerous task; even steamboats had difficulty. In the end Buffalo won after agreeing to dredge its harbor, and from that time forward was assured of becoming a major economic center. Completed on October 25, 1825, the Erie Canal was 363 miles long from Buffalo to the Hudson River, consisted of 83 locks, and cost $7,600,000 to build. The canal proved to be a "sluice of wealth," and was not only an export route for lake products, but also a gateway for settlers and manufactured goods entering the lake region.

Figure 7.5. Canals in Ohio. *(Ohio Historical Society)*

A spurt of canal building

The Erie Canal was just the beginning of a canal building craze which kept the lake region busy for decades. In 1821 Canada passed an act for the improvement of internal navigation, and under its provisions a commission was formed to explore a feasible route for a canal between Lakes Erie and Ontario. Formed in 1824 was the Welland Canal Company, and through its efforts work began a year later. Starting at Port Dalhousie on Lake Ontario and following Twelve Mile Creek up the Niagara escarpment, a channel connected the canal with the Chippewa River, which ran into the Niagara above the falls. From there vessels had to be towed up to the lake. The Welland Canal opened on November 27, 1829, two vessels passing that day from Lake Ontario to Buffalo, New York. Work on the canal continued, however, since it was desirable to eliminate the difficult stretch on the Niagara River, and four years later it was at last finished, with the Lake Erie terminus located at Port Colbourne, Ontario. The 150-year battle with the

Niagara River, beginning with LaSalle in 1679, was finally won. Improvements on the canal continued with new sections dug and old ones deepened or widened, until eventually it became the 28-mile-long Welland Ship Canal of the present day.

Before the Erie Canal opened, and even before the Welland Canal was started, Ohio also joined in the act. Feeling the economy of the state was dependent on a good canal system, Ohio formed a canal commission in 1822 and hired an engineer to study prospective routes. The Commission aimed towards connecting Lake Erie with the canals, by the state's river system. Three different routes were initially studied: an eastern route joining the Cuyahoga and Muskingum Rivers, a central canal linking the Sandusky and Scioto Rivers, and a western route connecting the Maumee and Miami Rivers.

Work on the Ohio-Erie Canal, the former of the three, began on July 4, 1825, near Newark, the groundbreaking ceremony presided over by none other than DeWitt Clinton, along with Ohio Governor Jeremiah Morrow. A similar ceremony, attended by the same two individuals, was performed a few weeks later for the groundbreaking of the Miami-Erie canal at Middletown. The original concept of three canals was modified; instead of a separate canal the Scioto River would be joined to the Ohio-Erie Canal, thus eliminating completely the Sandusky tie-in.

Progress on the Ohio-Erie Canal was rapid, much of the work being performed by Irishmen from the Mohawk Valley of New York, the same hardy individuals who labored on the Erie Canal. Hundreds of jobs were generated and immigrants poured into northcentral Ohio. The path of the canal exuded prosperity. Unfortunately the route of the canal was also lined with the graves of hundreds who died from fever during its construction. Completed in 1833, the Ohio-Erie Canal linked Cleveland with the Ohio River at both Portsmouth and Marietta, and the port cities at either end thrived.

At the other end of the state it was the southern part of the Miami-Erie Canal, the section which served Cincinnati, that was excavated first, and it was not until 1845 that the entire canal, its northern terminus at Toledo, was finished. Eventually several feeder canals were dug connecting *with* each, but not *to* each, of the other two main canals, and they served practically every major population center in the state.

The canal obsession was in full swing when Indiana decided to join the bandwagon. Begun in 1836 was the Wabash-Erie Canal, which when finally completed connected the Ohio River with Lake Erie from Evansville, Indiana, to Toledo, Ohio, stretching a total of 460 miles and adjoining the Miami-Erie Canal at Defiance, Ohio.

A canal marrying Lake Erie to the Ohio River was also dug in western Pennsylvania. Stretching from Erie, Pennsylvania, down the Beaver River, the canal hitched up with the Ohio River at Beaver, Pennsylvania, a few river miles below Pittsburgh. This latter canal also had a feeder canal connecting it with the Ohio-Erie Canal at Akron. A veritable spiderweb of canals now laced the entire midwest.

This complex system of inland waterways was practically completed by 1847, and the contribution it made to the development of the Lake Erie region is incalculable. Jobs and immigrants were brought in, the shipment of all types of agricultural and industrial goods was made relatively cheap and simple, and places like Toledo, once ramshackle collections of crude huts, were turned into major port cities and economic giants. Unfortunately, by the time the system was completed it was already obsolescent. Railroads were pushing into Ohio by the 1830's and while the canals prospered for awhile, they were unable to compete with the burgeoning railway system. By the onset of the Civil War the canals, with the exception of the Erie and Welland Canals, were in a steady decline from which they could never hope to recover.

Sickness and conflict

Lake Erie was passing into a new age, but even so it could not be rid of all its old world troubles. In the Spring of 1832 cholera was detected in Quebec, and before long the pestilence spread to Albany and Buffalo. It swept along the banks of Lake Erie and continued westward, leaving a trail of death. Cholera cemeteries like the one in Sandusky still dot Lake Erie's shores. Mostly forgotten and ignored, they remain as pitiful reminders of the heartbreak and misery suffered by our forefathers.

The Ohio—Michigan border dispute

No sooner had the cholera epidemic ebbed when a full-fledged border dispute erupted between Ohio and Michigan; the "Toledo War" was on. The debate could be traced all the way back to the Ordinance of 1787, which stipulated the boundary between any northern and southern states in the Northwest Territory to lie on a line perpendicular with the southern tip of Lake Michigan. Both the Ohio Enabling Act of 1802 and the act forming the Michigan Territory in 1805 conceded this line, and only Congress had the authority to change it. The Ohio Constitutional Convention, fearing the never actually surveyed line might be much further south than first anticipated, arbitrarily transposed the boundary and drew it perpendicular to the northern cape of the Maumee River; Congress didn't react one way or the other. In 1817 Ohio surveyed and marked the boundary according to its constitutional mandate. Michigan objected, but nothing was done at the time.

The affair simmered until 1835. In that year Michigan was lobbying for statehood, and to clear up the dispute Michigan offered a compromise to Ohio Governor Robert Lucas; Lucas turned it down, and Michigan geared up to prevent Ohio from stealing its land. Both sides passed laws establishing jurisdiction in the same area, and both leveled stiff penalties for interference with officials in the performance of their duties in that area. Ohio even went so far as to organize Lucas County within the disputed area and form a common pleas court at Toledo. Fanning the flames was Toledo itself, in competition at this time for the Lake Erie terminus of the Miami-Erie Canal, thereby injecting serious economic implications into the feud. Tensions rode so high that Ohio and Michigan Militia were called out to protect individual interests.

The politically astute Governor Lucas finally played his ace. Sending a deputation to Washington to remind Andrew Jackson that 1836 was an election year, he pointed out that Indiana and Illinois would also lose territory if Michigan won a decision, making it clear to Jackson that his popularity in the affected states of Ohio, Indiana, and Illinois would be seriously eroded, not to mention the loss of critical electoral votes. That was enough for Jackson. Disclaiming any fealty towards individuals or states he passed the buck, turning the matter over to Congress. The latter devised a surprisingly sagacious compromise, rendering a decision in favor of the three lower states and territories, and compensating Michigan by allowing that territory to claim the Upper Peninsula within its boundaries when it was admitted to the Union on January 26, 1837.

Rebellion in Canada

No sooner had one crisis been averted at the southwestern end of the lake than another erupted along its northern border. When it came to governing its colonies England's policies tended to be self-serving and somewhat less than far-sighted—Canada was no exception. The Act of 1791 had divided Canada into two provinces. Lower and Upper Canada, the former comprising mostly French speaking inhabitants and the latter English. Naturally the national, religious, and political differences inherent in any such division were bound to cause problems, mostly in Lower Canada since Upper Canada was more closely attuned culturally to the home government in England. Inevitably English influence wormed its way into Lower Canada's French dominated culture and compounded the problem. Upper Canada, however, was not immune from the meddling English or their governmental system of aristocratic rule. After the War of 1812 Lower Canada's own aristocracy monopolized its bureaucratic system, and this "Family Compact" ruled exclusively with an iron hand, closely tied to the mother country. One of the major causes of dissention was the distribution of land. The Family Compact, in concert with the Church of England, controlled huge tracts of land under the guise of Clergy Reserves; favoritism and nepotism abounded in parcelling out this land, and immigrants from the United States were not even allowed the right to own land. Press censorship, restricted educational policies, and persecution of dissenters further fueled the flames of discord.

Open rebellion came in 1837. Although both Upper and Lower Canada rose almost simultaneously, the two movements were quite distinct and separate owing to individual grievances. In Lower Canada the egotistical Louis Joseph Papineau, with a small band of followers, struck the first blow at Montreal on November 6th. He was easily crushed. In Upper Canada it was extremist William Lyon Mackenzie who, after founding a Committee of Vigilance, issued a proclamation of independence on November 11th. Attempting to capture Toronto on December 7th, Mackenzie's ill-conceived and ill-prepared sally was rapidly quashed. Both Papineau and Mackenzie fled to the United States to continue their quests.

In the U.S. both revolutionaries found sympathetic elements among the populace by preaching the popular topic of rebellion against England. At Buffalo Mackenzie called a public meeting and gained wide support for his cause after a speech denouncing English tyranny. Hundreds pledged Mackenzie their support, but as most often occurred during this uprising, promised support far exceeded actual participation. Even so, Mackenzie, with a small party of volunteers commanded by Rennselaer Van Rennselaer, son and grandson of War of 1812 generals, seized a number of weapons and promptly grabbed Navy Island. There, on December 13th, Mackenzie set up his Provisional Government of Canada.

Sympathy for these so-called patriots ran high; supplies and more volunteers were soon forthcoming. To transport both men and supplies to Navy Island the schooner *Caroline* was pressed into service. Flying the American flag, the *Caroline* shuttled from Buffalo to Schlosser to Navy Island, mooring at Schlosser on the night of December 28th. On the west bank of the Niagara the *Caroline*'s movements had not passed unobserved. In the early morning hours of the 29th a cutting out party of British troops and militia boarded the *Caroline*, killed a number of her crew, and set the blazing hull adrift. The action was subsequently approved by the British government, even though the *Caroline*'s masthead flew the American flag. Washington's response was to send General Winfield Scott to the Niagara frontier with American troops, an action which induced the British in Canada to begin gearing up—America and England were once again on the brink of war.

In the meantime more volunteers and supplies were rushed to Navy Island. All for nought as it turned out; Mackenzie's dreams and designs for an independent Canada based on the American political system were doomed to failure. British troops and Canadian Militia at Chippewa heavily outnumbered Van Rensselaer's small force on Navy Island, and Scott, on arrival at Buffalo, blocked any further attempts to reinforce the island. Isolated and helpless, Mackenzie and Van Rennselaer abandoned Navy Island on January 14th, 1838. Both leaders were eventually caught and arrested, tried for violations of the neutrality laws, and sentenced to short prison terms.

Mackenzie failed, but the rebellion was far from over. Active operations just shifted westward. Republicans held a public meeting at Detroit on January 1, 1838, resulting in the formation of the Patriot Army of the Northwest, a small, ragged group of volunteers. What ensued turned into a farce; attempts at organizing and equipping the force were complicated by the ambivalent Governor of Michigan and frustrated by the U.S. Army, and when sixty volunteers did manage to seize Bois Blanc Island, the foray collapsed when their supply vessel, the schooner *Anne*, was ineptly handled and captured by Canadian Militia.

The revolutionaries regrouped, schemed, and organized a series of attacks to coincide with Washington's birthday, 1838. The first action occurred at Fighting Island, several miles below Detroit, on February 25th. Approximately 400 poorly equipped and equally poorly led volunteers were easily defeated by British troops and Canadian Militia. The second thrust, scheduled to seize Fort Henry at Kingston, Ontario, fizzled when its leaders fell to bickering. The most significant attack occurred in early March. A substantial force of volunteers from Canada, New York, Pennsylvania, Ohio, and Michigan seized Canadian owned Pelee Island, largest of western Lake Erie's archipelago. Discovering the invasion, a mixed group of British Regulars and Canadian Militia crossed the ice, stormed the island, and after a sharp and bloody skirmish compelled the volunteers to retreat to Sandusky, where the latter were disarmed and disbanded by Ohio Militia. Two more attempts to cross the border, one at Lewistown, New York, in June and the other at Detroit in July, were equally unsuccessful.

After these dismal, disorganized failures, revolutionary activities concentrated in an organization known as the Hunters, a society of lodges founded specifically for the purpose of sustaining the rebellion. Reportedly the lodges contained thousands of members in states bordering Canada, and in September, 1838, a convention of Hunter Lodges was held in Cleveland. Embodied at the convention was a republican government for Upper Canada, and invasion plans were hammered out to place the new government in power. The Hunters moved on the night of November 11th, crossing the St. Lawrence River at Ogdensburg, New York, with the intention of capturing Fort Wellington at Prescott, Ontario. Discovered by an alert guard the attack on the fort was thwarted, but the Hunters persisted, capturing instead a strong stone mill. Of the 1,000 men originally slated to participate only 200 actually crossed the river; their numbers were small and their methods probably misguided, but the hardy little band put up a stout resistance. The end result, though, was a forgone conclusion, and the stalwart mill defenders were crushed by British troops.

The following month the die-hard Hunters struck again. Two companies crossed the Detroit River on December 4th and managed to burn a few buildings and a steamer moored at Windsor. British troops rushed from Fort Malden killed or captured 71 of the invaders, ending once and for all large scale operations by the Hunters.

The border settled down after the Hunters' last debacle at Windsor. The Hunters' and Patriot armies' lack of success was due in no small part to the efforts of Winfield Scott and the U.S. Army. Though unable to completely prevent armed incursions, the army did yeoman service in baffling and foiling the revolutionaries' attempts to arm and equip. After all, the governments themselves did not want war, even if certain factions on either side of the border were striving to instigate just that. To keep the pot boiling the Hunters resorted to terror tactics, venturing to blow up Isaac Brock's monument on Queenston Heights in April, 1840 and attempting to sabotage the Welland Canal in September, 1841. For all intents and purposes, though, the fight had reverted to the political and legal arena, the threat of war hinging on the case of one man, Alexander McLeod.

McLeod was a member of the boarding party that captured and burned the steamer *Caroline*, and he boasted afterward of killing one of her crew. When McLeod foolishly crossed into New York in November, 1840, he was, of course, immediately arrested and indicted for murder. The British government demanded McLeod's release, insisting he was acting under the auspices of His Majesty's service and was simply obeying orders. Incredibly, the U.S. Government could find no legal means of superseding New York's jurisdiction over the case; federal courts were thus impotent in dealing with what was clearly a delicate case of international law. The question of McLeod's release spiraled all the way to the New York Supreme Court, which after lengthy deliberations ruled that Mc Leod killed at least one of the *Caroline*'s crew, nevertheless, he was acquitted; it was ironic that political expediency apparently abrogated justice for the sake of peace. Not surprisingly Congress subsequently passed a law consigning any such future cases to federal jurisdiction.

War fever abated when the McLeod affair was settled, even though the Hunters continued to foment revolt. Border tension was further defused when the governor of Upper Canada was at last replaced with a liberal. Then the threat from the Hunters evaporated when their last invasion plan collapsed, as no men could be enticed to face the strengthened British force in Canada. The rebellion's denouement occurred on August 9, 1842. Negotiations between Secretary of State Daniel Webster and Lord Ashburton had concluded with the signing of the Webster-Ashburton Treaty at Washington, D.C., returning peace and prosperity once more to the Lake Erie region.

Development of Lake Transportation

By the mid-1840s the frontiersmen, like the Indians before them, had quietly faded into the imaginations of children. The shores of Lake Erie were now civilized; new technology replaced time honored methods and archaic materials. The first propeller driven vessel—an invention perfected by John Ericsson, designer of the U.S.S. *Monitor* of Civil War fame—appeared on Lake Erie in 1842, and the U.S. Navy's first vessel constructed entirely of iron, the gunboat *Michigan*, was launched at Erie in 1843. A system of lighthouses was springing up to assist and guide ever increasing merchant fleets to move ever increasing tonnage of every imaginable cargo. Canals and railroads were being completed, business was booming; Lake Erie was rapidly developing into a major artery for travel and trade.

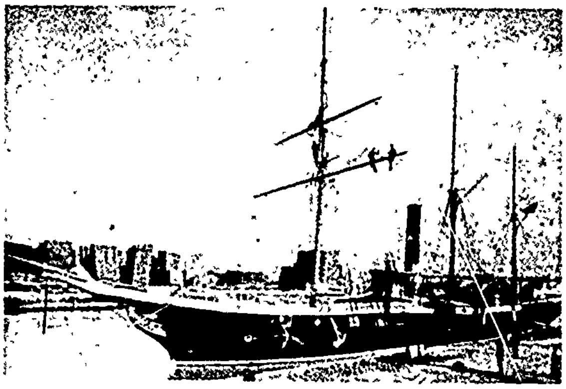

Figure 7.6. *U.S.S. Michigan. (Erie County Historical Society*

The potential for continued growth on Lake Erie suffered a major setback in 1846. Recently introduced and passed by Congress was the Rivers and Harbors Bill, designed to appropriate funds for needed improvements in port cities. Well over $150,000 was slated for Buffalo, Erie, Ashtabula, Cleveland, Huron, Sandusky, River Raisin, and Detroit; the Bill even carried a proviso for a Lake Erie dredge boat. President James Polk vetoed the Bill. Polk was of the opinion that benefits derived from such legislation would be felt only on the local level, and that projects lacking national significance should therefore not be funded by the government. Clearly Polk did not comprehend the fundamental import of the inland water-borne transportation routes or their potential to the future of the country, and his shortsighted attitude aroused widespread anger and indignation. So aroused was the Great Lakes region that a Rivers and Harbors Convention was held in Chicago in the summer of 1847, attracting over 2,300 delegates from at least 19 states. Some of the most influential men in the country attended, including a lanky representative from Sangamon County, Illinois, by the name of Abraham Lincoln, and a number of resolutions were adopted. Essentially the resolutions urged that the nation's lakes and rivers be accorded the same considerations as the oceans when pertaining to commerce, safety and defense. The government couldn't possibly ignore such an outpouring of national sentiment, and funds were soon forthcoming. Ever afterward the national significance of the lakes was not underestimated, and Lake Erie was assimilated as an integral cog in the national maritime wheel.

The Underground Railroad

Politics, in this instance, produced a favorable solution for the harbors of Lake Erie, but another political development was amassing a threatening storm cloud which loomed on the horizon of the entire country; the issue was slavery. The first thunder was a by-product of only a few ardent abolitionists, their distant peals barely heard and the dark clouds low in the sky. Lightning flashed with the Great Compromise of 1850, and one particular aspect of the Compromise generated extra electricity, the Fugitive Slave Law. Prior to the law most northerners were relatively ambivalent toward the institution of slavery; it was a vaguely unpleasant business that somehow didn't seem quite right, but it was a remote nuisance isolated in the distant southern states. Slavery had little effect on their lives and average Northerners prided themselves on minding their own business. Slaves had, of course, been escaping to Canada for many years, and this desire for freedom from enslavement was something northerners could easily understand. They were sympathetic, but it was nothing to get excited about and certainly not justification to interfere with Southern internal affairs.

The Fugitive Slave Law changed all that. The thought of slave catchers roaming the north was loathsome, the thought of free Blacks in the north being abducted back into slavery on the flimsiest of pretexts was abhorrent, and the thought of being fined or jailed for helping someone escape human bondage was odious. Most objectionable was the fact that the Fugitive Slave Law repudiated a fundamental dictum of the U.S. Constitution; when caught in the North slaves were denied the basic right to trial by jury. Backfire is what the law actually did. It spurred northerners to help slaves escape rather than to assist in returning them, and it placed slavery in the forefront of the political arena.

Law or no, slaves would continue to flee. The easiest path to freedom for a slave was escape from the United States, the simplest way to escape the U.S. was to cross into Canada, and the shortest and quickest means of egress to Canada was via Lake Erie. Slaves migrated to freedom via what became known over the years as the underground railroad, and every port on the north shore of Lake Erie became a terminus of the railroad. Safehouses, or railroad stations, dotted the tracks, financed by abolitionists and manned by Quakers, other religious sects, or just plain humanitarians. Invisible tracks of the railroad crisscrossed Ohio, Pennsylvania, eastern Michigan, and western New York. Two of the most popular destinations were Buffalo and Detroit, a veritable stone's throw from freedom. Other popular stations were the port cities that lined the southern shores of Lake Erie. Seldom did steamers undertake voyages to Buffalo or Detroit without first stopping at Fort Erie or Fort Malden, and vessels with a Canadian destination were almost guaranteed to have frightened but exultant passengers whose lives were about to take a sudden upswing. Steamers like the *Arrow* and *Morning Star* even gained a certain notorious reputation as abolitionist ships. The run of the underground railroad is an inspiring story of people risking reputations and their own freedom to help defeat repression, a forerunner of the modern human rights movement. Through the efforts of a few hundred altruistic and selfless samaritans uncounted thousands of slaves gained their liberty in Canada, and Lake Erie, for a vast number of those slaves, was the road to freedom.

The Civil War

Slavery, however, was but one of the hot potatoes legislators juggled in the political forum. Combined with the headier issue of states' rights, and the impassioned temperament of the period, it was inevitable that the storm cloud of war would eventually climb over the horizon. The tempest burst on April 12, 1861.

Enmeshed in an internecine Civil War, the U.S. was too preoccupied with its own predicament to comprehend the apprehension this conflict engendered on its northern border. Relations between the U.S. and Canada were for the most part harmonious in the decade preceding the American Civil War. In late 1853 the Great Western Railroad was completed across lower Ontario, and when a spur connected Detroit it was cause for great celebration. Then in 1857 an underwater telegraph cable linked Windsor and Detroit. An unmistakable sign of improving relations was the recall of British troops from Fort Malden in 1851. The fort itself was converted to a lunatic asylum in 1859. Generating tremendous enthusiasm in 1860 was the tour of Edward, Prince of Wales, his excursion including visits to cities on both sides of Lake Erie. Tranquility characterized the northern border in 1861.

The outbreak of the Civil War negated much of this harmony, and old tensions quickly returned. Canada understandably did not look kindly upon thousands of soldiers mobilizing near her borders. The fear of invasion was in many minds. In May, 1861, Queen Victoria issued a Proclamation of Neutrality, making England's intent clear; nevertheless, arms and British regulars were hurried across the Atlantic to strengthen Canadian garrisons. A secret study was undertaken by Britain's military to investigate the feasibility of placing warships on Lake Erie and how best to prevent American seizure of the Welland Canal. Some Americans actually hoped for war with Great Britain, feeling such an eventuality might reunite the divided nation. That predilection for war was brought all too close by the indiscretion of one headstrong man.

On November 6th, 1861, Charles Wilkes, impulsive commander of the U.S.S. *San Jacinto*, stopped the British mailship Trent on the high seas and forcibly removed two Confederate diplomatic commissioners on their way to London. Enraged British citizens clamored for war and a provoked British government demanded redress and a full apology. Canadian volunteers poured in to help the British troops in Canada, who were placed on a footing and massed at strategic cities like Toronto, Kingston, Hamilton, and London to counterattack any invasion attempt. Some hotheads in America, in an incredulous turnabout from the War of 1812, felt search and seizure of foreign vessels their right under the circumstances, and argued for war with Great Britain. The outlook was bleak. One small mistake at this stage and the U.S. would be inextricably embroiled in a two-front war.

Fortunately the pragmatic hand of Abraham Lincoln took a firm grip. Understanding the U.S. could not possibly survive a simultaneous confrontation with a formidable Great Britain and an upstart Confederacy, Lincoln issued a formal apology and returned the Confederate commissioners, denouncing the *San Jacinto's* actions in the process. Great Britain's Secretary of State for War appreciated Lincoln's dilemma, stating the U.S. would have to be insane to challenge the greatest maritime nation in the world while fighting its own bloody Civil War.

Tempers along the northern border cooled, but tension wasn't totally eliminated. Once again, because of their proximity to Canada, Detroit and Buffalo became popular, this time as a means of escape for Union deserters and draft dodgers across the border after conscription was instituted in 1863. Another sore point was that both North and South, desperate for professional soldiers, recruited among British units in Canada, offering large sums of money in some cases, or encouraging desertion in others. Also, large numbers of Northern and Southern spies roamed freely in Canada, their bungling, maladroit incompetence an embarrassment to everyone. All in all there were enough incidents to keep nerves frazzled, but war between the U.S. and Canada never came closer than it had during the *Trent* affair. Negative aspects are all too frequently emphasized, while often forgotten and little heralded are the countless Canadians who enlisted and fought in the Northern armies during the Civil War, men who suffered and died to preserve a greater United States.

Other than the occasional border incident, Lake Erie was a backwater of the Civil War. Tens of thousands of men from her shores enlisted in the Union armies, donned their blue uniforms, and marched into the maelstrom, thousands never to return, victims of a fratricidal slaughter that rapidly degenerated into a savage contest of attrition. The bones of Lake Erie's best young men populated the battlefield cemeteries of the South.

Inevitably the war had to come to the Lake in one form or another, over and above the constant flood of telegrams from the War Department to soon to be grieving mothers. Both sides were totally unprepared to cope with vast numbers of prisoners of war. To expand its prison system the U.S. Government ordered Lieutenant Colonel William Hoffman, Commissary General of Prisoners, to western Lake Erie in October, 1861, to investigate sites for a new prison. Ideal would be one of the remote Lake Erie islands, a sanctum which would seriously impede any escape attempt. Hoffman rapidly ruled out both North and Middle Bass Islands as too near the Canadian border, and South Bass and Kelley's Islands were eliminated from competition because of their vineyards and wineries, too great a temptation for even disciplined guards. Eventually selected was Johnson's Island, inside Sandusky Bay and just south of Marblehead Peninsula. By mid-November half the island's 300 acres were leased by the government, and over the next four months thirteen large barracks and dozens of smaller support structures were constructed. By April, 1862, the prison was ready; on the 11th of that month the first consignment of 200 Confederate prisoners arrived.

Figure 7.7. Johnson's Island, site of Confederate prison. ***(photo by Vic Mayer)***

Over the next three years more than 25,000 prisoners unhappily passed through the portals of Johnson's Island. For the most part they were rebel officers, but included also were enlisted men, Union deserters and a few political prisoners. To this day 206 of them remain there. During peak months of operation between 2,500 and 3,000 prisoners were incarcerated at any one time. Several escapes and escape attempts took place, keeping the guards on their toes, ar rumors of at least two major raids to rele prisoners in masse precipitated the movement troops and artillery in and out of the Sandusky area. A third rumored attempt, no rumor at all, proved to be a bizarre little incident known today as the Lake Erie Conspiracy, the lake's most exciting moment of the war.

As the steamer *Philo Parsons* was about to depart Detroit on September 19, 1864, for its usual run to the Lake Erie Islands, it was boarded by a number of quiet, pensive men. A stop at Malden produced a similar group of passengers. The regular stops at the three Bass Islands passed uneventfully and the *Philo Parsons* steamed over to Kelley's Island. Shortly after leaving Kelley's at 4:00 p.m. the first mate, called aside by a bearded passenger, was surprised to find a pistol stuck under his nose. Within the next few minutes John Yates Beall, an officer in the Confederate Navy, along with his band of 30 men, commandeered the ship. By 5:00 p.m. the small steamer was approaching Sandusky Bay. The conspirators could see the U.S. Navy gunboat *Michigan* anchored by Johnson's Island. The plan was to board and capture the *Michigan* and then release over 2,500 prisoners onto the Ohio mainland.

The conspiracy was the brainchild of Jacob Thompson, former Governor of Mississippi, Secretary of the Interior under President James Buchanan, and currently principal Confederate agent in Montreal. After devising the scheme Thompson appointed Charles F. Cole, another Southern naval officer, to enact it. Cole registered at a Sandusky hotel in October, where he was joined by Beall. Together they conducted surveillance of the island and concocted a plan. Cole would remain at Sandusky while Beall performed the actual deed.

Up until the time Beall spotted the *Michigan* the plan worked perfectly, but then it went haywire. Beall discovered the *Philo Parsons* carried too little fuel for his intended high speed escape run to Canada, so he opted to return to Middle Base to top off the fuel bunkers. At Middle Bass the conspirators encountered the steamer *Island Queen*, and having no means of avoiding the inevitable questions, they executed a swashbuckling attack and overwhelmed that hapless vessel. The *Philo Parsons* refuelled and ed away from Middle Bass with the *Island* *een* in tow, the latter's passengers and crew marooned on Middle Bass Island. Determined though Beall was to carry out the original plan, it was not to be. As the *Philo Parsons* again neared Sandusky Bay something misfired—a hint of danger, a signal from shore not received—exactly what isn't known; for some reason or other the new masters of the *Philo Parsons* lost their nerve. Shortly after midnight the *Island Queen* was set adrift and scuttled, and the *Philo Parsons* steered a course for the Detroit River. The next morning the would-be liberators fled into Canada.

The "what ifs?" in this case are really not that compelling. Three days prior to the *Philo Parsons* takeover a Confederate deserter informed the military commander at Detroit of the planned coup. The army officer discreetly inspected the vessel and deemed it too insignificant to pose a serious threat. To be on the safe side, though, he did telegraph the intelligence to Sandusky, so both forts on Johnson's Island plus the gunboat herself were ready and waiting. Beall wouldn't have stood a chance.

Cole was rooted out and captured soon after the telegraph message was received. Tried for conspiracy, he served two years in prison, part of it on Johnson's Island itself. Beall was later captured after a sabotage attempt near Niagara Falls. Tried for piracy, there would be no exculpation for John Yates Beall: he was executed at Governor's Island, New York, on March 24, 1865.

The Civil War came to an end on April 9, 1865, and a stream of weary soldiers returned home. A populace sick and tired of depressingly lengthy casualty lists was ready for peace. But on Lake Erie peace would be slightly delayed. Anti-British feelings still existed among Irish factions in both America and Canada. Agitators organized armed squads along the border to raid into Canada. Once again Canadian Militia and British troops, mobilized and stationed at strategic locations, were poised to repel invasion. After a few scares the U.S. Government decided to take a hand. Federal troops sent to the border regions quickly suppressed the Fenian elements. By late Fall, 1865, peace settled into the Lake Erie region, this time to stay.

Conclusion

For a period of 200 years nations conducted their intrigues, fought their wars, and buried their dead, all for the sake of flying a flag over Lake Erie. In the end the original occupants, if not forgotten, are long gone, and the lake itself divided, half Canadian and half American. For 200 years the lake sounded with the crash of gunfire—no more. Today there are no warships, no forts, and no troops waiting to invade or be invaded. The road has not always been without potholes. On different occasions there were some very close calls, but in the end cooler heads have prevailed. Wars are now conducted at the negotiating table and battles are fought with words. Canada and American have learned to share the lake in harmony. Lake Erie lives in peace!

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8/ A History of Great Lakes Shipping

by Alexander C. Meakin

The history of Great Lakes shipping is a broad subject. It begins with primitive dugout canoes and stetches across the years to modern bulk carriers that are so large that it is impossible for them to pass through any of the canals and rivers that link the lakes to the oceans. Thus, they are literally locked into the lakes.

In attempting to understand the role of shipping from a historical perspective, it can be said that the upper midwest and central Canada were developed because of the Great Lakes. The exploration of the central portion of North America was carried out largely by water. Most of the early settlers entered the region by water. And the development of heavy industry in North America's heartland occurred largely because of the concentrations of minerals and other raw materials in the region itself. The relatively low cost transportation of such materials over the lakes led to the development of the largest part of the United States' and Canada's steel industries, which were the backbone of these two nations' economies until the recent economic recession. In a very real way, the Great Lakes were the lifeline that supported the development of the United States and Canada over a span of almost a century and a half.

The vessels that were developed over that period were propelled by both sail and steam, as well as more modern types of engines in recent years. They have included the development of technological features which in some cases have spread into worldwide use. It is worth noting at this point that all vessels of whatever size that operate on the lakes are called "boats," although the terms "vessel" and "ship" are also proper.

A brief survey of various vessel types and their development will give a broader insight into the role of the lakes in moving people and cargoes through the years.

Primitive beginnings

Over a period of many centuries, the heavy wooden dugout canoes used by the earliest Indians evolved into small hide and bark covered canoes. These lighter canoes were quite efficient in relation to what they could carry and the effort needed to move them from place to place. The ultimate in small canoes were those covered with birch bark. They were very light in weight and could be moved easily. It is generally believed that the finest canoes of this type were those developed by the Algonquian tribes.

The wide use of smaller canoes led to the development of a class of somewhat larger canoes which were used by the Indians for transporting animals killed by hunting parties. Some of this type of canoe were also used for the movement of war parties, hence the name "war canoe."

Many of the earlier explorers and missionaries also traveled by canoe. Most of these craft were of the larger varieties: a 25-foot canoe could carry about a ton and a half of cargo, plus seven or eight men. The legendary voyageurs further developed the canoe into a highly efficient type of cargo vessel. Some of these were 35 to 40 feet in length and could carry a crew of 14 to 16 people plus 6 to 8 tons of furs or other cargo. They plied the Great Lakes, carrying goods from Montreal to trade for furs in the northern lake area.

Sail power

Probably the first new type of vessel developed especially to meet the needs of Great Lakes commerce was what in later years came to be known as a "Mackinaw boat." Originated by the French in the mid 18th century, it continued in use well into the present century. These boats were double-ended to make them easier to manuever. Many carried sails, and some had center boards for stability. They were used largely on the upper lakes and for every imaginable purpose, including commercial fishing.

The first large sailing vessel in service on the lakes was the *Griffin*, which was built by the explorer LaSalle in 1679. As time went on, sailing vessels of many different types were built, both for the movement of people and for various commercial cargoes. Some of these vessels reflected certain characteristics associated with particular cargoes, such as open decks for carrying large, rough cut timbers. Others reflected the skills, or lack thereof, of their builders. Thus, vessels built in one port were often quite different from those built elsewhere.

