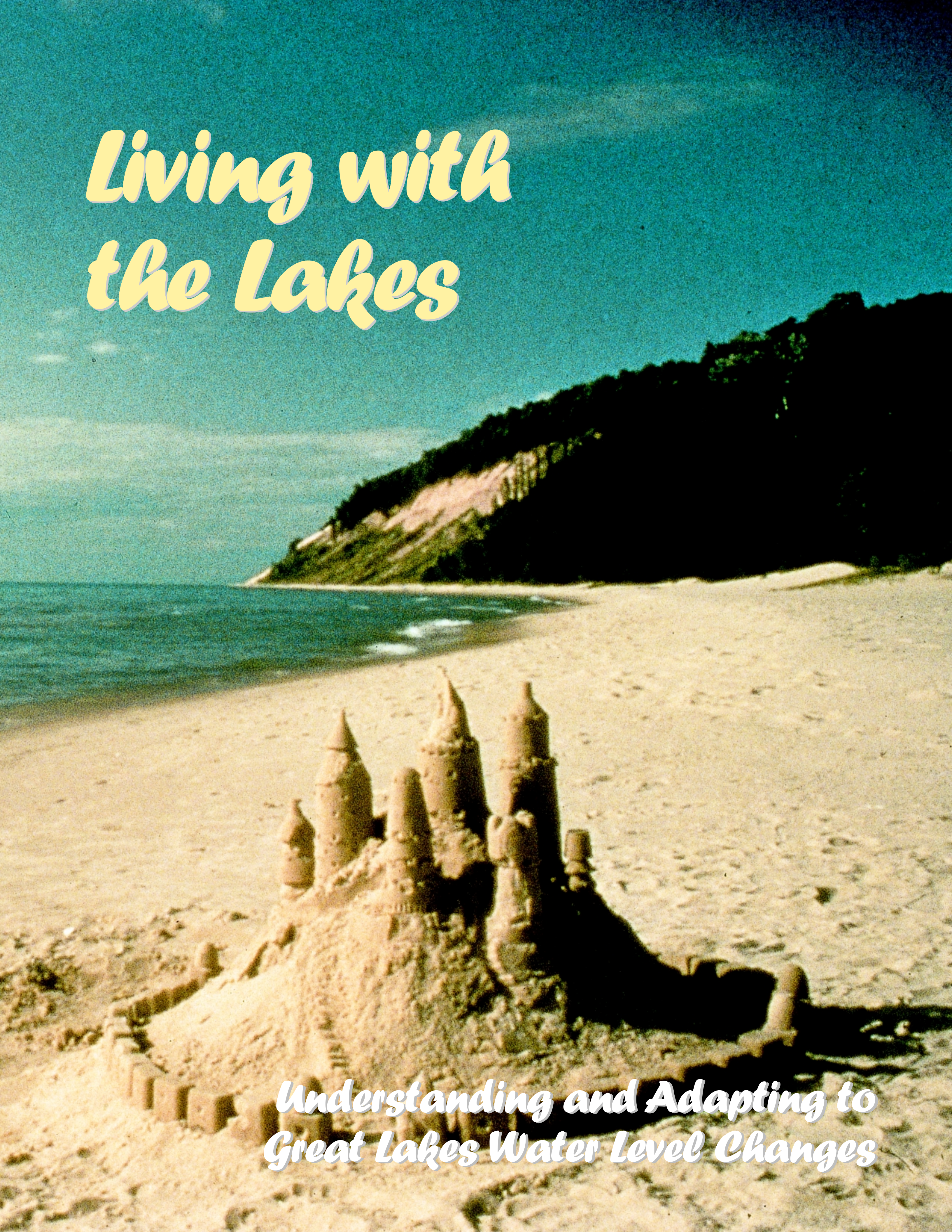
Living with the Lakes



Understanding and Adapting to Great Lakes Water Level Changes

US Army Corps of Engineers
Detroit District

The Detroit District, established in 1841, is responsible for water resource development in all of Michigan and the Great Lakes watersheds in Minnesota, Wisconsin and Indiana.

Great Lakes Commission

The Great Lakes Commission is an eight-state compact agency established in 1955 to promote the orderly, integrated and comprehensive development, use and conservation of the water resources of the Great Lakes basin.

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MEASUREMENTS CONVERTER TABLE

U.S. to Metric

Length
feet x .305 = meters
miles x 1.6 = kilometers

Volume
cubic feet x 0.03 = cubic meters
gallons x 3.8 = liters

Area
square miles x 2.6 = square kilometers

Mass
pounds x 0.45 = kilograms

Metric to U.S.

Length
meters x 3.28 = feet
kilometers x 0.6 = miles

Volume
cubic meters x 35.3 = cubic feet
liters x 0.26 = gallons

Area
square kilometers x 0.4 = square miles

Mass
kilograms x 2.2 = pounds

This publication is a joint project of the U.S. Army Corps of Engineers, Detroit District, and the Great Lakes Commission.

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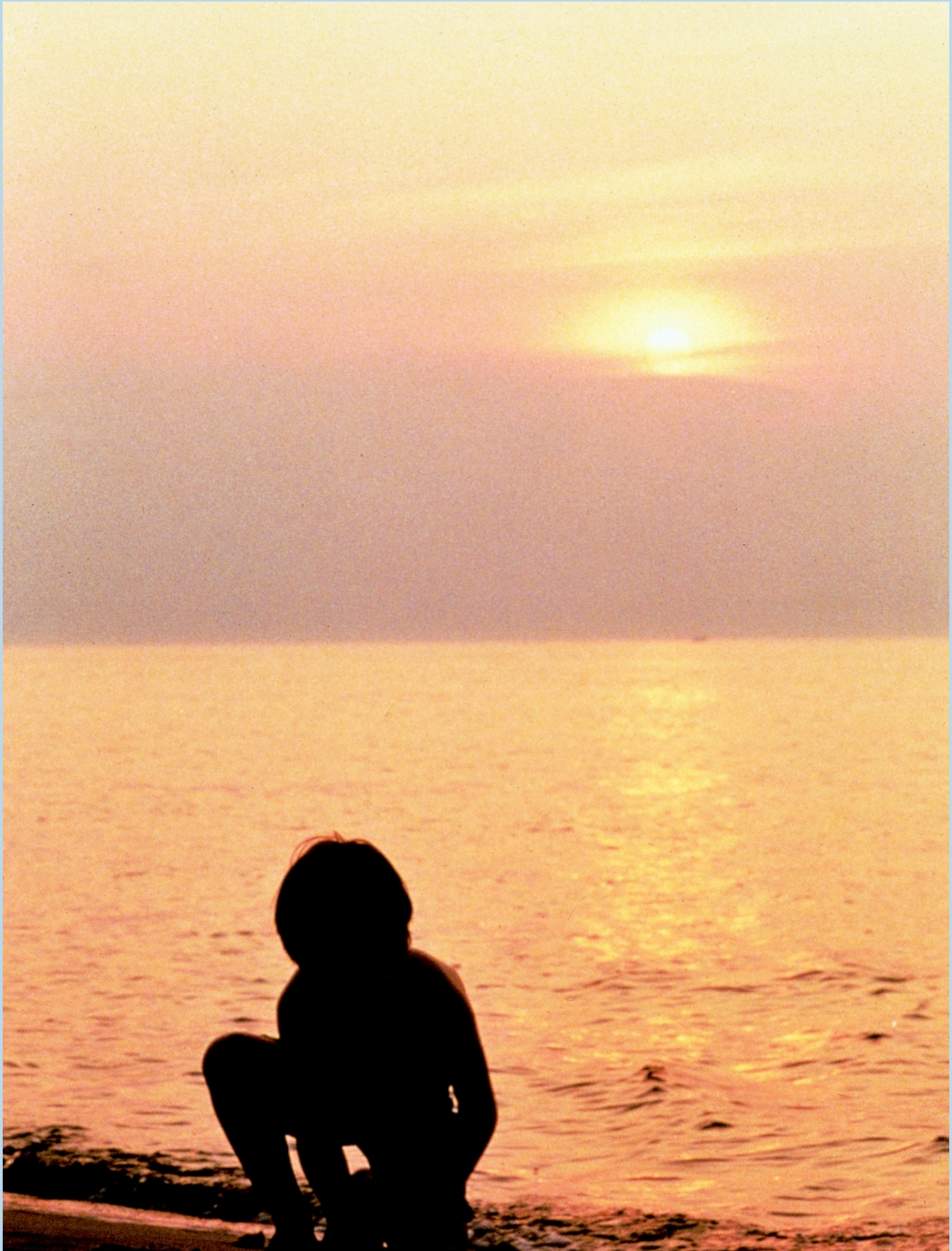
Contents

Port Huron to Mackinac Race, Lake Huron; Lake Michigan beach at Petoskey, Michigan; and Calumet Sag Channel, Calumet Park, Illinois, on Lake Michigan

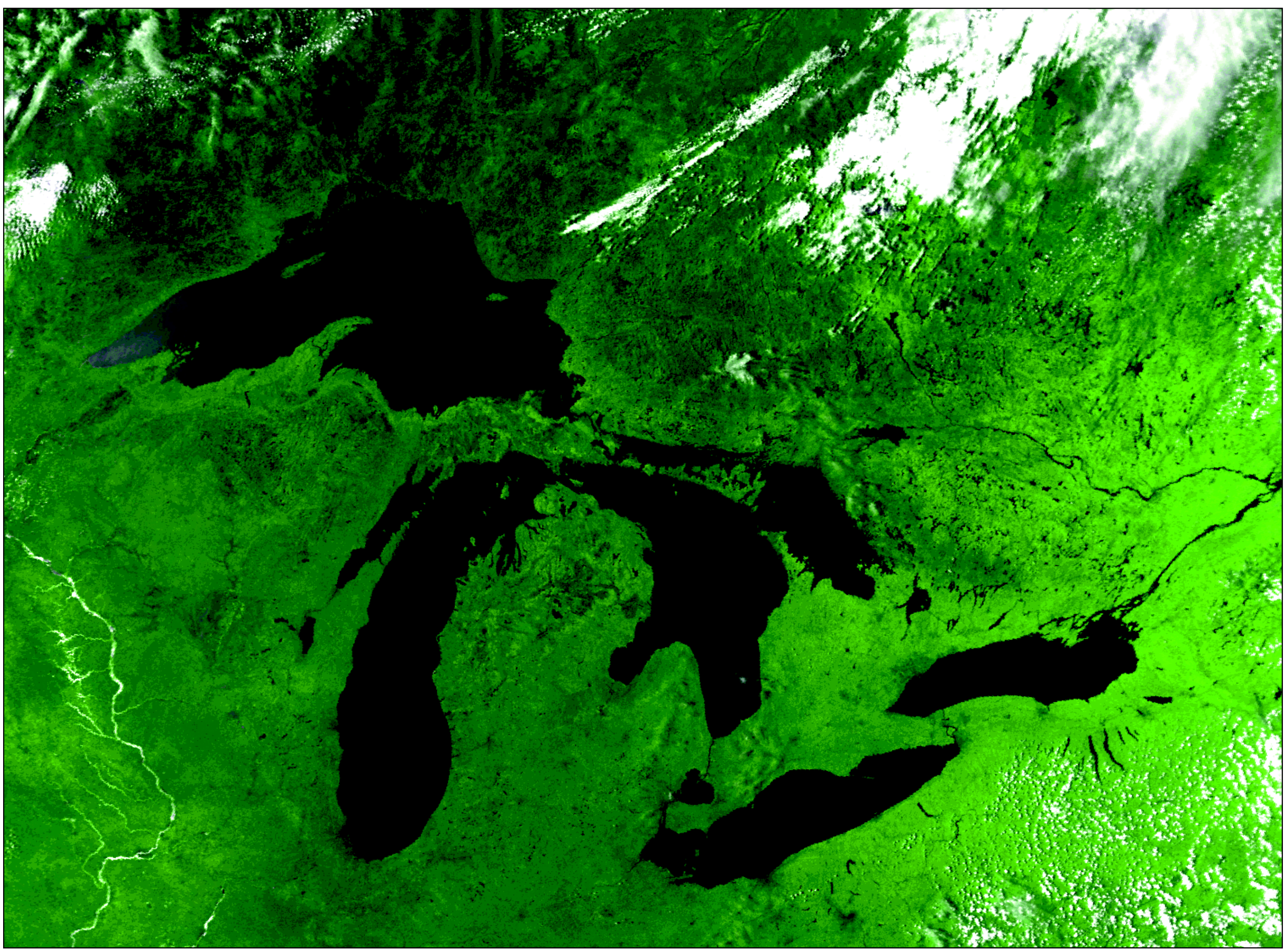
As stewards of the natural resources, it is our responsibility to understand the causes and implications of Great Lakes water level changes. Only through this understanding can we make informed decisions and educate future generations about living with the lakes.