As sailing vessels continued to be built over the years, they gradually evolved a few standard rigging designs. Some of these sailing vessels, such as the *David Dows*, were truly gigantic. At a length of 265 feet, with five masts and a displacement of 1,419 tons, she was large even by ocean standards. Built in 1881, she carried farm products, general merchandise and some bulk cargoes until she was lost near Chicago in a violent storm in late 1889. Although sailing vessels continued to be built into the later years of the nineteenth century, the development of steam vessels paralleled the development and use of sail.

The age of steam

The first commercial steamer above Niagara was the *Walk-In-The-Water*. She was built in 1818 at Black Rock, New York, near the present city of Buffalo. She could make the run from Buffalo to Detroit in 38-40 hours, including several stops for loading and unloading.

The sidewheeler *Michigan*, built in 1833, marked a major change in vessel design. For the first time passenger accommodations were placed above the main deck. This was a significant change and somewhat lessened the danger to the passengers from the fires and explosions which were common in early steamers.

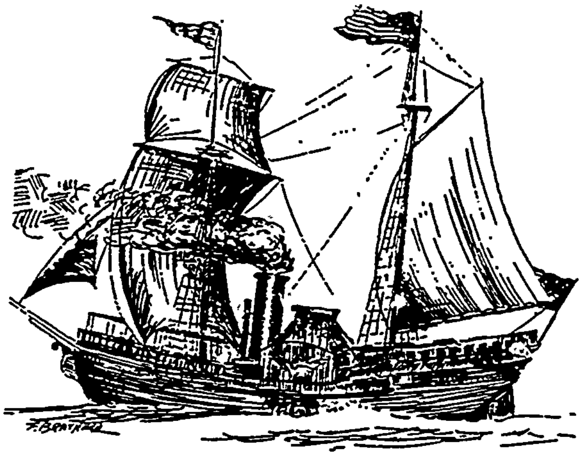

Figure 8.1. The *Walk-in-the-Water*, a sail-assisted steamer. *(Steamship Historical Society of America)*

Many of the earlier sidewheelers, as well as some of the larger sailing vessels in use during the first half of the nineteenth century, carried thousands upon thousands of settlers to the new communities then springing up along the shores of the lakes. In contrast to other areas of the midwest and far west, people settling in the Great Lakes basin came to the region by water, rather than by covered wagon.

Great Lakes trade

With the opening of the North American heartland for settlement following the War of 1812, large quantities of household goods and raw materials for light industry began to be moved by ship across the lakes. Similarly, agricultural products, fish, minerals, and timber were shipped across the lakes as a first link in their transportation to other regions of Canada and the United States.

Following the discovery in 1843 of large quantities of copper in the Upper Peninsula of Michigan, that metal became a major cargo on the lakes for many years. After being smelted into ingots, most of this copper eventually reached the growing industrial areas along the lower lakes and the east coast.

Soon after the close of the original exploration of the lakes region, the shipment of timber became a major operation in certain areas, particularly on Lake Ontario and the St. Lawrence River. During the eighteenth and early nineteenth centuries, the British Navy looked to both Canada and the United States for much of the timber used for construction of its vessels. In later years, lumber in rough form became the largest commodity moved on the lakes.

By the early 1900s, the volume of lumber moved began to decline. The lakes region was divided into a number of districts which were established for statistical purposes related to the cutting and shipping of lumber. Since there was no single source that collected all of the data on a continuing basis, nor were the methods of accounting uniform, it is difficult to determine the total volume of lumber cut and shipped on a long term basis. It was determined, however, that the lakes region provided in excess of 8.9 billion board feet of lumber in 1892! By 1896 the total had shrunk to a bit less than 5.54 billion board feet. From that time on the volume continued to drop annually, although the movement of large quantities of pulp wood continued to be a major shipping activity until about the time of World War II.

With the discovery of iron ore in the Upper Peninsula of Michigan, and later in Minnesota, the development of the iron and steel industry in the United States and Canada entered a new era. The lakes became the main route for the movement of the ore to the new steel making centers. Over the span of only a few decades, iron ore became the major cargo moving on the lakes. As time went on, this ore, together with the coal and limestone used to make steel, became the life blood of North America's heavy industry and the economies of both the United Staes and Canada. As recently as the 1970s and largely because of the volume of iron ore moving on the lakes, the locks at Sault Ste. Marie annually passed more cargo in an eight-and-a-half-month season than did the Panama, Suez and Kiel Canals combined over a full year!

The importance of iron ore continued until the 1980s when the entire steel industry collapsed. The collapse of the industry, including the shipping of iron ore, was the result of a number of factors. The primary reason, however, was the constantly rising cost of finished steel over a period of many years. As a result, the American steel industry was gradually priced out of its own traditional markets. In turn, notwithstanding the higher shipping costs, American manufacturers could purchase foreign steel at a considerably lower cost.

Crushed limestone was a major cargo that grew in importance with the development of the steel industry, since limestone is a basic ingredient of most steel making. For many years limestone has been moved by self-unloading vessels that run from the quarries to the steel mills, or to rail heads leading to the mills.

Cement is another cargo requiring specialized carriers. Most of the vessels in this trade began life as standard bulk carriers. In order to handle cement, hatches and holds have been rebuilt to facilitate the use of pneumatic unloading equipment.

Historically, coal has been one of the major lake cargoes. For many years, coal was shipped up the lakes for heating and manufacturing purposes. This was most advantageous to shippers since the iron ore moved downbound. Without the coal cargoes, most vessels would have been empty on the upbound trip. With the drop in the demand for coal for railroad and heating use, this cargo was significantly reduced. During the past few years, however, the movement of coal has increased once again. Several Canadian fleets pick up coal at Ohio ports and deliver it by way of the Seaway to the lower St. Lawrence where it is transferred directly into ocean vessels for overseas delivery. Another recent development is the delivery of western coal from the lakehead to shoreside power plants located on the lower lakes and rivers. In recent years coal has been moved across the lakes entirely in self-unloading vessels.

But of all of the cargoes moved on the lakes and Seaway today, the movement of grain is second only to iron ore in tonnage. Almost all of this grain goes overseas. Much of it moves downbound in standard bulk carriers of seaway size. Some of it also leaves the lakes in ocean vessels as well. A considerable part of this grain comes from the western provinces of Canada and from the midwestern United States.

More cargo, bigger boats

The handling of bulk minerals including iron ore was originally done with barrels or kegs. As specialized loading and unloading equipment was developed, such cargoes began to be handled in bulk. The first vessel especially designed and built for the moving of such bulk cargo was the wooden steamer *R.J. Hackett*, which was built in Cleveland in 1869. An interesting peripheral development took place in relation to the *Hackett*. Several years after she was built, a consort, the *Forest City*, was built to be towed by the *Hackett*, thus increasing the cargo capacity of the steamer. The barge carried a limited suit of sails for propulsion in the event that she was let loose or broke loose from the towing steamer. This use of barges became quite widespread as time went on. Many of the older wooden schooners finished out their careers as tow barges. In later years a number of steel barges were built for such service. The use of consorts continued on a limited basis until shortly after World War II.

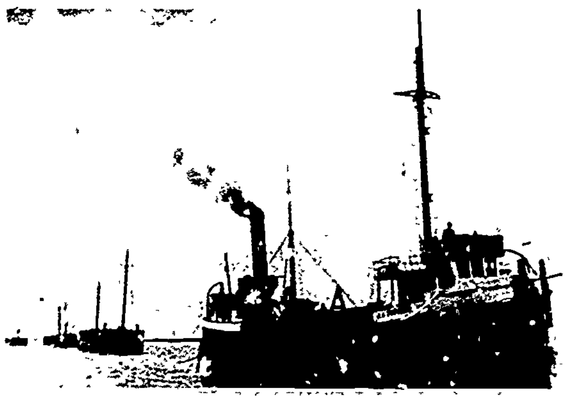

Figure 8.2. Lumber steamer towing consort barges. ***(Meakin Collection)***

The use of steel in the construction of vessels was in full swing by the end of the 1880s. A few of the earlier steel framed vessels were sheathed with lumber, an effort that sought to utlize the particular values of both materials.

A unique development in vessel design was that of the so-called whalebacks or pig boats. They were used for the movement of bulk cargo, primarily iron ore, coal and limestone. Designed and built by Captain Alexander McDougall, these iron vessels resembled floating cigars. The theory behind the design was that waves would roll over the top of the cylindrical hull, especially when the boat was loaded and riding low in the water. A fleet of these vessels was built between 1888 and 1897.

Several of the whalebacks even saw ocean service. One, the *Christopher Columbus*, was originally built as a passenger vessel in connection with the Columbian Exposition which was held in Chicago, but she went on to serve for many more years. She was so well designed that she could safely load and unload up to 5,000 passengers in less than five minutes! In later years, two whalebacks were also converted to a tanker and an automobile carrier. The last of the whalebacks was finally removed from service after the 1969 season. Although the size of these vessels was small in relation to the cargo demands of later years, they proved to be real work horses.

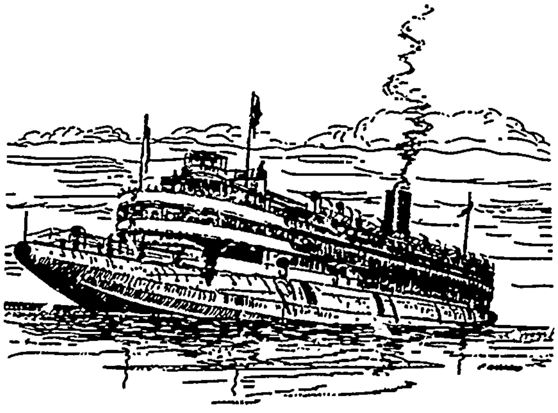

Figure 8.3. The ***Christopher Columbus*****, a whaleback steamer.** ***(Steamship Historical Society of America)***

As the twentieth century appeared on the horizon of history, the largest bulk vessels being built were about 500 feet long. Only six years later the first 600-foot vessels appeared. With some continued growth in breadth and depth, these vessels became a standard type for almost thirty years. As time went on, technological improvements in engines, boilers and structural design continued at a steady pace. Larger hatches, improved hatch covers and shipboard cranes contributed to greater efficiency in the loading and unloading of bulk cargoes. The development of new and unusual types of loading and unloading equipment added even more to the efficiency of ore handling. These improvements made Great Lakes bulk vessels among the world's most efficient freight carriers Electronic vessel navigation equipment was in widespread use on lake vessels while it was still regarded as an unnecessary novelty by most ocean fleet owners and operators.

By the end of World War II, the newest vessels had grown to only 620 feet in length, but they had swelled to about 70 feet in breadth. The dimensions of vessels are determined by several factors. One is the limiting dimensions of the locks at several locations on the lakes, plus the parallel limitation of channel depths. The other major factor is the spacing of loading chutes for handling cargo on the docks. Thus, until the opening of the St. Lawrence Seaway, vessels entering or leaving the lakes were limited to a maximum length of about 250 feet in length and 43 feet in breadth. With the completion of the present St. Lawrence Seaway in 1959, channels were dredged where necessary to a minimum depth of 27 feet. The new St. Lawrence locks were built to permit the transit of vessels up to 730 feet in length and 75 feet in breadth. This change in restricting dimensions led to the rapid development of a large fleet of new vessels built to take full advantage of the deeper channels and larger locks.

With the completion of the new super-sized Poe Lock at Sault Ste. Marie in 1968, a still newer and larger class of vessel appeared. These monsters measured 1,000 feet in length and 105 feet in breadth. While still limited by the 27 foot depth of the channels in some ports and restricted areas, this new class of vessel is so much larger that virtually all former shoreside facilities are outdated and unable to serve these vessels. Over a period of a few years, these vessels gradually increased in length: the *William J. Delancey*, built in 1981, measures 1,013 feet in length. At the present time, there are thirteen vessels measuring at least 1,000 feet in length operating on the lakes. As vessel dimensions increased over recent years, hulls became more boxlike, yielding a still greater cargo capacity. Unfortunately, these "super" carriers are so large that they can not pass below Lake Erie because of the limiting dimensions of the Welland Canal. Similarly, these vessels are also restricted to a relatively small number of ports adequate for their needs. Thus these huge carriers must travel a few specific runs over and over again.

Recent years have also seen the lengthening or "jumboizing" of a number of other existing vessels to take advantage of the present lock capacity at Sault Ste. Marie. All of the "jumboized" vessels, as well as the new super class vessels, are self-unloaders which are not dependent upon shore machinery for unloading their cargoes.

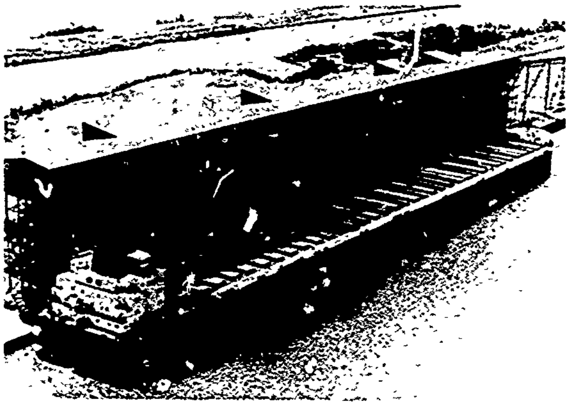

Figure 8.4. A self-unloading ore carrier. *(Meakin Collection)*

As the years have gone by, other types of vessels have come and gone from the lakes. At this time, apart from a few remaining ferries and excursion boats, there is no regularly scheduled passenger service on the lakes. Once there was a large fleet of cruise ships on the lakes, as well as an even larger number of combination passenger-package freight vessels that provided point to point service on regular schedules.

A few specialized rail car ferries still operate on Lake Michigan, although this limited activity is a far cry from the large number of such vessels that were in operation as recently as a generation ago. At one time the movement of new automobiles by lake vessels was quite common, and some older ships were rebuilt especially for this trade.

Petroleum and chemical tankers have long been a part of the vessel traffic on the lakes. But with the expansion of the petroleum pipeline network serving the mid-continent region, the number of tankers formerly engaged in such service has been substantially reduced in the last few years.

Barges and scows towed or pushed by tugs move numerous cargoes from port to port. With the gradually increasing costs of vessel labor, a considerable amount of experimentation has gone on in recent years in an effort to handle more cargoes by this means. A tug-barge (or barges) can operate with a much smaller crew than a standard lake vessel, thus leading to a considerable saving in labor costs.

Gateway to the sea

With the opening of the St. Lawrence Seaway in 1959, it became possible for large ocean type vessels to enter the Great Lakes. Today, the lakes play host to hundreds of these "salties" each year. These ships represent many different vessel types, and carry almost any imaginable kind of cargo in and out of the lakes region. Regrettably, this part of the lake shipping industry was restricted for many years by extremely high toll charges for the use of the Seaway locks and channels, and still is restricted by the limitation of a short shipping season.

Ocean traffic in and out of the lakes, however, did not begin with the present Seaway. Rather, through traffic from the lakes to the sea began with the opening of the first Welland Canal in 1846. Ocean to lake commerce grew slowly, but with each enlargement of locks and deepening of canals and channels, the volume of tonnage increased. The present Seaway makes it possible for much larger ocean vessels to enter and leave the lakes than was previously possible, as discussed in the next chapter.

The development of vessels on the Great Lakes and their connecting waterways has over the years, in a very real sense, been a reflection of the state of development of the economies of both Canada and the United States. New vessel types were developed to meet new needs. And these, in turn, were modified or even replaced by the needs of each new day. So it has been in the past, and so it still is today. And if the lessons of the past have any meaning, so it will continue to be in the future.

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9/ Condition of Shipping on the Great Lakes

by Jeffrey A. Bryant

Like the constant ebb and flow of the Great Lakes waters, issues and problems facing the commercial shipping industry on the Great Lakes remain in a state of flux. This chapter outlines prevalent issues affecting the Great Lakes shipping industry. There is no question that problems exist which are peculiar to Great Lakes ports. But the economic impact of these ports will continue to make key laketront cities invaluable resources in the decades ahead.

The St. Lawrence Seaway and the shipping industry

Dedicated in April, 1959, by President Eisenhower as a "magnificent symbol to the entire world of the achievement possible to democratic nations," the St. Lawrence Seaway had been the fastest-growing sea route in the world during its first 10 years of existence. But a number of problems which confront the 2,342 mile Seaway threaten its successful competition with saltwater ports. From the Seaway's start, it has been the only deep-draft navigational project in the United States required to repay its $88 million appropriation for construction, maintenance and operation by the users. In addition to this, it has been losing markets because of the trade deficit, the decline of heavy industry (mainly coal, iron, and steel), the development of container vessels, steel imports and a reduced global demand for grain, the lakes' major cargo (Figure 9.1). What was a record high of 57.4 million metric tons of cargo passing through the St. Lawrence Seaway in 1977 became a very low 37.3 metric tons in 1985.

Ice limits the system's seasonal operations. Many locks are not large enough to accommodate the large "supertankers" or are in desperate need of repair. Bridge failures also plague the Seaway's efficiency. The local economy, in addition to the aforementioned problems, has experienced a notable decrease in shipbuilding operations. In the face of these growing challenges, the Seaway is forging ahead to maintain the Great Lakes' official status as "America's Fourth Seacoast."

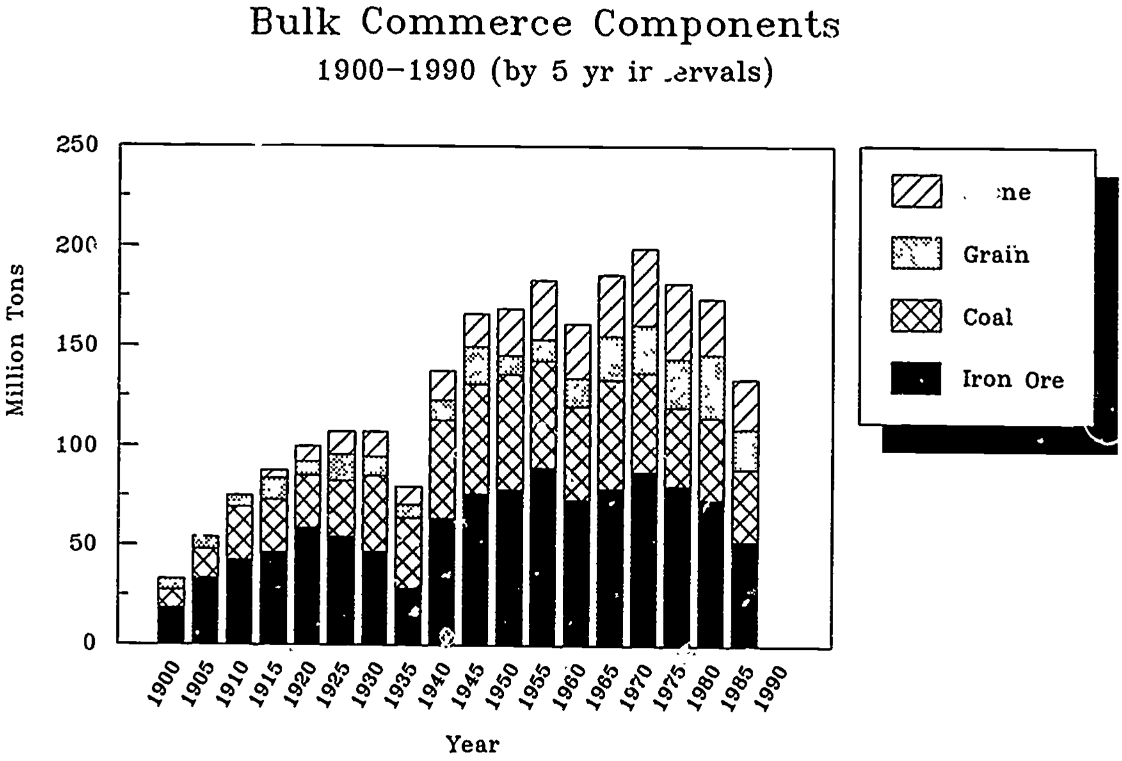
Great Lakes shipbuilding

Current status

Shipbuilding in Lake Erie ports declined in the 1980s with the closing of American Shipbuilding Company yards in Toledo, Cleveland and Lorain. The demise in shipyards, shipbuilding jobs and related support industries has taken its toll in terms of economic impact. For example, the same Toledo shipyard which employed nearly 1,300 workers before the Great Depression was closed in 1983 when American Shipbuilding, faced with declining orders, transferred all orders to its Tampa, Florida, and Lorain, Ohio, yards.

Today, the Toledo Shipyard has been reopened by the Toledo-Lucas County Port Authority and employs some 200 workers. The Toledo dry dock facility is the only active shipyard in Lake Erie. In 1986 the yard produced two new vessels, a 360-foot self-unloading, bulk cement barge and a 600-passenger excursion boat.

Shipyards are more numerous in the Upper Great Lakes; with sophisticated shipbuilding facilities such as Bay Shipbuilding Corporation



(Data compiled from Lake Carriers Association annual reports)

Figure 9.1. Relative contributions of cargo types to total Seaway tonnage.

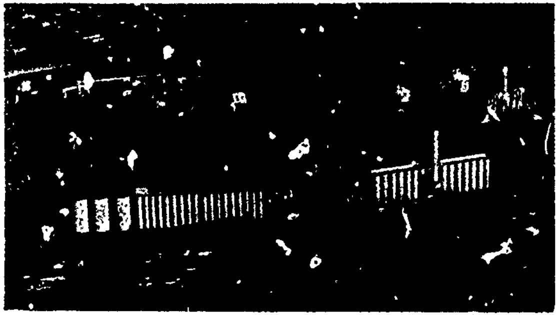


Figure 9.2. Toledo's grain shipping firms loaded 91 million bushels of grain to international destinations in 1985. *(photo courtesy of the Toledo-Lucas County Port Authority)*

and Peterson Builders, Inc., in Sturgeon Bay, Wisconsin, and Fraser Shipyards, Superior, Wisconsin, to name a few. The reason more shipyards survive in the upper lakes is an historical one, based on the availability of timber in the Upper Great Lakes states. Early lake vessels were constructed with wood, rather than steel, thus more graving docks were built near timber country on the upper Great Lakes and proportionately more shipyards survive in the north today.

In light of a continuing worldwide slump in commercial orders, government contracts provide the economic lifeline needed to keep the American shipbuilding industry solvent. Great Lakes shipyards have constructed self-unloading bulk carriers up to 1,000 feet in length, floating barracks, Navy patrol boats, ice breakers, rescue/salvage craft, minesweepers and other vessels under government contracts. The region receives limited Department of Defense shipbuilding dollars, however.

The Great Lakes Task Force states that historically, and at present, the Great Lakes region does not receive an equitable share of Department of Defense shipbuilding dollars. The Great Lakes has received only three percent of the Navy's recent construction budget, and virtually none of its repair and/or overhaul budget.

Need for governmental support

The capabilities, the technology, the skilled labor and the shipbuilding tradition exists in the Great Lakes region. But unless government orders increase, the Great Lakes shipyards will continue to struggle economically. Even an upswing in the U.S. economy and revitalized heavy industry would not spur shipbuilding orders on the Great Lakes for three reasons. 1) The inexpensive cost of labor in Korean and Japanese shipyards allows those countries to submit lower bids than U.S. yards. 2) Ocean vessels built in Great Lakes yards are limited in length to 730 feet, because of the size restrictions of the Seaway locks. 3) American and Canadian lake fleets are not currently working at full capacity, with decommissioned ships ready to be refitted if needed.

American flag vessels

An issue related to government support for shipbuilding is that of preferential use of American ships. Because of cargo preference laws in the United States, American-flag liner (regularly scheduled) service is important in the Great Lakes to help attract U.S. Department of Agriculture (USDA), U.S. Department of Defense (DOD) and Export-Import Bank (ExIm) cargo shipments.

In 1986, however, only two U.S.-flag liner operators, Fednav Lakes Services, Inc., of Detroit and Lykes Brothers Steamship Lines of New Orleans, scheduled regular Great Lakes/Seaway service. Fednav operates two 682-foot sister ships with fortnightly service between Toledo, Detroit, Milwaukee and Northern Europe. Lykes calls at Milwaukee, Chicago and in the Mediterranean. Since the lakes are served by only two U.S.-flag operators, most Midwest-produced government cargoes are lost to coastal ports with more frequent U.S.-flag service.

In 1984, for example, of the 7.7 million measurement tons of DOD cargoes shipped overseas, less than one-tenth of one percent were loaded at Great Lakes ports, despite the fact that 91 percent of the cargo destinations are serviceable from the Great Lakes, and many of the cargoes were manufactured in the Midwest.

The diversion of these "preference" cargoes to coastal ports costs the midwestern economy a very high price in terms of economic impact and employment. According to COMMUNICORE, an international maritime trade and consulting firm, each time a shipment of cargo as small as 5,000 to 10,000 tons is loaded at a Great Lakes port, a direct expenditure of about $230,000 takes place at the port. Multiplied by even a million tons—or 14 percent of the available DOD cargo—this could inject $23 million directly into the Great Lakes port economy.

The COMMUNICORE study also found that in 1984, DOD spent 23 percent of its contract budget on goods manufactured in the eight Great Lakes and five adjoining states which constituted the study. Yet, virtually none of those cargoes were shipped from midwestern ports. The presence of a U.S.-flag ship service in the Great Lakes has spurred competitive bidding for DOD cargoes, saving the government over $15 million dollars in shipping costs over a 12-month period, and Great Lakes port leaders are seeking expansion of additional American flag service into the lakes.

Limitations of the Seaway

Lock dimensions

The maritime fraternity is in agreement that the dimensions of the St. Lawrence Seaway locks form a structural constraint upon Great Lakes ports. The maximum-sized vessel capable of transiting the Seaway locks is 730 feet by 75.6 feet with a 25 foot draft. Ocean ports, of course, do not face this size limitation in vessel traffic and thus siphon more and more tonnage from Great Lakes ports, with the construction of each new super carrier.

The cost of building new locks to accommodate the large ocean vessels is estimated to be well over $3 billion. Future prospects for such construction do not rate highly.

In 1985, the Seaway was forced to close for 25 days at the height of the shipping season when concrete eroded in one of Lock No. 7's walls at the Welland Canal. The 1985 mid-season closing of the Welland for repairs marked only the second time that the Seaway, opened in

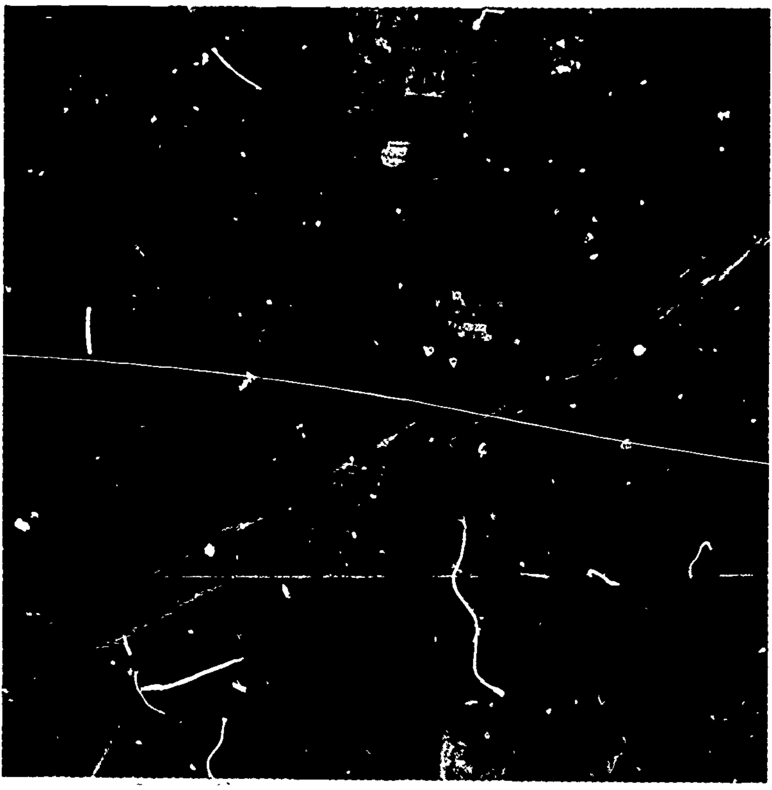


Figure 9.3. **The size limitation of the Seaway locks is displayed by the tight fit of these vessels in Canada's Welland Canal.** *(Saint Lawrence Seaway Development Corporation, The St. Lawrence Seaway, 1979)*

1959, ceased operation in mid-season. Unfortunately, however, the first closing occurred but one year earlier, on November 21, 1984, when a lift bridge malfunctioned about 40 miles west of Montreal. The bridge spans the Beauharnois Canal near Valleyfield, Quebec. Its malfunction blocked navigation for 18 days.

Both Seaway closings resulted in reported losses of millions of dollars to vessel operators and others. This was a potentially disastrous situation, considering that scores of ocean vessels could have been trapped for the winter. Fortunately, both times the problems failed to materialize because of mild temperatures and an extended Seaway season.

Although the Seaway system received a great deal of negative publicity from the closing incidents in 1984 and '85, the actual negative impact of the accidents and publicity appears to be non-existent. This conclusion is based on 1986 overseas cargo statistics at Ohio's largest tonnage port, the Port of Toledo, where overseas statistics through November, 1986, reflected a 43 percent increase and 170 overseas vessel calls compared to 123 for the same period in 1985.

Both the Canadian and United States governments have increased maintenance funds earmarked for upgrading and preventive maintenance of the Seaway lock system.

Limited Navigation Season

Lake Erie seaports, like all ports in the Great Lakes region, face two natural obstacles to the 12-month navigation season enjoyed by Atlantic, Pacific and Gulf coast ports. Unlike saltwater harbors which remain ice-free, the fresh water ports and connecting channels of the Great Lakes are susceptible to freezing throughout the course of both normal and severe Great Lakes winters.

Except for limited lake barge movements in selected ports in winter, all of Ohio's ports—

Ashtabula, Conneaut, Cleveland, Lorain and Toledo—are closed to normal shipping by the formation of ice nearly every winter. The commercial inter-lakes shipping season is generally limited to 10 months, from March 1 through December 31. The Seaway or ocean transit season has a normal opening date of April 1, and closing date of December 15.

Season extension

Any discussion of season extension for the Great Lakes/St. Lawrence Seaway (Seaway) shipping season is sure to attract interest from the maritime fraternity as well as the media and general public. Most experts are in agreement, however, that a 12-month shipping season is not viable in the immediate future.

While harbor tugs are sometimes pressed into service as ice breakers to assist late-season navigation in Lake Erie harbors, the idea of open lake icebreaking by Coast Guard vessels is cost prohibitive. The use of ice-breakers has in fact become less practical with the advent of larger lake vessels. In the past, smaller vessels meant more traffic through shipping lanes and channels, thus retarding the heavy buildup of ice and facilitating the effectiveness of ice breakers. Super lakers up to 1,000 feet in length, however, carry two to three times the freight of older lakers, meaning fewer vessel transits.

Navigational aids such as buoys must also be removed from channels and harbors before the formation of ice. Additional winter navigational problems include increased vessel insurance premiums, undue hardships on longshoremen and the need for preventive maintenance on the St. Lawrence Seaway locks.

Emerging developments

Seaway toll reduction

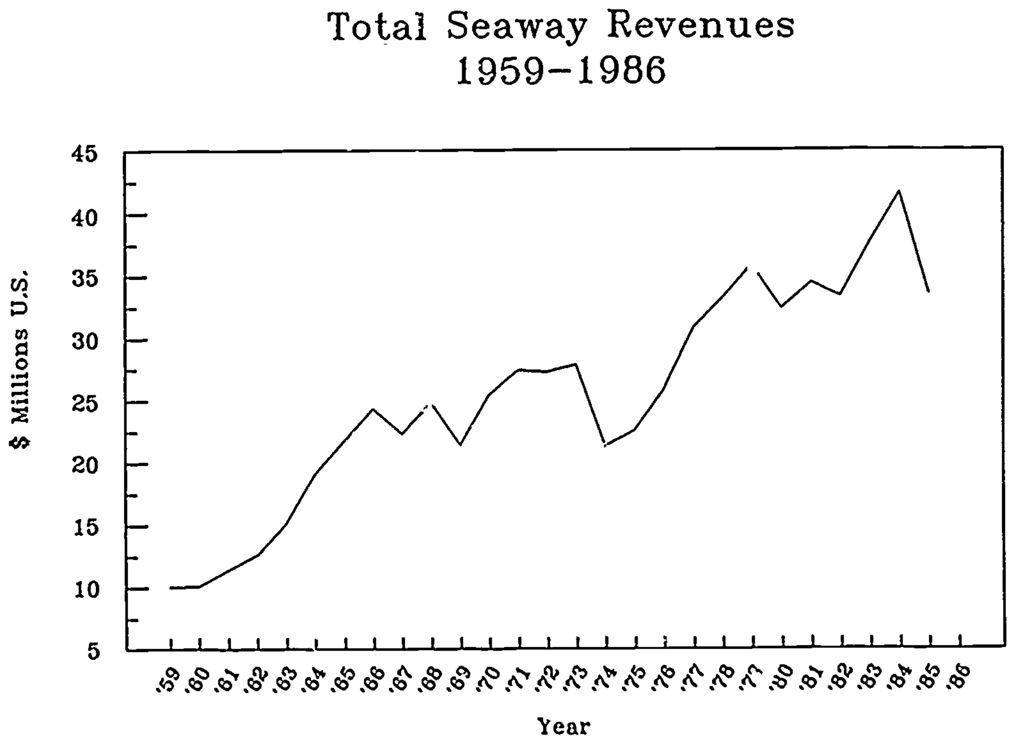
Since the opening of the St. Lawrence Seaway in 1959, Great Lakes ports have been burdened with a Seaway toll structure which charged vessels in excess of $40,000 to transit the Seaway System (Figure 9.4). Over 70 percent of the tolls are collected by the Canadian government's St. Lawrence Seaway Authority, overseers of five of the Seaway's seven locks.

The first step in the elimination of Seaway tolls—and an incentive to shippers—came on November 17, 1986, when President Ronald Reagan signed into law H.R. 6, the Water Resources Development Act. The first water resources bill passed by the Congress and signed by the President in 16 years, H.R. 6 authorizes a number of nationwide water projects, from shoreline erosion abatement to port development projects. The bill has a provision which eliminates the U.S. Seaway tolls.

When H.R. 6 went into effect April, 1987, (the traditional opening date of the St. Lawrence Seaway) the Great Lakes realized a decrease in operating costs to shippers. Until that date Great Lakes ports had been the only U.S. ports which, in effect, taxed vessel operators. The U.S. portion of St. Lawrence Seaway tolls is now rebated to shippers under the new legislation and replaced by nondiscriminatory, nationwide, ad valorem cargo fees. The new user fee is charged at all ports of call around the nation and these revenues will be used as the local share of dredging and other harbor-maintenance costs. As means of illustration, the new ad valorem cargo fee could be compared to a national gasoline or liquor tax, with all regions of the nation participating on an equal basis.

The elimination of the American portion of Seaway tolls will mean a 12 percent decrease in the cost of moving a bushel of corn through the Seaway System. This [illegible] translates into a savings of $3,673 per vessel transit, based on a 730-foot long lake vessel's average load of 28,200 tons, or 1,110,174 bushels of corn.

The passage of the water resources bill is seen by most maritime observers as a major victory for all Great Lakes ports and shippers. H.R. 6 also includes language which requires the United States government to negotiate with Canadian officials for the purpose of eliminating all Seaway tolls. The total elimination of tolls would mean a savings in excess of $40,000 for the vessel transit of a 730-foot laker laden with corn. The passage of H.R. 6, and subsequent ad valorem cargo fee assessment at all U.S. ports, puts Lake Erie ports in a much better position to compete with tidewater ports for overseas commerce. The future elimination of all Seaway



(Data from St. Lawrence Seaway Traffic Report 1985)

Figure 9.4. Revenues of the Seaway since 1959.

tolls is seen as a key incentive to attracting additional tonnage through the Seaway System.

Urban redevelopment

Lake Erie ports in particular face new challenges as major Great Lakes cities and ports, such as Cleveland, Buffalo, Toledo, Detroit and Erie forge their waterfront real estate into vital economic development tools. As ports continue to lose business from traditional cargo-related industries, they are turning to recreational and tourist-based industries in order to survive.

Construction along downtown Toledo's Maumee River waterfront, which began in the late 1970s, has totaled well over $200 million in completed projects and has provided over 4,000 new jobs in the 1980s. Major firms such as Toledo Trust and Owens-Illinois have constructed new headquarters buildings on the west shore of the downtown Toledo waterfront. Those structures, along with Portside Festival Marketplace, Promenade Park, recreational boat docks and the Hotel Sofitel anchor Toledo's new riverfront building boom.

Cleveland is in the process of reshaping its Municipal Stadium-lakefront area with a major retailing and restaurant center due to open in the late 1980s. The $258 million project will also include an aquarium and maritime education center. It is expected that $118 million in revenues and 1,380 permanent jobs will result. Already development in The Flats has resulted in renewed interest in Cleveland's links to its Lake Erie heritage.

In Buffalo, New York, a $50 million project, expected to generate more than 3,000 new jobs by 1993, is underway. A commerce and transportation facility will be created from part of a defunct steel mill. Already 21 companies are interested.

Expected to be completed by 1991, a $75 million revitalization project in Erie, Pennsylvania, will most likely replace three ship repair docks and a shipbuilding yard. The new con-

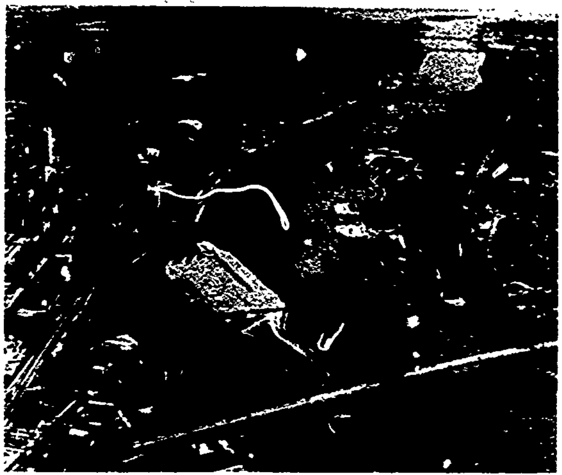


Figure 9.5. Toledo, Ohio, site of the most diverse port on the Great Lakes as well as a revitalized urban waterfront. ***(photo courtesy of Toledo-Lucas County Port Authority)***

struction will include condominiums, stores, marinas, restaurants, a hotel and a maritime museum to house the reconstructed *Niagara*, Commodore Oliver Hazard Perry's ship used to win the Battle of Lake Erie during the War of 1812.

But not all developments are viewed as positive by all parties involved. Though expected to enhance lake recreation, a proposed influx of new marinas in the Black River in Lorain, Ohio, and on the Cuyahoga River in Cleveland is viewed by the Lake Carriers Association (LCA) as a potential hindrance to commercial vessel transits. The Lake Carriers fear that a proliferation of recreational boaters on these two waterways will slow commerce and endanger both commercial vessels and pleasure craft.

In Detroit, the LCA opposed the City's plan to extend Cobo Hall over the Detroit River. Although Detroit withdrew its proposal to extend the convention center 360 feet into the river, the LCA remains adamant in its contention that there must be no expansion of any building into the navigational channel.

In addition to increased recreational boating traffic, the coordination of recreational activities and special events, such as annual holiday fireworks displays or hydroplane races, has led port agencies around the state to assume a growing role as calendar keepers and coordinators of special events, so that costly delays to commercial shipping activity can be minimized. One Ohio maritime official has gone so far to say that Lake Erie is in a state of "chaos and confusion."

"The relationship between industrial and recreational uses of Lake Erie has never been more intimate than it is today," stated Gary L. Failor, seaport director for the Toledo-Lucas County Port Authority. "Even though I may be slightly exaggerating in describing Lake Erie's economic rebirth as the midwife of chaos and confusion at Ohio's ports, the words excitement, sports-fishing, tourism, deep-sea romance and international commerce truly establish an ever-increasing synergistic relationship between commercial, industrial, and recreational uses of Lake Erie," Mr. Failor said.

As governmental, civic, community and industrial leaders continue to look toward Lake Erie for urban and recreational revitalization, the interspatial problems of new urban developments crowding existing port facilities, plus the coordination of commercial and recreational uses of Ohio's key to the sea, will continue to exist into the foreseeable future. This problem, however, is one of opportunity for Erie's lakefront cities.

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LesStrang, J. (ed.) 1985. *The Great Lakes—St. Lawrence System*. Boyne City, MI: Harbor House.

Saint Lawrence Seaway Development Corporation. 1979. *The St. Lawrence Seaway*. Washington, D.C. 2 pp.

[In order to keep abreast of developing issues and problems concerning shipping on the Great Lakes, two annual works are suggested.]

Annual Report:
Lake Carriers' Association
614 Superior Ave., N.W.
915 Rockefeller Building
Cleveland, Ohio 44113-1306

Great Lakes Report to Congress
A publication of:
The Great Lakes Task Force
2200 Bonisteel Boulevard
Ann Arbor, Michigan 48109

10/ Lake Erie Coastal Uses

by Richard Bartz

While this chapter focuses on coastal uses of Lake Erie in Ohio alone, it provides a general example of the types and magnitude of activities occurring all around the lake.

Lake Erie is the second smallest of the Great Lakes, having a surface area of 9,910 square miles bounded by 871 miles of shoreline, including the mainland, islands and bays. The province of Ontario, Canada and the states of Michigan, Ohio, Pennsylvania, and New York border Lake Erie, which provides a rich international and interstate resource. About one third of Lake Erie's surface area and 265 miles of its shoreline lie in Ohio, and about one third of Ohio's geographic area is in the Lake Erie drainage basin. This area contains at least part of 35 of Ohio's 88 counties and 40% of Ohio's population.

The physical features along Lake Erie's shoreline, including the shore types themselves, affect how the lake is used. In the central basin of Lake Erie, high bluffs front the shoreline. At the western end of this basin near Sandusky, Ohio, the bluffs are about five or six feet high, but at the far eastern end of the basin the bluffs may be 65 feet high. These bluffs are extremely susceptible to erosion, but help to confine flooding in the central basin to the areas around river mouths.

The western basin of Lake Erie is fronted by low plains which are susceptible to both erosion and flooding. The drainage area of the western basin is very flat and very low. During major storm events, flooding may extend up to 2 miles inland because of this flat topography. In this basin are the remnants of a barrier beach-wetland system that once extended from Sandusky to Toledo, Ohio, and on up to Detroit, Michigan. This area is characterized by barrier beaches all along the shoreline with wetlands behind them.

The presence or absence of a beach affects how the shoreline is used. In 1974, the Division of Geological survey found that 52% of Ohio's Lake Erie shoreline had a beach zone; the other 48% was without a beach. Since we have had high lake levels for the last 16 years, the percentage of shoreline without a beach may have increased.

Table 10.1. Lake Erie Facts. *(Michigan Sea Grant)*

Length	210 mi/338 km
Breadth	57 mi/92 km
Depth	62 ft/19 m average; 210 ft/64 m maximum
Volume	116 cu mi/483 cu km
Water Surface Area	9,906 sq mi/ 25,657 sq km
Drainage Basin Area	22,703 sq mi/ 58,800 sq km
Shoreline Length	856 mi/1,377 km (includes islands)
Elevation	571 ft/174 m
Outlet	Niagara River and Falls
Detention Time	2.6 yrs (shortest of the lakes)
Population	1,515,000 (Canada) 11,347,000 (U.S.)

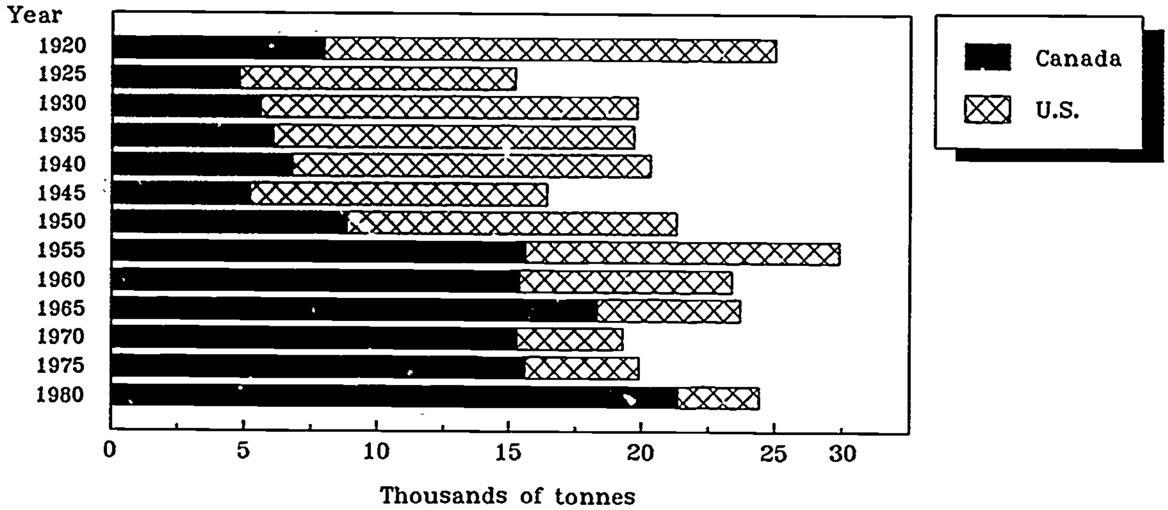

Figure 10.1. Commercial catch of selected species in Lake Erie.

Diverse habitat

Lake Erie provides habitat for many species of animals living in and on the water. Because Lake Erie is so shallow, it is the most biologically diverse of all the Great Lakes. Its varied bottom features and water characteristics provide habitat for benthic (bottom-dwelling) organisms, fish, and waterfowl. This diversity of animal life is both economically and esthetically important. Catching the many species of fish found in the lake provides recreation for some fishermen and a livelihood for others.

In 1986, Ohioans harvested 14.5 million pounds of fish from Lake Erie. Of this total, 11.3 million pounds were harvested by recreational sport fishermen and 3.2 million pounds by commercial fishermen. The greatest success on Lake Erie is the walleye fishery. Lake Erie has been named the walleye capital of the world. In 1975, we harvested 112,000 walleyes from the lake. In 1986, we harvested 4.4 million walleyes, the largest walleye harvest from Lake Erie in the last eleven years. The walleye sport fishery in the western basin of Lake Erie alone has been estimated to generate $100 million in revenues each year. This figure represents only revenues for walleyes caught from private boats in the western basin; it does not include revenues from the central or eastern basins, the perch or bass fisheries, or the 700 charter boat captains that operate on Lake Erie. The impact of the walleye fishery on Ohio's economy is therefore substantial. Andrew White discusses the Lake Erie fishery in detail elsewhere in this volume.

Figure 10.2. Great Blue Heron. *(Marcia L. Seager)*

Wildlife and natural areas along the lakeshore help to maintain habitat and protect wetlands. Wildlife areas are managed primarily for waterfowl habitat. These areas are concentrated mainly in the western basin and are remnants of the old barrier beach-wetland system. We have been able to protect about 20,000 acres of wetland habitat through federal and state initiatives and through the efforts of private duck hunting clubs. These wildlife areas provide habitat not only for waterfowl but for other important species, including the bald eagle.

Several natural areas along Lake Erie's Ohio shoreline were set aside mainly to protect wetlands. Four of these are state nature preserves. In addition, The Nature Conservancy, a non-profit organization, maintains two areas along the lake, one at Arcola Creek and one in Sandusky Bay.

Water supply

Lake Erie and the other Great Lakes represent a huge reservoir of fresh water. The Great Lakes contain 20% of the world's fresh surface water and 95% of the United States' fresh surface water. About 110 billion gallons of water flow through Lake Erie each day. Ohio uses about 4% of that, or 4.3 billion gallons per day. Of that total, Ohioans use approximately 530 million gallons per day for drinking water in municipal water supplies, 628 million gallons per day for industrial processing, and 3.2 billion gallons per day for electrical generation. Note that we speak of water being "used" rather than "consumed," because much of that water is returned to the Great Lakes after appropriate treatment.

There is an old adage which claims that "the solution to pollution is dilution." To some extent that still holds true, but Ohio has made great strides toward improving Lake Erie's water quality. All of Ohio's municipal wastewater treatment plants have been upgraded to include secondary treatment. Industries have also improved their waste treatment processes. Thanks to these improvements, the amount of pollution entering Lake Erie is decreasing. For example, less phosphorous is entering the lake than ever before, and we are approaching our statewide goal of reducing the amount of phosphorous entering Lake Erie from sources in Ohio to 11,000 metric tons per year.

Most of the future improvements in water quality will come from regulating non-point sources of pollutants like agricultural runoff. Ohio is developing a program to work with farmers in 25 counties in the Lake Erie basin in northwestern Ohio, Indiana, and Michigan. This program is designed to encourage conservation tillage and other tillage practices which will reduce soil erosion and decrease phosphorous levels in runoff. It is estimated that between one and two million acres of farmland will have to be put into conservation tillage and/or no tillage type practices in order for this program to have a notable effect on pollution levels in runoff.

Commercial uses

Lake Erie plays a very important role in the economies of the bordering states and Ontario. In 1985 about 67 million tons of goods moved in and out of Lake Erie ports. The greatest number of shipments on Lake Erie occurred in 1979. In that year, 98 million tons of goods were moved on the lake, 90% of which were represented by four commodities: grain, limestone, coal, and iron ore. Ports and commercial navigation are thus very important to agriculture, the steel industry and the power industry. These 98 million tons of goods were estimated to have contributed $1.4 billion to Ohio's economy in that record year.

There are eight commercial harbors along Lake Erie that are maintained by the United States Army Corps of Engineers. They are important to the economy as a cost efficient means of transportation which helps to keep product costs lower. Many harbors are dredged by the Corps to about 28 feet below the low water datum. Dredging involves the movement of large amounts of materials, and it is very costly. The four recreational harbors in Ohio also require dredging. Keeping these harbors clear in 1986 meant dredging about two million cubic yards of material at a cost of about 6.4 million dollars. Dredging activity on the Great Lakes is decreasing, however. As of 1979, about 9.3 million cubic yards of material were being dredged annually from all of the Great Lakes. More than half of that came from Lake Erie alone. About 3.6 million cubic yards were dredged in Ohio that year, accounting for 40% of all the dredging that occurred on the Great Lakes.

The traditional method of disposing of dredged materials on the Great Lakes is to return them to the open lake. However, many of the sediments that are dredged are polluted with organics, nutrients, and heavy metals. The polluted materials must be disposed of either at upland sites or in containment areas offshore. Thus in the last twelve years a new coastal use has developed along the lakes: confined disposal facilities. This program was initiated to protect the water quality of Lake Erie and the other Great Lakes. Several facilities have already been constructed along Lake Erie's shoreline. We are currently looking for new sites at both Toledo and Cleveland Harbors, as well as in other states bordering the lake.

This is a very expensive program which has already cost over $68 million. In addition to the high cost of building contained disposal facilities, the large area needed for each facility takes up valuable nearshore habitat. For example, the existing facility at Toledo Harbor takes up 242 acres of shallow water. We face a tradeoff between protecting water quality and preserving nearshore habitat.

Commercial operators extract sand and gravel from Lake Erie from four designated areas in Ohio. These areas are old geologic deposits and not part of the littoral system. There are also two salt mines along the shore, which have shafts 2,000 feet deep extending one-half to one mile under the bed of the lake. Natural gas extraction has been occurring in Lake Erie for some time, although not in the United States. Over 1,000 wells have been drilled in Ontario waters with no adverse effects, but no oil or natural gas extraction occurs in Ohio waters because of the concern for possible environmental damage.

Power generation is an important industry in Ohio. There are six coal-fired electricity generating plants along the Lake Erie shoreline. Ohio also has two nuclear power plants, the Davis-Besse Plant in Ottawa County and the Perry Plant in Lake County. Nuclear power plants depend on large amounts of water to cool their reactor cores.

Specialty agriculture depends on the lake's moderating effect on climate. Lake Erie affects the climate along its shoreline for about five miles inland, causing a warmer autumn and increasing the length of the growing season. Along the shoreline, then, are fruit farms, nurseries, and vineyards. Leamington, Ontario, claims to be the tomato capital of the world, its success largely due to the lake effect. Winemaking is an established business in many areas along Lake Erie and is expanding in Ohio. Details of the lake effect are discussed in other chapters in this book.

Recreational uses

Areas for fishing, boating, swimming, sunbathing, walking, or just viewing the lake cover approximately 23% of Ohio's Lake Erie shoreline. The Ohio Department of Natural Resources operates six major state parks along the lake. At the request of a State Representative, the Department of Natural Resources recently completed a study to locate a new state park along the shoreline. However, the study showed that there are few, if any, remaining areas along Lake Erie's shoreline that would be appropriate for developing a major new state park.

State parks are not the only recreational facilities along Lake Erie. Almost every shoreline community has one or two municipal parks which are designed for local needs. For the last several years, we have seen increasing demands for more regional recreational facilities. Through the Lake Erie Access Program, the Department of Natural Resources is trying to work with communities to improve their municipal parks to better meet regional needs.

Additional public access is provided through joint public and private ventures. An example of this is Portside in Toledo, where facilities include public access along the Maumee River, commercial shops, the international headquarters for Owens-Illinois, and new boat slips in the park.

Nearly one-fourth of all the boats registered in Ohio list Lake Erie as their primary area of use. That represents over 70,000 boats using Lake Erie from Ohio alone. The economic value of Ohio's boating industry on Lake Erie has been estimated at $133 million per year, and recreational boating contributes a large amount to that total.

There is a 95-square-mile area in the western basin of Lake Erie offshore from Camp Perry that the military use as an artillery range for testing and target practice. This area is often restricted for boating and fishing use during the summer. The Sea Grant program and other organizations are working to minimize the conflicts between recreational and military uses in this area.

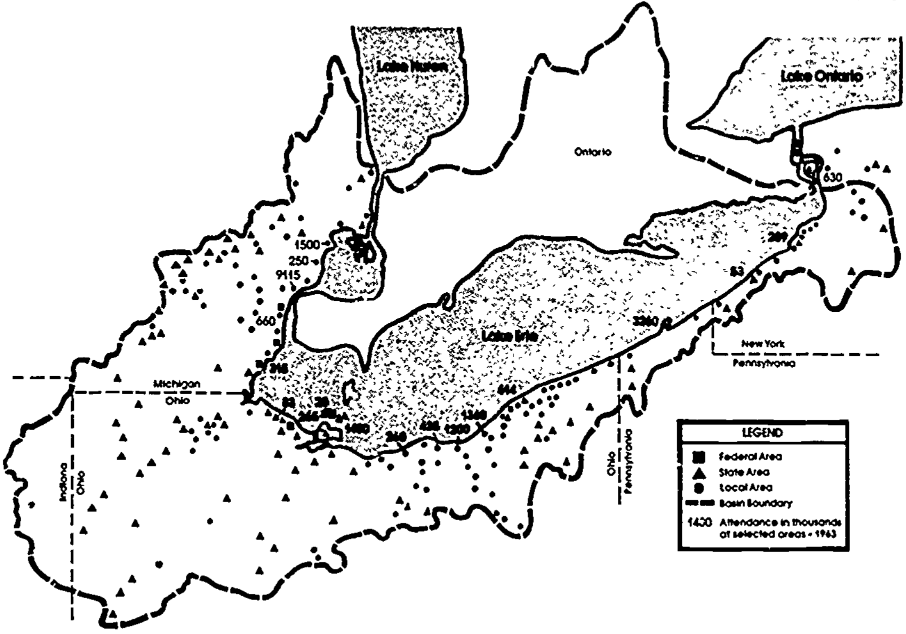

Figure 10.3. **Recreational areas in the Lake Erie Basin.** ***(U.S. Department of the Interior, Lake Erie Report, 1968)***

Figure 10.4. **Lake Erie marina.**

Residential housing

More so on Lake Erie than on any of the other Great Lakes, residential housing represents a major use of shoreline property. Residential housing takes up about 116 miles of the Lake Erie shoreline in Ohio. Building along the waterfront causes problems when the structures get too close to the shoreline. Flooding and erosion are significant problems for many shoreline property owners. A survey to assess the damages due to shoreline flooding and erosion from 1972 to 1976 found that over $65 million of damage was done to property along the Lake Erie shoreline during that period. Shoreline property owners also spent an additional $34 million to protect their properties. It is very expensive to try to protect shoreline property; costs during the survey period ranged from about $150 per linear foot to supply large stone riprap up to $2,000 per linear foot to build a breakwater.

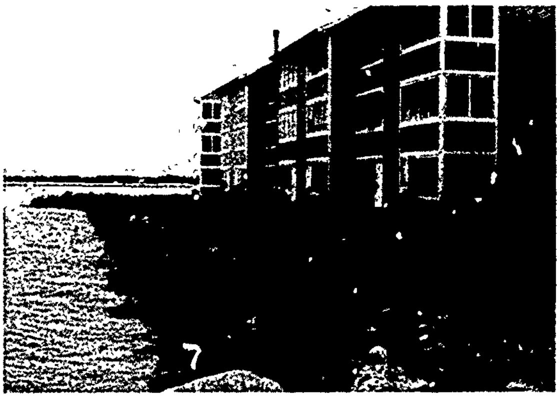

Figure 10.5. **Lakefront condominiums near Port Clinton, Ohio.** ***(Victor J. Mayer)***

We have experienced high lake levels since 1972. Most of the construction along the Lake Erie shoreline occurred between 1900 and 1970 during a period of lower water levels. Until the last 15 years, water levels had not been significantly above the long term average for any length of time since before 1900. As a result, property owners developed the shoreline based on expectations of lower average water levels. Recent trends indicate that these expectations may no longer be realistic.

Most of the damage that occurs along the Lake Erie shoreline is a result of major storms. Lake Erie is oriented along a southwest-northeast axis. Whenever a storm occurs which involves high winds blowing along this axis for a long period of time, the water is literally pushed to one end of the lake in a storm surge which causes an exceptionally high water level. In a recent storm on December 2, 1985, gale force winds of over 60 miles per hour blew from the southwest for several hours. The lake was already at a record high level, and on top of that the wind pushed eight feet of water along the lake toward the Buffalo area. At the same time, water levels in Toledo, on the southwestern shore of the lake, were much lower than normal. During a similar storm event in November, 1972, winds from the northeast raised the water level at Toledo by more than 4 feet, causing $22 million of damage.

One last important point should be made about the ownership of the Lake Erie shoreline. The State of Ohio holds in trust for the people of the state the submerged lands of Lake Erie. The littoral upland owners hold the land down to the waterline. The Great Lakes are not like many other coastal states where the citizens have customary rights to use the tidal areas. In these other states, people grew up able to go to the beach and walk expansive lengths, picnic, camp, swim, or whatever they would want to do. In Ohio and other Great Lakes states, the beaches are held for the exclusive use of the upland owner. We can only visit beaches along the Great Lakes at public parks. As a result, most of us have not grown up with a close association to the lakes. It has been difficult under these conditions to foster the statewide stewardship for Lake Erie and Great Lakes programs. However, with the improvement in the fishery, the increasing awareness of the importance of clean fresh water, and the efforts of educators, we have seen a heightened sense of stewardship for the Great Lakes begin to grow. Much still remains to be done.

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11/ Water Level Fluctuations on the Great Lakes[1]

by Thomas E. Croley II

Introduction

The Great Lakes are one of our greatest water resources, containing 95 percent of the nation's and 20 percent of the world's fresh surface water. The prime measures of water quantity are the lake levels of the individual Great Lakes and Lake St. Clair. As a result of the continuing record high lake levels which began in the spring of 1985, there has been renewed interest in lake level trends and in factors accounting for the current high water levels. Many lake shore interests are particularly concerned about continuing storm damage and flooding during the fall storm season on the lakes.

There is a major tendency to think of Great Lakes water levels in terms of extremes rather than of normal conditions. Within recent memory we experienced the record low lake levels of 1964. This resulted in docks sitting out of the water, insufficient depths for navigation in many harbors and channels, and greatly reduced recreational opportunities. These low levels were followed nine years later in 1973 by record high lake levels with resultant flooding, shore damage and erosion. The lake levels have remained high over the intervening period and new record highs were once again set on Lakes Superior, Michigan, Huron, St. Clair and Erie in 1985 and 1986.

This chapter presents the physical characteristics of the Great Lakes from a water quantity perspective, outlines the basin and lake hydrologic cycles, summarizes the climatology of the Great Lakes, examines the types of natural lake level fluctuations and their causes, compares the natural fluctuations with existing diversions, describes current conditions and concludes with a long-term perspective on lake levels.

Physical system

The Great Lakes basin contains an area of approximately three hundred thousand square miles, about one third of which is water surface. The basin extends some 2000 miles from the western edge of Lake Superior to the Moses-Saunders Power Dam on the St. Lawrence River. The water surface drops in a cascade over this distance some 600 feet to sea level. The most upstream, largest and deepest lake is Lake Superior. Lake Superior is completely governed according to a regulation plan, Plan 1977, under the International Joint Commission. The lake has two interbasin diversions of water into the system from the Hudson Bay Basin, the Long Lac and Ogoki Diversions (Figure 11.1). Lake Superior waters flow through the lock and compensating works at Sault St. Marie and down the St. Marys River into Lake Huron where they are joined by water flowing from Lake Michigan.

Lakes Michigan and Huron are considered to be one lake hydraulically because of their connection through the deep Straits of Mackinac, and together they have a vast surface area that provides a buffer to flow changes leaving the lake. The third interbasin diversion takes place from Lake Michigan at Chicago. Here water is diverted from the Great Lakes to the Mississippi River Basin. The water flows from Lake Huron

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[1] GLERL Contribution No. 508.

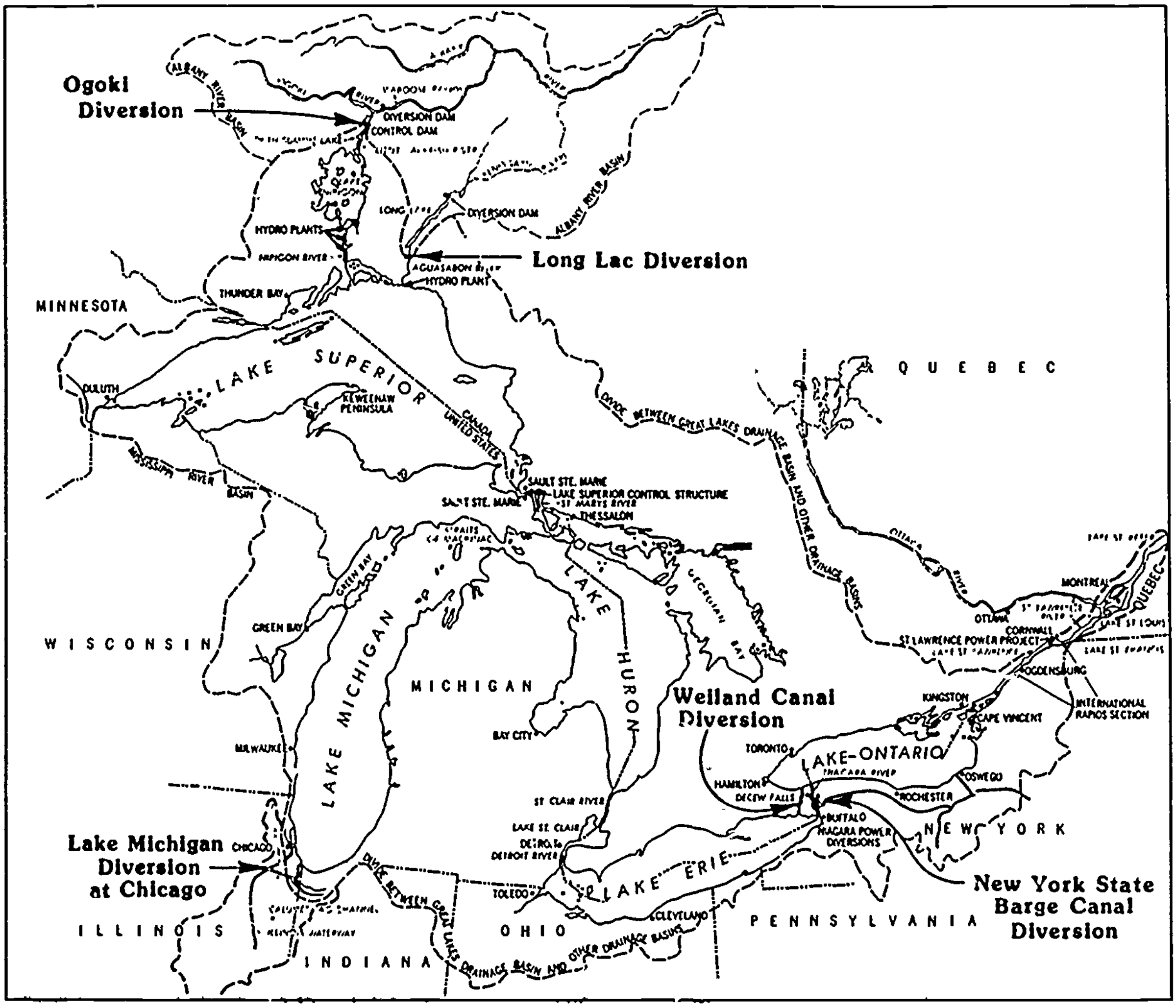

Figure 11.1. Diversions within the Great Lakes Basin. *(IJC, 1985)*

through the St. Clair River, Lake St. Clair and Detroit River system into Lake Erie. The drop in water surface between Lakes Michigan-Huron and Lake Erie is only about 8 feet. This results in a large backwater effect between Lakes Erie, St. Clair, and Michigan-Huron; changes in Lakes St. Clair and Erie levels are transmitted upstream to Lakes Michigan and Huron.

From Lake Erie the flow is through the Niagara River and Welland Diversion into Lake Ontario. The major drop over Niagara Falls precludes changes on Lake Ontario from being transmitted to the upstream lakes. The Welland Diversion is an intrabasin diversion bypassing Niagara Falls and is used for navigation and hydropower. There is also a small diversion into the New York State Barge Canal System which is ultimately discharged into Lake Ontario.

Lake Ontario is completely regulated in accordance with Regulation Plan 1958D. The outflows are controlled by the Moses-Saunders Power Dam between Massena, NY, and Cornwall, Ontario. From Lake Ontario, the water flows through the St. Lawrence River to the Gulf of St. Lawrence and the ocean.

Hydrologic cycle

The primary process that determines the lake levels is the hydrologic cycle of the Great Lakes Basin. As shown in Figure 11.2, precipitation enters the snowpack, if present, and is then available as snowmelt depending mainly on air temperature and solar radiation. Snowmelt and rainfall partly infiltrate into the soil and partly run off directly to rivers, depending upon the moisture content of the soil. Infiltration is high if the soil is dry, and surface runoff is high if the soil is saturated. Soil moisture evaporates or is transpired by vegetation depending upon the types of vegetation, the season, solar radiation, air temperature, humidity and wind speed. The remainder percolates into deeper basin storages which feed the rivers and lakes through interflows and groundwater flows. Generally, these river supplies are high if the soil and groundwater storages are large. Because of this buffering effect of the large snowpack and the large soil, groundwater, and surface storages, runoff from rivers into a lake can remain high for many months or years after high precipitation has stopped.