Indiana Dunes State Park, Lake Michigan

Introduction

The Great Lakes-St. Lawrence River system is a dynamic environment, still evolving over time. Ever since the last glaciers retreated more than 10,000 years ago, Great Lakes water levels and outflows have varied dramatically. The Great Lakes affect human activities and all aspects of the natural environment, from weather and climate, to wildlife and habitat. Unlike oceans, where tides are constant and predictable, water levels on the Great Lakes can vary significantly in frequency and magnitude making them difficult to accurately predict.



Satellite image of the Great Lakes and their drainage basins

The Great Lakes - St. Lawrence River system

The Great Lakes - Superior, Michigan, Huron, Erie and Ontario - and their connecting channels and the St. Lawrence River form the largest fresh surface water system on Earth.

Covering more than 94,000 square miles and draining more than twice as much land, the Great Lakes hold an estimated 6 quadrillion gallons of water.

The Great Lakes-St. Lawrence River drainage basin includes part or all of the eight U.S. states of Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania and New York and the Canadian provinces of Ontario and Quebec. More than one-tenth of the population of the United States and one-quarter of the population of Canada inhabit this watershed.

The ecosystem is blessed with huge forests and wilderness areas, rich agricultural land, hundreds of tributaries and thousands of smaller lakes, extensive mineral deposits, and abundant wildlife, including a world-class fishery. The binational region is North America’s industrial heartland, and also supports a multi-billion-dollar outdoor recreation and tourism industry, a strong maritime transportation system and a diverse agricultural base.

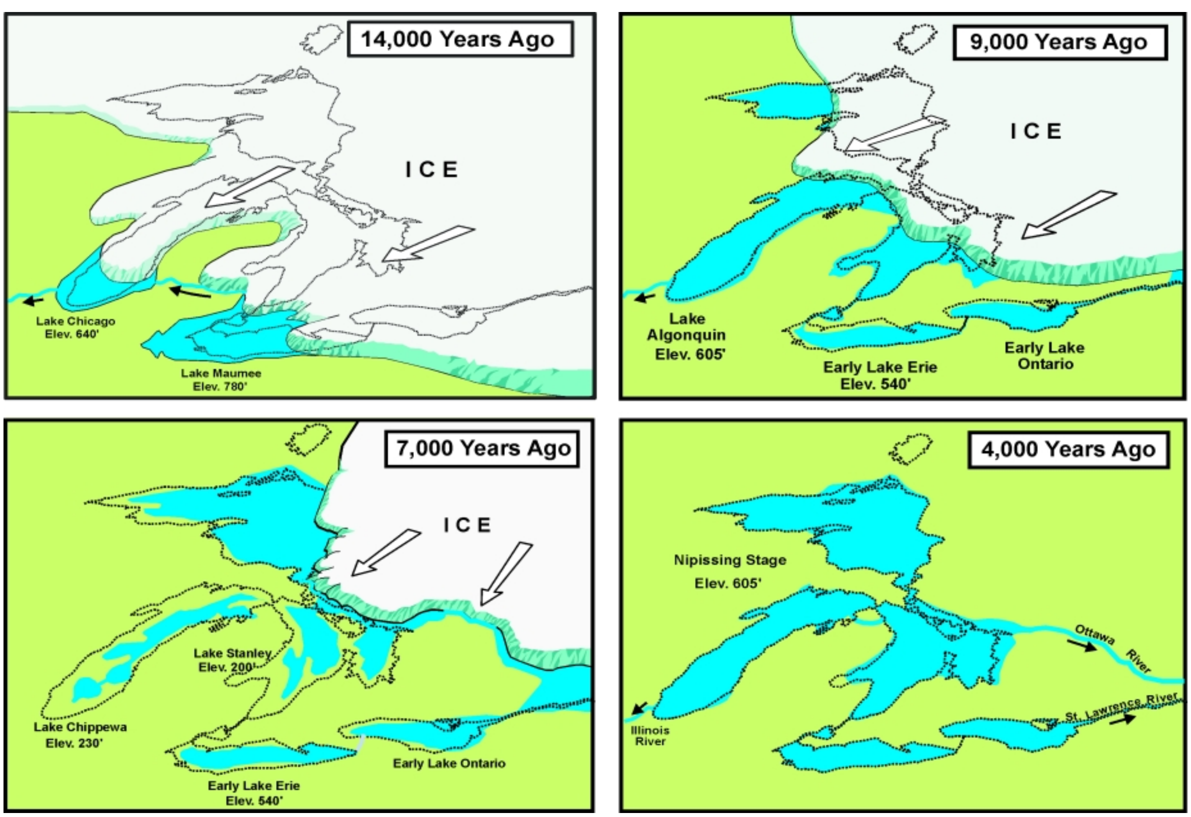
How the lakes were formed

About a billion years ago, a fracture in the earth running from what is now Oklahoma to Lake Superior generated volcanic activity that almost split North America. Over a period of 20 million years, lava intermittently flowed from the fracture. This geomorphic age created mountains covering the regions now known as northern Wisconsin and Minnesota, and the Laurentian mountains were formed in eastern Canada. Over time these mountains eroded, while occasional volcanic activity continued. Molten magma below the highlands of what is now Lake Superior spewed out to its sides, causing the highlands to sink and form a mammoth rock basin that would one day hold Lake Superior. Eventually the fracture stabilized and, over time, the rock tilted down from north to south.

The glaciers began to retreat almost 14,000 years ago. Most of the icefields left the Great Lakes region about 7,000 - 9,000 years ago.

The region went from fire to ice with the arrival of the glaciers, which advanced and retreated several times over the last 5 million years. During the periods of glaciation, giant sheets of ice flowed across the land, leveling mountains and carving out massive valleys. Where they encountered more resistant bedrock in the north, only the overlying layers were removed. To the south, the softer sandstones and shales were more affected. As the glaciers melted and began receding, their leading edges left behind high ridges, some of which can be seen today in the cliffs of Door County, Wisconsin, and the Bruce Peninsula in Ontario. Huge lakes formed between these ridges from the retreating ice fronts, and continually changed over time as the ice sheet moved northward.

Early drainage from these lakes flowed southward through the present Illinois River Valley toward the Mississippi River, through the Trent River Valley between present lakes Huron and Erie and through the Lake Nippissing-Ottawa River Valley from Georgian Bay on Lake Huron downstream to the present Montreal, Quebec, area.



Prehistoric glacial movements and lake shapes

Pt. Aux Barques, Michigan, on Lake Huron

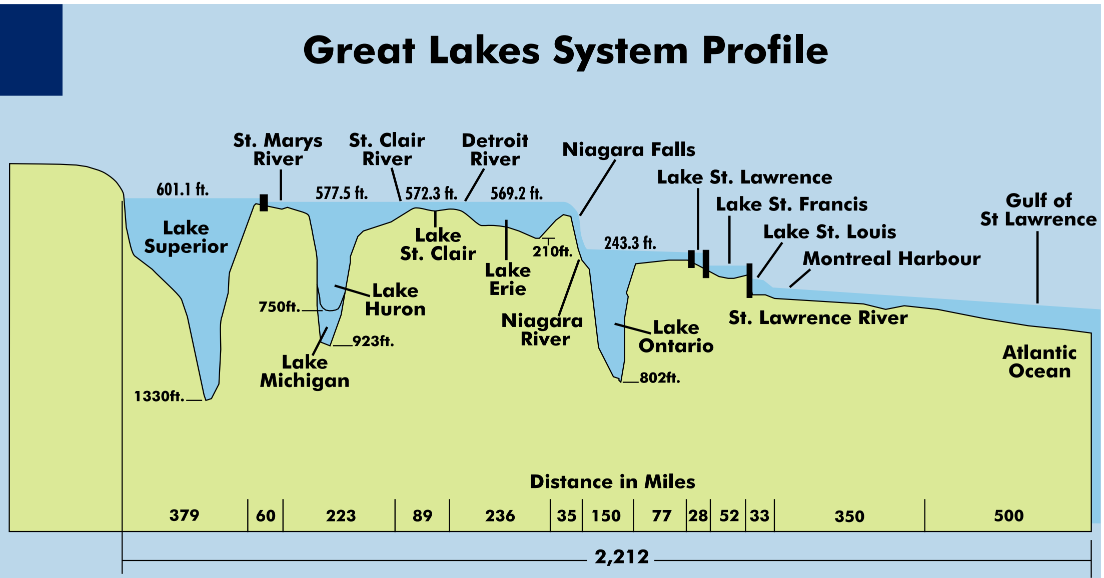
Even today, virtually all of the land in the Great Lakes basin continues to rise.

Without the immense weight of the glaciers—thousands of feet thick in places— the land began to rebound. Even today, virtually all of the land in the Great Lakes basin continues to rise. Southern parts of the basin are rising slightly, less than 3 inches per century. The northeastern corner of the Lake Superior basin, however, is rebounding in excess of 21 inches per century. *(See description of crustal rebound on page 17.)*

Since the retreat of the glaciers, water levels continued to undergo dramatic fluctuations, some in the magnitude of hundreds of feet. These extremes were caused by changing climates, crustal rebound and natural opening and closing of outlet channels. Within the last 1,000 years, evidence suggests that lake levels exceeded the range of levels recorded since 1865 by an additional five feet on lakes Michigan and Huron. As a consequence of these recent fluctuations, shoreline position and environments have dramatically changed. Dunes, baymouth barriers, embayments and river mouths have all been modified by the forces of water. Many dune formations—some hundreds of feet thick—were established during glacial periods. The tops of these dunes have been continuously sculpted by winds to form the majestic structures now visible.

Today, rebounding of the earth's crust, erosion, and changes in climate continue to alter the shapes and sizes of the Great Lakes. As one of the youngest natural features on the North American continent, the lakes remain a dynamic, evolving system.

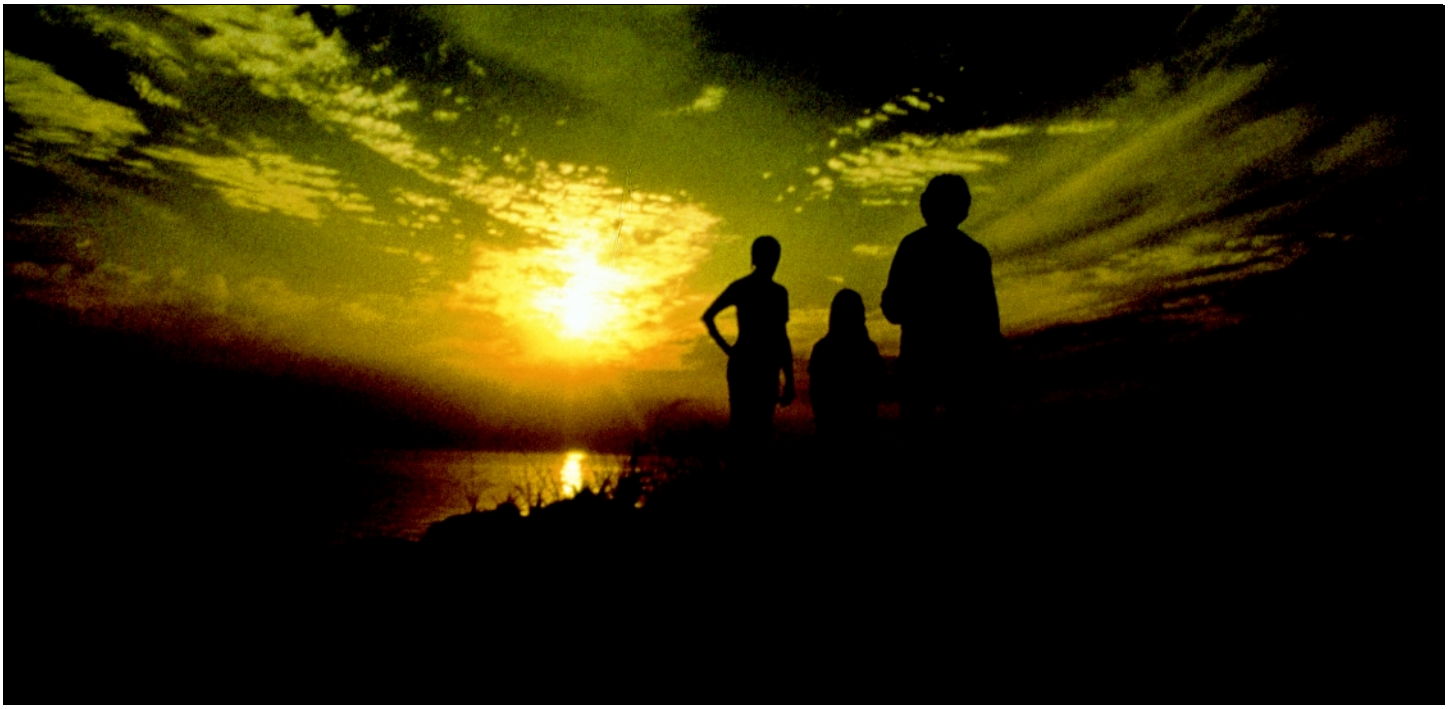
The Great Lakes and connecting channels



Elevations referenced IGLD, 1985.