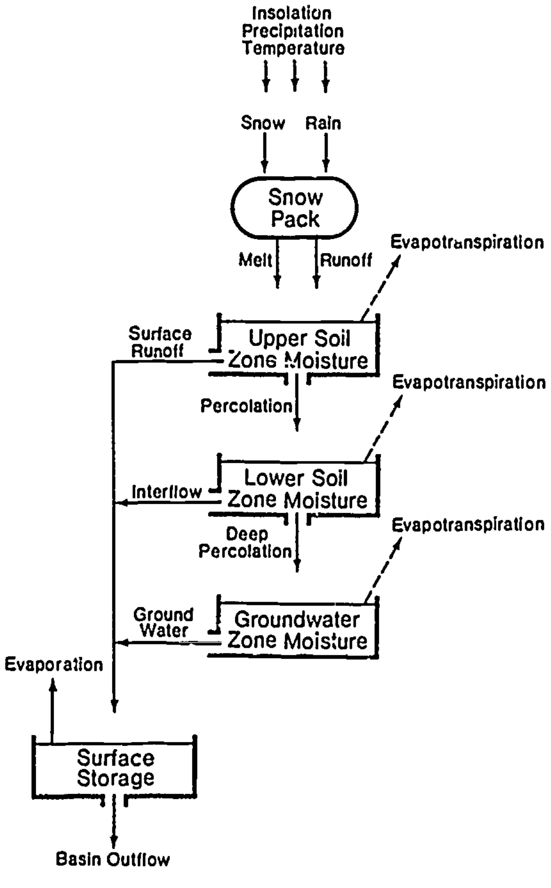

Figure 11.2. Runoff hydrology concepts.

Major sources of water entering a lake include precipitation on the land basin which results in runoff into the lake, precipitation over the lake surface, inflow from upstream lakes, and diversions into the lake. Net groundwater flows directly to each of the Great Lakes are generally negligible. The outflows consist of evaporation from the lake surface, flow to downstream lakes, and diversions. The imbalance between the inflow and outflow results in the lake levels either rising if there is more inflow than outflow, represented by a positive change in storage, or falling if there is more outflow than inflow, represented by a negative change in storage.

Climatology

Precipitation causes the major long term variations in lake levels. Figure 11.3 depicts total annual precipitation over Lakes Michigan-Huron, St. Clair and Erie for the 1900-79 period. From 1900 through 1939, a low precipitation regime predominated with the majority of the years falling below the mean. From about 1940 to 1987, a high precipitation regime has existed. Of particular interest is the high precipitation in the early 1950s, the low precipitation in the early 1960s that led to the record lows, and a consistently very high precipitation regime from the late 1960s through the present time.

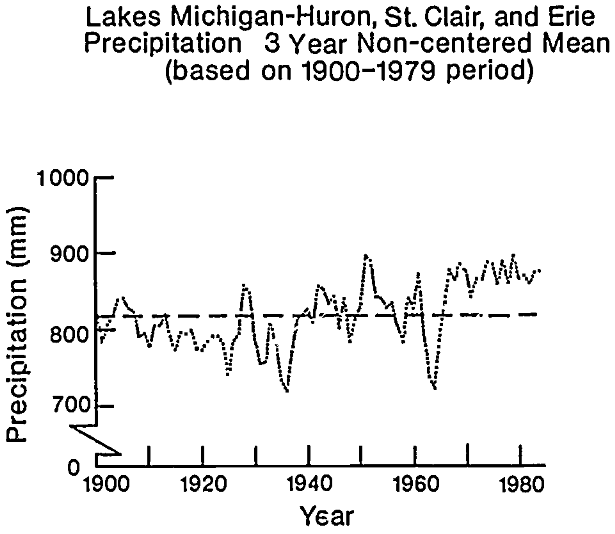

Figure 11.3. Historic precipitation.

Table 11.1. Great Lakes annual precipitation summary

Period	Superior (in)	Superior (%)	Michigan (in)	Michigan (%)	Huron (in)	Huron (%)	Erie (in)	Erie (%)	Ontario (in)	Ontario (%)
Normal[a]	29.6	100	31.1	100	31.5	100	34.1	100	34.3	100
1900-39 (low)	28.5	96	30.8	99	30.5	97	33.5	98	33.8	99
1940-85 (high)[b]	31.8	107	32.0	103	33.6	107	35.8	105	35.6	104
1970-85[b]	33.0	111	32.9	106	35.0	111	37.4	110	37.0	108
1985[b]	41.2[c]	139	38.2[c]	123	41.6[c]	132	42.0	123	36.9	108

[a] Normal is defined as the mean for the period 1900-69.

[b] June-December 1985 provisional data from the U. S. Army Corps of Engineers (Detroit District).

[c] Record high for 1900-85.

Table 11.1 summarizes Great Lakes annual precipitation totals by basin for several periods. Of particular interest are the progressions of increasing precipitation for each basin. While the 1940-85 period is above normal (from 3 to 7% higher), the last 15 year period is higher still (6 to 11%); 1985 set many new records with the highest precipitation to date (24 to 35% higher for the upper lakes).

Variations in air temperature also influence lake level fluctuations. At higher air temperatures, plants tend to use more water, resulting in more transpiration, and there are higher rates of evaporation from the ground surface. This yields less runoff for the same amount of precipitation than would exist during a low temperature period when there is less evaporation and transpiration. The annual mean air temperature around the perimeter of the Great Lakes since 1900 (Figure 11.4), indicates three distinct temperature regimes: a low temperature regime from 1900 to 1929, a higher temperature regime from about 1930 to 1959 and an additional low regime from 1960 through the present period. The difference between the previous and current regime is a drop of about 1 degree Fahrenheit.

The magnitudes of the hydrologic variables vary with the season, as shown in Figure 11.5 for Lake Erie. The monthly precipitation is fairly uniformly distributed throughout the year, while the runoff has a peak during the spring which results primarily from the spring snowmelt. The runoff is at a minimum in the late summer and early fall because of large evapotranspiration from the land basin. The lake evaporation reaches a minimum during the spring and gradually increases until it reaches a maximum in the late fall or early winter. The high evaporation period is due to very cold dry air passing over warm lake surfaces. The integration of these components is depicted in the net basin supply, which consists of the precipitation plus the runoff minus the evaporation. The net basin supply reaches a maximum in April and a minimum in the late fall. The negative values indicate that more water is leaving the lake through evaporation than is being provided by precipitation and runoff.

Lake level fluctuations and trends

There are three primary types of lake level fluctuations: annual lake levels, seasonal lake levels, and short period lake level changes due to wind setup and storm surge. Annual fluctuations result in most of the variability leading to the record high and low lake levels. The annual lake levels are shown in Figure 11.6 from 1860 through the present to illustrate the long-term variability of the system. The record highs in 1952 and 1973 and record lows in 1935 and 1964 are readily apparent. There is an overall range of about 6 feet in the annual levels. Of par-

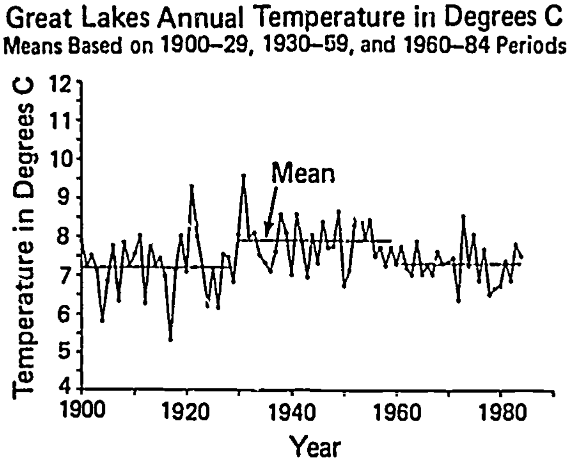

Figure 11.4. Historic air temperature.

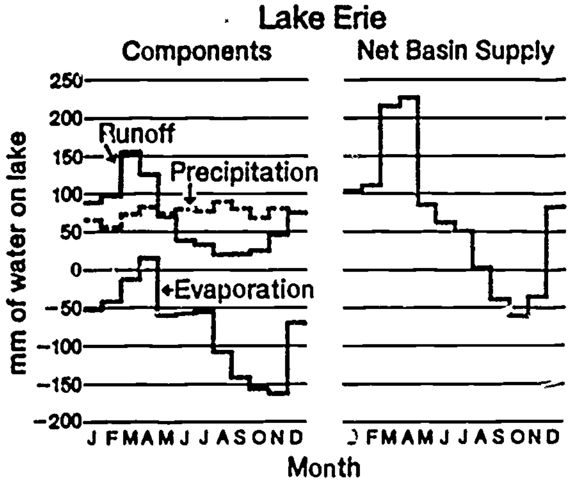

Figure 11.5. Seasonal net basin supply.

ticular interest is the fall in the levels of Lakes Michigan and Huron occurring in the mid-1880s, from which the lakes never recovered. This probably results from dredging for deeper draft navigation in the St. Clair River. Other changes in the St. Clair River include sand and gravel dredging between about 1908 and 1924, a 25-foot navigational project in the mid-1930s and a 27-foot navigational project in the late 1950s and early 1960s. Without these changes, the level of Lake Michigan-Huron would be approximately 1.5 feet h[illegible] than it is today.

[illegible] three-year precipitation mean in Figure 1[illegible] [illegible]es very well with annual lake levels a[illegible] [illegible]y superimposing the annual precipitation on the annual Lake Erie water levels in Figure 11.7. Precipitation tends to lead the water levels by approximately one year, as shown here by the 1929 highs, the 1935 lows, and the 1952 highs. Particularly noticeable is the impact of the last 15 years of high precipitation, resulting in very high water levels. Thus, the continuing high levels are the result of the increased precipitation regime since 1940 coupled with the lower temperature regime since 1960.

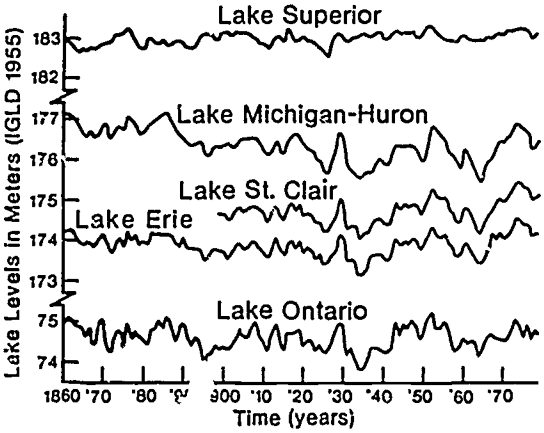

Figure 11.6. Historic Great Lake levels.

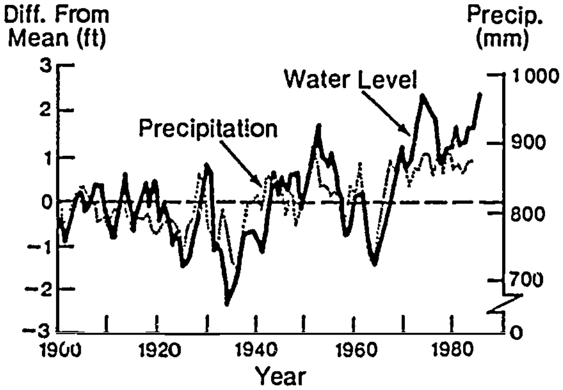

Figure 11.7. Annual Lake Erie water levels

Superimposed on the annual levels are the seasonal cycles shown in Figure 11.8; each lake undergoes a seasonal cycle every year. The magnitude depends upon the individual water supplies. The range varies from about 1.5 feet on Lakes Erie and Ontario to about 1.0 foot on Lake Superior. In general, the seasonal cycles have a minimum in the winter, usually January or February. The levels then rise in response to increasing water supplies from snowmelt and spring precipitation until they reach a maximum in June for the smaller Lakes, Erie and Ontario, and September in the case of Lake Superior. When the net water supplies diminish in the summer and fall, the lakes begin their seasonal decline.

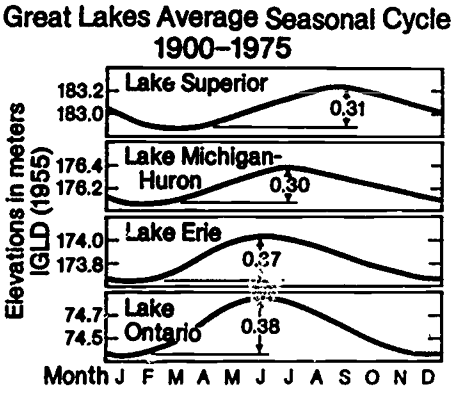

Figure 11.8. Seasonal water level cycles.

The final type of fluctuation which is common along the shallower areas of the Great Lakes, particularly Lake Erie, Saginaw Bay, and in some cases on Green Bay, are storm surges and wind set-up. Under these conditions when the wind is blowing along the long axis of a shallow lake or bay, a rapid difference in levels can build up between one end of the lake and the other. This difference can be as large as 16 feet for Lake Erie. These storm conditions, when superimposed on high lake levels, cause most of the damage along the Great Lakes shoreline.

Looking in more detail at the past trends in lake levels, along with the more recent conditions for Lake Erie, we see a steady progression of changes in the lake levels over time in Figure 11.9. These changes reflect the changes in precipitation illustrated in Figure 11.3 and summarized in Table 11.1. At the bottom of Figure 11.9 are the record low lake levels for each month which were set primarily in 1964. Proceeding upwards we have the 40-year average from 1900 to 1939. From 1940 to 1979, the lake is at a still higher average level. Taking the 11-year period from 1970 to 1980, we see that the lake level average is higher yet, followed by the record highs set in 1973. In 1985, record levels were set in April and May on Lakes Michigan-Huron, St. Clair and Erie. By October 1986, Lake Michigan-Huron had set record high monthly levels for 12 consecutive months and Lake St. Clair had set records for 13 consecutive months. Lake Erie had set records each month since October 1985 except for April 1986.

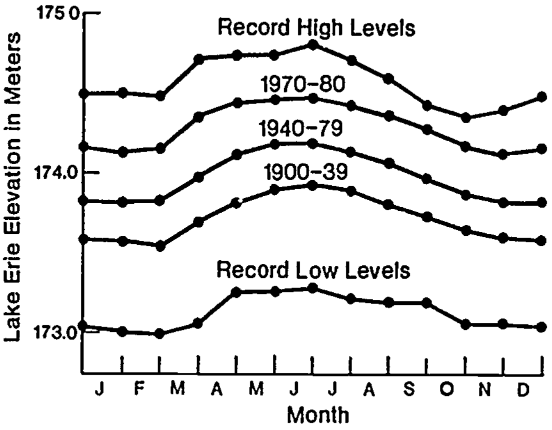

Figure 11.9. Lake Erie level comparisons.

Diversions

It is interesting to compare the impacts of the existing diversions on lake levels in Table 11.2 with natural lake-level fluctuations. This enables a comparison of human impacts with natural fluctuations. The combined effect of Ogoki-Long Lac, Chicago and Welland Diversions on the lakes ranges from a plus 0.11 ft. for Lake Superior to a -0.33 ft. for Lake Erie. The combined effect on Lake Michigan is only -0.02 ft. and on Lake Ontario 0.08 ft. The diversion effects are therefore small in comparison with the 1.5-foot seasonal cycle and the 6-foot range of the annual variations.

The small effects of the diversions along with the long response time of the system illustrate why diversions are not suitable for lake regulation. Because of the large size of the Great Lakes system it responds very slowly to human-induced changes. This is illustrated in Figure 11.10 by the length of time it takes from the start of the hypothetical diversion on Lakes Michigan and Huron (of the magnitude of the Chicago diversion) until the ultimate effect of

Table 11.2. Impact of existing diversions on lake levels.

Diversion	Amount (cfs)	Superior (feet)	Mich-Hur (feet)	Erie (feet)	Ontario (feet)
Ogoki-Long Lac,	5,600	+ 0.21	+ 0.37	+ 0.25	+ 0.22
Chicago,	3,200	- 0.07	- 0.21	- 0.14	- 0.10
Welland,	9,400	- 0.06	- 0.18	- 0.44	0
COMBINED		+ 0.07	- 0.02	- 0.33	+ 0.08

that diversion is reached on Lakes Michigan-Huron and Erie. It takes approximately three to three and one-half years to achieve 50 percent of the ultimate effect and 12 to 15 years to get 100 percent of the effect. Thus, regulation by diversion would not produce changes responsive to natural fluctuations. Recent studies at the Great Lakes Research Laboratory indicate that an increase of 10% in the Niagara River discharge from Lake Erie would lower it 10.5 inches in about 11 to 12 years.

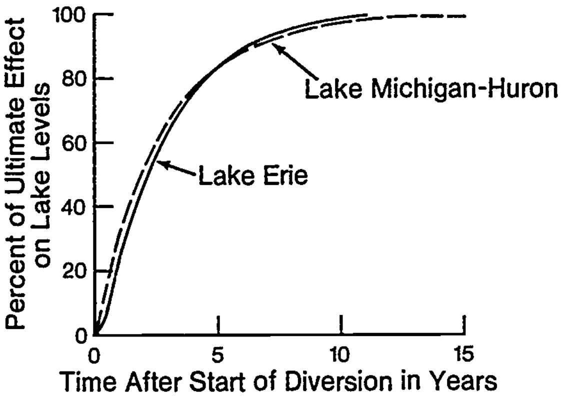

Figure 11.10. Lake level response to diversion

Additional interbasin diversions are a highly controversial issue around the Great Lakes. Possible uses of Great Lakes water outside the basin are flow augmentation for navigation, energy uses such as synfuels or pipelines, agriculture and aquifer recharge and municipal water supplies. A small pipeline project such as the Powder River coal slurry pipeline would require 5-8 cubic feet per second of water and would have no measurable impact on lake levels. A synfuels project, highly unlikely at this time, could require approximately 800 cubic feet per second and result in lake level lowerings of 0.04-0.06 feet. A major agricultural or aquifer recharge project could require 10,000 cubic feet per second and would result in lake level decreases ranging from 0.4 foot on Lake Erie to 0.7 feet on Lake Michigan-Huron. It should be emphasized that these are hypothetical projections for illustration only.

Current conditions

Precipitation was much higher than normal throughout the Great Lakes Basin every month from December 1984 through March 1985, sometimes ranging 100% higher than normal in some parts of the basin. A major spring snowmelt also occurred during the last week in February 1985, compounding the problem. On 18 February 1985, there was a large snow cover throughout the Great Lakes Basin. One week later most of the snow in the southern part of the basin melted and quickly ran off causing the lake levels to rise. April through June of 1985 was dry to normal but every month from August through December of 1985 was again very wet, with August and September 100% higher than normal in some parts of the basin. Air temperatures throughout the summer were below normal, reducing transpiration and evaporation. Air temperatures were close to normal throughout the fall and lower than normal during the winter, resulting in major snowpack storage. In March of 1986, both precipitation and air temperatures were higher than normal, resulting in snowmelt runoff which kept the lake levels high.

The results of these conditions for January through May 1985 are shown in Figure 11.11 as they affect water levels for Lakes Erie, St. Clair and Michigan-Huron; also shown are the record monthly mean levels established during 1973. At the start of 1985, the lake levels were below the record levels. The effect of the February 1985 snowmelt is shown by the sudden rise, in Figure 11.12, of Lakes Erie and St. Clair. The lakes began exceeding the record levels in March. Heavy rains on the southern portion of the basin occurred in late March and early April of 1985, which resulted in Lakes Erie and St. Clair setting new record highs in April. Lake Michigan-Huron also set record high levels but rose at a much slower rate due to its very large water surface, roughly 45,000 square miles. The record high levels continued in May 1985, but because of the drier conditions on the basin no June records were set.

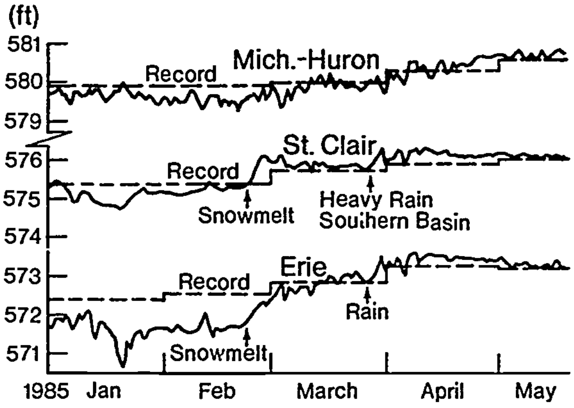

Figure 11.11. Daily lake levels, 1985.

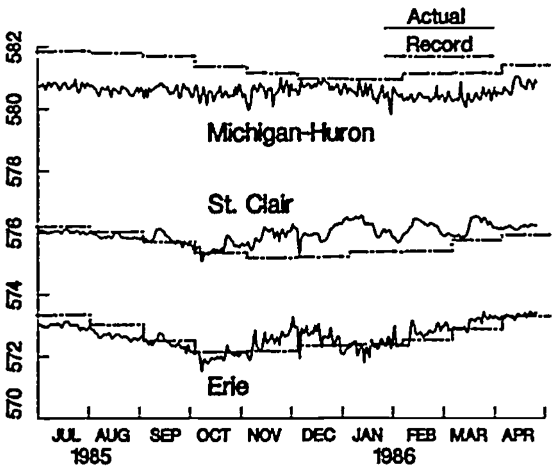

Figure 11.12. Daily lake levels, 1985-6.

Similarly, for July 1985 through April 1986, water levels and record monthly means are shown in Figure 11.12 for Lakes Erie, St. Clair and Michigan-Huron. Lake levels continued to be high but slightly under record levels on Lakes Erie and St. Clair from July through September or October 1985. In November 1985, levels on these two lakes again began exceeding the record. Extremely wet conditions during the fall of 1985 prevented the lakes from following their normal seasonal decline, causing levels in early 1986 to rise near 1985's seasonal peak levels. Above normal precipitation in June 1986 further increased lake levels. In September 1986, the basins received more than twice their normal rainfall, causing levels to continue to set records through January 1987 on Lakes Michigan-Huron and Erie; an ice jam in the St. Clair River enabled Lake St. Clair levels to drop below the record level that month. However, as a result of extremely dry conditions beginning in November 1986, Lakes Michigan-Huron and Erie experienced almost no seasonal rise in levels during 1987; by September 1987, Lake Michigan-Huron was 1.4 feet and Lake Erie was 0.8 feet below September 1986 levels.

Future

Water supplies will not change fast, as shown by the above consideration of diversions. Other studies at the Great Lakes Environmental Research Laboratory indicated that if normal meteorological conditions were again realized ("normal" being the average conditions over 1900-69), it would still take about 6 years for Lake Michigan-Huron to return from its January 1986 level to its normal (1900-69) level. About 7 years would be required for Lakes St. Clair and Erie to return to within 4 inches of normal and about 9 years would be required for them to return to within 4 inches of normal and about 9 years would be required for them to return to within 2 inches of normal. Even supposing that we encountered a drought similar to the 1960-64 conditions, the studies showed that about 3.5 years were required for Lake Michigan-Huron and about 4 years were required for Lakes St. Clair and Erie. Drought conditions since late 1986 caused levels to drop more rapidly than these studies indicated; precipitation during November 1986—June 1987 was 12% less than the driest equivalent period in the 1960s. However, the lakes still are 1.0 to 1.5 feet above average levels; fall and spring storms could still cause much damage along Great Lakes shorelines.

A long-term perspective on Lake Michigan levels for 7000 years was reconstructed through geologic and archaeologic evidence by Curtis Larson in 1985 under work sponsored by the Illinois Geologic Survey. Conditions several thousand years ago were not necessarily the same as today because of isostatic rebound and uplift during the intervening time. But, in general, this provides us with additional perspective on possible conditions we may experience in the future. Looking at just the last 2500 years, during which time the Great Lakes were in their current state, there were major lake level fluctuations. During most of this time the levels were much higher and more variable than they have been during the last 102 years of record. If the past is any indication, lake levels in the future could go through a considerably larger range than we have experienced lately. Indeed, the period of record which makes up what many consider to be normal, the early 1900s through the 1960s, may be abnormal conditions.

Conclusions

The Great Lakes are experiencing high lake levels, except for Lake Ontario, making it likely that lake shore interests will experience continued flooding, erosion and shore damage. Based upon the persistence of the current high precipitation and low air temperature regimes it is likely that the current high lake level regime will continue for the next several years. It is also important to keep in perspective that while we have ranges in annual lake levels of 4 to 6 feet, and additional short term effects on the order of 7 or 8 feet, human effects on the system are relatively small, on the order of a couple of tenths of a foot. Therefore people can have relatively little impact in bringing about major reductions of the existing high lake levels.

Acknowledgment

This report relied extensively on presentations of, and other materials gathered by, Dr. Frank H. Quinn, and on studies performed by Ms. Holly C. Hartmann, both from the Great Lakes Environmental Research Laboratory.

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12/ Effect of Human Activities on the Ecology of Lake Erie

by Elliot J. Tramer

No sizeable lake anywhere in the world has experienced such extensive changes as Lake Erie in the past 150 years. The changes in Lake Erie's fish fauna, algae, bacterial populations, bottom conditions and oxygen concentrations have been especially profound. Without exception, the key to understanding these changes lies in a study of the activities of people who have settled in the lake's drainage basin since the early 1800s. This chapter provides an overview of those activities, and attempts to correlate changes in lake conditions with major events in the development of modern human societies along Lake Erie during the 19th and 20th centuries.

The modern history of Lake Erie and its people can be divided into five time intervals, corresponding to events that caused major changes in the lake's ecology. These are (1) early European settlement, 1790s-1825, (2) the period of transportation development, 1825-1865, (3) the period of industrial "revolution" and rapid population growth, 1865-1930, (4) the era of full industrial development and maximum lake degradation, 1930-1975, and (5) the present interval, which I will hopefully and optimistically call the period of lake recovery, from 1975 to onward.

In general, the rates of population growth and lake change were very slow during the first period, accelerated during period (2) until just before the Civil War, increased explosively during period (3), and gradually slowed during period (4). Although modest population growth has continued in Lake Erie's watershed during the past 10 years (period 5), conditions in the lake have gradually improved for the first time in human memory.

(1) Early settlement period, 1790s-1825

When the first white settlers arrived on Lake Erie's shores just before 1800, virtually the entire region was covered by dense hardwood forests that had stood undisturbed for thousands of years. South and east from Cleveland, the rolling hills of the Appalachian Plateau supported rich forests of beech and sugar maple, with lesser numbers of oaks, red maples, hickories, white ashes, tulip trees and other species. In the deep ravines that drained this plateau, hemlocks towered 80 feet and more, shutting out the light on even the brightest summer days. West from Cleveland and on the Canadian side of the lake, the land formed a low level plain of rich clay soil laid down thousands of years earlier, when the lake had extended further inland, inundating vast areas of the plain. Towering forests of silver and red maple, elm, black ash, pin oak, sycamore and walnut covered this plain. Cleveland itself was nicknamed the Forest City in the nineteenth century. Some of the trees exceeded 100 feet in height, and ranged upward of five feet in diameter. An ancient sycamore near Cleveland that was so wide a card table and four chairs could be set inside its hollow base. In pioneer days this lake plain had innumerable low swampy areas that were under water for up to ten months each year.

It is difficult for us to appreciate the intensity of the early settlers' antipathy toward this forest. Today, trees are valued for their shade and beauty, and thousands of people flock to our state and metropolitan parks each year to enjoy

Figure 12.1. **The largest sycamore.** ***(Cleveland Museum of Natural History)***

the few wooded areas that still exist. But in pioneer days the forest was a dark forbidding presence that sheltered wolves, bears, and other animals perceived to be dangerous, not to mention hostile Indians. It was an enemy to be vanquished, and later, a source of lumber to be exploited for profit. The forest was an impediment to travel and inhibited the growth of commerce and agriculture. The first duty of any settler after staking out his plot of land was to clear the timber and underbrush as quickly and completely as possible. It is not surprising that virtually none of the original forest remained in the Lake Erie basin by 1890. In fact, only about 10% of the land in the basin has been allowed to return to forest cover. Of all the changes wrought by modern humans, deforestation has been by far the most powerful agent of change in the character of Lake Erie.

At first, the pace of deforestation was slow. There were few settlers because of problems with the Indians and a lack of good avenues of transportation. Trees had to be felled with hand axes or primitive saws, and teams of horses or oxen were required to move the huge logs. Deforestation was easiest (and thus occurred first) on level dry lands. Swampy areas were flooded and thus inaccessible during much of the year, and the steep-sided ravines along the lake's southeastern flank were also difficult to exploit. Roads being almost non-existent, most settlers arrived from the east by boat. Therefore the early settlements were located on the lakeshore or the banks of larger rivers. In 1820 the population of Cleveland was about 600; Detroit had 1,442 citizens and Toledo did not exist.

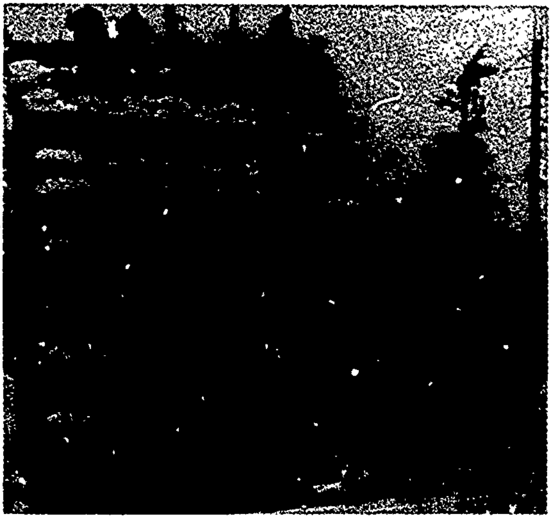

Figure 12.2. A "brag" load of white pine logs, Michigan, 1880. ***(Michigan Department of Conservation)***

Few descriptions of Lake Erie have come down to us from the early days of settlement. In the earliest accounts, stream and lake waters are described as pure and "sweet," and the clarity of the water is often mentioned. Fishes were apparently exceedingly abundant, especially during spawning runs in the lake's major tributaries. The species of fish mentioned as common in the early days include those typical of clear, well-oxygenated waters (see Andrew White's paper in this volume), indicating that the lake and rivers feeding into it were probably of very high quality.

At the end of the early settlement period (1825), forest cover still extended over most of the region. Episodes of siltation caused by forest removal, or of sewage contamination from human settlements, either had not yet occurred or were so local and of such small magnitude that they were not worthy of remark.

One change well under way by 1825 deserves mention: the creation of mill dams across rivers and creeks. Transportation was slow and unreliable, so early settlers could not depend on shipments of flour from the east. They needed to be able to grind their own grain to produce flour for baking. In this connection it is interesting to note that Detroit was already a French fort in 1701, long before there were other European settlements near Lake Erie. Famines occurred there with great frequency—in 1780, 1784, 1789, etc.—in part because the French thought the land too swampy or sandy for successful cultivation. The famines did not cease until 1825, when cultivation was successful and mills were built, allowing flour to be produced locally and ending dependence on flour shipments from elsewhere. The only source of abundant power in early days was to harness the force of gravity by using falling water to drive mill wheels. In much of the lake basin, where the land was flat and streams lacked natural waterfalls, the only way to harness this power was to build an artificial waterfall—a dam.

Figure 12.3. Mill dam. ***(Ohio Historical Society)***

These dams decimated many populations of migratory fishes by blocking their spawning runs, and created areas of ponded water upstream where silt was allowed to settle out on the bottom. By the end of the early settlement period hundreds of dams were under construction, and virtually every river or creek bed that led to Lake Erie had at least one mill dam across it.

(2) Transportation development, 1825-1865

This era was ushered in by an event of profound significance in the history of the Lake Erie basin, the completion of the Erie Canal. This canal, which extended westward some 300 miles from the Hudson River at Albany, New York, to its terminus on Lake Erie at Buffalo, was completed in 1825. Roads were so poor at that time that canals were the fastest and most reliable means of travel. The Erie Canal made possible a steady flow of some people and goods from the developed Atlantic coastal states into the Lake Erie basin. At first the canal primarily brought settlers westward, but as the population of the Great lakes increased, the canal began to carry goods produced by those people back to eastern markets eager for grain, lumber and other products of the frontier.

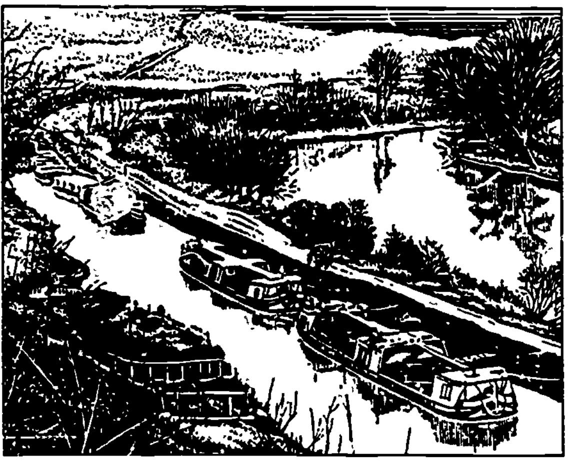

Figure 12.4. Canal scene. ***(Ohio Historical Society)***

Between 1825 and 1837 a virtual orgy of canal building ensued. In 1829 the Welland Canal connected Lake Ontario with Lake Erie, circumventing Niagara Falls and the rapids of the Niagara River. Canals extended from Cleveland to Portsmouth, Ohio, and from Toledo to Cincinnati, linking Lake Erie with ports on the Ohio River. These connections to the south were important in expanding the grain trade in the Lake Erie region.

Buffalo was the first city on Lake Erie to experience a "boom" during the canal era. It had seen only 120 boats enter its harbor in 1820, but by 1850 over 9000 vessels were trading there each year. By the 1850s Buffalo was the largest grain market in the world. This growth was spurred by Buffalo's location at the eastern end of the lake, a natural transfer point for grain grown in the midwest and shipped to the large eastern cities, and by the invention at Buffalo in 1843 of the grain elevator, which permitted fast loading and unloading of grain from big ships.

The canal system was the dominant form of transport for only about 20 years, from 1825 to perhaps 1845. The human labor devoted to constructing that system was incredible by any

Figure 12.5. Buffalo Harbor in the 1850s. ***(Mariners Museum, Newport News)***

standard: canals were dug by hand, using picks and shovels. Imagine digging a trench 26 feet deep, 40 feet wide, and 300 miles long without the aid of machinery! Ironically, improved roads and increasing competition from railroads in the 1840s and 1850s quickly made the canals obsolete.