Four of the five Great Lakes are at different elevations, leading like a series of steps toward the Atlantic Ocean. The five individual lakes are connected to each other through channelways, forming one system. Water continually flows from the headwaters of the Lake Superior basin through the remainder of the system.

The St. Marys River is a 60-mile waterway flowing from Lake Superior down to Lake Huron, descending more than 20 feet in elevation. Lakes Michigan and Huron are connected by the deep Straits of Mackinac and are considered to be one lake hydraulically with lake levels rising and falling together. The St. Clair and Detroit rivers, and Lake St. Clair between them, form an 89-mile-long channel connecting Lake Huron with Lake Erie. The fall between Lake Huron and Lake Erie is only about 8 feet. The 35-mile Niagara River links lakes Erie and Ontario, with the majority of the 325-foot difference in elevation occurring at Niagara Falls. The man-made Welland Canal also links the two lakes, providing a detour around Niagara Falls. From Lake Ontario, water flows into the St. Lawrence River, which converges with the Ottawa River near Montreal to flow to the Atlantic Ocean.



Lake Michigan in Indiana

People and the Great Lakes

People arrived in the Great Lakes basin about 10,000 years ago. By the 1500s, an estimated 60,000 to 120,000 aboriginal people lived in the area. The fertile soils, plentiful water and game supported the native people, who took to the lakes and tributaries in their birch bark canoes. In the north, they mined copper, using rocks to hammer pure chunks from the bedrock; this copper made its way by trade as far as present-day New York. The descendants of these first inhabitants were to become many current Native American Indian tribes, including the Oneida, Mohawk, Wyandot, Chippewa, Iroquois, Algonquin, Menominee, Ojibwa, Ottawa, Potawatomi and Winnebago.

By the early 1600s, explorers, missionaries and fur traders arrived, with Lake Huron the first of the Great Lakes to be seen by Europeans. Samuel de Champlain called the lake *La Mer Douce*, "the sweetwater sea."

French fur traders followed the water routes used by the Indians, traveling the lakes in their canoes with loads of beaver and other pelts bound for east coast settlements and Europe. Some of these canoes carried crews of six to 12 voyageurs and loads of more than 5,000 pounds. The French established bases, and later military forts, to protect the fur trade. The British followed suit, opening the way for settlement. The fur trade lasted until the early 1800s, followed by a logging campaign that stripped vast areas of virgin forests from most of the watersheds.

Plentiful water and game have drawn people to the Great Lakes region for nearly 10,000 years.

Consumptive uses

Uses of Great Lakes resources have all had profound impacts on the regional landscape and ecosystems. Many of these uses affect the quality of the water resources available, while some can affect the quantity of water throughout the system.

The term **consumptive use** refers to any quantity of water that is withdrawn from the Great Lakes system and not returned. Current consumptive uses of the lakes include drinking water for humans and livestock, irrigation and industrial uses. Due to the large volume of water in the Great Lakes, consumptive use has only a minor effect on water levels.

Drinking water

Municipalities throughout the Great Lakes basin draw tens of billions of gallons of water per day from the Great Lakes to satisfy their public water supply needs. Public water supply systems provide water to homes, schools and offices, as well as to industrial facilities and businesses. The average household uses 100 gallons of water per person per day. In addition, millions of people in both rural and urban areas of the Great Lakes basin rely on groundwater for their sole supply of water. Groundwater is important to the Great Lakes ecosystem, serving as a reservoir that replenishes the lakes in the form of base flow in tributaries.

Industry

It's no coincidence that most of the region's large industrialized urban areas are located on the shores of the Great Lakes, not only because of transportation advantages but because of the seemingly inexhaustible supply of freshwater for domestic and industrial use. In fact, half of Canadian manufacturing and one-fifth of U.S. manufacturing is based on the region's freshwater coast. The binational Great Lakes region accounts for approximately 60 percent of steel production in North America. The pulp and paper industry also demands large quantities of water in its manufacturing operations. About 10 percent of the water used in industrial processes is consumed, with the remainder returned to the watershed following treatment.

A farm in Michigan in the Lake Erie drainage basin

Agriculture

Agriculture in the Great Lakes region is diverse and productive, with grain, corn, soybeans, dairy, and livestock as the region's mainstays. Unique climate niches have created a wealth of specialty crops. For example, the western shore of Michigan's lower peninsula provides excellent conditions for orchards and vineyards. Today, about one-third of the land in the basin is used for agriculture, supporting nearly 25 percent of the total Canadian agricultural production and 7 percent of the U.S. production. Irrigation represents a modest but growing consumptive use of Great Lakes water.

Power plant and dunes on Lake Michigan shoreline in Indiana

Thermoelectric power

Fossil fuel and nuclear power plants around the lakes use water for cooling equipment and to produce steam to drive turbines. Less than 2 percent of these withdrawals are consumed, lost primarily through evaporation. The remainder is returned to the lakes.

Nonconsumptive use refers to any water withdrawal or instream use in which the entire quantity is returned to the system. Nonconsumptive uses of the lakes include transportation, hydroelectric power generation and water-based recreation.

Recreational boating, sport fishing and commercial fishing

The Great Lakes offer outstanding tourism and recreation opportunities, ranging from wilderness areas such as Isle Royale, a U.S. island national park, to waterfront parks in major cities. A well-defined four-seasons climate supports many types of outdoor recreation, from ice fishing in the winter to boating, swimming and fishing in the summer. The eight Great Lakes states have about 3.7 million registered recreational boats, or about a third of the nation's total. Michigan and Minnesota lead the U.S. in the number of boat registrations, and six Great Lakes states rank in the nation's top ten in total number. Approximately a million recreational boats ply the U.S. waters of the Great Lakes each year. The commercial and sport fishing industry is collectively valued at more than $4 billion annually.

Charter fishing on Lake Michigan

Commercial fishing in Duluth, Minnesota, on Lake Superior

Hydroelectric power

Hydroelectric power generation is by far the largest instream use for Great Lakes water. Hydroelectric power production at plants located on the St. Marys, Niagara and St. Lawrence rivers is dependent upon the "head" or difference between upstream and downstream water levels. During most periods, differences in these levels are relatively constant and power production is not significantly affected. During periods of significant increases in outflows from a lake, power production can increase substantially. The converse is true under very low outflow conditions. Utilities also use coal, oil, natural gas and nuclear power to produce electricity in the Great Lakes region.

Shipping

The Great Lakes and St. Lawrence River are part of a vast system linking North America's heartland with ports and markets throughout the world. The world's longest deep-draft inland waterway, the system extends from Duluth, Minnesota, on Lake Superior, to the Gulf of St. Lawrence on the Atlantic, a distance of more than 2,340 miles. This shortcut to the continent's interior was made possible with the construction of a ship canal and lock system opened in 1855 at Sault Ste. Marie, Michigan, the development of the Welland Canal since 1829, and the completion of the St. Lawrence Seaway in 1959.

Ocean-going vessel in Duluth, Minnesota - Superior, Wisconsin, Harbor on Lake Superior

Crooked Lake, Emmet County, Michigan: One of thousands of inland lakes in the Great Lakes basin

Natural Factors

The difference between the amount of water coming into a lake and the amount going out is the determining factor in whether the water level will rise, fall or remain stable. When several months of above-average precipitation occur with cooler, cloudy conditions that cause less evaporation, the levels gradually rise. Likewise, prolonged periods of lower-than-average precipitation and warmer temperatures typically result in lowering of water levels.

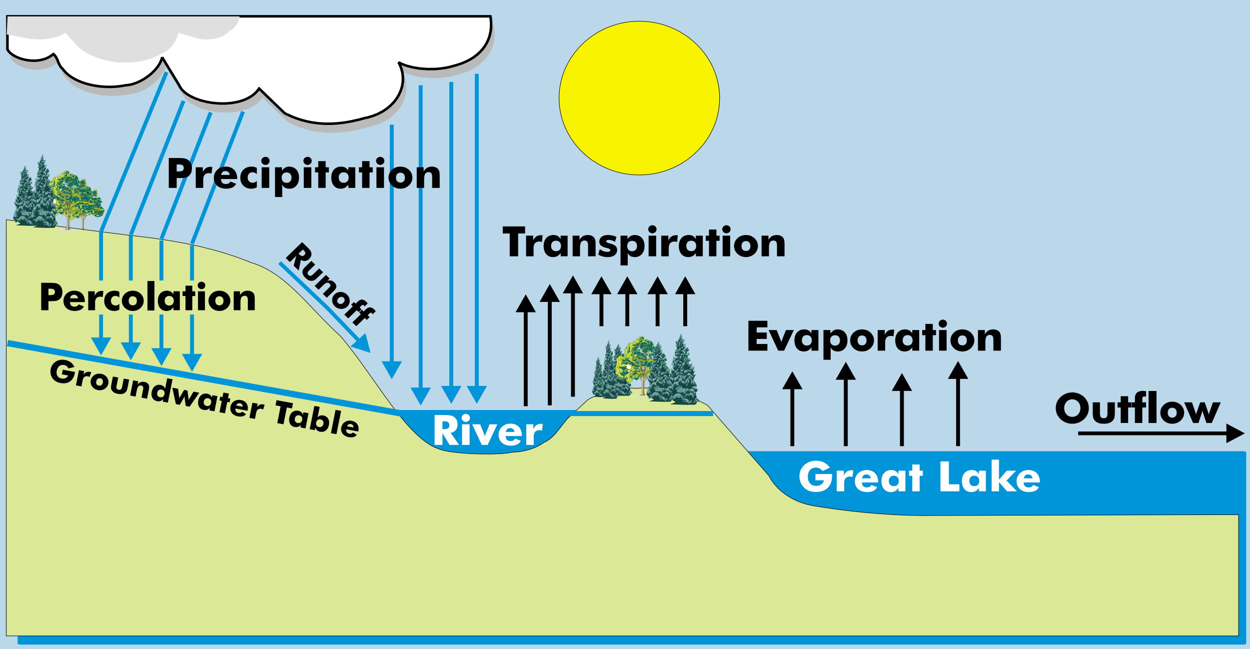
Grand Haven, Michigan, lighthouse on Lake Michigan during storm

The hydrologic cycle

Water, a renewable resource, is continually recycled and returned to the ecosystem through the hydrologic cycle. Moisture is carried into the Great Lakes basin most commonly by continental air masses, originating in the northern Pacific Ocean, that traverse the North American continent. Tropical systems originating in the Gulf of Mexico or Arctic systems originating in the north polar region also carry moisture into the basin. As weather systems move through, they deposit moisture in the form of rain, snow, hail or sleet. Water enters the system as precipitation directly on the lake surface, runoff from the surrounding land including snowmelt, groundwater, and inflow from upstream lakes. Precipitation falling on the land infiltrates into the ground through percolation to replenish the groundwater.

Water leaves the system through evaporation from the land and water surface or through transpiration, a process where moisture is released from plants into the atmosphere. Water also leaves the system by groundwater outflow, consumptive uses, diversions and outflows to downstream lakes or rivers. Ultimately water flows out of each of the Great Lakes through their connecting channels and the St. Lawrence River to the Atlantic Ocean.

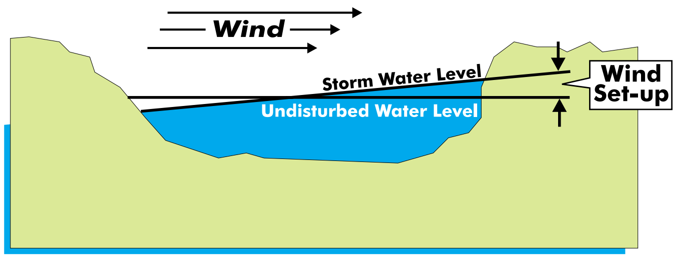
Evaporation from the lake surface is a major factor in the hydrologic cycle of the Great Lakes. Water evaporates from the lake surface when it comes in contact with dry air, forming water vapor. This vapor can remain as a gas, or it can condense and form water droplets, causing fog and clouds. Some of this moisture returns in the form of rain or snow, completing the hydrologic cycle. The best example of this is lake-effect snow squalls, which commonly occur on the leeward side of most lakes. Generally, much of the evaporated water is removed from the system by prevailing wind patterns.



Hydrologic Cycle

Short-term fluctuations

Some water level fluctuations are not a function of changes in the amount of water in the lakes. These fluctuations, generally short in duration, are due to winds or changes in barometric pressure. Short-term fluctuations, lasting from a couple hours to several days, can be very dramatic. Fluctuations due to storms or ice jams are two examples.



Lake profile showing wind set-up

There are three kinds of water level fluctuations: short-term, seasonal and long-term.

Wind set-up, storm surge and seiche

Sustained high winds from one direction can push the water level up at one end of the lake and make the level drop by a corresponding amount at the opposite end. This is called wind set-up or storm surge. Changes in barometric pressure can add to this effect. When the wind abruptly subsides or barometric pressure changes rapidly, the water level often will oscillate until it stabilizes again. This phenomenon is known as **seiche** (pronounced “sayshe”). The pendulum-like movements within seiches can continue for days after the forces that created them vanish. Lake Erie is most susceptible to storm surges and seiches due to its east-west orientation in an area of prevailing westerly winds and its generally shallow western end.

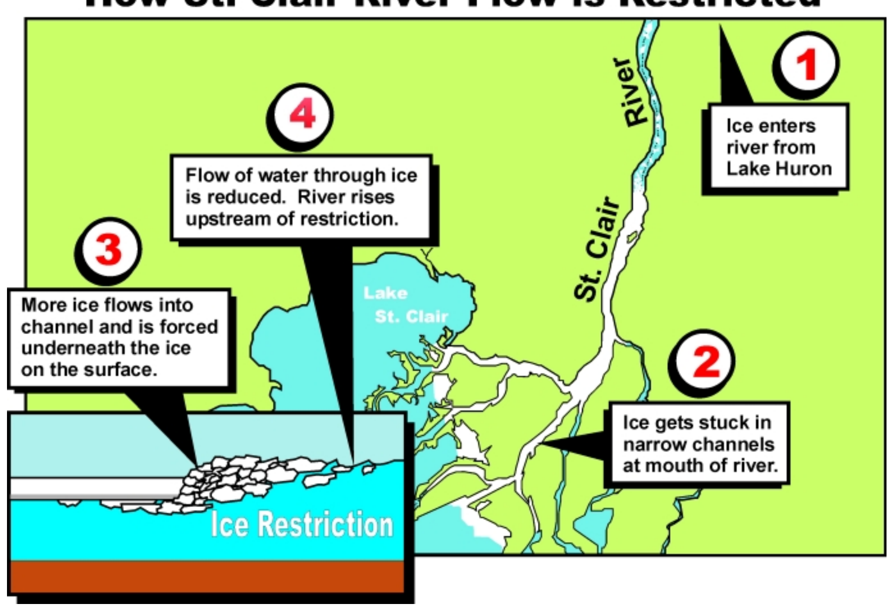
Plant growth and ice development in the connecting channels

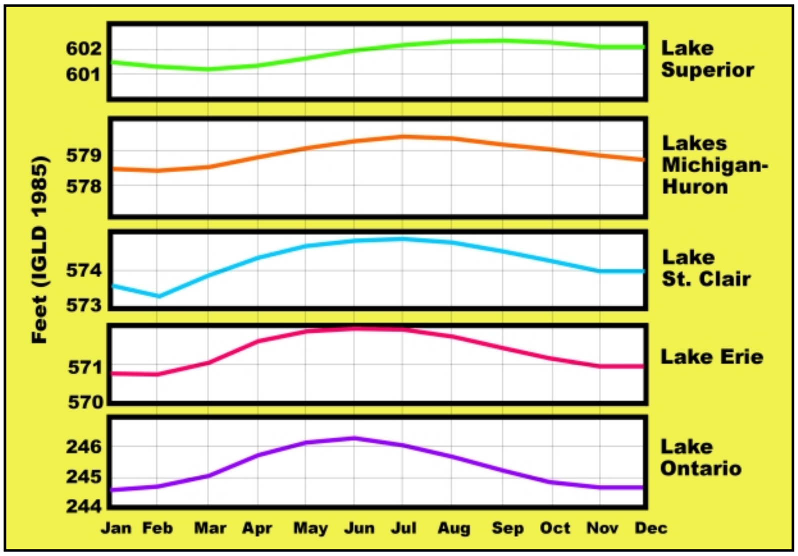
The natural growth of aquatic plants can affect the flow of water in the tributaries and connecting channels of the lakes. Plant growth decreases the flow of water by narrowing or partially obstructing the channel through which the water flows. Plant growth in part depends on the weather, and can vary from month to month and year to year. In the summer, aquatic plant growth in the Niagara River reduces its flow, on average, by about 2 percent.

An ice jam in an outlet river can drastically slow the flow of water out of one lake and into another. Water levels rise upstream of the jam and fall downstream. The effects are most noticeable on the water levels of the affected river, and of smaller lakes such as St. Clair and Erie.

On the St. Clair River, normal ice build-up can reduce the flow in the river by about 5 percent during the winter. A serious ice jam can reduce flows by as much as 65 percent for short periods of time. Ice jams can develop in a matter of hours, but it may take several days for the jam to be relieved and water levels and flows to return to normal.

How St. Clair River Flow is Restricted





Seasonal fluctuations

The lakes are generally at their lowest levels in the winter months. In the fall and early winter, when the air above the lakes is cold and dry and the lakes are relatively warm, evaporation from the lakes is greatest. With more water leaving the lakes than entering, the water levels decline to their seasonal lows.

As the snow melts in the spring, runoff to the lakes increases. Evaporation from the lakes is least in the spring and early summer when the air above the lakes is warm and moist and the lakes are cold. At times, condensation on the lake surface replaces evaporation. With more water entering the lakes than leaving, the water levels rise. The levels peak in the summer. In the early fall, evaporation and outflows begin to exceed the amount of water entering the lakes.

The range of seasonal water level fluctuations on the Great Lakes averages about 12 to 18 inches from winter lows to summer highs.

The range of seasonal water level fluctuations on the Great Lakes averages about 12 to 18 inches from winter lows to summer highs. The timing of the annual peaks and lows varies geographically due to differences in climate across the basin. Seasonal rises begin earlier on the more southern lakes where it is warmer with peaks usually occurring in June or July. Lake Superior, the northernmost lake, is generally the last lake to peak, usually in August or September.

All water levels on the Great Lakes are measured relative to sea level and expressed relative to the International Great Lakes Datum (IGLD), last updated in 1985. *(For further information on the reference datum, see page 27.)*

Weather in the Great Lakes basin

"Wait a day and the weather will change" is an apt description of weather in the Great Lakes region, especially in the spring and fall. That's because the region is affected by both warm, humid air from the Gulf of Mexico and cold, dry air from the Arctic. In general, the north experiences cooler weather, while the south has warmer temperatures. The entire basin experiences four distinct seasons.

The Great Lakes also have a significant influence on the climate. Acting as a giant heat sink, the lakes moderate the temperatures of the surrounding land, cooling the summers and warming the winters. This results in a milder climate in portions of the basin compared to other locations of similar latitude. The lakes also act as a giant humidifier, increasing the moisture content of the air throughout the year. In the winter, this moisture condenses as snow when it reaches the land, creating heavy snowfall in some areas, known as "snow belts" on the downwind shores of the lakes. The shores of Lake Superior are particularly prone to this "lake-effect" snow. Some areas around the lake have recorded more than 350 inches of snow in a single year. During the winter, the temperature of the lakes continues to drop. Ice frequently covers Lake Erie but seldom fully covers the other lakes.

Long-term fluctuations

Long-term fluctuations occur over periods of consecutive years and have varied dramatically since water levels have been recorded for the Great Lakes. Continuous wet and cold years will cause water levels to rise. Conversely, consecutive warm and dry years will cause water levels to decline. Water levels have been measured on the Great Lakes since the 1840s. Older records may not be as accurate as current observations, since measurements were only taken at a single gage per lake until 1918 and observations were not taken as frequently as they are today.

Over the last century, the range from extreme high to extreme low water levels has been nearly 4 feet for Lake Superior and between 6 and 7 feet for the other Great Lakes.

The Great Lakes system experienced extremely low levels in the late 1920s, mid-1930s and again in the mid-1960s. Extremely high water levels were experienced in the 1870s, early 1950s, early 1970s, mid-1980s and mid-1990s. Long-term fluctuations are shown on the hydrograph presented on the graph on the following page. A **hydrograph** is a plot of water levels versus time.

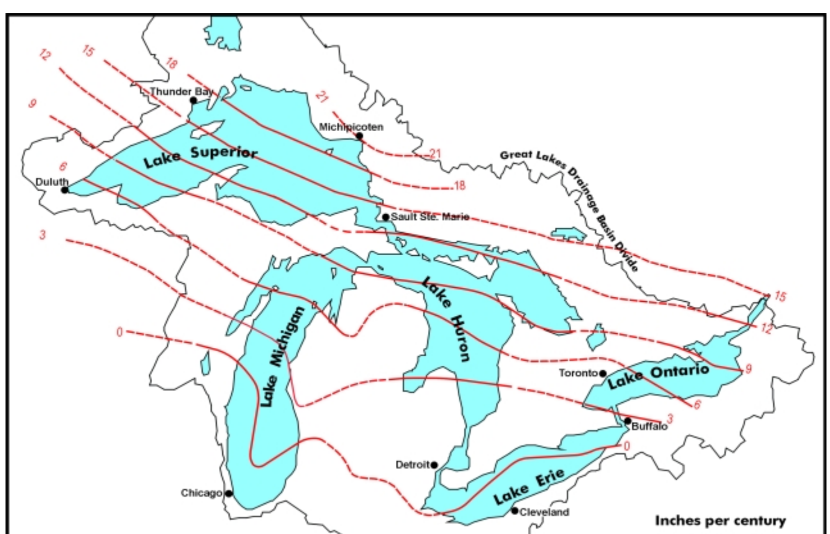
Global warming and a phenomenon known as the 'greenhouse effect' could cause significant changes in long-term lake levels. Although debatable, most predictions indicate that global warming would cause prolonged declines in average lake levels into the future. These declines could create large-scale economic concern for virtually every user group in the Great Lakes basin. Dramatic declines also could compromise the ecological health of the Great Lakes, particularly in the highly productive nearshore areas.

Besides natural climatic variability and potential man-made climate change, other factors can affect long-term fluctuations, including changes in consumptive use, channel dredging or encroachment and crustal movement.

Crustal movement

Crustal movement, the rebounding of the earth's crust from the removed weight of the glaciers, does not affect the amount of water in a lake, but rather affects water levels at different points around the lake. Crustal rebound varies across the Great Lakes basin. The crust is rising the most, more than 21 inches per century, in the northern portion of the basin, where the glacial ice sheet was the thickest, heaviest and the last to retreat. There is little or no movement in the southern parts of the basin. As a result, the Great Lakes basin is gradually tipping, a phenomenon most pronounced around Lake Superior.