Despite the development brought about by canals, there was still an acute need to improve overland transportation in the 1820s and 1830s. Horses were faster than barges, and both the canals and Lake Erie were frequently made impassable by winter ice. Violent storms made Lake Erie unpredictable and often dangerous for travelers by ship. A serviceable wagon road connected Buffalo and Cleveland with the east by 1820, but west of Cleveland the situation was different. Most of northwestern Ohio was swampy or marshy land that remained flooded from October or November until July of the next year. A particularly wet area of more than 3000 square miles lay like a moat across the route from Cleveland to Detroit. This huge area, called the "Black Swamp," was the major obstacle to overland travel along Lake Erie's southern flank.

Pressure to establish an overland mail route between Cleveland and Detroit caused Congress to appropriate funds for a road through the Black Swamp in 1821. Completed by 1827, the road was an elevated, 40-foot-wide strip with ditches on either side. For the first 15 years of its existence, it was known as the worst road on the North American continent. Its surface was mud, and horses and wagons became hopelessly mired during the nine months each year that the swamp was flooded. Hauling teams out of mudholes provided a steady income for settlers along the route. Inns existed at each milepost between Fremont and Perrysburg, Ohio (the worst section), because travelers often progressed less than a mile a day.

The Black Swamp greatly impeded the development of northwest Ohio compared to other parts of the Lake Erie basin. Until the Black Swamp road (now U.S. Highway 20) was finally macadamized in 1842, the preferred overland route from Buffalo to Detroit was through southern Ontario. The extent to which northwest Ohio was bypassed by the early tide of settlers is reflected in the 1830 census figures. At that time, the six counties of southeastern Michigan contained 14,585 people, while an almost identical-sized area (now comprising nine counties) in northwest Ohio had only 2,955 residents.

The growth of population and commerce in the Lake Erie basin accelerated tremendously with the coming of railroads. A railroad link between Buffalo and Albany was completed in 1843, following the same general route as the Erie Canal. The system expanded rapidly until by 1848 railroad tracks extended all the way to Chicago.

In the early 1850s a number of events made the south shore of Lake Erie a focus of industrial development in the midwest. One was the construction of railroads northward to the lake from the coal fields of Pennsylvania, West Virginia and southeastern Ohio. Another was the discovery at Titusville, Pennsylvania, in 1859 that crude oil could be brought to the surface from wells drilled deep into the earth. A third was the discovery of vast deposits of iron ore along Lake Superior. The latter event was the prime impetus for the construction of the Soo Locks connecting Lakes Huron and Superior; shipments of iron ore to the lower lakes began immediately upon completion of the locks in 1855.

The Lake Erie shore had no oil, coal or iron ore of its own, but it was strategically located between huge deposits of all three. In addition to being major transportation hubs, the cities on the lake had another great resource of inestimable value for industrial development—an abundant supply of clean water.

The railroads facilitated development of the lake's cities as important marketing centers for agricultural products as well. Buffalo became the leading grain port, and wool, beef, pork, lumber and a host of lesser products were shipped by way of the lake ports. The railroads hastened

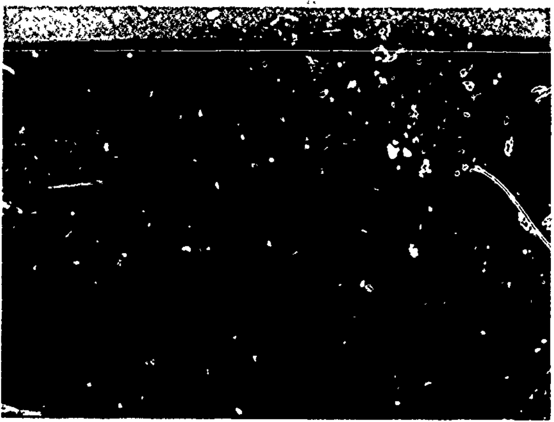

Figure 12.6. Railroads meet shipping terminals in modern Toledo. *(Toledo-Lucas County Port Authority)*

deforestation of the region by making possible the rapid transport of large quantities of lumber to the east, where the forests had been destroyed two generations earlier and an insatiable market for building materials existed. The railroads themselves consumed vast quantities of wood, both as fuel for the locomotives and as ties for the tracks. Lumber quadrupled in value during the railroad period as the population grew and the need for housing increased. A kind of positive feedback phenomenon took hold, with the establishment of railroads creating new opportunities for agriculture, industry and urban growth, which in turn increased the need for lumber and other resources, creating the need for more railroads, and so on. By 1860 Cleveland had 43,000 residents while Buffalo's population exceeded 81,000.

The spread of agriculture, industry and population began to have noticeable effects on Lake Erie by the end of this period. By 1855, big lake sturgeons no longer ascended the rivers to spawn. Dams and the contamination of river mouths by sewage and industrial pollutants had already decimated populations of fish species that moved from the lake into rivers to reproduce. In the 1850s mention of silt in streams and turbidity of river and nearshore lake waters appears for the first time in the writings of people living around Lake Erie. The bulk of the population was still rural, and conversion of forest lands to farms was virtually complete except for portions of the Black Swamp in northwestern Ohio. Some idea of the spread of agriculture in the basin may be gained from the observation that the bobwhite quail, a bird that thrives only in weedy agricultural landscapes, reached its all-time peak of abundance in southern Ontario in the 1850s.

With the growth of cities and the absence of any means of sewage treatment, the appearance of water-borne diseases was inevitable. The first New World outbreak of cholera began in 1832 at Quebec on the St. Lawrence River, brought to this hemisphere on a ship from Europe. Sailors who drank contaminated water at Quebec soon brought the disease to ports on the Great lakes, where it spread rapidly. Buffalo had several outbreaks in the 1840s after some of its shallow wells became polluted. After a particularly virulent cholera epidemic in 1849 killed over a thousand citizens, Buffalo installed a water intake in the rapids of the Niagara River and urged its residents not to drink from wells.

Cleveland also experienced difficulties with polluted water. A typhoid epidemic in 1851 was attributed to contamination of wells and the Cuyahoga River. The lower Cuyahoga was already becoming infamous for its foul quality in the 1850s, when a resident described it as "...yellowish...bad-tasting...slimy in August with all manner of impurities floating on top" (Avery 1918). Because of the unsanitary condition of the river and well water, Cleveland in 1853 installed a water works whose intake was 1000 feet offshore in Lake Erie. By the 1860s the Cuyahoga was little more than an intercepting sewer, carrying raw human sewage, slaughterhouse wastes, coal, sawdust, oil and other contaminants out to the lake. Even small towns were not immune to the ravages of growth; Perrysburg, a small community on the Maumee River at the edge of the Black Swamp, suffered a cholera epidemic in 1854.

After 1860 the Civil War briefly sapped the country's energies and slowed development in the Great Lakes basin. As soon as the war ended, however, the stage was set for the industrial "revolution" to move into high gear. Despite problems with water-borne diseases and the early evidence of environmental deterioration described above, the prevailing attitude was that Lake Erie was too big to ever become seriously polluted.

(3) Industrial "Revolution" and explosive growth, 1865-1930

The growth of Cleveland was typical of the rapid economic expansion that occurred throughout the Great Lakes region following the Civil War. John D. Rockefeller, a resident of that city, began in 1861 to centralize the fledgling oil industry under his personal control. By 1869 Cleveland was an oil refining center, with Rockefeller's new Standard Oil Company leading the way. By the 1900s Cleveland was the leading oil refining city in the world.

Figure 12.7. An oil refinery near Cleveland. ***(Andrew M. White)***

In the 1860s coal was rapidly replacing wood as a fuel. It was particularly needed for the manufacture of iron and steel. Cleveland's iron foundries already employed 3,000 men by 1860, and these factories were important suppliers of arms to the Union forces during the Civil War. In 1865, 456,000 tons of coal were shipped to Cleveland, most of it for use in the iron industry. This was only the beginning. Iron ore shipped to Cleveland increased from 723,000 tons in 1883 to almost 3 1/2 million tons in 1890 and over 11 million tons in 1930. Leaders of the steel industry found the existing lake sailing ships too slow for the commercial transport of iron ore, so they built their own fleets of steam powered freighters, uniquely suited for carrying heavy cargoes of ore on the lakes. Consequently, Cleveland became the leading shipbuilding center in the Great Lakes, and by 1890 it led the nation in shipbuilding. In addition to the ore used by Cleveland's foundries, thousands of additional tons of ore were shipped through Cleveland, Conneaut and Ashtabula on their way to the steel-making region between Youngstown and Pittsburgh.

Grain continued to be Buffalo's chief port business into the 1870s, with meat-packing, lumber, iron and steel becoming increasingly important thereafter. By 1900 Buffalo was the second largest lumber market in the midwest. The construction of a hydroelectric plant at Niagara Falls in 1895 provided cheap electric power, and further spurred industrial growth in the Buffalo area. The world's largest industrial steel plant, owned by the Lackawanna Steel Company, was located at Buffalo in 1907.

Toledo also expanded rapidly. By the 1890s it was second to Cleveland as an oil refining center. The Libbey Glass Company came to Toledo in 1888 from New England, lured by abundant sand for glass-making and cheaper wood and soft coal fuels. Natural gas was discovered at Findlay, Ohio, in 1885, precipitating a brief but intense economic boom. Gas fires proved to be ideal for glass-making, and the proximity of Toledo to the gas fields further stimulated the growth of that city's glass industry. After the invention of a machine for mass-producing glass bottles by Libbey Company's Michael J. Owens in 1902, Toledo became the world's leading manufacturer of glass products.

Detroit's growth was only moderately fast until 1900, when Henry Ford began mass-producing automobiles there. Then Detroit grew explosively. Other cities on the lake also participated in the auto boom; Toledo provided windshield glass and spark plugs, Akron's rubber industry produced tires, and Cleveland, Sandusky and other cities manufactured a variety of auto body and engine components.

In all these places, the growth of industry provided unprecedented opportunities for employment that drew people from near and far to settle in the Lake Erie basin. The period 1870-1918 was a time of political and social unrest in central and eastern Europe, and hundreds of thousands of European refugees fled to this country seeking to build new lives. The industrial revolution put them to work, often in the factories on Lake Erie's shore. Reflecting this flood tide of immigrants, Buffalo's population quadrupled between 1860 and 1900. Cleveland grew from 43,000 inhabitants in 1860 to 92,000 in 1870, more than doubling its population in just 10 years. By 1930 Cleveland had over 900,000 residents, and was the fifth largest city in the United States. Detroit had over one million people, and ranked fourth.

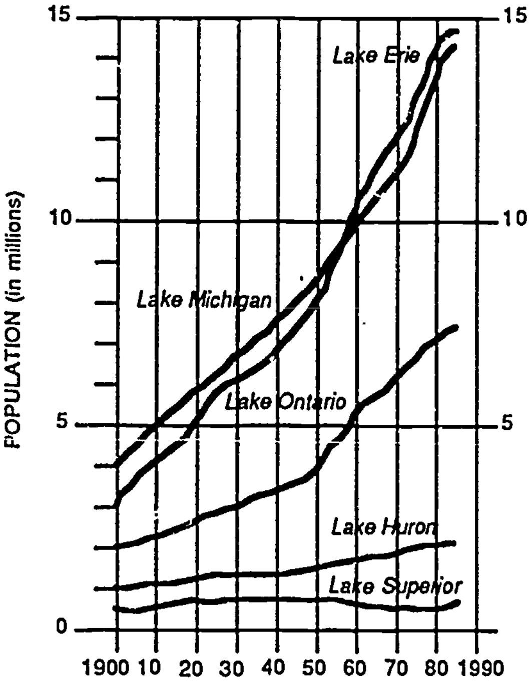

Figure 12.8. Population growth in the Great Lakes' basins since 1900. *(Botts and Krushelnicki. 1987. The Great Lakes. p. 18)*

The need for wood also expanded greatly after the Civil War. Wood was still the nation's primary building material, and lumber was becoming increasingly scarce. The primary focus of the lumber industry in the late 1800s was on the white pine forests of Michigan and western Ontario. For a generation or more this region provided the bulk of the nation's needs for wood and wood products. Huge shipments of pine lumber arrived at Toledo almost daily in the 1880s, towed from the sawmills on Saginaw Bay on Lake Huron. Paper products also consumed vast amounts of wood, especially after 1890, when newsprint was made entirely of wood pulp instead of a mixture of wood pulp, straw and rags. A single newspaper, the Chicago *Tribune*, used 200,000 tons of newsprint annually in the 1920s. By 1890 Michigan was stripped of most of its forests; western Ontario followed by 1915, although the immediate lakeshore area had been deforested far earlier.

This era also saw the final demise of the Black Swamp in northwest Ohio. The swamp was the last vestige of primeval forest left in the Lake Erie basin. Despite early efforts to convert it to agriculture, the swamp was still more than 50% forested in 1870. The key to clearing the swamp was efficient drainage, and advanced techniques of tile drainage already in use elsewhere, were not generally known to the local residents until the 1870s. Persistent problems with "ague" (malaria) and knowledge that the soils of the swamp were very fertile provided strong impetus for drainage projects. Finally, between 1874 and 1881, local governments invested 1.5 million dollars in roads, drains and ditches in the swamp. Creeks were cleared of snags, and the water table quickly dropped, drying out most of the swamp. Cutting of the forest followed at once, lowering the water table still further. By 1887 the swamp was more than 90% deforested. Between 1890 and 1930 the Black Swamp produced the best agricultural yields in the entire Great Lakes region, with corn the dominant crop. In the years immediately after World War I the region became the most intensively farmed area in the United States, and visitors to the area could see no evidence whatsoever that an impenetrable swamp had stood there a mere half century before.

In fact, agriculture thrived in most of the Lake Erie basin during this period. In northeastern Ohio, Pennsylvania and New York, the hilly lands of the Appalachian Plateau were well suited for dairy cattle. Apples, grapes and other fruit crops thrived, especially along the narrow lake plain from Sandusky eastward. Rich harvests were produced in southeast Michigan and Ontario as well. Grain production was very successful, with 26 million bushels of wheat marketed at Detroit in 1886. Extreme southern Ontario had rich soils and a long growing season because of the ameliorating influence of Lake Erie on spring and fall temperatures. The area quickly became a center of production for fruits, vegetables and grains. Tomatoes, grapes, apples and peaches were particularly successful, and Leamington, Ontario, soon declared itself "the tomato capitol of Canada."

Farming at the close of the 19th century was very different from today. The average farm was only about 100 acres. Fields were small and were bordered by wide brushy fencerows or hedges that provided wildlife cover and windbreaks. Crops were rotated and land was often "rested" for a year or more, or cycled between crops and pasture. Manure and legumes were plowed under to maintain soil fertility, and farmers grew much of the food they consumed at their tables. After 1915, however, agriculture began to change. The advent of motorized farm machinery made it more economical to grow monocultures on much larger fields. Farmers raised just one or two cash crops and kept little or none of what they grew, buying most of what they ate from the store, like city dwellers. Hedgerows and brush were cleared away, reducing cover for wildlife and accelerating the erosion of topsoil. With the topsoil went chemical fertilizers, directly into the waterways.

Siltation of waterways leading to Lake Erie was extremely heavy during this period. Biologist E.L. Moseley traveled from Toledo to Cleveland in a heavy rainstorm in June 1902, and wrote: "I found all the ditches between Sandusky and Cleveland carrying torrents of muddy water, and creeks swollen to the size of small rivers bearing their loads of sediment on toward the lake."

The commercial fishery thrived in the 1880s despite rapidly increasing contamination and the loss of spawning habitat. However, the tons of sediment carried into estuaries such as Maumee and Sandusky Bays soon suffocated the rooted aquatic plants there, ruining the spawning areas of the most desirable food fishes. By 1900 these bays had been converted from lush aquatic meadows to feckless, turbid basins devoid of rooted plants. Thanks to silt, sewage and toxic industrial wastes, a profound shift in the species composition of the Lake Erie fish fauna was well underway by the early 1900s. Andrew White describes in detail the devastating effects of these changes on our commercial and sport fisheries elsewhere in this volume.

Increasingly, water was confined to river channels as floodplains were diked or filled and built upon, ditches and drains dug, roads paved and plant cover removed. Storm runoff was channeled immediately into creeks and rivers and hastened downstream: areas of streambed with fast flow were scoured out, while slow-water areas became choked with silt. Unprecedented flood crests occurred, causing heavy damage to riverside communities. In February 1883 a heavy rain raised the Cuyahoga River ten feet in several hours. Cleveland's industrial flats were flooded, causing millions of dollars of damage. The situation was exacerbated when an oil tank exploded and flaming oil was spread across the water's surface. The author witnessed another flood after a heavy rainstorm in June 1959 that put University Circle, Cleveland's cultural center, under six feet of water. This 1959 flood was caused by extensive paving and channel confinement in the watershed of Doan Brook, which drains two of Cleveland's eastern suburbs.

Bacterial contamination of drinking water became a pervasive problem in the lakeshore cities in the late 19th century. Cleveland's water intake had to be moved 6,600 feet offshore by 1874 and in 1904 it was relocated again, this time about 4 miles offshore! In 1917 a filtration plant was built to purify Cleveland's drinking water. In Buffalo water use increased 33-fold between 1868 and 1906. After the Civil War Buffalo's sewage emptied via interceptors and canals into the Buffalo River, whence it entered the eastern end of Lake Erie, proceeded down the Niagara River, and was returned (in part) to the citizens of Buffalo via their drinking water intake! In 1883 an interceptor was built to carry some of the sewage to the Niagara River downstream from the intake. Finally, in 1896 drinking water was pumped from another intake in Lake Erie, well offshore. These changes, together with increased surveillance of the quality of Buffalo's drinking water, improved the health of the city's residents in the 1890s. In 1891 Buffalo's death rate was 2.35% (6,001 deaths among 255,000 people); by 1900 the death rate had fallen to 1.4% (4,998 deaths among 352,000). Virtually all of this improvement was the result of reduction in deaths from water-borne diseases.

By the end of this period there was finally some official concern for the deteriorating quality of Lake Erie. By 1930 scientific surveys of the lake's algae, zooplankton and fish populations had begun. Oxygen levels in the central basin off Cleveland and around the Lake Erie islands were being monitored. No one was yet attempting any remedial action and conditions were to become far worse, but at least there was now some public awareness of the lake's problems.

(4) Peak of industrial development and lake degradation, 1930-1975

The world-wide depression of the 1930s brought industrial growth in the Lake Erie basin to a virtual standstill. The depression was also hard on farmers, and many had to leave their farms to seek employment in the cities. Substantial acreage of rural land was abandoned and reverted to second growth thickets. This episode was brief, however, and World War II brought full employment and renewed economic vigor to the region. After the war ended in 1945 the economic boom continued at an even faster pace. Factories that had devoted their resources to producing armaments and other war materials turned once again to the production of automobiles, appliances and other consumer goods.

Agriculture became more and more mechanized, and the use of chemical herbicides, insecticides and synthetic fertilizers became almost universal. Increasingly, farmers had to be agribusinessmen and auto mechanics as well as horticulturists and stockmen. Farming became more economically risky as chemicals, fossil fuels and farm equipment increased in cost. Farmers were forced to put every square foot of land under cultivation. Fields were no longer rested by fallowing; crop rotation was based on market considerations rather than the long-term health of the soil, and wildlife cover became nonexistent on many farms. Waterways were stripped of vegetation and channelized to allow farmers to cultivate floodplains right to the edge of streams and ditches; the adverse affects on topsoil, water quality, fish species and human populations living downstream were ignored. This pattern occurred most extensively in the Maumee River watershed south and west of Toledo: the Maumee was and still is the largest contributor of silt to Lake Erie.

The 1950s brought profound changes in urban areas as well. The basin's large industrial cities leveled off or even declined in population as urban pollution and crowding drove the more affluent people out to the suburbs. This shift in population was abetted by the interstate highway system, begun in the 1950s, which allowed people to live far from their jobs and commute to and from the city each day. Improved highways and the development of high-speed jet aircraft for commercial aviation revolutionized travel, and virtually eliminated railroads and ships as passenger carriers in the Great Lakes as well as elsewhere. Goods still traveled by ship and rail, but tractor-trailer trucks carried a larger and larger share of the nation's produce during this period. The explosive growth of truck and car travel exacerbated air pollution problems already made acute in many cities by heavy industry. By the 1960s Cleveland had the third-worst air quality in the U.S. (after New York and Los Angeles), a designation based on particulate matter and ozone concentrations.

Auto production was at record levels through most of this period, and oil, paint, glass, electrical and other industries vital to the economic welfare of the region continued to prosper. However, by 1970 there were some danger signs. Especially distressing were ominous changes in the steel industry. Steel production in the Lake Erie cities peaked during World War II and then began a gradual but accelerating decline. The steel industry in Ohio and Pennsylvania was beset with outmoded plants and equipment and high labor costs.

The late 1960s were also a time of social unrest caused by a combination of factors, including urban decay and an unpopular war in southeast Asia. For several consecutive summers riots occurred in many American cities, with Detroit and Cleveland experiencing some of the worst. The costs of unrest ran into the hundreds of millions of dollars, most of it from arson and destruction of property. Many employers reacted to this situation by moving their businesses out of downtown areas. Stores, restaurants, banks and offices of all kinds relocated in the suburbs. Many industries, already stressed by high labor costs, simply left the region altogether, a trend that still continues in the 1980s. Midwestern cities that had been beacons of opportunity to poor immigrants in the 1890s seemed on the verge of becoming impoverished backwaters, occupied only by those too poor to leave, and run by governments unable to generate the revenues to meet their obligations.

Throughout the years of industrial development and population growth, Lake Erie had been used as the dumping place for the wastes and byproducts of tens of millions of people. In the mid-1950s, the cumulative effects of a century and a half of indifference became too obvious to ignore. Water quality investigations revealed an alarming spread of anoxic (deoxygenated) waters, especially in the lake's central basin. Bearing the accelerating costs of harbor dredging and sewage treatment had become a burdensome necessity for taxpayers. Nuisance blue-green algae growths caused by overfertilization of the lake encumbered boating, fouled beaches and tainted drinking water with their toxins. Excessive bacterial counts closed beaches to swimming, and the spectacular collapse of the commercial fisheries for blue pike, cisco, lake whitefish and sauger made headlines.

By 1970 Lake Erie had attracted so much negative attention in the popular press that its name had become a kind of "sick joke," a euphemism for ecological disaster. Television talk show hosts and stand-up comedians could guarantee a laugh by mentioning "Lake Erie" in the context of something grossly unpleasant or ruined beyond repair. Some ignorant or irresponsible authors even popularized the idea that Lake Erie was "dead," an absurd notion in view of the vast blooms of all-too-living blue-green algae and tons of forage fish being produced annually in the lake.

Figure 12.9. Cleveland beach closed in 1972 by coliform contamination. ***(Andrew M. White)***

Fortunately, the turbulent years at the end of this period were also the dawn of a new era of environmental awareness. On April 22, 1969, years of growing concern culminated in the first Earth Day, which gave tremendous positive publicity to the environmental movement and showed government officials that a huge constituency existed that favored strong, decisive action on environmental problems. Federal laws were soon enacted setting goals for air and water quality and protecting endangered species of wildlife. The International Joint Commission was empowered to deal with a wide range of environmental issues affecting the Great Lakes. An Environmental Protection Agency was created to enforce the nation's new environmental laws, and federal grants were made to many Great Lakes cities to help them upgrade their wastewater treatment facilities to meet the new standards. For the first time, there was cause for optimism about Lake Erie's future.

(5) The Lake's recovery and future prospects, 1975-?

Improvement in the quality of Lake Erie has occurred on at least four fronts. First, the nuisance algae blooms of the late '60s and early '70s have subsided. This change may be attributed to lower phosphorus concentrations, a reduction caused by tertiary sewage treatment and by the phasing out of high phosphate laundry detergents in many states around the Great Lakes. Ohio, however, does not enforce a phosphate ban. Especially beneficial has been improved sewage treatment by Detroit, formerly the largest single contributor of phosphorus to Lake Erie. Overall, phosphorus loadings declined by almost 56% between 1968 (the peak year) and 1982 (see Herdendorf's article in this volume.)

Improved sewage treatment is undoubtedly a major contributor to progress on two other fronts as well, reduced coliform bacteria counts and the gradual shrinkage of the volume of anoxic water in the lake's hypolimnetic zone. A fourth area of improvement is the lake's fishery. For the time being, at least, fish populations seem to have stabilized, and the walleye has fully recovered from its steep decline of the 1960s.

Lady Luck may also be lending a hand. The years 1972 through 1974 and 1985 through early 1987 have seen record high lake levels. High lake levels are not new; they result whenever abnormally high rainfall and snowfall occurs in the basins of Lakes Michigan, Huron and Superior, all of which empty into Lake Erie. In recent times lake levels have reached record highs and have been well above average more frequently, probably because of extensive paving, deforestation, drainage and stream channelization throughout the Great Lakes basin. Although high lake levels have wreaked havoc with lakeshore property owners, the effects on water quality have been beneficial because a much larger volume of water is available to dilute the effects of nutrient and toxic waste inputs. In fact, the degree to which lake improvement since 1975 is "real" (i.e., the result of better sewage treatment and tougher effluent standards as opposed to high water levels) remains somewhat controversial.

In a perverse way, the decline of heavy industry in the Lake Erie basin may also aid in the lake's recovery. Reductions in steel production, oil refining and so on mean less industrial waste entering our waters; the flight of heavy industry from the Great Lakes to cheaper labor markets to the south and west also means slower rates of population growth in the region. As long as employment opportunities can be made available in the non-polluting service sector of the economy, this change may be highly desirable. In fact, making a successful transition from a heavy industry to a service economy is one of the major challenges facing political, social and financial institutions in the midwest as we approach the last decade of the 20th century.

I will close by suggesting four areas of concern. Our success in dealing with these concerns will determine the lake's future quality. First, municipal wastes are still a significant source of oxygen-depleting organic material. Cleveland, Detroit, Toledo—in fact, most of our older cities—are served in part by combined storm and sanitary sewers. No matter how much we improve operations at our central treatment plants, our outmoded collection systems still bypass the plants and send raw sewage into the lake after even modest rainfalls. The cost and inconvenience of replacing these ineffective systems are generally prohibitive, although some cities (including Toledo) are at least considering half-measures that will partially alleviate the problem.

A second, increasingly serious problem is the disposal of toxic wastes. Although Lake Erie is far from dead, lakes can and do die. They can be "killed" by toxic substances so foreign to the evolutionary experience of aquatic life that they cannot be tolerated, even at low concentrations. Examples include acids, heavy metals like mercury, lead and cadmium, and synthetic chemicals like PCBs and some of the pesticides. These materials threaten drinking water, edible fish stocks and recreational use as well as wildlife, and should be kept out of the lake regardless of the cost or inconvenience of doing so.

Third, we still need a better understanding of the life cycles and needs of species important to the lake's commercial and sport fisheries, not only the fishes themselves but also the algae, zooplankton, insects, aquatic birds and other organisms that make up the food web of which fishes are a part. We still do not have enough data to set reasonable limits of exploitation on the fish nor do we know enough about the lake's biotic community to predict with confidence the effects of a given human activity on the lake ecosystem. An obvious corollary is that as scientific data become available we need effective laws (rigorously enforced) that will protect the lake's biotic resources.

Finally, the most intractable problem is probably siltation. Up to two million tons of silt still enter Lake Erie each year from the Maumee River alone. With the silt comes the major part of the phosphorus now entering the lake. Most of it still comes from agricultural land, but an increasing proportion is the result of construction projects of various kinds. Increasingly in the 1980s farmers have been forced off their land by economic hardship, and their farms converted to tract housing, shopping malls, industrial "parks" and highways. As the ground is bulldozed at the onset of construction, a massive pulse of topsoil is injected into nearby streams. Once the area has been "developed," the large expanses of non-absorptive pavement and rooftops cause episodes of extremely rapid runoff during rains, raising flood peaks and destructively altering the channels of nearby watercourses. This is a difficult problem to combat. Of course, a certain amount of "development" with its attendant soil disturbance is necessary. More to the point, the problem occurs as a diffuse, non-point source of pollution. One construction project (or, for that matter, one farmer plowing his field) may make a relatively small impact on Lake Erie, but the cumulative effects of thousands of such projects (or intensively-tilled fields) have been devastating.

Since this problem stems from both agricultural practices and urban sprawl, it must be combated on both fronts. The adoption of reduced tillage or no-tillage agriculture, now being tried on an increasing number of farms in the region, will sharply reduce losses of topsoil to rivers and streams. Agronomists hope this shift will allow farmers to spend less on gasoline, equipment maintenance and fertilizers while retaining high crop yields.

Urban sprawl and its associated soil disruption pose a more difficult issue. Current efforts to revitalize the inner cities so that people will actually want to live in them are helpful, but real progress will require the adoption and enforcement of regional zoning laws based on ecological criteria. Such laws would prohibit development of steep slopes, floodplains, marshes, lake margins and other sensitive areas and would establish guidelines for construction methods, the revegetation of areas after development, and so on. Such ordinances are badly needed almost everywhere; they are also anathema to developers and growth-oriented politicians, unpopular with many farmers, and simply haven't been considered seriously by most of the rest of us.

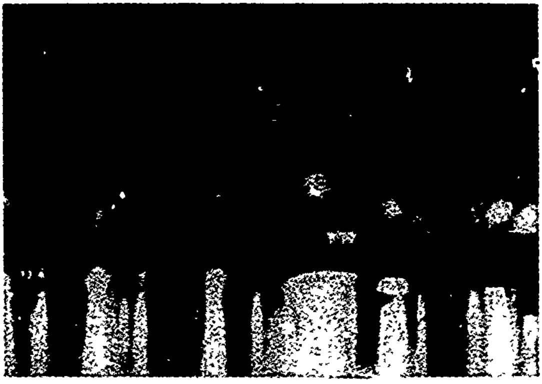

Figure 12.10. Cleveland shoreline from Lake Erie. ***(photo by Susan Fisher)***

Clearly there is much to do to further the progress made in the last 15 years. There is also much cause for optimism. The reduction in phosphorus loadings and the decline of algae blooms in a few short years have been nothing short of spectacular. Lake Erie has a turnover time of only about three years; as long as high quality water continues to enter from Lake Huron we can effect very rapid improvements. Our region is blessed with the largest supply of fresh water anywhere on earth. Its future depends on our will to exert wise stewardship over the quality of that most precious of natural resources.

Acknowledgements

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13/ History of Changes in the Lake Erie Fishery

by Andrew M. White

We all tend to think of history within our time frame of reference, usually our lifetime, and our view of fisheries is no different. Over the short term, we have probably all heard the infamous statement, "...you should have been here last week." On a slightly longer time frame, I am convinced that fishing was much better when I was a boy. However, my father always told me that fishing was much better when *he* was a boy than when I was a boy. It all begins to sound like one fish story piled upon another. In fact, fishing *was* better when he was younger, and before that, and before that. Of course, the converse of this is that the fishery has progressively deteriorated over the past 150 years, and it is this progression of events that is the focus of this chapter.

The first thing we must understand is the nature and characteristics of Lake Erie. Lake Erie is actually a very wide spot in a large river. It is not really one lake but three, each with its distinguishing characteristics (Figure 13.1). The western basin, extending from Cedar Point west to Toledo, Ohio, contains islands and rock and is very shallow, less than 25 feet deep in most areas. In fact, during storms in low water years, lake freighters often bump on the bottom while passing through Pelee Passage in the island region. In addition, the western basin includes two large estuarine areas, Sandusky Bay and Maumee Bay.

The central basin extends from Cedar Point eastward to Erie, Pennsylvania. This area has a different water circulation pattern; thus it tends to be somewhat isolated from the western basin. The lake plain of the western basin provides vast areas of flat lands which were originally immense marshes. The central basin on the other hand is bordered by cliffs; it has no reefs or islands and only one small lakeshore marsh, Mentor Marsh, located near Painesville, Ohio. This basin is deeper, with depths of 15 to 30 feet within one mile of the shore and slightly more than 80 feet many miles offshore.

The eastern basin is also bordered by cliffs. Here, however, the streams are small; there are no reefs or islands and only one bay, Presque Isle Bay. Depths in this basin are generally greater along the shore and reach a maximum of 130 feet just east of Long Point. It is the western and central basins that will be the focus of this discussion since the eastern basin fishery has not been as seriously affected by human activities as have the other two.

The fish fauna of Lake Erie and its tributaries consists of 139 species and subspecies. This is more freshwater species than in virtually any other state in the Union, and more than in all of New England. It is a great "mixed bag" of fishes. How did this one lake and its drainage come to be populated with this fauna? Primitive Lake Erie once drained through the Maumee into the Wabash of Indiana and out into the Mississippi. At another time, waters flowed northwest through the Teays River from the Carolinas into Lake Erie, allowing the invasion of fishes from Kentucky, West Virginia and the east coast. The connection across Michigan allowed species to invade from the upper Mississippi and western Canada. The glacier, in its retreat, left glacial species behind. And the Great Flood through New York allowed species to enter from upstate New York and other New England areas.