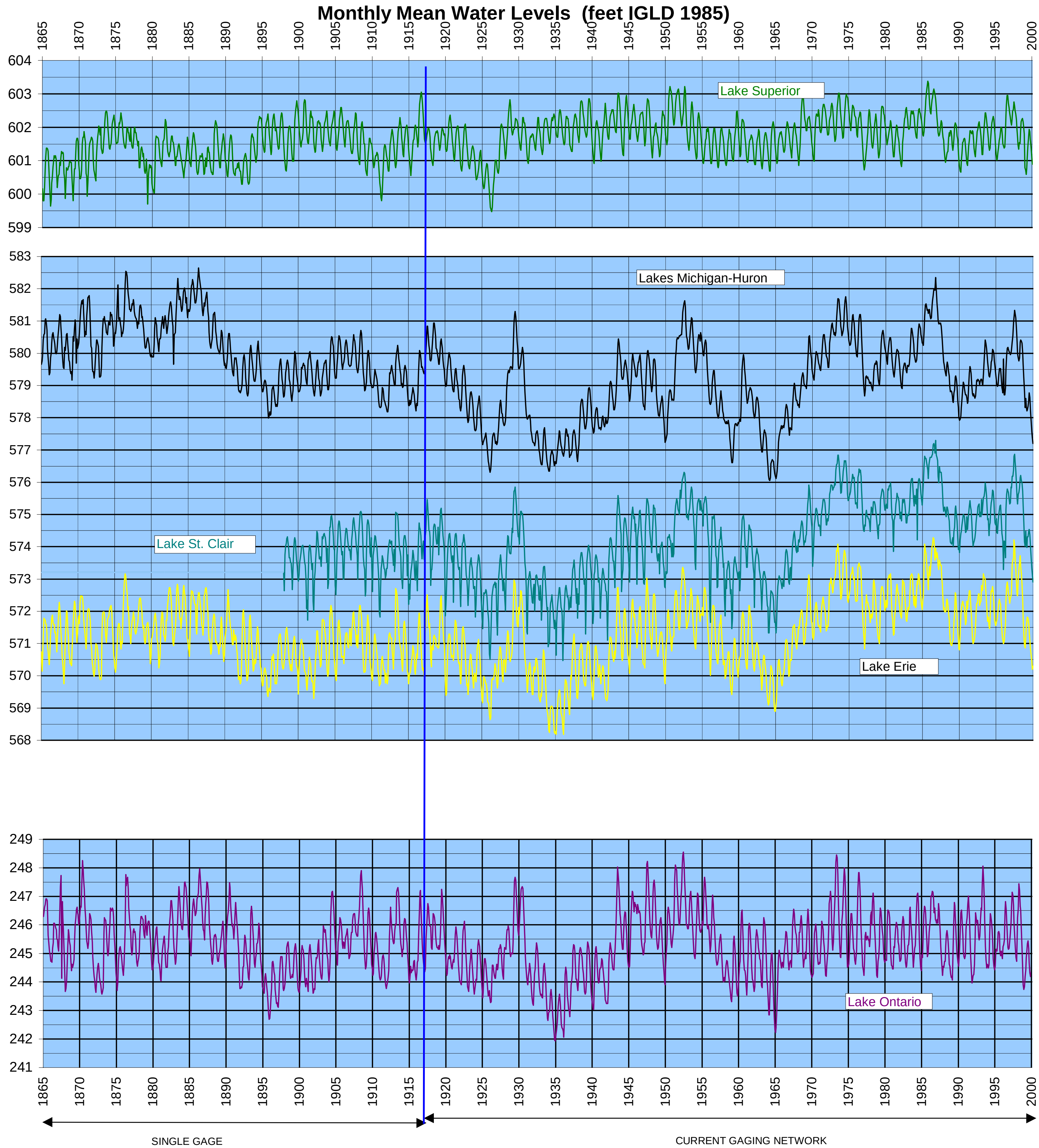
To see what this means for water levels, an analogy can be made using a cup of water. As the cup is tipped, the surface of the water comes closer to the edge of the cup on one side and is farther from the edge on the other side. This is why water levels are measurably higher today at Duluth, Minnesota, and lower at Michipicoten, Ontario, on the opposite side of Lake Superior, than they were several decades ago. This tipping phenomenon is particularly significant for Lake Superior, and somewhat lesser for lakes Michigan, Erie and Ontario as their outlet channels are rising faster than the western shores of these lakes. As such, there is a gradual decrease in outflow capacities for each of the lakes over time.



Rates of crustal rebound

Great Lakes system historical levels

A hydrograph is a plot of lake levels versus time. These hydrographs show monthly average water levels for each of the Great Lakes and Lake St. Clair. Levels have been measured on most lakes since 1865, with the present network of water level gages operating since 1918. Lake levels change seasonally each year and can vary dramatically over longer periods. Short-term fluctuations are of a greater magnitude than the monthly averages.



Human Influence on the System

The Great Lakes are like a series of interconnected bathtubs. Their outlets are like the drains in the tubs. Outflows increase as water levels rise in an upstream lake, but are limited by the size of their outlet channels. As water moves through the Great Lakes-St. Lawrence River system, it passes through progressively larger outlets draining all the lakes above it in the system. The outlet from Lake Superior, at the top of the system, moves about 76,000 cubic feet of water per second on average. By comparison, the outlet from Lake Ontario, the last lake in the chain, moves about 243,000 cubic feet per second on average.

Major hydropower plants in Ontario and New York on the Niagara River

Lake Superior and St. Marys River

A rock ledge at the head of the St. Marys Rapids provided a natural control for Lake Superior outflows. The rock ledge acted like a weir permitting flows to increase and decrease as Lake Superior's levels rose or fell.

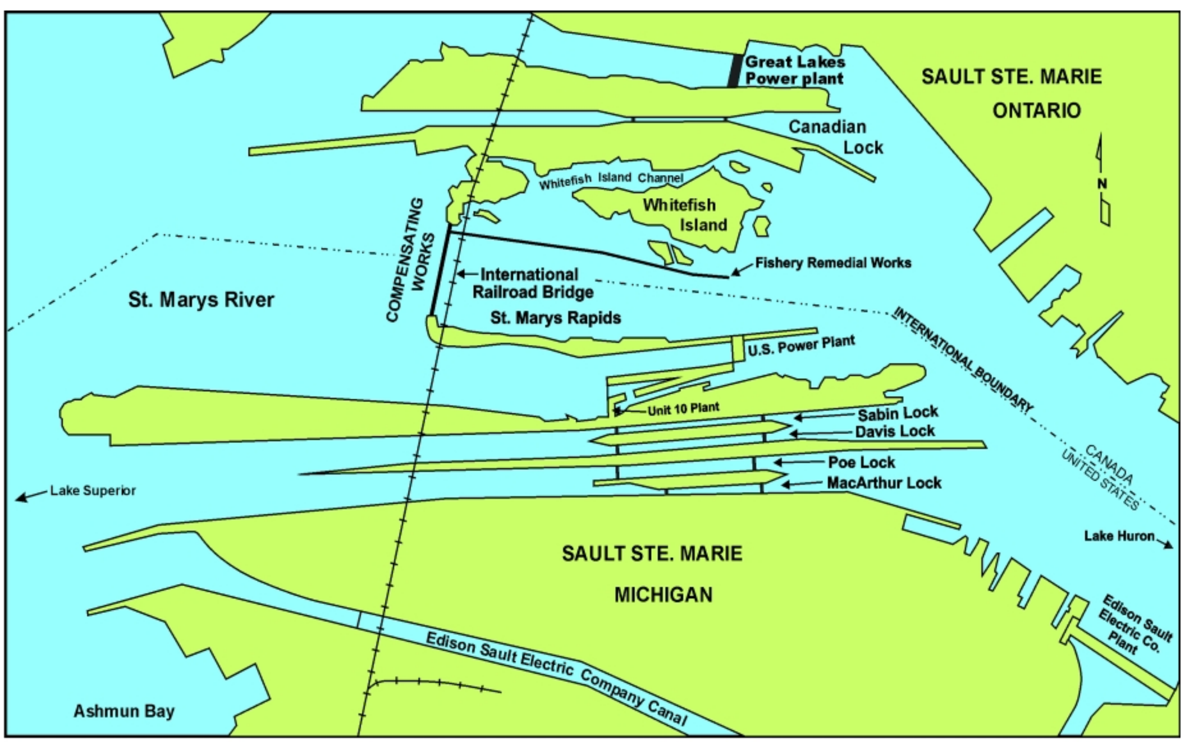
The outflow from Lake Superior is controlled near the twin cities of Sault Ste. Marie, Ontario and Michigan. The outflow began to be changed as early as 1822, when water was diverted from above the St. Marys Rapids for operation of a sawmill. A ship canal was constructed in 1855. Subsequently, various expansions to these facilities took place.

The current flow control facilities consist of three hydropower plants, five navigation locks and a 16-gated control structure, called the Compensating Works, at the head of the St. Marys Rapids. Since the Compensating Works were completed in 1921, Lake Superior outflows have been regulated by humans. This regulation is carried out by the International Lake Superior Board of Control in accordance with conditions specified by the International Joint Commission (IJC). The IJC, a binational agency of the United States and Canada, is responsible for ensuring that the outflow regulation meets the terms of the Boundary Waters Treaty of 1909 between the two nations.

Lake Superior's outflows are adjusted monthly, taking into consideration the water levels of lakes Superior and Michigan-Huron. The objective is to help maintain the lake levels both on Lake Superior and lakes Michigan and Huron in relative balance compared to their long-term seasonal averages. For example, if the Lake Superior level is above its average and the level of lakes Michigan-Huron is below its average, outflows will increase. Converse conditions would lead to decreases in outflows.

The regulated outflow is achieved by adjusting the flows through the three hydropower plants and the 16-gate Compensating Works, after requirements are met for lockages, the St. Marys Rapids fishery and industries at Sault Ste. Marie, Michigan and Ontario. At a minimum, one gate is kept half-open at the Compensating Works to maintain water in the St. Marys Rapids critical for fish spawning. More gates are opened when flows in the river exceed the capacities of the hydropower plants.

Lake Superior outflows have averaged 76,000 cubic feet per second (cfs) per month and have been as high as 132,000 cfs and as low as 41,000 cfs per month.



St. Marys River control structures

The St. Clair, Lake St. Clair and Detroit River system is naturally regulated; flows in the St. Clair and Detroit rivers are limited by the size of their channelways and the levels of Lake Huron upstream and Lake Erie downstream.

The St. Clair River is an interconnecting channel between lakes Huron and St. Clair, running approximately 39 miles from its head between Port Huron, Michigan, and Sarnia, Ontario to its very extensive delta in Lake St. Clair. The St. Clair River has a 5-foot fall over this distance. Flows have averaged 182,000 cfs since records have been kept. During extreme conditions, flows have been recorded as high as 232,000 cfs and as low as 106,000 cfs per month.

St. Clair - Detroit river system

Although not a Great Lake, Lake St. Clair is an extremely important body of water to millions of users. It receives inflow from the St. Clair River and, to a minor degree, from tributary rivers such as the Clinton River in Michigan and the Thames River in Ontario. The lake's average depth is less than 20 feet. Due to its being shallow and nearly round in shape, Lake St. Clair is highly susceptible to rapid changes in wind and wave patterns, storm surges and lake level changes.

The Detroit River receives inflow from Lake St. Clair and discharges into the west end of Lake Erie, running approximately 32 miles. Over this distance, the water surface drops nearly 3 feet. The flow in the Detroit River has averaged 186,000 cfs since records have been maintained. During extreme conditions, flows have been as high as 238,000 cfs per month or as low as 112,000 cfs per month.

Flows in the St. Clair River, Lake St. Clair and Detroit River are naturally regulated.

Dredging in the St. Clair-Detroit system began in the 1930s and continued through the 1950s to deepen navigation channels. Dredging is the enlarging or deepening of navigation channels to allow ships to enter and leave ports more efficiently, quickly and safely. Without dredging, most rivers and harbors would be inaccessible for commercial navigation. Dredging has increased the flow capacity of these rivers and, as a result, has permanently lowered the levels of lakes Michigan and Huron by nearly 15 inches. The effect on Lake Erie's water level was temporary.

Flows in both the St. Clair and Detroit rivers can be dramatically reduced for short periods during ice jams. Flows in the Detroit River can virtually stop or even reverse for a few hours during an extreme storm surge at the west end of Lake Erie.


Traffic on the Detroit River at Detroit, Michigan

Niagara River

The Niagara River runs approximately 35 miles between lakes Erie and Ontario. Hydropower plants take advantage of the abundant energy potential represented by the nearly 330-foot difference in elevations between lakes. These facilities are owned and operated by the New York Power Authority, Ontario Power Generation and Canadian Niagara Power. The plants divert water from the Niagara River above Niagara Falls and return it to the river below them.

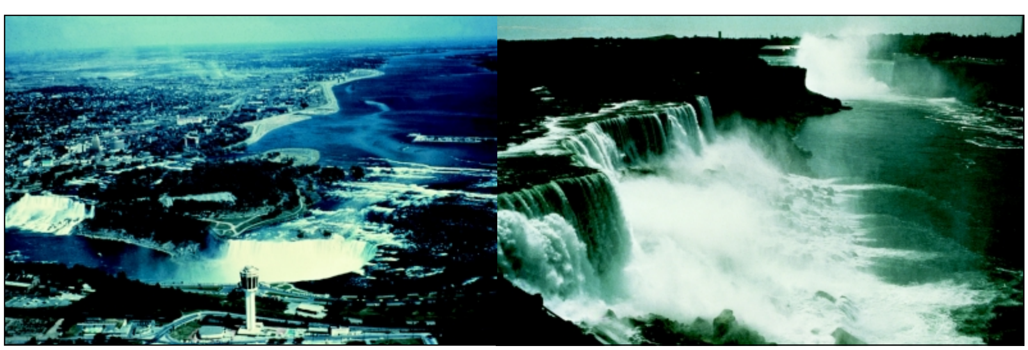
To ensure that sufficient water continues to go over the falls to maintain their scenic beauty, the United States and Canada signed the 1950 Niagara River Treaty. This treaty specifies minimum falls flow requirements for tourist and non-tourist hours with the remaining amount of water shared between the United States and Canada for hydroelectric power production.

Niagara River, Welland Canal and hydropower plants

In accordance with the treaty, a gated structure was built part-way across the river just upstream of the falls to adjust flows to meet the minimum falls requirements and to regulate water levels at the intakes for power generation. This structure does not control the overall amount of water flowing into the river from Lake Erie, only the manner in which it is distributed. Flows in the Niagara River average 203,000 cfs, and have been as high as 265,000 cfs and as low as 116,000 cfs per month since records have been kept.

The outflow from Lake Erie is a function of its elevation, being controlled by a natural rock ledge under the river's mouth between Buffalo, New York, and Fort Erie, Ontario.

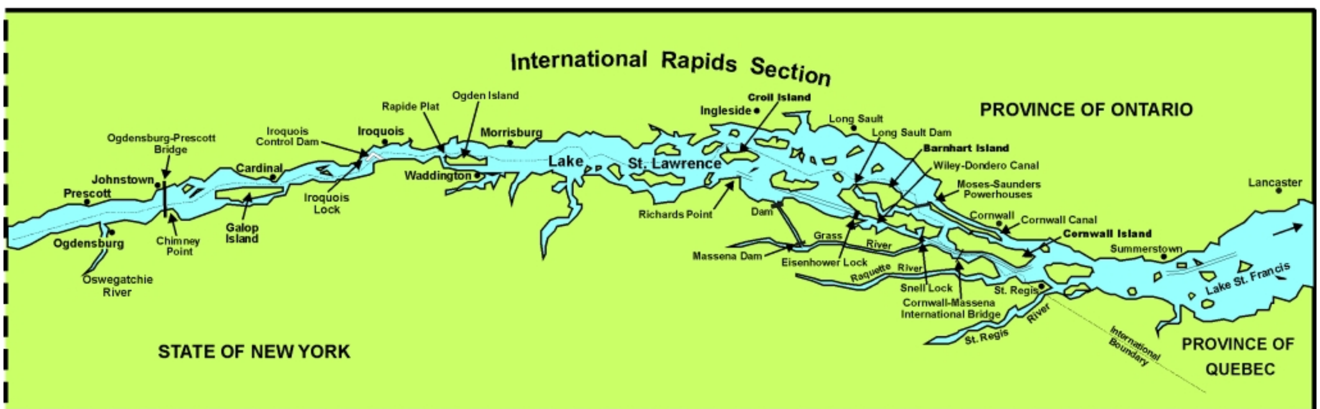
A factor that affects lake levels is man-made construction in the connecting channels between the lakes and in the St. Lawrence River system. This construction includes fills, piers, marinas and other structures built into the river course beyond pre-existing shorelines. Development activities such as these can affect the outflow of a channelway. Although an individual construction project may not have a measurable consequence, continual development over time can have a significant cumulative impact. For example, the mouth of the Niagara River at Fort Erie, Ontario and Buffalo, New York, is an area where encroachment has occurred over the last 100 years. Human activities here have affected Lake Erie water levels by retarding outflows. The magnitude of this retardation is currently under debate.



Aerial and ground views of Niagara Falls

Lake Ontario and St. Lawrence Seaway and Power Project

The St. Lawrence River is a majestic and expansive river course which drains Lake Ontario. It flows into the Gulf of St. Lawrence of the Atlantic Ocean approximately 540 miles to the northeast, dropping more than 240 feet along its length. The river's course is made up of several important segments. For the first 105 miles, the river is formally called the St. Lawrence Seaway and Power Project. This section is an international body of water shared by the United States and Canada. It includes the beautiful Thousand Islands and Lake St. Lawrence. Downstream of Massena, New York, and Cornwall, Ontario, the river is solely in Canada, flowing for 435 more miles until it reaches the Gulf of St. Lawrence. Near Montreal, Quebec, it receives a vast inflow from the Ottawa River watershed.



St. Lawrence Seaway and Power Project

The outflow from Lake Ontario is managed under the auspices of the IJC and its International St. Lawrence River Board of Control. The IJC's criteria for regulating outflows explicitly recognizes the needs of three major interest groups: riparian (shore property owners), hydropower and commercial navigation. The regulation plans used since 1960 are designed to meet these criteria. Outflows are regulated on a weekly basis.

The outflow from Lake Ontario has been regulated since the completion of the St. Lawrence Seaway and Power Project in 1960.

There are four key objectives of the Lake Ontario regulation plan: 1) maintain the Lake Ontario level within a four-foot range during the navigation season; 2) maintain adequate depths in the International Section of the river for safe navigation; 3) maintain adequate flows for hydropower generation; and 4) protect the lower St. Lawrence River below the control works from flooding. Sometimes when water supplies are extemely high or low, not all of these objectives can be met. For example, Lake Ontario outflows may be limited due to flooding problems downstream around Montreal, Quebec, or if higher flows become a hazard to commercial navigation, particularly upstream of the Massena, New York - Cornwall, Ontario, area.

Diversions

There are five locations on the Great Lakes where water is diverted into, out of or between lake basins.

There are five diversions on the Great Lakes: the Long Lac and Ogoki diversions into Lake Superior, the Lake Michigan diversion at Chicago, and the Welland Canal and New York State Barge Canal between Lake Erie and Lake Ontario. The Welland and New York State Barge Canal do not divert water into or out of the Great Lakes, but rather provide navigation channelways between two of the lakes. Man-made diversions play a minor role in the balancing of Great Lakes water levels when compared to natural forces. The cumulative impacts of all five diversions have raised water levels on Lake Superior by less than 1 inch, had no measurable effect on lakes Michigan-Huron, lowered Lake Erie by almost 4 inches and raised Lake Ontario by less than 1 inch.

Long Lac - Ogoki diversions

The Long Lac and Ogoki diversions take water from the Hudson Bay watershed and augment the natural flows driving hydropower plants in the northern portion of the Lake Superior basin. These projects, in operation since the early 1940s, have increased the water supply to Lake Superior. Combined, these diversions move an average of about 5,300 cfs.

Great Lakes Diversions

Lake Michigan Diversion at Chicago

Since 1848, water has been diverted from Lake Michigan at Chicago, Illinois, for various purposes, including water supply, sewage disposal and commercial navigation. Water from Lake Michigan enters the Chicago Sanitary and Ship Canal, which links the lake through the Illinois Waterway and Des Plaines River to the Mississippi River. Diversion of Lake Michigan waters has varied substantially over the years, and has been the subject of some controversy; several Great Lakes states have gone to court to limit the diversion. Since 1967, the U.S. Supreme Court has limited the diversion to 3,200 cfs averaged over five years.

Welland Canal

The Welland Canal is a deep-draft navigational waterway that joins Lake Erie and Lake Ontario. Originally built in 1829 and since modified several times, the canal allows ships to travel between the two lakes, bypassing the falls and rapids of the Niagara River. The canal also provides water for hydropower generation. Today, this diversion averages about 8,500 cfs.

New York State Barge Canal

The New York State Barge Canal is the smallest of the Great Lakes diversions, averaging only about 1,000 cfs. This canal draws its water from the Niagara River at Tonawanda, New York. It has no effect on the water level of or outflow from Lake Erie, but does slightly reduce the flow in the Niagara River below Tonawanda and above the falls. The diverted water is returned to Lake Ontario through four water courses within New York.

Controlling Water Levels

Major factors affecting the water supply to the Great Lakes—precipitation, evaporation and runoff—cannot be controlled or accurately predicted for more than a few weeks into the future. The influences of man-made controls on lake levels are therefore limited. Regulation of outflows from lakes Superior and Ontario have had significant impacts on levels throughout the system since they were introduced. The effects of these artificial controls, however, have been dwarfed by the results of natural climatic variations.

The control of lakes Superior and Ontario outflows are governed by the International Joint Commission's boards of control. Each of the binational control boards has an equal number of members from both countries.

St. Marys Rapids (including the Compensating Works in center foreground), railway bridge and International Bridge; Sault St. Marie, Ontario, in background

How much control is possible?

The Boundary Waters Treaty of 1909 between the United States and Canada provides the principles and mechanisms to help resolve disputes and to prevent future ones, primarily those concerning water quantity and water quality along the boundary between the two countries. The IJC has created boards of control that oversee the operations of the regulatory structures and direct outflows that meet conditions set forth by the IJC to protect the interests of both countries.

The IJC has carried out several studies on water levels issues in response to references, or requests, from the U.S. and Canadian governments. In 1964, when water levels were very low, the governments asked the IJC whether it would be feasible to maintain the waters of all the Great Lakes, including Michigan and Huron, at a more constant level. This study was completed in 1973, when lake levels had risen to record highs. The IJC advised the governments in its report that the high costs of engineering further regulation of lakes Michigan and Huron could not be justified by the benefits. The same conclusion was reached during another study on regulating outflows from Lake Erie in 1983.

In 1985, the IJC released a report on consumptive uses and the effects of existing diversions into and out of the Great Lakes system. Until this study, consumptive use had not been considered significant for the Great Lakes because the volume of water in the system is so large. The study concluded that climate and weather changes affect levels of the lakes far more than existing man-made diversions. However, the report also concluded that if consumptive uses of water continue to increase at historical rates, outflows through the St. Lawrence River could be reduced over time.

Following the period of high lake levels in the mid-1980s, the IJC conducted a Levels Reference Study on the feasibility of modifying lake levels through various means. In the results of this study, released in 1993, the IJC concluded that the costs of major engineering works to further regulate the levels and flows of the Great Lakes and St. Lawrence River would exceed the benefits provided and would have significant negative environmental impacts. The IJC recommended that comprehensive and coordinated land-use and shoreline management programs needed to be implemented throughout the basin to reduce vulnerability to flood and erosion damages. These recommendations called for state, provincial and local government leadership to help alleviate or minimize property damages under high levels scenarios. Three of the key recommendations were to improve forecast abilities and emergency preparedness plans, to strengthen information databases including extensive monitoring of shoreline erosion, bluff recession and land use, and to initiate comprehensive shoreline management programs.

Left to right: Mackinac Bridge, across the Straits of Mackinac between lakes Michigan and Huron; Lake Superior shoreline in Minnesota; Manistee Breakwall Lighthouse, Manistee, Michigan, on Lake Michigan

Measuring water levels

Water levels are measured and recorded at many locations around the Great Lakes and on their connecting channels.

Effective management of Great Lakes water levels depends largely on the periodic collection and analysis of data from the lakes and public dissemination of this information. The National Ocean Service of the National Oceanic and Atmospheric Administration (NOAA) presently operates 31 water level gages on the Great Lakes and 18 gages on their connecting channels. Historic records for some of these gages go back to 1860. In Canada, the Canadian Hydrographic Service maintains 29 water level gages on the Great Lakes and 27 gages on the St. Lawrence River. Several other agencies operate recording gages at various locations around the Great Lakes system. These agencies include the U.S. Army Corps of Engineers, the New York Power Authority and Ontario Power Generation.

Typical water level gaging station with satellite data relay instrumentation

Great Lakes water levels are officially measured from the International Great Lakes Datum 1985 (IGLD 1985). This datum is referenced to sea level, as measured at Rimouski, Quebec, near the mouth of the St. Lawrence River. Because the crust of the earth in the Great Lakes region is continuously rising with respect to sea level, and the rate of movement is not uniform throughout the region, the International Great Lakes Datum must be periodically updated on a 25- to 30-year schedule.