Even later, after European settlers had arrived, canals formed connections with Lake Erie and the Ohio River drainages. This allowed

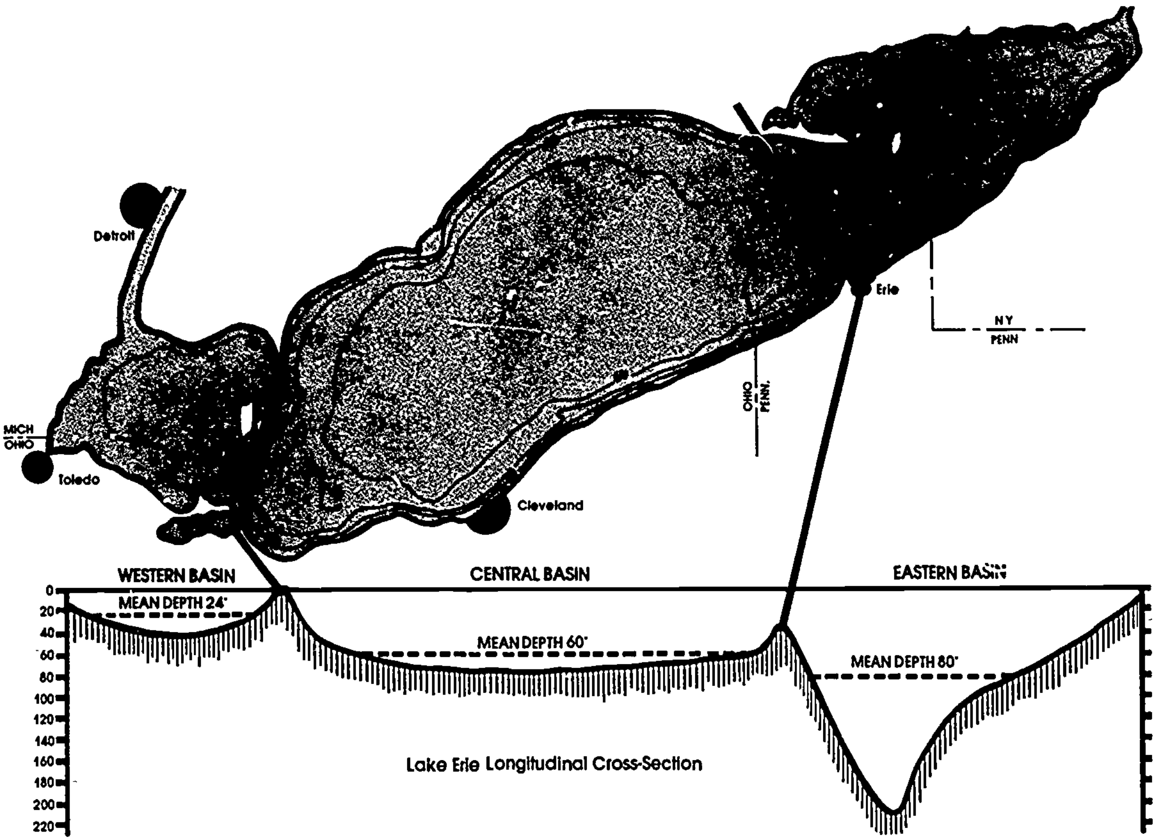

Figure 13.1. The three basins of Lake Erie. *(Adapted from Department of the Interior, "Lake Erie Report," Washington, D.C., 1968)*

southern species to invade the Lake Erie basin. As recently as one hundred years ago a direct route from Louisiana to Cleveland was created. Other species were purposefully introduced from areas across the sea: carp and brown trout from Europe and the goldfish from Asia. Others (smelt and perhaps the grass carp) escaped from experimental ponds. Still more recently, the St. Lawrence Seaway (especially the Welland Canal) has allowed the invasion of the white perch, alewife and the dreaded sea lamprey. Within the past five years a new invader, the pink salmon, has entered through Great Lakes connections from northern Canada.

The fauna of Lake Erie is thus a collection of fishes from more than 18 states, Canada, Europe and Asia. This fauna of diverse origin, placed into one area, must have a tremendous diversity of requirements. Not only that, but since they have such a wide range of origins, it is important to recognize that Lake Erie is the edge of the range for more than half of these fish species. Since they are at the edge of their geographic range, they must also be at the edge of their physiologic tolerance. Otherwise, they would have continued their invasion into the upper Great Lakes, or south into the Ohio River. It is obvious then, that before white settlers ever stepped foot into the Great Lakes, over half of the Lake Erie fish fauna were "in trouble." Since they were on the edge of their range, by definition they were residing in an area where conditions were barely tolerable. For southern species it may have been a little too cold, for northern ones, a little too warm, and so forth. It would take very little disturbance to decimate the population of a species that was already living precariously. Any change would have had an effect on at least one species, probably more. With this in mind, what was Lake Erie like when the first settlers arrived?

It is difficult to determine the precise composition of Lake Erie's fish fauna prior to the arrival of the European settlers, but all indications are that populations in Lake Erie were dominated by predaceous species (pike, muskellunge, walleye and smallmouth bass) rather than omnivores or planktivores which currently dominate (carp, goldfish, gizzard shad). It is also generally agreed that individuals were much larger then than at present. Numerous anecdotes in the writings of early pioneers and settlers contained remarks about six-foot pike (muskellunge) and 250-pound sturgeon.

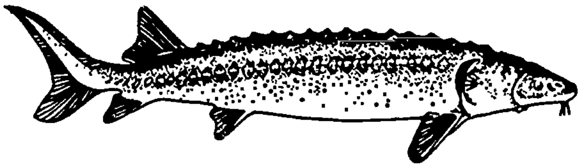

Figure 13.2. **Lake Sturgeon *Acipenser fulvescens.* *(University of Wisconsin Sea Grant Institute)***

A man who caught a catfish to feed his family of seven noted that they "ate of it three times." That's a very big catfish. But then he wrote that "...we gave the rest to the Indians."

The writings of the early settlers also attest to the great abundance of fishes in Lake Erie and its tributary streams. Brown, in 1815, wrote that

> "...soldiers at the fort [Maumee] killed fish with clubs and sticks, and by blindly throwing spears into the stream. I saw several hundred taken in this manner within a few hours, and over 1000 were also taken with hook and line."

In 1825, Kirtland wrote that the smallmouth bass were so abundant in the Cuyahoga River [Cleveland] during the spawning run that they were captured for commercial sale using guns. He also stated that muskellunge and sturgeon ascended the Cuyahoga River for many miles.

These writings are also valuable reference points for the environmental conditions of the lake and its tributaries. Numerous references to sighting fishes in the clear waters of Lake Erie are present in these early writings. One in particular describes watching walleye and pike in the Maumee River at the present location of downtown Toledo, Ohio. The Maumee now carries a mud plume several miles out into Lake Erie, and if you placed your finger into the water today at the location described by this early pioneer, you would barely be able to see the first knuckle.

In 1797, the survey party of Moses Cleaveland reported that the Cuyahoga and Grand River valleys were immense marshes. They also made numerous references to the abundance of small streams and springs and to the clarity of the waters. Concerning the Sandusky and Maumee Bays in 1816, Brown wrote that,

> "...[they] resemble a little lake and within the bosom of the bays grow several thousand acres of wild rice."

Conditions seemed to remain about the same until the 1820s. After that time the first series of severe disturbances to the Lake Erie system began to have an effect. Mill dams, the first source of power for the largely agricultural state of Ohio, had been constructed as early as 1790. By 1820, nearly every stream entering Lake Erie was blocked by several of these dams, often within less than a mile of the lake. At Painesville, there was a dam eight tenths of a mile from the mouth of the Grand River. Henry Howe reported that by 1830 there were over one thousand mill dams in Ohio. These dams effectively blocked the spawning migrations of many Lake Erie species but were especially disastrous to the pike, muskellunge and sturgeon, all of which spawn in headwater streams and marshes. Imagine a 250-pound sturgeon ascending the Maumee River on its way to Ft. Wayne, Indiana, to spawn. Encountering even the smallest of these dams, it could progress no further and therefore could not reproduce. Other species came to the same fate: the smallmouth bass, the pike, the muskellunge, migratory populations of channel catfish, and even smaller species of suckers and minnows. We had, in one crushing blow, effectively blocked the spawning runs of dozens of species and denied them access to critical upstream riffles, creeks and marshes.

To add insult to injury, many of the headwater swamps and marshes which still served as spawning grounds for some of these species were drained during this period. Streams formerly used by suckers, sturgeons, and others were channelized into muddy ditches and canal-like tributaries. These three factors were so effective in eliminating reproduction in the central basin that Kirtland wrote in 1850 that the sturgeon and muskellunge no longer ascended the rivers to spawn. He further stated that,

> " All the migratory species have been excluded from the...river by the construction of dams..."

By 1850, the population of Ohio had increased fourfold, to nearly 2 million. Since the constructin of the Ohio Canal, Cleveland had become a boom town. In contrast to its meager population of 150 in 1820, it now boasted nearly 22,000 citizens. Added to the stream obstructions of the mill dams came the clearing of streambanks, increased erosion, and muddy waters. Soon the remnants of marshy habitat in the lower Cuyahoga River were gone, and the pollution loadings of 22,000 persons flowed directly into the river. Sawdust, coal dust and cinders, wheat chaff and flour, slaughter house offal (including entire animal carcasses), and human waste covered the river from bank to bank. In 1851, what was finally recognized as a typhoid epidemic in Cleveland was directly associated with drinking water contamination. The city responded, after much deliberation, not by cleaning the river of wastes, but by placing the city's water intake 400 feet out into Lake Erie.

It seems certain that by 1855, the production of sturgeon in the tributaries of Lake Erie had ceased. However, since the species lives more than 50 years, the effects of the mill dams would not be fully realized until the early 1900s.

Muskellunge and pike fared better, since the Sandusky and Maumee Bays still contained abundant marshlands and clear waters. Declines were only observed in the central basin where natural shoreline marshlands and estuaries were almost nonexistent. Other species such as smallmouth bass and walleye did not yet demonstrate drastic declines, since the shoreline of the lake was still clean and clear. Thus began a scenario that would be repeated over and over in the history of the fishery: the disappearance of one species in one area of the lake was countered by the abundance of the same species in another area of the lake or its replacement by another species which was an untapped resource and almost equally as favorable a fish. In this case, the loss of muskellunge, pike and sturgeon and the decline in smallmouth bass and catfish was offset by abundant populations of walleye, whitefish, cisco and sauger. Thus, shifts in attention to alternate species or alternate areas of the lake kept people from realizing the full extent of the impact on the fishery.

By the end of 1855, serious problems were developing because of the blockage of spawning migrations, but in spite of the warnings of Kirtland they went largely unnoticed. The fishery of the western basin seemed largely unchanged, and even in Cleveland the lake was teeming with fine food fishes. In 1853 Kirtland wrote that the water of the lake was often black with boats, and fine catches were made of walleye, bass, lake trout and other species. Soon, however, the honeymoon would be over.

Beginning in 1850, two events occurred simultaneously which proved to be perhaps the greatest adversities that the central basin fishery has faced, ones from which it has never fully recovered. In many areas such as Cleveland, Lorain and Toledo, industrialization of the lakeshore had continued. Effects from pollution had become noticeable. By 1863 the conditions began to effect the Lake Erie shoreline, and in that year Kirtland wrote,

> "Formerly [in Cleveland Harbor] it was not unusual to capture 100 bass and walleye by hook and line in a few hours, now this is no longer possible at all."

On May 6, 1868, the Cleveland *Plain Dealer* stated in an editorial that,

> "...from the filthy looking conditions of the [Cuyahoga] river we imagine that but a short time will be required to remove all evidences of beauty and cleanliness from there."

Although the sawdust, animal carcasses, sewage and refuse of now nearly 600,000 people were also present, this particular reference addressed a new pollutant, oil.

By 1869, streams were increasingly polluted with oil and brine. Oil contaminated Lake Erie from top to bottom for nearly a mile at the mouth of the Cuyahoga River. Muskellunge and sturgeon were now all but gone, and the walleye and smallmouth occurred in greatly reduced numbers.

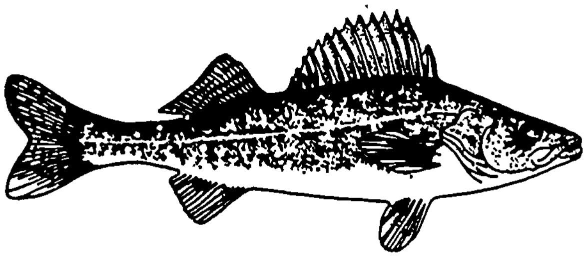

Figure 13.3. Walleye *Stizostedion vitreum vitreum.* *(University of Wisconsin Sea Grant Institute)*

In the western basin, an area relatively unaffected until 1850, similar events occurred. First, the Great Black Swamp, hundreds of square miles of marshlands that were formerly occupied by glacial Lake Maumee, began to be drained and converted into agricultural lands. This conversion to croplands had several adverse effects: increased runoff accompanied by increased erosion of soils, loss of valuable spawning habitat for pike and other fish, increased flooding, a lowered water table, and the loss of vegetation in downstream areas due to high turbidity. By 1875, much of the draining had been completed and most of northeast Ohio and portions of Indiana had come under cultivation. By 1900, the Maumee and Sandusky Bays were nearly devoid of aquatic vegetation.

The few remaining marshes adjacent to Sandusky Bay had now been diked, effectively blocking spawning runs of many species, and siltation began to cover the gravels and sands of the western basin. In 1978 we collected a core sample of sediment from near the mouth of Maumee Bay and found that nine feet of mud overlaid the original gravel and sand bottom. This seriously affected the production of gravel-spawning species such as sauger, walleye and smallmouth bass. High turbidities may also have resulted in the reduction of the populations of many sight-feeding species and species preferring clear, unsilted waters. Species which became extinct or extirpated from Lake Erie and its tributaries during this period included the paddlefish, spotted gar, gilt darter, and the harelip sucker. Concerning the conditions in the western basin, Potter stated,

> "The wonder is that there are so many fishes left as there are." (1877).

and Kirsch, speaking of the Maumee Bay in 1892, wrote,

> "Local sportsmen told me that formerly sturgeon were very abundant at this place while now one is seldom taken, also that pike and walleye are rapidly decreasing in number."

Second, a commercial fishery began which would soon be harvesting adult fishes at a phenomenal rate, often wasting numbers equal to or greater than the landings for lack of markets. Simultaneously, the harvest of species by sportsmen increased. Fish species could not reproduce fast enough to replace the huge numbers of adults being removed from the lake. In 1877, Sterling wrote to the Ohio Fish Commission that hook and line catches of 750 smallmouth bass per day by a single person was excessive and that they should be protected. By 1901 the combined effects of environmental degradation, stream obstruction, commercial and sport fishing, draining and diking, pollution and siltation left the bass population in Lake Erie so depressed that the harvest of the species was regulated. Today it has still not recovered to its former status; in 1977 when it was stated in advertisements that the western basin was the "smallmouth capital of the US," the average catch of smallmouth bass was less than 1.0 per hour.

During this period, exotic species were also introduced into the ecosystem. Two of them, the carp and goldfish, reproduced and soon became plentiful, to the detriment of the remaining areas of vegetated shallows. The carp, spawning in late May and early June, uprooted vegetation and created turbidity which smothered the eggs of nesting species, especially sunfish, crappie and bass. Other exotics, including salmon, were unsuccessfully introduced.

Pollution in the central basin increased dramatically. In 1882, the City of Cleveland

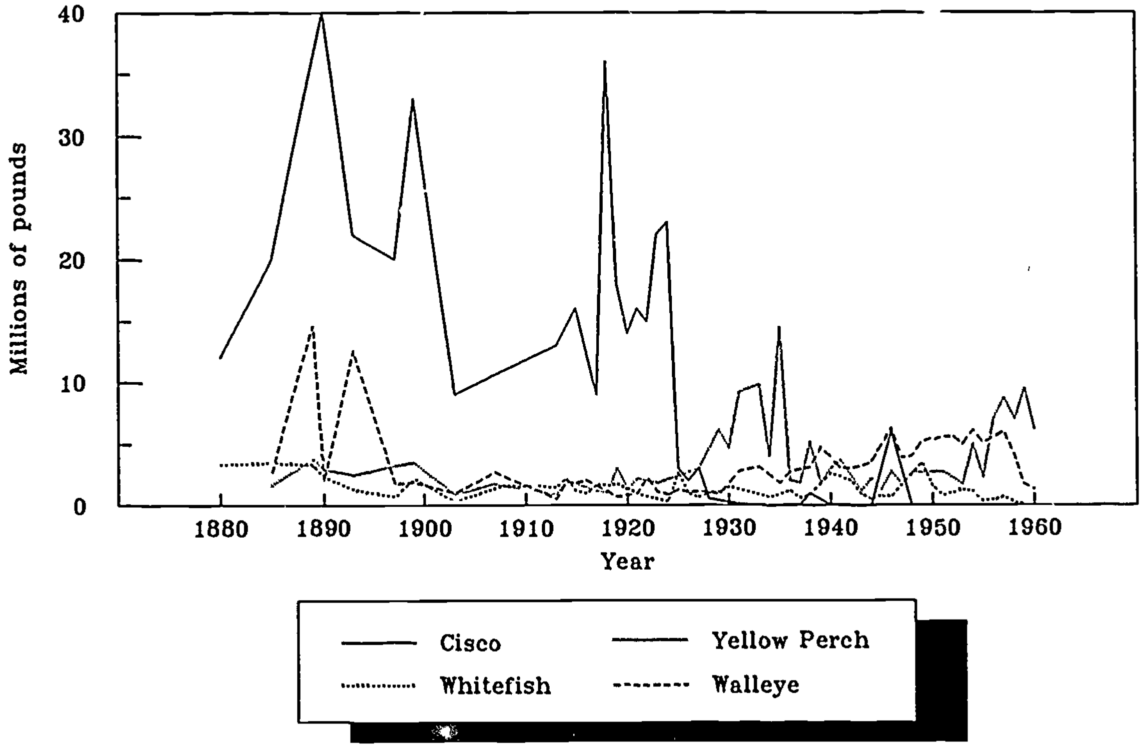

Figure 13.4. Changes in the commercial catch of selected species, 1880-1960. ***(Adapted from Marks, 1962)***

experienced its first algal bloom in the water intake, now located 6,200 feet from the lake shore. By 1890 the city's first sewage system effectively collected all human waste and dumped it, untreated, into the river. Later, the water intake would again be moved, this time to a location nearly 2.5 miles into the lake. Similar pollution loadings were probably present in Toledo, Lorain, Ashtabula and other shoreline cities.

The fishery in the central basin became even more depressed than that in the western basin. By 1900 the sturgeon, muskellunge, pike, lake trout, cisco, whitefish, sauger, smallmouth and brook trout were rare or absent from the central basin shoreline areas. Across the entire lake, the walleye populations were very depressed. The commercial catch had gone from a peak of nearly 13 million pounds in 1893 to less than 2 million in 1900. Other commercially fished species also declined dramatically. In 1895 the harvest was dominated by cisco, blue pike, sturgeon, sauger, whitefish and walleye, and in that order. By 1930 the harvest, in order of contribution, was blue pike, yellow perch, freshwater drum, whitefish, carp and walleye.

Thus, the combined effect of stream obstruction, draining and diking marshlands, extreme pollution of streams and harbors, loss of rooted aquatic vegetation, heavy siltation, increased flooding, overfishing and the introduction of exotic species had resulted in the reduction of the populations of many native fishes to perhaps 20% of their former abundance. These species were replaced by an increase in the populations of others, especially carp, goldfish, bullhead and other less valuable species.

The period from 1900 to 1940 was one of relative stability in the fishery. The low levels of walleye, smallmouth bass, sauger and others now became the "norm." The lost populations of lake trout, brook trout, muskellunge and northern pike became the "fish stories" told by grandfather but not really believed. On the other hand, the blue pike seemed to maintain its numbers and in most years produced more than 10 million pounds of harvest. It was a valuable food and sport

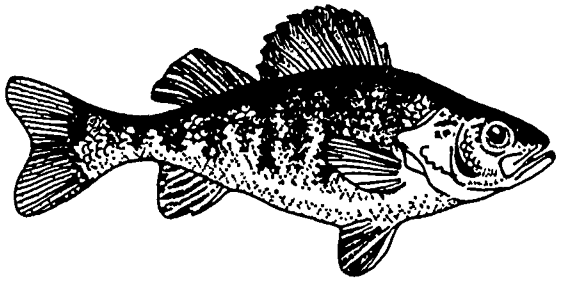

Figure 13.5. Yellow Perch *Perca flavescens*. *(University of Wisconsin Sea Grant Institute)*

fish and, once again, supplanted and substituted for lost species. The only major change in the fish fauna was the nearly complete loss of the cisco. This species produced nearly 39 million pounds in 1890, and 21 million pounds in 1924. Production fell abruptly to 2 million pounds in 1925, and by 1929 only 127 thousand pounds were taken.

Yellow perch now became a valuable food species and was sought after by commercial fishermen and sportsmen alike. It alone tells the story of shifting preferences due to the loss of higher quality fishes. In 1877, Klippart wrote of the yellow perch in the first annual report of the Ohio State Fish Commission. In this report he declared that,

> "...its flesh is soft, rather coarse and insipid; at best it is a third rate panfish. The writer's opinion is that perch make better glue than food."

Sterling also commented on the yellow perch in the late 1800s when he wrote to a fellow fisheries biologist.

> "...perch are a most worthless animal. You can have all you want from fish dealers for the trouble of carrying them away. I once saw three tons sold for manure,... for as many dollars."

Prior to 1925, less than 4 million pounds of perch were landed annually, mostly as an incidental catch. In the years between 1929 and 1935 a harvest of ten to fourteen million pounds was made annually, and it was considered one of the finest food species in Lake Erie.

All of the adverse conditions present during the late 1800s continued, and indeed, worsened. But the worst was yet to come. The steady increase in the human population (and its sewage) and the steady increase in the use of agricultural fertilizers were coupled with the introduction of phosphate detergents. The already-depressed fishery was now faced with a tremendous increase in nutrient loadings resulting in more extensive algal blooms in the lake. Temporarily, the populations of blue pike, yellow perch and walleye increased in the early 1950s, but in 1957 the populations of walleye and blue pike crashed. From a production of nearly 20 million pounds of blue pike and 15.5 million pounds of walleye in 1956, the 1960 blue pike yield was zero and walleye had dipped to less than 3 million pounds.

Figure 13.6. Commercial beach seine operation. *(Andrew White)*

Yellow perch increased, partially as a result of the lack of competition from blue pike and walleye, and production skyrocketed to nearly 28 million pounds. These numbers may not necessarily reflect a yellow perch population increase, but may have resulted from space in the boats for ever-increasing numbers of the species. Since the species had already been accepted as a food species, it compensated for the lack of the other two, but this time not entirely. Finally, after nearly 150 years, consumers and sportsmen had exhausted all available acceptable substitute species. The extinction of the blue pike and the loss of the walleye had now left the yellow perch, white bass, catfish, carp, sheepshead and smelt (accidentally introduced in the mid 1930s) as food fish. None of these were acceptable substitutes for the walleye and blue pike.

The 1960s were a period of what might be termed "what happened?" ***Lake Erie is dead*** was the cry from the media. Actually this was far from the truth. Lake Erie, as Dr. Robert Sweeney of Buffalo aptly described it, was "A Living Corpse." In all respects, the lake was just exactly that. Species which were tolerant of all the modifications made by humans ruled Lake Erie, while the others (usually the more desirable ones) were all but gone. Still, the lake produced 52 million pounds of fish per year. But what species were being produced? According to the list of commercial harvest for 1885, cisco, blue pike, sturgeon, sauger, whitefish and walleye were the top six producing species. Changes by 1930 yielded a list in which three of the top six were new species to the list: carp, drum and yellow perch. However, the other three were walleye, blue pike and whitefish. In 1969 the top six producing species contained none of the original six. Cisco was replaced by yellow perch; blue pike were extinct and had been replaced by smelt. The number three species in 1885, sturgeon, was now all but extinct and was replaced by carp. The next, sauger, had been replaced by the drum. Whitefish were also nearly extinct and white bass, a species not even marketed in the late 1800s, had taken over its habitat. Finally, and perhaps the greatest insult, the walleye, number six in 1885, was replaced by a new commercial category, miscellaneous scrap.

By 1972, publicity had convinced nearly everyone that Lake Erie was dead, an example of an environmental disaster. Data became available from research. The news was incredible. Chloride levels in the Great Lakes should be low, perhaps less than 5 milligrams per liter. How was it then that levels of more than 23,000 milligrams per liter existed in the Portage River as early as 1904 and went unnoticed? In 1966, loadings of some pollutants from the Cuyahoga River alone into Lake Erie were measured. The annual input from this single source included 60,000 tons of iron, more than 2,000 tons of phosphorus and 2,620 tons of nitrogen. Add to this about 250,000 tons of solids and 17,200 tons of oil and grease. No wonder there were no fish in the lower river.

Figure 13.7. A steel mill on the Cuyahoga River. *(Andrew White)*

Other rivers suffered similar fates. The Grand River had a measured conductivity of 23,000 micromhos on one day in 1973 (the conductivity of pure water is nearly zero), and the Black River was truly black, covered for miles and for months with waste oils. Little matter here though, for dissolved oxygen at the base of an upstream riffle was zero, the result of a lack of sewage treatment upstream. So also with other central basin streams which once had spawned smallmouth bass, walleye and pike. The Grand, Cuyahoga, Ashtabula and Black Rivers all experienced annual anoxic (deoxygenated) conditions which lasted for days and sometimes weeks.

The western basin did not suffer from industrial pollution as much as the central basin did, but siltation and fertilizer runoff were sufficient to seriously affect much of the fish fauna. Algal blooms became an annual event. Then in 1973 the final blow occurred. Algal productivity and sewage reached such proportions that their decomposition in the hypolimnion (near the bottom) of the lake produced anoxia throughout much of the western and central basins. In 1974, more than 50% of these areas were anoxic. Now even the offshore, deep water species suffered. Formerly unaffected by riverine pollution, drainage of marshes or damming of streams, these species had two choices: either enter the shallows of the lake where water temperatures were in excess of 78° F, or remain in the cooler depths and suffocate. The loss of major populations of deep water, bottom dwelling species between 1965 and 1975 can partially be attributed to this lack of oxygen. Burbot, trout-perch, silver chub, mooneye and others nearly disappeared from the lake. The commercial fishery collapsed and sportsmen went elsewhere to fish.

In 1973 we reported to the USEPA that more than 50% of the central basin fish fauna near Cleveland were to be considered rare, endangered or extirpated and that the community was now largely composed of carp, gizzard shad, goldfish, yellow perch, drum and smelt. By 1979 even the smelt began to decline. Thus ends the sad portion of my tale.

But this fish story is not finished, for now it continues on a better note. In 1973 we had also reported that nearly every species that formerly inhabited the central basin was still present, albeit in restricted areas and often in very limited numbers. One can hardly imagine the resilience of these fishes, nor their ability to survive extreme adversity. We had blocked their migrations, drained their spawning grounds, muddied the waters, removed all vestiges of vegetation, heated and polluted their waters, captured them by the billions for food and, as a last attempt to kill them all off, we had taken away their oxygen. But still they persisted.

The actions taken by various governmental agencies, growing public awareness, the "environmental movement," and quirks in the economy throughout the 1960s, 1970s and early 1980s have resulted in a most remarkable recovery of the lake and its fish fauna. The USEPA and the Ohio EPA provided funds for research and for pollution control. Levels of pollutants have dropped dramatically in rivers, so loadings to the lake have become much less. The Grand River, for example, once was contaminated by organic solvents, phenol, raw sewage, salt brine, caustic soda, hexavalent chromium and anoxic conditions. This was all hidden beneath nearly a foot of soap suds. Today the river is clear, contains 72 species of fishes, and produces angler catches of brown trout, salmon and walleye. Legislation, monitoring, public pressures, and often litigation and fines have resulted in greatly reduced pollution levels.

The economy also has played an important role in the restoration of the lake. Siltation is one of the most critical problems in the lower rivers and the lake. Ninety-nine per cent of the bottom material in most harbors is now composed of fine clay and silt. In 1973, total extinction of light was measured at three inches below the surface in the Ashtabula Harbor of Lake Erie. In 1976, divers working in 22 feet of water needed radio contact from above so they could be directed by the movement of their air bubbles. Economic pressures have resulted in different farming practices along the shoreline. The high cost of fuel reduced the fall plowing of fields, no-till planting began to occur, and in many instances farms collapsed and soils returned to old field communities. Fewer new housing projects and less road construction in recent years also contributed to less runoff of silt. Today, visibility is nearly ten feet in the Ashtabula Harbor, and light penetrates more than 20 feet.

Stocking programs of the various states surrounding Lake Erie have also been successful. Coho salmon, brown trout and rainbow trout are now populous in Lake Erie, and a lake trout restoration program is in progress in Pennsylvania. Walleye populations have also increased dramatically. Slightly more than 100,000 walleye were caught by Ohio anglers in 1975; almost 4.5 million were taken in 1986. The commercial catch for many species has increased beyond the numbers caught in the 1960s, even though it is now more strictly regulated today.

Nutrient control through sewage treatment and decreased farm runoff have resulted in a reduction of algal blooms. Anoxia in the central basin has been greatly reduced and certain species such as the burbot have made partial comebacks. Silver chub and trout-perch populations have also made good recoveries.

In the streams, the response has been even more striking. The removal of the dam in the Grand River now allows walleye, white bass, smallmouth bass and many other species access to stream spawning habitat. Increases in young of these species in this drainage is very evident. The smaller species, intolerant of pollution and siltation, have suddenly reappeared. Silver shiners, sand darters, brook lampreys, brindled madtoms and bigeye chubs are now becoming common in the Ohio tributary streams of Lake Erie. With success, however, sometimes comes a little adversity. The sea lamprey, a predatory invader through the Welland or Erie canals, had destroyed the salmonid (lake trout) and coregonid (cisco and whitefish) fishery in the upper Great Lakes.

However, because of the heavily polluted, dammed and silted conditions of Ohio tributaries, it could not successfully reproduce here. With stream improvement, lamprey are now increasing rapidly in numbers. A population in Conneaut Creek (Ohio and Pennsylvania waters) today is estimated to contain nearly 1,000,000 larval individuals. With the lamprey's food source stocked and/or re-established and cleaner rivers available, the lamprey is becoming a serious problem in the lake. Efforts are currently underway by the US Fish and Wildlife Service and surrounding states to control the population.

Whether you are a resident of the Great Lakes community or not, whether you are intimately familiar with the fishery of Lake Erie or not, the history of the fishery of the lake stands as a great lesson in the response of a freshwater ecosystem to the multitudes of pressures placed upon it by the demands of society, its people and its use of the land as well as the waters. Some of these lessons have been learned too late; the blue pike is probably extinct, and several other species have been extirpated from Lake Erie.

Some of these disastrous environmental modifications to the Lake Erie ecosystem would have been done even if the effects had been known. Indeed, the draining of the Great Black Swamp and its subsequent conversion into some of the richest corn and soybean cropland in Ohio and Indiana would have been done sooner or later. One cannot "have the cake and eat it too." We simply cannot expect to raise tons of soybeans and corn and produce pike and muskellunge as well. Other changes, however, need never have occurred. Sewage and chemical pollution of rivers could have been controlled and marshlands could have been protected. Siltation from farming and construction need not have been as rampant, and shoreline development could have been made more compatible with the needs of the fishery.

Most of us have a tendency to accept easy answers to complex problems and are quick to place blame for problems on either the easiest target (commercial fisheries, for example) or the anonymous "they." How often have we heard, "*They* raised the level of Lake Erie," or "*They* killed all the fish." Rather, the deterioration of the Lake Erie fishery was due to a complex series of ecological disruptions, and "they" are in fact "we."

It is hoped that this discussion has been enlightening, but more than that, that some of the hard lessons which we have learned from Lake Erie may prevent history from repeating itself in other freshwater systems. Also imperative is that we who live in the Lake Erie drainage basin do not spend too much time basking in the glory of this partial restoration of the lake. Fishing is better than in 1965 and many species have demonstrated remarkable recoveries, but fishing is not better than ever. Mill dams replaced by flood control dams are still in place, no siltation control legislation is available and remaining marshlands are in a precarious position for their survival. Poor land management is still common and toxic substances continue to enter the lake from groundwaters, resuspension of sediments, and the atmosphere. We have made a beginning, but there is yet much to be done.

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14/ Recovering from Phosphorus Enrichment

by Charles E. Herdendorf

Lake Erie, as one of the Great Lakes of North America, represents a significant source of fresh water for the people of the United States and Canada. The shallowest and southernmost Great Lake, it was furthest along in the process of eutrophication, the natural aging of lakes, even prior to settlement. In the early 1800s human activities began accelerating this process, until by the middle of this century the lake had aged alarmingly. The early settlers drained the vast coastal wetlands and stripped away the natural protective cover from the rich uplands. Lake Erie's tributaries then carried high amounts of sediment to the lake, silting over fish spawning reefs in the shallow western basin. Industry followed agriculture along the banks of the lake's main tributaries: Detroit, Maumee and Cuyahoga Rivers giving rise to the large cities of Detroit, Toledo, Cleveland, and along the Niagara River giving rise to Buffalo. Industry and increased populations, along with the use of artificial fertilizers on farm lands, brought nutrients, primarily nitrates and phosphates, that hurried the lake's aging process. Because the process is affected by wastes that arise from human activities, it is referred to as *cultural eutrophication*. Not only is the aging process sped up, it is altered as well due to the nature and concentration of introduced nutrients.

The nitrate and phosphate pollution nourished the algae, creating mats of blue-green organisms that blanketed most of the western basin and large reaches of the central basin's south shore in the early 1960s. As the algae spread, bottom oxygen, needed to support other forms of life, was consumed by decomposers breaking down the algae. By 1970, large portions of the hypolimnion, the bottom layer of water, of the central basin were anoxic, being totally depleted of oxygen in the late summer months. At this time many of the recreational beaches along the lake were closed because of high coliform counts from sewage discharges, or were not used because of objectionable algal debris.

During the latter 1960s, remedial actions were planned and by the late 1970s, many of the plans were at least partially implemented. In the early 1980s the first signs of lake recovery were observed; the extent of algal blooms had been greatly reduced. Today, the area of summer anoxia is reduced significantly from that of the early 1970s, the concentration of dissolved solids is down to 1950s values, and production of prized fish species (such as walleye) is at a record high.

Nutrients in Lake Erie

Nitrogen and phosphorus, the most frequently discussed of all nutrients, enter the lakes from many sources, including municipal and industrial wastewater discharges, agricultural fields, highways, parking lots, shoreline erosion, and precipitation. These nutrients within the lake act in the same fashion as fertilizers on lawns. The three major nutrients in fertilizer that help grass to grow are nitrogen, phosphorus, and potassium. Similarly, these nutrients in the water cause phytoplankton (microscopic plants, or algae) to grow. This is important since phytoplankton represents the base of the food chain in lakes: zooplankton (microscopic animals) eat phytoplankton; small fish eat the zooplankton; and, large fish eat the smaller fish. The growth of algae or phytoplankton is often called primary productivity of a lake. To a degree, the more algae produced, the more productive a lake will be. However, there are limits beyond which algal growth becomes detrimental to other aquatic life.