Another datum to which Great Lakes water levels are often referred to is called Chart Datum. All soundings on navigation charts are referenced to this datum. *(For further information on chart datum, see page 32.)*

Measuring outflows

Outflows from the Great Lakes are relatively small (less than 1 percent per year) in comparison with the total volume of water. The rate of flow, or discharge, in a river is determined by measuring the channel depth and width, and the velocity of the flow. These measurements are made at various sections of the river, such as constrictions in the river course. Measurements can be made by boat, from a bridge, or from a cableway strung across the river as in the picture below.

With sufficient measurements of flow over a range of water levels including extreme low and high levels, mathematical relationships can be developed between levels and discharges for various points along the connecting channels and the St. Lawrence River. These stage-discharge equations are essential to the coordination of outflow data, particularly related to hydropower usage of Great Lakes waters.

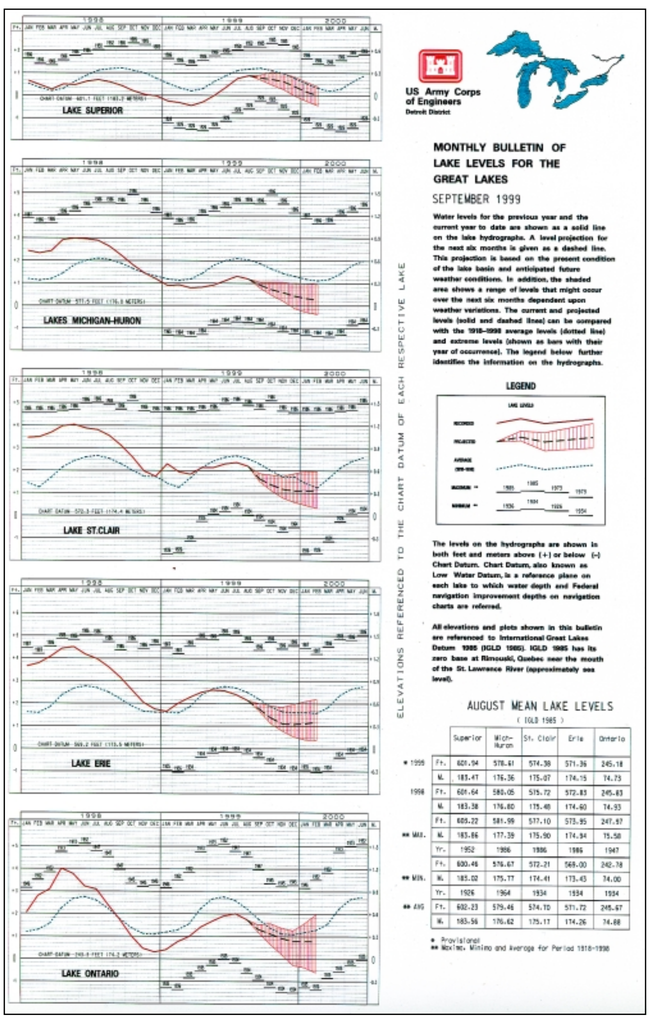
Measuring outflows at the Niagara Cableway across the Niagara Gorge

Water level forecasting

Monthly water level forecasts are available free from the U.S. Army Corps of Engineers and Canadian authorities

Forecasts of water levels for each of the Great Lakes are routinely published by the U.S. and Canadian governments and distributed free to the public. The former U.S. Lake Survey District of the U.S. Army Corps of Engineers began publishing water level forecasts in 1952. Since 1975, the Detroit District of the Corps has continued to produce the forecasts monthly. This product is available on the Internet and by mail in paper form. A weekly forecast update is also produced and is available on the Internet. The Canadian forecasts began in 1973 and currently are generated by Environment Canada and published by the Department of Fisheries and Oceans. These also are published on the Internet and mailed to Canadian recipients. The U.S. and Canadian forecasts are coordinated between agencies to ensure that there is agreement. *(See the Points of Contact and Additional Resources listings on pages 38 and 39.)*

Since it's difficult to predict the weather, it is not surprising that present weather forecasts for one month or beyond are of limited value in forecasting water levels. In practice, water level forecasts depend heavily on looking at recent seasonal fluctuation patterns of water supply. Future water supplies can also be significantly influenced by the condition of the lake and its drainage basin at the time the forecast is made. Key issues associated with this include the wetness of the soils, amount of water stored in the snowpack, depth of the frost in the ground, height of the groundwater table, and/or the temperature of the lake surface.



MONTHLY BULLETIN OF LAKE LEVELS FOR THE GREAT LAKES

SEPTEMBER 1999

Water levels for the previous year and the current year to date are shown as a solid line on the lake hydrographs. A level projection for the next six months is given as a dashed line. This projection is based on the present condition of the lake basin and anticipated future weather conditions. In addition, the shaded area shows a range of levels that might occur over the next six months dependent upon weather variations. The current and projected levels (solid and dashed lines) can be compared with the 1918–1998 average levels (dotted line) and extreme levels (shown as bars with their year of occurrence). The legend below further identifies the information on the hydrographs.

LEGEND

The levels on the hydrographs are shown in both feet and meters above (+) or below (–) Chart Datum. Chart Datum, also known as Low Water Datum, is a reference plane on each lake to which water depth and Federal navigation improvement depths on navigation charts are referred.

All elevations and plots shown in this bulletin are referenced to International Great Lakes Datum 1985 (IGLD 1985). IGLD 1985 has its zero base at Rimouski, Quebec near the mouth of the St. Lawrence River (approximately sea level).

AUGUST MEAN LAKE LEVELS

(IGLD 1985)

		Superior	Mich-Huron	St. Clair	Erie	Ontario
* 1999	Ft.	601.94	578.61	574.38	571.36	245.18
	M.	183.47	176.36	175.07	174.15	74.73
1998	Ft.	601.64	580.05	575.72	572.83	245.83
	M.	183.38	176.80	175.48	174.60	74.93
** MAX.	Ft.	603.22	581.99	577.10	573.95	247.97
	M.	183.86	177.39	175.90	174.94	75.58
	Yr.	1952	1986	1986	1986	1947
** MIN.	Ft.	600.46	576.67	572.21	569.00	242.78
	M.	183.02	175.77	174.41	173.43	74.00
	Yr.	1926	1964	1934	1934	1934
** AVG	Ft.	602.23	579.46	574.10	571.72	245.67
	M.	183.56	176.62	175.17	174.26	74.88

* Provisional
** Maxima, Minima and Average for Period 1918-1998

Monthly Bulletin of Lake Levels for the Great Lakes

With recent scientific advances, particularly in satellite and airborne monitoring systems, ground-based radars and computer modeling techniques, forecasters are gaining valuable knowledge on basin and lake conditions that was not previously available. Sophisticated computer models, in particular, are being created and tested, which can account for daily changes in nearly 25 separate hydrologic variables that can affect water supply to a lake and, therefore, water levels in the future.

There is a limit, however, to how much current basin conditions can influence water supplies to the lakes in the future. For this reason, published water level forecasts normally extend only six months into the future. All forecasts are generated and published showing a probable range of lake levels due to the inherent uncertainty of future weather conditions.

Effects of Lake Level Fluctuations

Stretching more than 9,500 miles, the shores of the Great Lakes are constantly reshaped by the effects of wind, waves and moving water. Shoreline characteristics vary significantly, from flat, low-lying areas susceptible to flooding, to high bluff areas that are often prone to erosion. Erosion is a natural process that occurs during periods of low, average or high water levels. Erosion and flooding can be magnified during periods of high water or storms.

In some areas of high-density development, minor deviations from long-term average levels can produce pronounced economic losses. In less developed areas, these impacts can be modest or negligible.

Natural areas, such as wetlands, have evolved as a result of wide variations in water levels. Reducing these variations can have significant environmental consequences.

Empire Bluffs at Sleeping Bear Dunes National Lakeshore on Lake Michigan

Erosion processes

Although erosion is a natural process, its rate and severity can be intensified by human activity.

On the coast, natural forces causing erosion are embodied in waves, currents and wind. Most waves arrive at an angle to the shore. As successive wave fronts advance and retreat they set up a longshore current. As waves break, run up the shore, and return, they carry sedimentary material onshore and offshore. This sedimentary material is called **littoral drift**.

The energy in the moving water determines the size and amount of the material that will move and how far. The energy in a wave depends on the speed of the wind, its duration and the unobstructed water distance, or fetch, it blows over. Gentle waves move fine sand, whereas storm-generated waves move rocks and boulders. Materials picked up from shoreline areas are deposited wherever the water is slowed down and may be picked up again when the velocity of the water increases.

If erosion is not balanced by **accretion**, the depositing of sediment, the shore will be washed away. Erosion and accretion are two faces of the same process. These processes can occur at extremely slow rates or may occur dramatically in a short time.

Lake Michigan shoreline in Michigan

Natural shores are nourished by material that has been eroded from other areas, becoming part of the littoral drift system. Attempts to reduce erosion by building shore protection structures, or armoring the shoreline in one area, will result in reduced littoral drift available, starving an adjacent area downdrift.

Fluctuating water levels can expose new surfaces to erosion. As seasons change, wind strength and direction also change, altering the path of waves and currents. Where ice forms, it redirects wave energies offshore protecting beaches, but can increase erosion of the lakebed. Ice may also exert tremendous forces that can weaken shore structures.

Gently sloping shores, whether beaches or wetlands, are natural defenses against erosion. The slopes of the land along the edge of the water form a first line of defense called a **berm**, which dissipates the energy of breaking waves. During high water periods, a berm can prevent water from moving inland. Dunes and their vegetation offer protection against storm-driven high water and also provide a reservoir of sand for replenishing the littoral drift and rebuilding beaches.

Although erosion is caused by natural shoreline processes, its rate and severity can be intensified by human activity. Dredging marinas and bulldozing dunes remove natural protection against wind and waves. Pedestrian and vehicle traffic destroy vegetation, degrade dunes, and weaken bluffs and banks. Docks, jetties and other structures interrupt the natural shoreline movement of water and redirect erosive forces, possibly in undesirable directions. Inappropriate building practices in high bluff areas can seriously reduce bluff stability. In particular, drainage patterns from new building construction can cause infiltration of runoff directly into a bluff and can weaken its normal cohesive forces. Wise management of shoreline construction and land uses can significantly reduce economic losses due to erosion.

Habitat diversity

The region’s glacial history and the tremendous influence of the lakes themselves create unique conditions that support a wealth of biological diversity, including more than 130 rare species and ecosystems. The Great Lakes are the only lakes of their size in a temperate climate. With the lakes’ moderating effect on the climate, the ecosystem is able to provide habitat for a wide variety of species that otherwise might not survive. The Great Lakes - St. Lawrence River ecosystem features sand dunes, coastal marshes, rocky shorelines, lakeplain prairies, savannas, forests, fens, wetlands and other landscapes.

The place where land and water meet is by far the most diverse and productive part of the Great Lakes - St. Lawrence River ecosystem. This interface includes small wetlands nestled in scattered bays to extensive wetlands such as those along Saginaw Bay on Lake Huron, river-mouth wetlands such as the Kakagon Sloughs of northern Wisconsin and the enormous delta marshes of the St. Clair River. Nearly all species of Great Lakes fish rely on nearshore waters for everything from permanent residence, to migratory pathways, to feeding, nursery grounds and spawning areas.

With the lakes’ moderating effect on the climate, the ecosystem is able to provide habitat for a wide variety of species that otherwise might not survive.

Most common types of wetlands along the shoreline are marshes, where the vegetation can tolerate the large short- and long-term fluctuations in lake levels. In fact, these wetlands are shaped by dynamic lake processes, including waves, currents and changes in water levels. They occur in areas where the erosive forces of ice and wave action are low, allowing the growth of wetland plants. Many wetlands have species successions that are dependent upon water level cycles. Seasonal and long-term water level fluctuations also limit the invasion of woody plants at higher elevations and extensive beds of submersed aquatic plants at lower elevations. Individual wetland species and vegetative communities prefer, and have adapted to, certain water depth ranges, allowing wetlands to be more extensive and more productive than they would be if water levels were stable.

In addition to providing habitat, coastal wetlands play other vital roles. These include protecting nearshore terrestrial ecosystems from erosion by dissipating wave energy, and improving water quality in adjacent aquatic systems through sediment control and absorption of nutrients.