Like other green plants, algae, in the presence of light, produce more oxygen than they consume. An algae population in a lake is important in at least two ways: they are the primary food source for other lake life and they produce oxygen which other lake life needs to survive. At night, however, photosynthesis stops; and if an algae population is too large, it will use all the oxygen in the water through its own respiration. Algae can also indirectly cause a reduction in the amount of oxygen when they die because the bacteria which decompose the dead algae require oxygen to accomplish this task.

The phosphorus problem

Though phosphorus once naturally occurred in very small quantities in Lake Erie, high phosphorus loadings into the lake began to occur after World War II, when phosphorus-based detergents replaced soap for household uses. Once phosphorus was introduced, large algal blooms were noticed in areas around outfalls of municipal wastewater treatment plants.

Limiting fac' r

Scientists declared phosphorus to be the main culprit (over nitrogen compounds) behind cultural eutrophication. Phosphorus is recognized as a limiting nutrient, because when it is present in small amounts, despite nitrogen levels, algal growth is limited. Consequently high phosphorus levels ultimately lead to the abundant growth of blue-green algae. The typical nitrogen and phosphorus scenario is as follows: upon entrance into the aquatic system, an initial increase in growth occurs in all aquatic plants, including algae. As the algae reproduce and spread, they overshade areas with submerged aquatic plants. With insufficient solar radiation, the photosynthetic process of aquatic plants is inhibited, to their detriment. As more and more algae continue to grow and multiply, higher amounts of organic debris sink to bottom waters and become available to microbial decomposers. More dead algae means more food for decomposers, resulting in higher numbers of decomposers. The process of decomposition and respiration requires oxygen, which is gradually depleted in bottom waters under such circumstances. The situation favors organisms that can survive under stressed conditions (Figure 14.1). Bottom invertebrate species tolerant of low oxygen levels are: the tubificid worms (e.g. *Limnodrilus hoffmeisteri*, *L. cervix*, and *L. maumeensis*) and midge (Chironomidae) larvae. Once abundant in the western basin, the burrowing mayfly, *Hexagenia limbata*, unable to tolerate low oxygen levels, disappeared as anoxia became more widespread.

In addition to changes in the composition of the invertebrate community as a result of phosphorus pollution, the algal community also changes. *Cladophora*, a filamentous attached green algae, prospers with excessive nutrient loading. Becoming quite abundant, it washes up on recreational beaches causing odor problems and interferences with swimmers and sunbathers. After nitrogen starts to become depleted by fast-growing algae, a shift in species composition favoring blue-green algae results, because this particular algal type can extract nitrogen from the air and convert it into a usable form. Low pollution tolerant species such as *Dinobryon divergens* and *Ochromonas scintillans* are replaced by blue-greens such as *Microcystis*, *Aphanizomenon*, and *Anabaena* and other greens such as *Melosira granulata*, *Stephanodiscus tenius*, and *S. niagara* (Figure 14.2).

Entry into the Lake

Phosphorus enters Lake Erie in many forms, not all of which are usable by phytoplankton. Therefore, reducing total phosphorus input is not as important as reducing the input of usable (bio-available or soluble reactive) phosphorus. It is also known that detergents, sewage and agricultural fertilizers are major sources of phosphorus in a form capable of stimulating the growth of algae, with phosphorus-based detergents being 100% bioavailable, sewage from municipal sources 80% bioavailable, and agricultural runoff about 50% bioavailable. Phosphorus entering the lakes from the atmosphere is estimated to be about 50% bioavailable. Because total phophorus concentration is included in annual loading

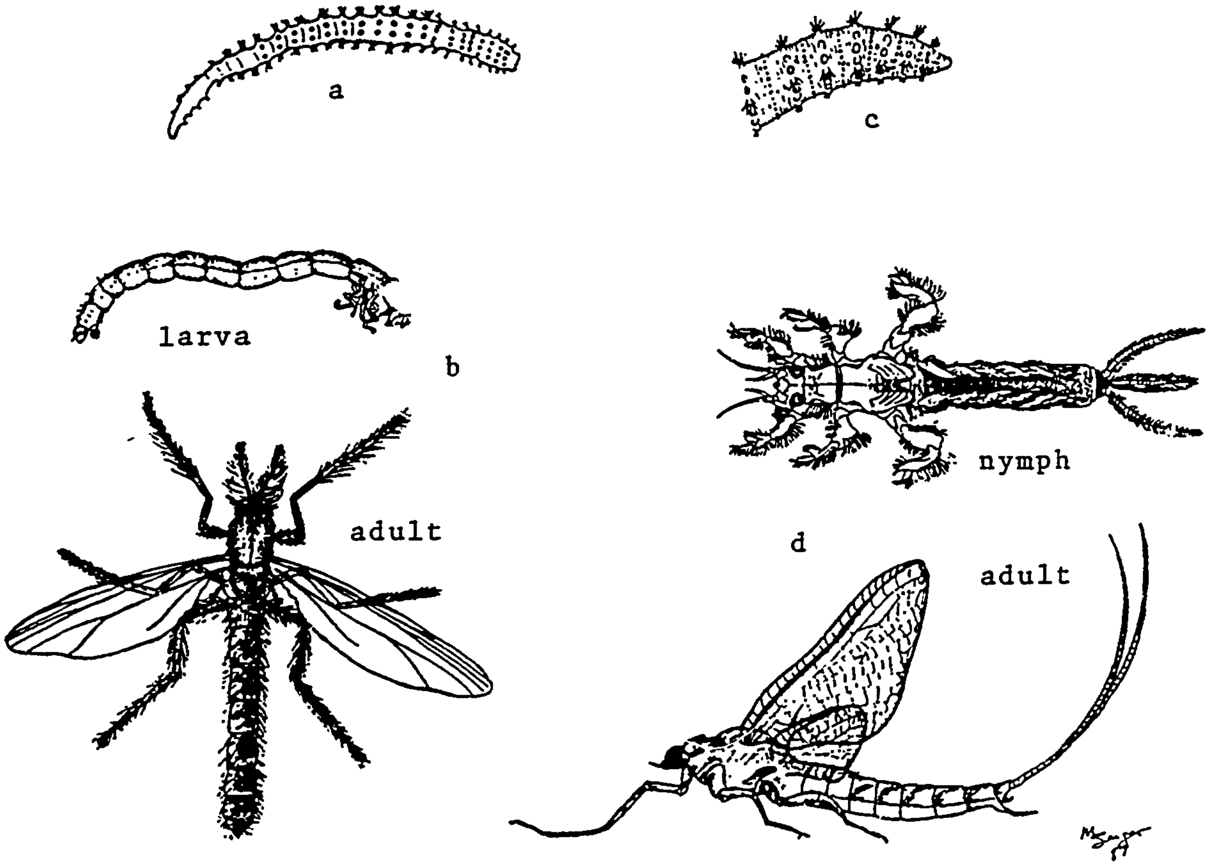

Figure 14.1. **Benthic invertebrates indicative of oxygen levels in Lake Erie: a) *Limnodrilus* sp. and b) *Chironomus*, both tolerant of low oxygen; c) *Peloscolex* sp., intermediate oxygen requirement, d) *Hexagenia*, requiring high oxygen.**

estimates, it is not an accurate measure in terms of the effects on biota.

Most phophorus is transported into the lake during high flow or storm events when river waters have the highest phosphorus loadings. Phosphorus that is resuspended in the water from bottom sediments may be in the form of fine apatite grains or strongly bound to clays, but recent work has shown that western Lake Erie sediments have a significant bioavailable fraction (34-60% of total phosphorus).

The entry of phosphorus into Lake Erie is usually categorized as being from point sources or non-point sources. Point sources are pipes, culverts or similar single points from which phosphorus is released. Non-point sources are just the opposite. Here the phosphorus enters lakes and streams from large, poorly defined areas such as agricultural fields, highways, and parking lots. Point sources of phosphorus arise from the discharge of municipal and industrial wastewater. The major non-point sources are agricultural and urban runoff, shoreline erosion and atmospheric deposition (precipitation).

Seasonal stratification effects

Lake Erie is surrounded by four states and two countries and is approximately 240 miles long and 57 miles wide. It is divided into 3 separate basins: a shallow western basin with an average depth of 24 feet and containing that water west of an imaginary line from Cedar Point to Pelee Point; a deep eastern basin with a maximum depth of 210 feet and containing all

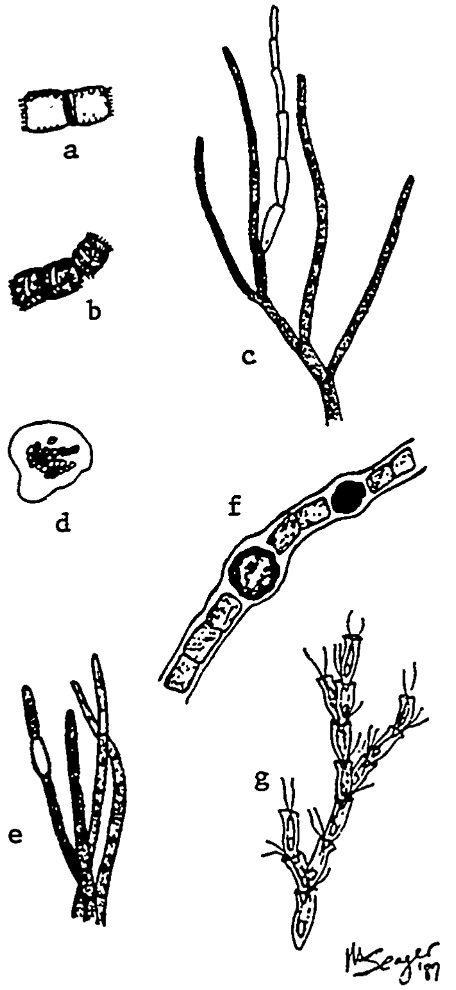

Figure 14.2. **Lake Erie algal species. Pollution tolerant forms (green): a) *Melosira*, b) *Stephanodiscus*, c) *Cladophora*; (blue-green) d) *Microcystis*, e) *Aphanizomenon*, f) *Anabaena*. Pollution intolerant form: g) *Dinobryon*.**

water east of an imaginary line from Erie, PA, to Long Point; and a central basin with an average depth of 60 feet and containing all the water between the western and eastern basins (Figure 13.1). Phosphorus loadings into the lake vary for each basin and subsequently vary in their effects upon the biota of each basin.

The process of lake stratification is depicted in Figure 14.3. Stratification is a natural occurrence in many lakes and usually only presents problems in eutrophic (very fertile) lakes. Each summer, the warmer water rises and the cooler, heavier water settles to the bottom. Eventually the lake stratifies and two distinct layers of water form: an upper, warm layer called the "epilimnion" and a cool, bottom layer called the "hypolimnion." The narrow band of rapid temperature change between the upper and lower layers is called the "thermocline." The western basin is too shallow to allow two layers to form so there usually is no thermocline there. However, a strong thermocline does develop in the central and eastern basins, usually at a mean depth of approximately 45 feet.

Once the thermocline is established, the upper and lower layers will not mix until the upper layer cools to the temperature of the lower layer in the fall. During this time of stratification, new oxygen cannot get to the lower layer because it is too deep to be affected by the wave action or to be penetrated by light (allowing photosynthesis and oxygen production to occur). As a result, by the end of the summer, all the oxygen which was originally present in the spring and early summer has been used by bacteria to decompose algae. As much as 90% of the bottom water (in worst years such as 1973) in the central basin of Lake Erie becomes anoxic each summer. In 1930, by comparison, only 10% was anoxic. This water remains anoxic until the upper layer of warm water cools in the autumn to the temperature of the cool, bottom water and then surface and bottom mixing occurs. It was in these cold, bottom waters that the cisco and lake trout once lived. The loss of oxygen kills many of the aquatic organisms which live in the bottom sediment and are normally eaten by fish. Oxygen loss also causes bottom-dwelling species, such as yellow perch, to move shoreward in search of more oxygen and food.

Reducing phosphorus in Lake Erie

Most experts agree that by reducing the amount of available phosphorus entering the lake, algae populations would be reduced and the oxygen problem in the central basin would be slowly eliminated. Cultural eutrophication of Lake Erie is being combated by programs to decrease phosphorus loading from all sources and is proceeding on three fronts: improved sewage treatment plants, no-till or reduced-till farming, and the implementation of detergent phosphorus

LAKE STRATIFICATION (Layering) and TURNOVER. Heat from the sun and changing seasons cause water in large lakes to stratify or form layers. In winter. the ice cover stays at 0 degrees C (32 degrees F) and the water remains warmer below the ice than in the air above. Water is most dense at 4 degrees C (39 degrees F). In the spring turnover, warmer water rises as the surface heats up. In fall, surface waters cool, become denser and descend as heat is lost from the surface. In summer, stratification is caused by a warming of surface waters which form a distinct layer called the epilimnion. This is separated from the cooler and denser waters of the hypolimnion by the thermocline, a layer of rapid temperature transition. Turnover distributes oxygen annually throughout most of the lakes.

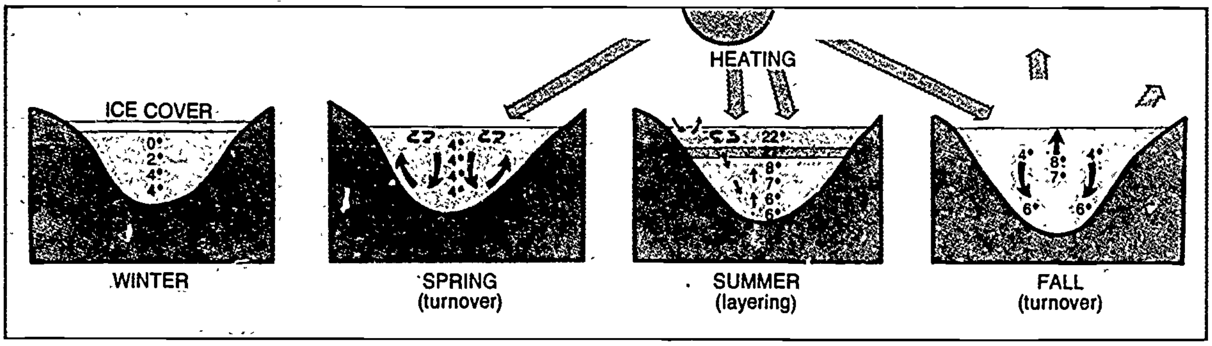

Figure 14.3. Sequence of events in thermal stratification of a lake.

bans. Such programs were first initiated under the 1972 Great Lakes Water Quality Agreement, a binational effort by both the Canadian and United States' governments. Each country appoints three members to the IJC (International Joint Commission) to oversee the compliance of both parties to the Agreement.

The 1978 Great Lakes Water Quality Agreement contains the basic requirement to reduce the phosphorus concentrations in municipal discharges to 1.0 mg/l in all the Great Lakes Basin. It also calls for other programs or additional requirements needed to reduce point and nonpoint sources in order to achieve target loads of 11,000 metric tonnes/year for Lake Erie (1 tonne = 1.1 tons). A reduction to this level is expected to eliminate anoxic conditions in the central basin hypolimnion. However, if all municipal treatment plants in the Lake Erie Basin were discharging phosphorus at 1.0 mg/l, the total phosphorus load to the lake would still exceed the target load. Further reductions from other sources are required.

Total phosphorus loading to Lake Erie from all external sources declined from a peak of 28,000 tonnes in 1968 to 12,400 tonnes in 1982. This represents a 56% decline over the 15-year period. The Detroit River, which supplies about 90% of the inflowing water to Lake Erie, has shown a remarkable improvement; phosphorus loadings decreased 60% from 1971 to 1980, primarily as a result of improvements to the Detroit wastewater treatment plant.

Phosphorus concentrations in the open waters of Lake Erie are highly variable and have not decreased along with reductions in phosphorus loadings, except along the north shore of the western basin. Here, in response to reduced loading from the Detroit River, concentration of phosphorus in Ontario waters decreased approximately 40% in the ten-year period from 1970 to 1979. Similarly, in the 15-year period from 1968 to 1982, the annual mean phosphorus concentrations in the central basin epilimnion have fallen from 21.3 to 12.0 μg/l (44% decline).

Municipal discharge

Phosphorus from municipal discharges is primarily orthophosphate, which is one of the forms readily available for algal productivity. Therefore, it is important that phosphorus from municipal sources be reduced. Remedial programs for reducing phosphorus loadings from municipal wastewater treatment plants (MWTP) in the Lake Erie Basin have resulted in a substantial decrease in phosphorus loading to the lake. In the early 1970s, the concentration of phosphorus in influent wastewater to municipal treatment plants averaged about 10 mg/l within the Lake Erie drainage basin and the mean effluent concentration was approximately 7 mg/l for each MWTP. In 1981, about half of the 40 major wastewater treatment plants in the Great Lakes Basin did not meet phosphorus requirements of 1.0 mg/l.

Since the installation of phosphorus removal systems by many plants by 1980, an average effluent concentration of 1.6 mg/l for all Ohio plants resulted by 1982. Concentrations as low as 0.6 mg/l for the Detroit sewage treatment plant were exhibited. Likewise, municipal loading of phosphorus to Lake Erie has declined from over 15,000 tonnes in 1972 to about 2,500 tonnes in 1983, a reduction of over 83% (Figure 14.4). By 1984, only 25% of the wastewater treatment plants in the Great Lakes basin exceeded the target concentration. Unfortunately, 6 of the 10 violators are in the Lake Erie Basin: (1) Wyandotte, Michigan, (2) Toledo, Ohio, (3) Akron, Ohio, (4) Cleveland, Ohio, (5) Euclid, Ohio, and (6) Erie, Pennsylvania. It should be noted that the average loading objective of 1.0 mg/l applies to major wastewater treatment plants only (i.e., those plants discharging one million gallons per day or more). For example, the average phosphorus concentration of minor wastewater treatment plants in Ohio is still approximately 4.0 mg/l.

Detergent phosphorus

All of the Great Lakes jurisdictions, with the exception of Ohio and Pennsylvania, have legislative controls limiting the phosphorus content of laundry detergents to 0.5 percent by weight (Table 14.1). The results have been amazing with reductions of up to 60 percent in the amount of phosphorus entering the lakes and streams. In Ohio, the International Joint Commission in 1980 estimates that detergent phosphorus accounts for 20 to 35 percent of phosphorus in municipal discharges, or 490 to 850 tons per year. Although Ohio does not have a state-wide ban, the city of Akron has a local ban. Presently, Canada's limit is 2.2 percent. In areas without bans, detergent manufacturers have reduced phosphorus from 10.8% to an average of 5.5% by weight. If phosphorus levels in detergent were decreased to 2.2% by weight in Ohio, the amount of phosphorus discharged by municipal sewage treatment plants could be reduced by 170 tons per year. If levels were decreased to 0.5 percent, the amount discharged could be reduced by up to 730 tons per year.

Table 14.1. Detergent phosphorus limitations (% P) in Great Lakes basin jurisdictions.

Jurisdiction	% P	Implemented
Ontario	2.2	1973
Chicago, Ill	0.5	1972
Indiana	0.5	1973
Michigan	0.5	1977
Minnesota	0.5	1977
New York	0.5	1973
Wisconsin	0.5	1979
Ohio	No Limitations	
Pennsylvania	No Limitations	

Agricultural phosphorus

Agricultural cropland phosphorus is estimated to account for 65% of the phosphorus entering Lake Erie, of which approximately 50% is bioavailable. To achieve the target loading of 11,000 tonnes/year, Ohio's portion of the goal is a reduction of 1,385 tonnes, of which about 900 tonnes is assigned to cropland phosphorus reduction. Many agencies are currently involved in programs to reduce loads through comprehensive land treatment, residue management, and livestock waste management. Although these programs are resulting in steady increases in conservation tillage acreage and increased knowledge of fertilizer management, they will not be enough to meet the target load reduction.

Conservation tillage including no-till or reduced-till farming involves cultivation (plowing) of the fields which reduces runoff and erosion. This practice requires the use of special equipment to seed the fields and to distribute herbicides for weed control. However, on certain soil types, some of which are present in northwest Ohio, this method is more economical than traditional cultivation. The use of this practice is currently increasing in 22 northwestern Ohio counties.

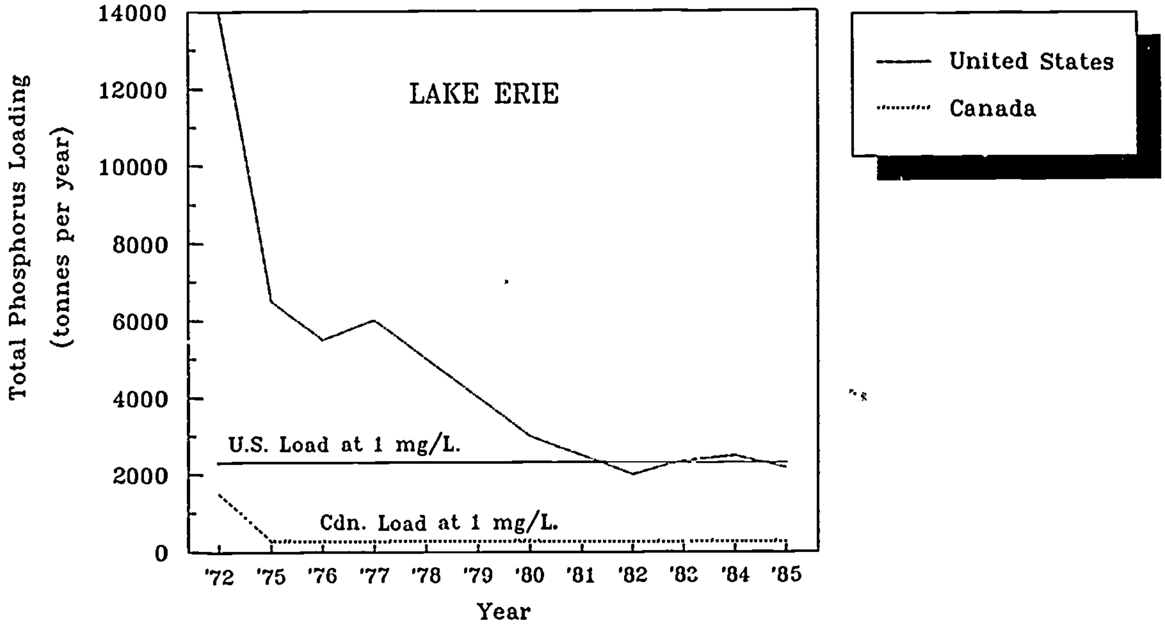

Figure 14.4. Municipal phosphorus loadings to Lake Erie.

Current estimates indicate that conservation tillage increases will result in a phosphorus reduction of 71 tonnes by 1988. Existing erosion and animal waste control programs (other than cropland management) will reduce phosphorus loads by another 120 tonnes. Because only 14% of the goal can be achieved using existing erosion control and water quality protection programs, the vast majority of the reduction must be met with new programs and funding. The Ohio Environmental Protection Agency estimates that nearly 2,000,000 acres of cropland must utilize conservation tillage to meet the phosphorus goal.

Response to phosphorus reduction

Dissolved oxygen in the hypolimnion

The central basin hypolimnion has suffered seasonal anoxic conditions for at least 40 years. Taking into account natural variability in oxygen depletion rates due to meteorological factors, the highest oxygen depletion rates occurred during the 1960s and 1970s. This was when Lake Erie was at the height of cultural eutrophication, exhibiting the highest phosphorus concentrations and algal biomass. From 1980 through 1984 oxygen depletion rates have decreased and are less variable.

In the central basin of Lake Erie, the rate of hypolimnetic oxygen depletion more than doubled between 1930 and the mid-1970s. In 1930, the volumetric rate has been estimated at 0.05 mg/l/day, while in 1974 it was measured at 0.13 mg/l/day. During the same period the area of the basin subjected to anoxic conditions rose from 300 km^2 in 1930 to 10,250 km^2 in 1974. Studies conducted from 1980 to 1982 show that the demand rate dropped to an average of 0.10 mg/l/day and the area of anoxia was reduced to 4,870 km^2. This improvement in bottom water quality can be attributed to decreased amounts of sedimented organic material due to nutrient reduction.

Algal response

In response to lower phosphorus concentrations basin-wide, blooms of planktonic blue-green algae (e.g. *Microcystis*, *Aphanizomenon*, and *Anabaena*) in western Lake Erie, and massive growths of attached filamentous green algae (e.g. *Cladophora*) which were so prevalent in the mid-1960s decreased in intensity and number during the 1970s, and no basin-wide blooms have been reported in recent years. Open lake phytoplankton analysis between 1970 and 1980 indicates a reduction in total phytoplankton biomass and a composition shift toward more oligotrophic species. Eutrophic species were less abundant in 1979 than in 1970, and oligotrophic species were first observed in 1979. With the recent trend of high lake levels, the dilution effect of more upper Great Lakes water flowing into Lake Erie, coupled with greater submergence of algal attachment sites, is thought to be partially responsible for the absence of basin-wide algal blooms and massive growths of *Cladophora* that were so prevalent in the mid-1960s.

Benthos response

The composition of the benthic macroinvertebrate communities of western Lake Erie has improved since 1967. Samples taken in 1979, when compared with 1967 data, showed that the bottom is still dominated by pollution tolerant tubuficid worms; however, other less tolerant tubificids (e.g. *Peloscolex* spp., Figure 14.1) were also common. The density of tubificid worms declined sharply at the mouth of the Detroit River between 1967 (13,000/m^2) and 1979 (2,400/m^2), while the number at the mouth of the Maumee River has remained constant. Midge (Chironomidae) larvae represented only 6% of the western basin benthic population in 1967 but rose to 20% by 1979, replacing some of the tubificids.

A modest reestablishment of the burrowing mayfly (*Hexagenia limbata*) has been observed at the mouth of the Detroit River and in adjacent areas of western Lake Erie. This species was extirpated from the western basin in the mid-1950s following periods of anoxia in this normally unstratified portion of the lake. Prior to 1953, bottom sediments yielded about 400 nymphs per square meter in the Bass Islands region. Following the catastrophic kills of the 1950s, no *Hexagenia* nymphs were found in Lake Erie sediments for over 20 years. In 1979, 20 nymphs were collected near the mouth of the Detroit River and for the past several years a small emergence of adults has been observed on South Bass Island.

Though it is too early to determine all of the causes of the recent increase in annual sport angler harvest of fish in Ohio waters, improvements have been attributed to good young-of-the year recruitment and international management approaches. Any assumptions relating the effects of decreased nutrient loadings into Lake Erie to fishery improvements are premature at this time.

A note about nitrates

Nitrogen is the only major dissolved constituent in the waters of Lake Erie which has shown a dramatic increase in the past decade. Increased use of chemical fertilizers and gaseous emissions of nitrogen compounds within the lake's drainage basin are major causes. Combined nitrate and nitrite loading from the Detroit River more than doubled in the period 1967 to 1979.

Database

In many respects Lake Erie has one of the longest and most complete historical databases in the Great Lakes. Early studies of Lake Erie focused mainly on bacterial contamination in nearshore water. The first detailed limnological surveys on Lake Erie were completed in 1928-1930, and in the 34 years following that there were occasional surveys of limited geographical and temporal scope. The next major study was completed by the Federal Water Pollution Control Administration in 1963-4. A notable research and surveillance effort was undertaken by Burns in 1970. This was followed by a series of studies by Herdendorf from 1973 through 1977, then by two years of binational intensive studies. Additional annual surveys and reports represent years of nearly continuous efforts to determine the impact of culturally induced eutrophication and contamination from toxic substances and to access the success of efforts to reduce those impacts. Recently, Burns, Rathke and Edwards have attempted to document the status of Lake Erie and trace its long- and short-term water quality trends.

Summary

In summary, during the late 1970s changes began to occur which are continuing in the

1980s: nutrient loading decreased, phosphorus concentrations in the lake dropped, sources of contamination by several toxic substances have been checked, levels of certain contaminants in lake sediments and biota are subsiding, "clear water" forms of plankton and benthos are showing modest signs of recovery, and fish populations are rebounding. However, cause and effect relationships of all of these changes are not obvious, most of the improvements have been small, and for many parameters, conclusive trends have yet to be established. But evidence for improvement is beginning to mount and it is becoming obvious to scientists, fishermen, and shoreline dwellers alike that Lake Erie is recovering from nutrient overload, but faces still a difficult challenge—the control of toxic substances. The extent of future improvements will depend on continuing efforts to control loading of nutrients and toxic substances to the lake, particularly those associated with industrial and agricultural practices. Surveillance of Lake Erie water, biota, and sediment conditions must continue if we are to establish clear relationships between remedial actions and lake quality.

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15/ Toxics in Lake Erie

by Clayton J. Edwards

The story of toxic substances in Lake Erie is also a story of human reliance on the element chlorine. Our agriculture depends on chlorinated compounds, which are used to control insects and weeds. The wood in our houses is treated with chlorinated chemicals to discourage termites and our plumbing is made of chlorinated vinyl polymers. We put sodium chloride on our roads during winter to melt the ice. In the summer we chlorinate our swimming pools. Chlorine is added to our sewage to kill the bacteria. As much as we depend on compounds containing chlorine to sustain our standard of living, we are wielding a two-edged sword.

The back side of this sword is, of course, pollution. The recent history of the toxic contamination of Lake Erie is testimony to the dangers of living in a chemical world, especially one dominated by chlorine. For instance, DDT is almost 50% by *weight* chlorine. Toxaphene, a general purpose pesticide created to replace DDT, is chlorinated camphene or pine pitch. The C in PCB represents chlorine, which comprises about 50% by weight of the commercial formulation of this substance. One of the most toxic compounds known is 2,3,7,8, tetrachlorodibenzo-p-dioxin or TCDD, which, as the name implies, contains four chlorine atoms per molecule.

Historians will probably mark the mercury pollution in Lake Erie as the forerunner of the toxics legacy whereby the fish were so contaminated that they posed a threat to human health. But where did the mercury in Lake Erie come from? It came from the chlor-alkali industry that uses chlorine to bleach wood pulp in the making of paper.

The route by which chemicals support our standard of living and influence our environment is straight forward. Raw materials are generally extracted from the earth through mining or drilling. These basic materials are then combined in the manufacturing process and the finished product is consumed.

The extraction process has its associated environmental hazards, such as asbestos pollution resulting from iron ore mining or oil spills occurring at the well head or during transportation. The manufacturing process creates unwanted byproducts, e.g. dioxin, that enter the environment from industrial wastewater pipes, smoke stacks or hazardous waste dump sites. Product consumption closes the cycle and involves application of the product on the land, such as in farming; ingestion; or simply discarding the product after use, as is frequently done with plastic bottles. Whether through the air, through the tributary network or through the subsurface flow of groundwater, the lake ultimately receives these chemicals.

Some particular traits of a chemical determine whether it will pose an environmental hazard. These traits are its toxicity, its persistence and its affinity for water. Generally, the worst combination is high toxicity, long persistence and low water affinity. The DDTs, TCDDs and PCBs all fall into this category. Such chemicals will accumulate in living tissue through a process known as biomagnification. If a chemical has a low affinity for water it will generally have a high affinity for lipids (fatty substances). The chemical combines with the lipid and, if persistent, remains with the organism until it dies or is consumed. A single celled alga (phytoplankton), for example, might accumulate one molecule of a chlorinated chemical, and a small invertebrate (zooplankton) might consume 10 of these

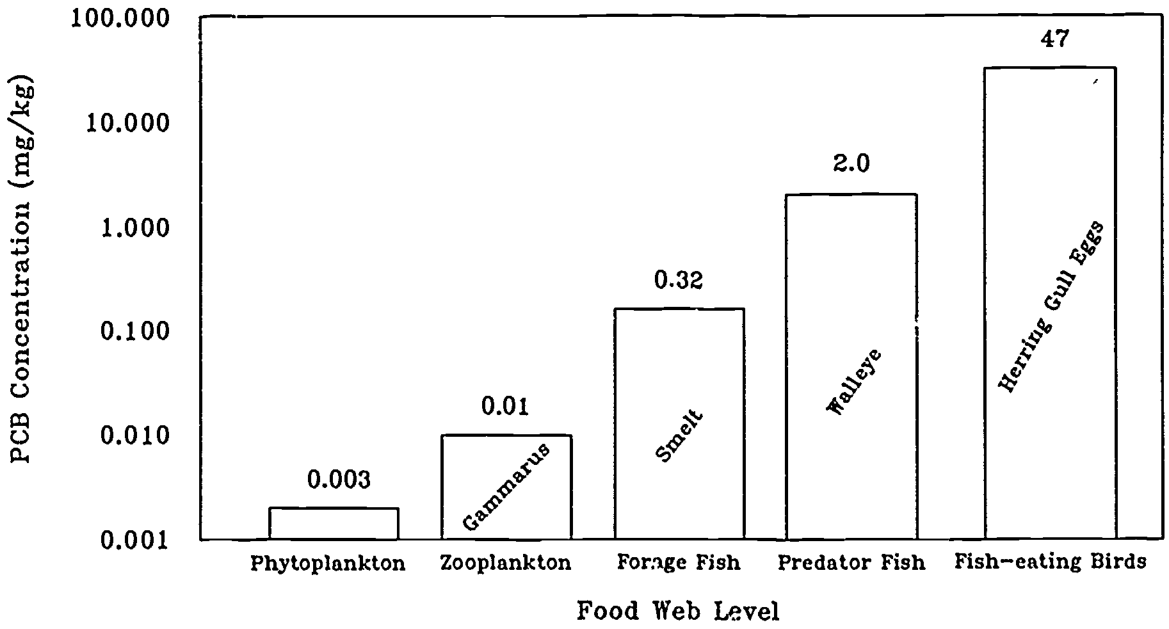

Figure 15.1. Total PCB concentration (mg/kg) in the food web of the Western Basin of Lake Erie. ***(Data sources: D.M. Whittle, Department of Fisheries and Oceans, Burlington, Ontario; D.V. Weseloh, Canada Wildlife Service, Burlington, Ontario)***

phytoplankton before it in turn is consumed by a small fish. If the small fish consumes 10 zooplankton before it is consumed by a larger fish, there are now 100 molecules of the chemicals transmitted to the next consumer, which might be a walleye. If the walleye consumes 10 of these fish before it is caught, then the fisherman is exposed to 1000 molecules of the chemical. The data in Figure 15.1 depict this food chain biomagnification process.

It follows from this description that the longer an organism remains in a contaminated system, the higher the degree of exposure and hence the accumulation of chemicals. This relationship is depicted in Figure 15.2. It explains why fish consumption warnings typically apply to the larger (older) members of species.

Until recently our ability to accurately quantify the levels of organic contaminants in water has been deficient. However, a 1986 survey by Canadian scientists to evaluate organochlorines in Lake Erie water showed PCB concentrations of 0.70 **g/L** in the open waters of the lake with the Detroit, Maumee and Grand (Ontario) Rivers as major tributary sources. Since the data in Table 15.1 reflect state-of-the-art collection and analytical techniques it is fairly certain that these figures are accurate and represent the baseline to which future monitoring data will be compared.

Before scientists had the state-of-the-art techniques to accurately detect contaminants in water, they took advantage of the biomagnification phenomenon and measured contaminant levels in biological tissue, such as fish and herring gull eggs, as surrogates for water quality. These surrogates, measured over time, are used to evaluate trends in organic contaminants. They determine the effectiveness of or need for government programs to reduce pollution from toxic contaminants. The results from two of these programs appear in Figures 15.3 and 15.4.

It is obvious from these data that environmental levels of PCB are declining. The data for DDT, dioxin and mercury show similar declines for Lake Erie and the Great Lakes in general. Some compounds, however, have not declined even though their use or production have been eliminated. Dieldrin, a compound containing six chlorine atoms per molecule (56% chlorine by weight) and a degradation product of the pesticide aldrin, is an example of such a chemical. Dieldrin and aldrin were widely used as pesticides from 1950 to 1974 when uses of both were cancelled.

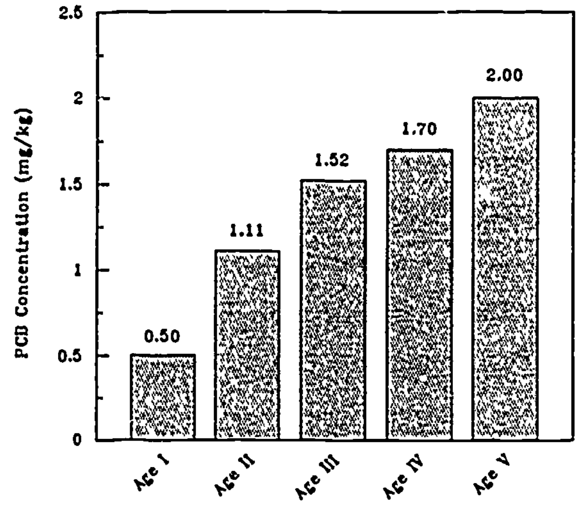

Figure 15.2. **PCB concentration (mg/kg) in five age groups of walleye from the Western Basin of Lake Erie.** ***(Data source: D.M. Whittle, Department of Fisheries and Oceans, Burlington, Ontario)***

Table 15.1. Organo-chlorine contaminants from Lake Erie surface water, 1986. *(Data source: R. Stevens, Inland Waters Directorate, Burlington, Ontario)*

	MEAN ± STANDARD DEVIATION	MINIMUM	MAXIMUM
α-BHC	3.33 ± 0.81	2.17	5.48
Lindane	0.90 ± 0.38	0.49	2.15
Dieldrin	0.34 ± 0.16	0.07	0.93
Heptachlor Epoxide	0.14 ± 0.04	0.09	0.26
α-Chlordane	0.04 ± 0.03	0.01	0.09
γ-Chlordane	0.03 ± 0.02	0.01	0.09
p,p'-DDE	0.03 ± 0.02	0.01	0.08
PCBs	1.16 ± 0.81	0.29	2.95
1,3-dichlorobenzene	0.20 ± 0.13	0.05	0.46
1,4-dichlorobenzene	0.96 ± 1.02	0.26	4.18
1,2-dichlorobenzene	0.18 ± 0.21	0.03	0.98
1,3,5-trichlorobenzene	0.03 ± 0.03	0.02	0.14
1,2,4-trichlorobenzene	0.30 ± 0.14	0.04	0.60
1,2,3-trichlorobenzene	0.04 ± 0.01	0.02	0.06
1,2,3,4-tetrachlorobenzene	0.04 ± 0.02	0.02	0.08
Pentachlorobenzene	0.05 ± 0.02	0.02	0.07
Hexachlorobenzene	0.07 ± 0.06	0.01	0.22

N.B. Mean and standard deviations calculated only with data greater than detection limit.

The environmental levels for dieldrin, as shown by herring gull eggs, have not changed appreciably since 1974 (Figure 15.5).

Other dangerous chemicals have been detected in the environment but they lack long-term data to make an evaluation of their trends. For such chemicals, the need for or effectiveness of programs to reduce or eliminate their input are undetermined. Because there are more than 50,000 chemicals in the Great Lakes ecosystem, the process of evaluating each one would be overwhelming. The governments of Canada and the United States, through the IJC, are therefore working on procedures to reduce the list by focusing on chemicals that are most likely to cause environmental harm.

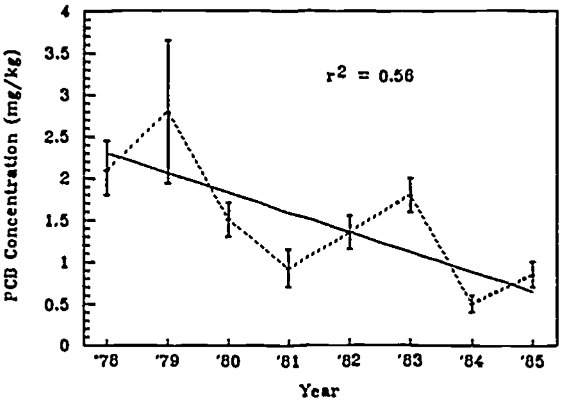

Figure 15.3. **PCB concentration in age 3+ walleye from Lake Erie.** ***(Data source: D.M. Whittle, Department of Fisheries and Oceans, Burlington, Ontario)***

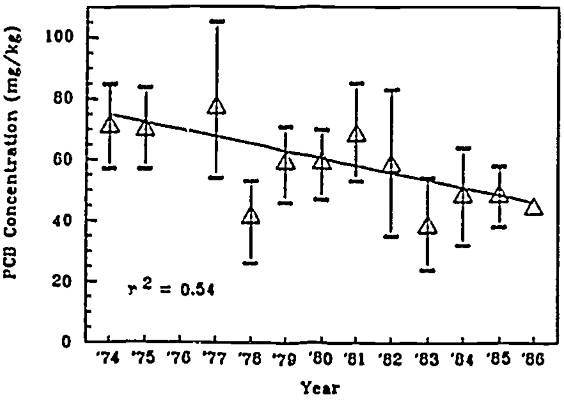

Figure 15.4. **PCB concentrations (mg/kg) in Lake Erie Western Basin herring gull eggs, 1974-1986.** ***(Data source: D.V. Weseloh, Canada Wildlife Service, Burlington, Ontario)***

There are some areas in the Great Lakes that are so grossly polluted that they have been singled out by the IJC as deserving special attention. The Water Quality Board of the IJC has identified 42 of these areas within the Great Lakes basin (Figure 15.6). Within the Lake Erie

Table 15.2. Summary contaminant information from the Lake Erie Areas of Concern. *(Data source: J. Hartig, IJC Great Lakes Regional Office, Windsor, Ontario)*

Area of Concern	Toxics Identified in Sediments	Consumption Advisory	Presence of Tumors
River Raisin	PCBs Trace metals	No consumption of carp	Gizzard shad
Maumee	Trace metals	None	No data
Black	Metals PAHs	No consumption - all species	Brown bullhead
Cuyahoga	Metals PCBs, DDT, PAHs	None	White suckers, brown bullhead
Ashtabula	Metals PCBs	No consumption - all species	No data
Wheatley Harbour	Metals PCBs, DDT	Yellow perch	No data
Detroit River	PAH, metals PCBs	Restrictions on rock bass, walleye, freshwater drum, carp	Bullheads
Niagara River	Metals PCBs	Restrictions on white sucker, eel, trout, salmon, white perch	Freshwater drum, white sucker

watershed there are eight such areas: the River Raisin in Michigan; Wheatley Harbour in Ontario; the Maumee, Black, Cuyahoga and Ashtabula Rivers in Ohio; and the Detroit and Niagara Rivers. Even with limited data, it is clear that sediments are severely contaminated, fish consumption warnings are commonplace and tumors in fish are prevalent (Table 15.2). In Wheatley Harbour, the suspected source of pollution is the accumulation of waste from the fish processing plant. The other seven areas represent a legacy from the industrial heartland production of steel, automobiles and chemicals.

Progress in reducing the threat of toxic substances in Lake Erie has been positive but slow. More stringent enforcement of point source discharge permit systems, stronger laws and enforcement to reduce airborne sources of toxics, and a rigorous toxic waste site clean-up program will be needed to achieve the goals set forth by the governments of Canada and the United States. Preventing a repetition of contamination from new chemicals will require a strict and vigorous application of the existing laws and programs designed to curb such pollution, i.e. the Toxic Substances Control Act (TSCA), the Federal

Insecticide, Fungicide and Rodenticide Act (FIFRA) and the Resource Conservation and Recovery Act (RCRA).

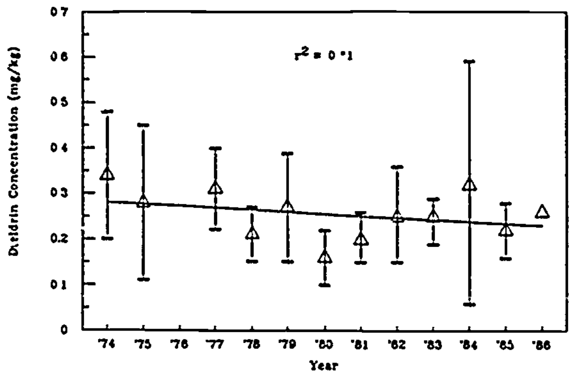

Figure 15.5. Dieldrin concentrations (mg/kg) in Lake Erie Western Basin herring gull eggs, 1974-1986. ***(Data source: D.V. Weseloh, Canada Wildlife Service, Burlington, Ontario)***

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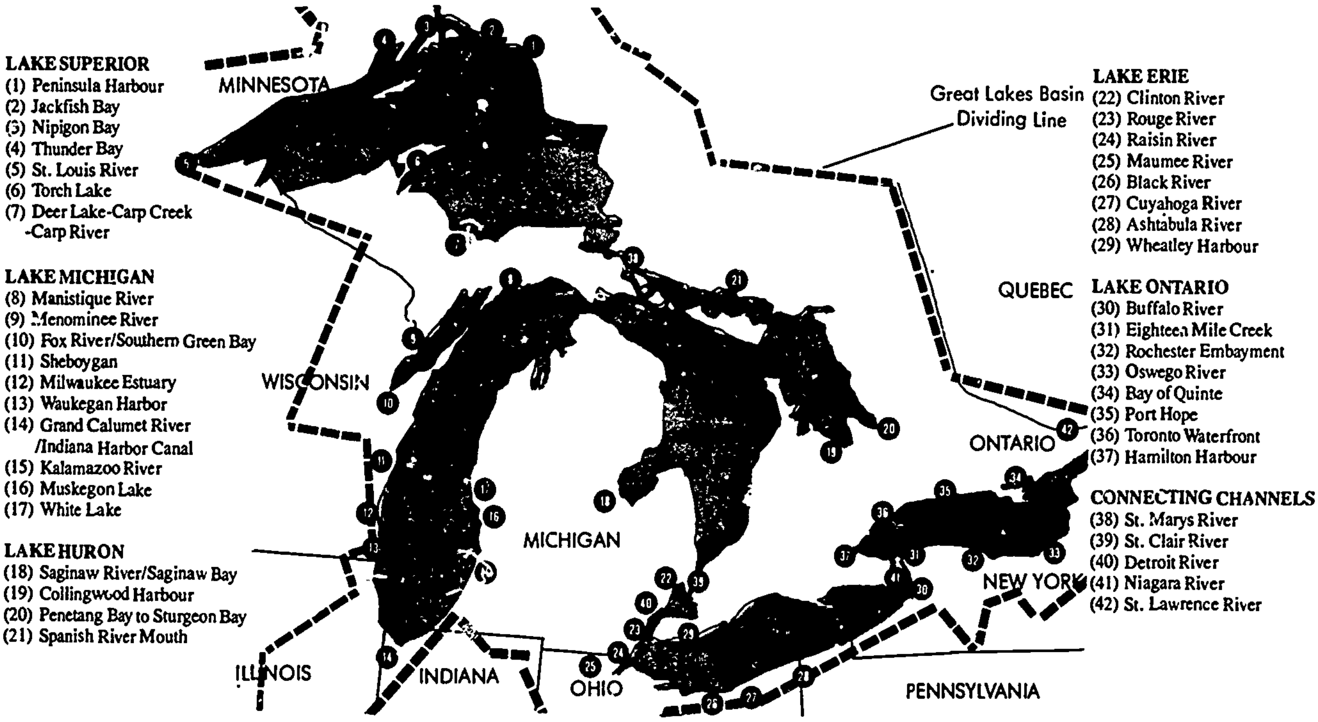

Figure 15.6 Great Lakes Areas of Concern.

16/ Governing the Great Lakes Basin

by Kathleen L. Barber

Popular and scientific concerns about gradual deterioration of water quality and fish supply in the Great Lakes in the 1970s led to a renewed interest in the question, "Who is in charge? Who is making the decisions about the uses and abuses of this great resource?" The abrupt emergence in the 1980s of the issue of diversion of Great Lakes water to arid regions of the country sharply escalated discussions of the adequacy of the governmental system.

Traditionally, decisions about both water quality and water quantity in the region have been made on an ad hoc basis by both private and public authorities with little consultation among affected parties. Public indifference to the natural ecosystem had to be converted to public concern before the problems of the institutional ecosystem could be addressed.

The critical characteristics of the mechanisms for making and implementing public policy in the Great Lakes Basin are first, the *complexity* of the institutional framework; and secondly, the *fragmentation* of power inherent in that complexity. A significant boundary for the purpose of ecosystem management is the outline of the Great Lakes Basin. Many people are astounded to learn that only a small portion of the land area of the region actually lies within the basin. Yet even that significant basin boundary is transcended by external influences. The discovery, for example, that water quality in the lakes is impacted by airborne pollutants carried great distances by natural atmospheric currents proves how difficult it is to draw geographical boundaries to our governmental concerns. The introduction of the sea lamprey, a predatory fish that attacks commercially important fish species, into the Great Lakes was an unintended consequence of governmental decisions made far from the basin to subsidize and encourage private commerce.

In order to understand the complexities of governance, one must identify international, national, state and provincial as well as local government bodies, all with bits and pieces of responsibility for human impacts on the functioning of the natural ecosystem. Four interjurisdictional agencies charged with coordinating activities of various governments will also be explored. Once the institutional outlines are sketched in, the need for integrative mechanisms can be addressed.

The international setting

History teaches us that bodies of water have traditionally been viewed as convenient political boundaries. Rivers, lakes and seas have been used for purposes of defense and demarcation, providing limits to settlements whether of communities or nations; so with the Great Lakes, four of which encompass an international boundary. The United States and Canada as sovereign and independent nations share possession of and responsibility for the water of the lakes. While Lake Michigan is not legally an international lake, being totally surrounded by U.S. territory, it is an integral part of the hydrological system of flows and levels. It has best been described as a cul-de-sac of Lake Huron; the waters flow downstream from Superior through Huron to Erie and Ontario, and into the St. Lawrence River on the way to the Atlantic Ocean.

The International Joint Commission

Binational responsibility for the Great Lakes system was recognized and formalized by the Boundary Waters Treaty of 1909, in which Canada and the United States agreed to settle differences over allocation and use of boundary waters by negotiation. Domestic supply of water was given the highest priority, with navigation next in importance. Significantly, the two nations agreed to prohibit diversion of streams crossing the boundary, and not to pollute in such a way as to cause injury to the other nation, an early recognition of the major issues of today. The Treaty established the International Joint Commission (IJC) to carry out the provisions of the agreement. This binational authority was given actual decision-making power in limited areas of water allocation at the border. With respect to all other policies and actions, the IJC was given advisory power only. Its authority to investigate problems and recommend policy is limited to questions referred to it by the two sovereign governments in a formal "reference." This passive institutional character means that the only international body governing the Great Lakes is subject to two national wills.

The IJC is composed of six commissioners, three of whom are appointed by the Canadian government for fixed terms, and three of whom are appointed by the U.S. President, confirmed by the Senate, and serve at the pleasure of the President. This method of appointment is only one of many differences between the two nations in governmental practices which hampers the effectiveness of a joint public enterprise.

However, most of the work of the Commission is carried out by binational boards staffed by civil servants "seconded" (or borrowed) from agencies of the respective governments. Such groups as the Water Quality Board, the Science Advisory Board, the Pollution from Land Use Activities Reference Group (PLUARG) are respected for the impartial and professional character of the studies they have produced. Since the adoption by the two nations of the Great Lakes Water Quality Agreement of 1972, revised and renewed in 1978, these boards have persuaded the IJC to support an ecosystem approach to the management of the natural resources of the region. Implementation of its recommendations, however, remains within the sovereign power of the two nations.

Great Lakes Fisheries Commission

Similar to the IJC in organization is the Great Lakes Fisheries Commission (GLFC), established in 1955 as a binational body to recommend means to manage the fish stocks of the lakes for maximum sustained productivity, and to eradicate the sea lamprey. Like the IJC, its research findings are accorded high respect, while its effectiveness depends on the commitment of the respective sovereign powers to carry out its recommendations.

The sovereign nations

United States

Within the American government, responsibility for these matters is widely shared. Congress sets the broad parameters of public policy, but must secure executive assent. Action is often impeded by lack of agreement between President and Congress, or between the two houses of Congress. Delay in the renewal of the Clean Water Act is a case in point. The Renewal Act contains the much-discussed Great Lakes Amendment, whose purposes include coordination of state and federal efforts to meet the standards of the Water Quality Agreement with Canada. Ironically, the Amendment remains in limbo because of lack of consensus among the multiple power centers of the American federal government. When both houses of Congress finally agreed on its provisions and passed the Clean Water Act in October 1986, President Reagan used his pocket veto power to kill the legislation, citing excessive costs to expand and update municipal sewage treatment systems.

Many departments of the federal government share authority to implement environmental policy. Only the State Department may issue a reference to the IJC, since international relations are involved. Responsibilities for air and water quality, navigation, commerce and fisheries are shared by the Departments of State, Defense, Commerce, Interior and Transportation, the Environmental Protection Agency and other units scattered through the federal bureaucracy. The U.S. Army Corps of Engineers plays a key role because of its responsibility for maintaining the channels of navigation and for regulation of levels in some lakes. The Corps co-chairs with Canada's Departments of Environment and Transport the Lake Superior and St. Lawrence River Boards of Control.

Not surprisingly in a nation where the practice of judicial supremacy is deeply rooted, even the U.S. Supreme Court is an ever-present decision maker in the Great Lakes region. Under its original jurisdiction, where it sits as a trial court for disputes among the states, the Supreme Court regulates the amount of water that can be diverted from the system through the Chicago Canal. This diversion of Lake Michigan water, created in 1848 to protect Chicago's drinking water by flushing its sewage down the Mississippi River, has been litigated over the years by other affected states and is carefully controlled by the Supreme Court.

Interpreting the interstate commerce power of Congress under the U.S. Constitution, the Supreme Court acts also under its appellate jurisdiction to shape state management of natural resources. For example, its famous 1982 decision, *Sporhase* v. *Nebraska*, 458 U.S. 941, declared water to be an article of commerce and therefore beyond the absolute control of the states. States cannot forbid export of water out of the state, unless damage to public health and welfare could be shown to be threatened by such export. Such an interpretation of the Constitution has massive potential implications for the ecosystem management of the Great Lakes Basin.

Canada

In contrast, Canada's system of parliamentary supremacy concentrates power rather than dispersing it. The Prime Minister, a member of Parliament himself, is the leader of the majority party in Parliament, and his Cabinet is composed entirely of members of Parliament. There can be no conflicts between executive and legislative initiatives such as are experienced in the United States, because there is no separation of these powers. If a parliamentary majority fails to support the Cabinet's policy, the government falls and new elections must be held. Unity and accountability are therefore strengths of the parliamentary system, rather than checks and balances, as in the United States.

The principal Canadian federal agencies responsible for management of Great Lakes Basin activities are External Affairs, Environment Canada, Transport Canada, and the Department of Fisheries and Oceans. Each of these executive agencies is headed by a member of the Cabinet who must be a member of Parliament, and who is usually a member of the Prime Minister's party. Therefore, the kind of executive-legislative stalemate which is familiar to Americans is unknown across the northern border.

Furthermore, Canadian courts have little policy-making power, seldom exercising judicial review. There is little or no private environmental litigation in Canada, so the Canadian courts' opportunities to become involved in questions of pollution and policy are significantly restricted. Class action suits and contingency fees for lawyers, practices which have led to important judicial involvement in environmental policy in the United States through interpretation of the laws, are unknown in Canada.

What's left for the States and Provinces?

Because both Canada and the United States are federal systems, their powers in the Great Lakes Basin are shared with two provinces (Ontario and Quebec) and eight states (Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania and Wisconsin). In both nations the navigable waters of the lakes are under federal jurisdiction, but the states and provinces own the submerged lands under their portions of the lakes. Beyond this similarity, there are significant differences between the two systems with respect to interjurisdictional relations. These differences will be discussed and illustrated by recent initiatives to overcome such institutional complexities.

Provincial responsibilities

Ontario's presence in the Great Lakes Basin so outweighs Quebec's that there are few interprovincial problems. But usually a cleaner line of demarcation between federal and provincial responsibilities is drawn in Canada, with environmental and natural resource responsibilities devolving more substantially on the provinces. The Canadian Constitution confirms provincial jurisdiction over exploration, development, conservation and management of non-renewable resources.

For this reason, Canada uses more formal mechanisms to allocate responsibilities. The Ministries of Natural Resources and Environment in Quebec and Ontario are dominant in natural resource matters. In fact, in order even to negotiate an agreement with the U.S. about Great Lakes water quality, Canada first signed an internal agreement with Ontario to guarantee the implementation of terms to be negotiated externally. The Canada-Ontario Agreement Respecting Great Lakes Water Quality (COA) was first signed in 1971 and revised in 1976 and 1982. One of the key provisions of COA was the specification that only minimum standards of water quality would be binding on Ontario, leaving the province free to adopt more stringent standards if it so desires.

Powers of the States

This provincial dominance contrasts significantly with the U.S., where Congress retains the power to set maximum as well as minimum standards for compliance with environmental laws. (However, individual states can control and prescribe environmental standards with approval from U.S. EPA). Federal supremacy is a more powerful tool under the U.S. Constitution for the enactment and implementation of environmental policy. Although the Tenth Amendment reserves to the states those powers not delegated in the Constitution to the federal government, the dividing line between federal and state responsibilities is imprecise and permeable. Furthermore, that line is subject to judicial intervention in cases and controversies, as, for example, in the *Sporhase* decision mentioned earlier. Among the American states, responsibility is dispersed in a variety of ways. With eight state legislatures and governors at work to make and implement policy, different approaches to public issues inevitably develop. Partisan differences among the states reflect contrasting levels of commitment to governmental solutions of environmental and economic problems. For many years, however, on a bipartisan basis, the states have intermittently pursued interstate consensus on Great Lakes issues through the Great Lakes Commission (GLC).

Organized by interstate compact in 1955, the Great Lakes Commission was not approved by Congress until 1968. This 13-year delay was caused by the states' plan to include the Canadian provinces of Ontario and Quebec in the Commission. Congress resisted this inclusionary approach because of reluctance to allow states to conduct foreign relations. When the states withdrew their insistence on a binational regional approach, Congress ratified the compact.

The purpose of the GLC is "to promote the orderly, integrated, and comprehensive development, use and conservation of the water resources of the Great Lakes Basin." Headquartered in Ann Arbor, Michigan (the only state lying totally within the Basin), the Commission has quietly addressed both environmental and economic issues, particularly the welfare of lake shipping. While the Commission can adopt issues by majority vote, its role remains advisory to the states.

The Commission's structural weakness lies in its lack of authority to act: it is not a suprastate, regional government. Methods for choosing its members (three to five commissioners from each state) are designated by state statute, with at least one appointed by the Governor of each state. The variety of selection methods and provisions for accountability to the respective states leads to differing degrees of state commitment to this interstate enterprise. Even under this limited authority the Commission has never exercised its total potential of regional advocacy and coordination of policy.

Regional alliances

A relatively new and rapidly evolving regional institution is the Council of Great Lakes Governors (CGLG), formally established in 1982 by the governors of six states (Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin). New York, Pennsylvania, Ontario and Quebec participate as voting members of the Council's committees. The Council's rise to prominence in the 1980s and its significant achievements demonstrate how political leadership can overcome fragmentation imposed by state boundaries. Although the Council, like the Great Lakes Commission, lacks the authority to implement its recommendations, the Governors have provided a dramatic focus for addressing policy issues in several key areas.

The Great Lakes Charter, signed in 1985 by eight governors and two premiers, marked a historic breakthrough in interjurisdictional cooperation. The states and provinces agreed on consultation and cooperative management of the water resources of the Great Lakes Basin to prevent damaging diversions and consumptive uses. Under the leadership of Governor Anthony Earl of Wisconsin, Chairman of the Council of Great Lakes Governors, the Council's Task Force on Water Diversion and Great Lakes Institutions worked its way through the institutional maze to develop an integrated approach to water quantity problems which respected the legal and political diversity of the many governments involved. The Charter is non-binding for legal and constitutional reasons which have already been discussed, but the good faith of the signatories is demonstrated by the prompt establishment of a working group of technical experts to develop a common data base on current uses of the region's water supplies.

Little more than a year later, another landmark interstate commitment to manage the lakes as an integrated ecosystem was made. In May 1986 a Toxic Substances Control Agreement was signed by the governors of the eight Great Lakes states. Because this agreement was formulated within the framework of U.S. regulatory law, the premiers did not sign, but expressed their support for the plan and promised to issue a similar official commitment to toxic cleanup in the near future. A key feature of this Agreement is the explicit determination to deal with the movement of pollutants through the system: in the air, in surface water and in ground water. Not only are common goals defined, but specific actions accompanied by deadlines are agreed upon for implementation.

The effectiveness of these bold regional measures clearly depends on the ability and will of the individual states and provinces to develop and pursue management plans, both for water quantity under the Charter and for water quality under the Toxic Substances Control Agreement. Here again, institutional diversity takes over.

Structure and function

It is difficult to generalize about the structures of governance within the states beyond the commonality of the separation of powers into executive, legislative and judicial branches. Within the state bureaucracies, agency responsibilities differ. Typically, however, parks and recreation, water planning, wildlife and fisheries management and coastal zone protection are allocated to Departments of Natural Resources, while air, water and land pollution control is assigned to state Environmental Protection Agencies. Significant overlap of duties may result, as when land uses degrade the quality of water in coastal wetlands and affect fish habitat. In Canada, a similar overlap is apparent among the Ministry of the Environment, Environment Canada and the Department of Fisheries and Oceans.

Even within a single department in a state, conflicting goals may present management challenges. For example, within Departments of Natural Resources, expansion of shoreline parks for recreational use may undermine efforts to preserve the remaining wetland areas. Public policy is difficult to make and even more difficult to implement under these pressures. Efforts to overcome intrastate fragmentation have been made in states such as Ohio where in 1984 Governor Richard Celeste appointed an interagency committee on water to coordinate policy initiatives and to prevent duplication of effort. The "Water Cluster" is composed of cabinet directors of Natural Resources, Environmental Protection, Health, Agriculture and Transportation. Its first responsibility was to develop a strategic plan for the state's natural and physical environment. Its attention is now directed to ground water planning.

The grass roots

The institutional labyrinth which has been described from state and provincial to international levels is not yet complete. There is yet another maze of overlapping governments to be taken into account in the region: the local level. Although the impact of each local government may be small, taken together the decisions of counties, municipalities and special districts are consequential indeed. Soil conservation districts

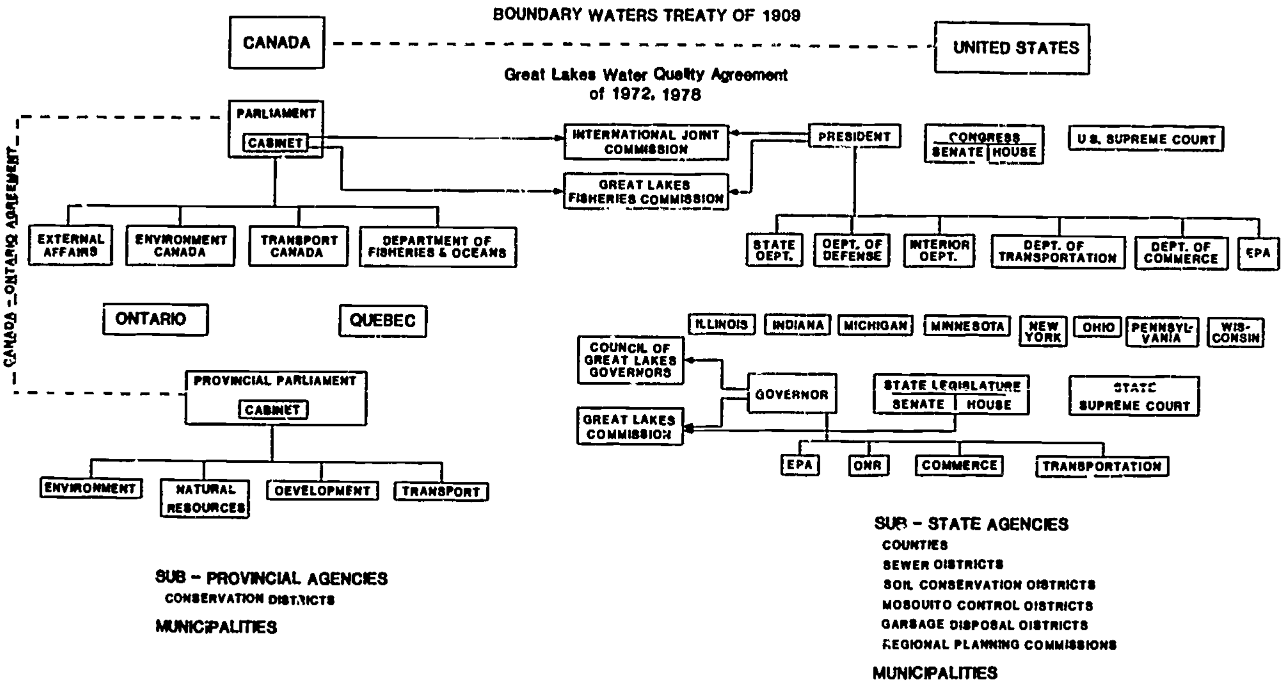

Figure 16.1. Simplified diagram of relevant governmental units in the Great Lakes Basin.

may affect amounts of non-point source pollution. Municipalities or special sewer districts are responsible for wastewater treatment. Erosion from construction sites and other urban runoff into tributary streams are local matters. Counties bordering the lakes may perform solid or liquid waste disposal functions.

Generally land use planning is a local governmental function on both sides of the international boundary. There are few more fervently protected local powers than planning and zoning. Here indeed is government that is close to the people. Subregional attempts to coordinate land use planning among communities are often resisted as unwarranted intrusions on local autonomy. These are political culture attributes which create the fragmented base for all other governmental attempts at coordination of policy.

No comprehensive inventory is available for local governmental units in the Great Lakes Basin; but the numbers are in the hundreds. These decision-making entities are critical for the overall management of the region's ecology, yet they deal with significantly differing local conditions and operate under the eagle eyes of local residents whose preferences are driven by a multitude of private motives. In some instances, the nations, states and provinces can mandate action by these local authorities, or can induce them to act by providing significant financial incentives. What the higher authorities cannot do is to stay with the local governments for every step to ensure compliance. Some degree of cooperation from below is necessary if regional goals are to be attained.

Conclusion

This brief survey of governmental complexity in the Great Lakes region has identified the roles in resource management played by two nations, two provinces, eight states, four regional institutions and hundreds of local governmental units. In the 1980s a significant breakthrough has occurred in public awareness of the inestimable importance of the vast freshwater system we appropriately call the Great Lakes. Support for environmental values is rising, and in the Great Lakes region this includes an appreciation both of water supply and of the quality of that water.

The surge in public interest and concern is reflected in the creation of new private organizations such as Great Lakes United and the Center for the Great Lakes, the former for advocacy and the latter for research and policy development. These groups offer expertise and encouragement to policy-makers to act aggressively to develop management strategies for repair of the damage human beings have done to the system, and for sustainable resource use in the future.

Some experts have argued that we need to create new institutions for regional management of this precious resource. Others find existing institutions underutilized and advocate "building new relationships among existing institutions."

"Political will," Donahue wrote in 1985, "is *the* overriding determinant of the success of a given regional institution. When present, it can transcend even the most restrictive institutional form. When absent, even the most innovative form can become impotent."

The sense of urgency which is widely felt today grows out of perceived crises: the danger to human health from toxic contamination in the water supply; the threat of water supply depletion if arid regions should use their political power to divert the lakes' water to the south and west. These particular crises may be dealt with in the next decade, but it is of vital importance to educate future generations to care about the lakes for the long range so that we need not go through alternating cycles of intense activity and indifference, crisis and neglect. As educators, communicators and concerned citizens we need to nourish sustained attention and active concern for the ecosystem.

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