A wealth of biological diversity (left to right): moose in Lake Superior watershed, wetlands along Saginaw Bay on Lake Huron and herons along Lake Ontario shoreline

Commercial shipping and recreational boating

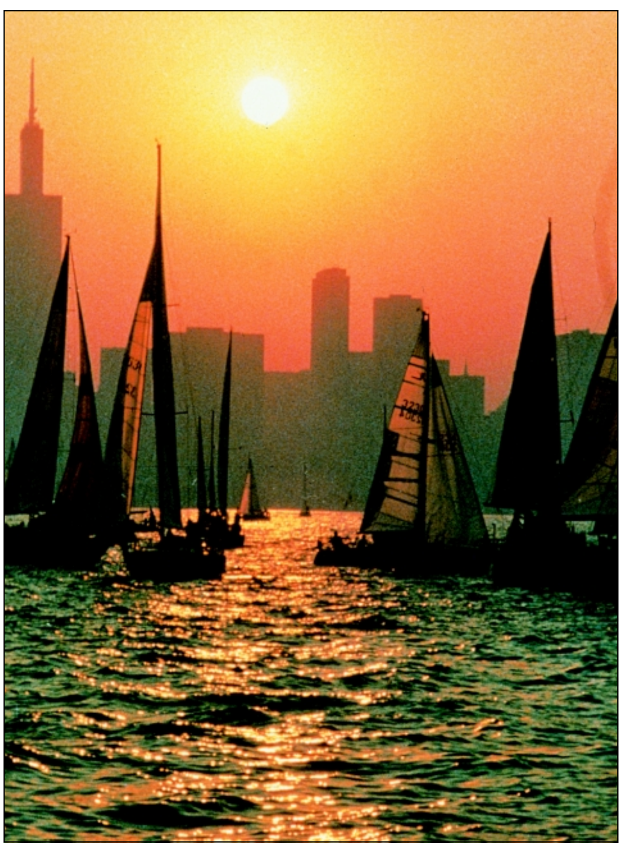
Lift Bridge in Duluth - Superior Harbor on Lake Superior

Water levels have a profound impact upon the economic viability of commercial shipping and recreational boating on the Great Lakes. In the U.S., for example, the federal government maintains 71 deep-draft harbors and 745 miles of dredged channelways to support commercial navigation. Along the nearly 5,800 miles of U.S. Great Lakes and St. Lawrence River shorelines, the government also maintains 65 shallow-draft recreational harbors. The depths to which the harbors and approach channels are dredged have been subject to U.S. congressional authorizations, many of which date back to the 19th century.

The authorized depth for dredging varies with the type of traffic involved, ranging from a low of 9 feet deep in most recreational boating harbors to 30 foot deep in channels used for ocean-going freighters. Since some harbors serve both commercial and recreational purposes, it is common to see a deeper entrance channel near the harbor mouth for commercial vessels, with progressively shallower depths for recreational interests as one moves upstream.

Boaters should be familiar with and make regular practice of using navigation charts for the waters they expect to navigate. These navigation charts are published in the U.S. by the National Oceanic and Atmospheric Administration (NOAA) and by the Department of Fisheries and Oceans in Canada. All depths or **soundings** on the navigation charts are referenced to **chart datum**, also known as Low Water Datum. Chart datum is different for each lake and is expressed relative to IGLD 1985. Current and forecasted water levels are reported relative to chart datum. With an up-to-date chart and current water level information, navigators can find the depth of water available for transit. For example, if the water level is currently 3 feet above chart datum and the soundings on the chart are 8 feet below chart datum, then there is an actual depth of 11 feet at that location.

Boaters should always be aware that the Great Lakes, their connecting channels, and the St. Lawrence River are subject to fluctuating water levels on a short-term basis through storm events, through seasonal changes, and over longer periods due to climatic shifts. Boaters should always use caution and reduce vessel speeds when navigating unfamiliar waters.



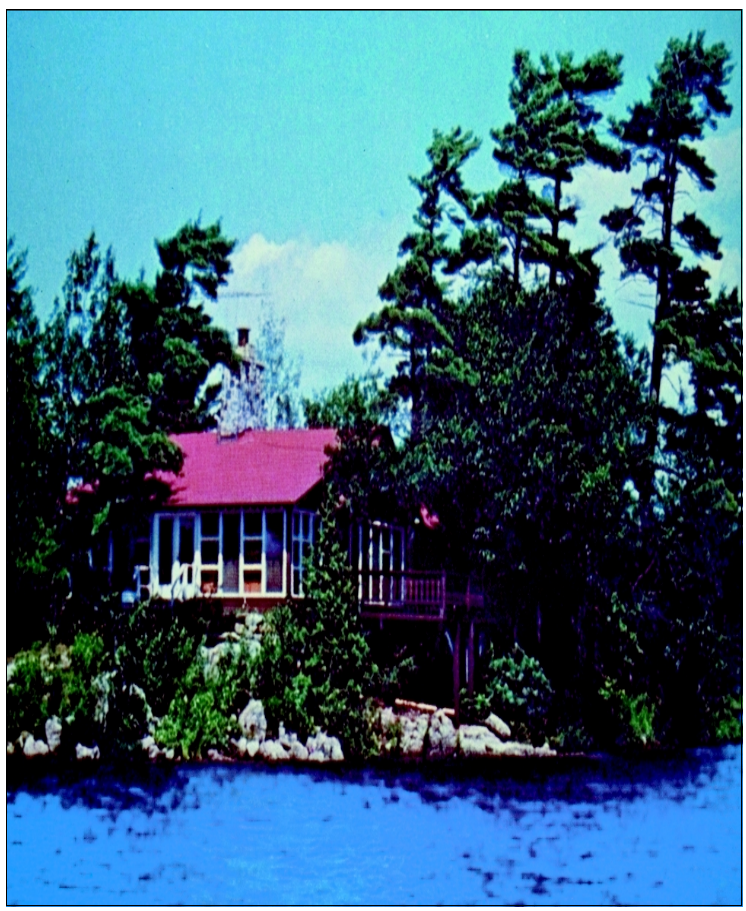
Chicago lakefront on Lake Michigan

Marina on Lake St. Clair

Living Along the Shoreline

Whether you're a boating enthusiast, business owner, residential property owner, prospective buyer of shoreline property or a member of a coastal community, it's in your best interest to understand the benefits and risks associated with living close to the lakes. A willingness to anticipate and adapt to ever-changing lake levels and their impacts could save you vast amounts of time, money and worry.

Levels are only one of the complex physical processes exerted upon our Great Lakes shorelines. While individual property owners are powerless to stop these processes, they do have a variety of options for combating erosion and flooding, including structural and nonstructural measures. Careful planning, prudent siting of new construction and awareness of risks are all advised.



Cottage in Thousand Islands area of the St. Lawrence River

Structural options

A variety of structural options are available to shore property owners to protect and stabilize bluffs and beaches vulnerable to the impacts of lake level fluctuations and storm events. The best structural option depends upon the site characteristics. Professional design consultation is advisable. None of these options, however, are permanent solutions against the continued and relentless forces of nature. Many structures cause erosion downdrift, which can only be mitigated by replacing lost material. In most areas, without mitigation, the relatively thin layer of existing sand is stripped away, exposing underlying clay. The clay is rapidly and irreversibly eroded in a process called **lakebed downcutting.** This process lets larger waves attack closer to shore, increasing the failure rate of coastal structures and bluffs.

Revetment at Luna Pier, Michigan, on Lake Erie

- A **revetment** is a heavy facing, or armor, that protects the slope and adjacent upland from the erosive effects of wave scour. Revetments, which are best suited for gentle to moderate slopes, are comprised of three layers: armor, filter layers and toe protection. Typical armor materials, which include stone and gabions (wire baskets filled with stone) are designed to disperse wave energy that would otherwise impact the shoreline. The filter layer, comprised of graded stone, provides a stable foundation for the armor and permits groundwater drainage. Toe protection, which prevents settlement of the revetment and stabilizes the revetment's lakeward edge, is an extension of the armor material. Private revetments can temporarily protect some types of bluffs, but will likely cause erosion in downdrift areas by starving these shorelines of natural sand supply. Any beach present prior to construction will typically be lost.

A bulkhead and companion breakwater in Sanilac County, Michigan, on Lake Huron

- **Bulkheads (or seawalls)** are retaining walls that prevent soil from eroding into a water body due to wave action. Construction can vary from thin structures that penetrate the ground like sheet piling to massive structures that rest on the surface such as poured concrete structures or stone-filled timber cribs. Bulkheads protect only the land immediately behind them by retaining soil at the toe of a bluff; they do not ensure the overall stability of the bluff and do not offer protection to adjacent areas. Bulkheads may worsen erosion downdrift in the same manner as revetments. In the long term, erosion of the lakebed will worsen immediately in front of the bulkhead.

- **Breakwaters** are offshore structures typically placed parallel to the area of shoreline to be protected. Constructed of stone, steel, wood or concrete, breakwaters block and disperse wave energy, which can minimize shore damage. Breakwaters help build a beach in their protected shadow, but can worsen erosion downdrift by blocking transport of sediments along the shore.

Groin and revetment system near St. Joseph, Michigan, on Lake Michigan

- **Groins** are structures that are placed perpendicular to shore and extend out into the water. Used either singly or in a series as part of a **groin field**, they trap and accumulate sand on the updrift side of the groin. Provided enough sand moves naturally along the shoreline, groins can be effective in building up beaches. Groins are typically constructed of the same materials used for revetments and breakwaters. Groins will aggravate erosion problems downdrift by blocking sediment transport along the shore.

Nonstructural options

Nonstructural options for bluff stabilization and shoreline protection offer the shore property owner a variety of measures that have a strong land-use management emphasis.

Beach grasses along Lake Michigan

- **Revegetation** is a planting program to establish desired species for bluff and beach stabilization, which is among the least expensive of all protection measures. A variety of groundcover, including species of grasses, sedges and bulrushes, are effective at trapping sand particles and stabilizing beach and bluff areas. Upland species of grasses, shrubs and trees are effective in higher beach elevations. While useful for slope stabilization and erosion control, revegetation alone is not effective under conditions of heavy wave action in high bluff environments. Conversely, in areas of shallow relief, extensive coastal wetlands can effectively eliminate wave forces on adjacent beaches.

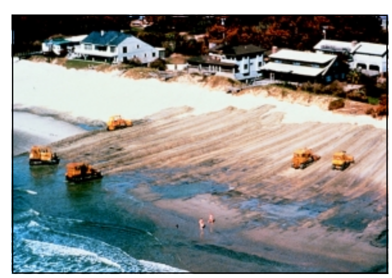
Marsh grasses along Lake Superior shores

- **Bluff drainage** is a measure that addresses seepage problems common to clay or composite bluffs. Seepage contributes to bluff instability when upper layers are saturated, slough off, and are ultimately carried away by wave action. Open joint tile drains, laid in a trench set back from the top of the bluff and back-filled with crushed stone, can help resolve shallow (less than 6 feet deep) groundwater drainage problems. Vertical wells with sump pumps can be used for deeper drainage problems.

- **Slope re-grading** is a measure by which unstable bluffs can be re-graded to a more gradual or stable slope. Coupled with revegetation, this measure can be effective in reducing the rate of erosion and bluff recession, assuming the lakebed has not been irreversibly downcut.

Sandy beach along southern Lake Superior

- **Beach nourishment** is the placing of quantities of sand, gravel, or stone on the shoreline by overland hauling or nearshore pumping from barges. The deposits serve as a buffer zone that slows erosion. Wave action carries the material offshore, where it can form sand bars that may cause waves to break farther from the beach. To extend its life span, beach nourishment often requires using larger and heavier deposits than would naturally occur, causing a change in beach characteristics. The useful life of a nourished beach depends upon the size and quantity of materials placed on the beach as well as the frequency and severity of storms that erode the deposits.



Beach nourishment along Lake Michigan

- **Relocation** is the removal of structures vulnerable to damage from storm-induced flooding and erosion. This option recognizes that erosion and associated bluff recession is a natural process that, even with installation of structural protection, is difficult to stop entirely. Provided that the shoreline property is of sufficient size and depth to accommodate relocation of the structure(s), this option is often more cost-effective and reliable in the long-term than most structural options.

Community measures

Additional nonstructural options entail the development and implementation of land-use and shoreline management measures that can prevent new damage from occurring. Many such techniques lend themselves to public policy actions, such as local ordinances, but also can be implemented by the individual property owner on a voluntary basis. These include:

High bluff along Lake Michigan shoreline

- erosion setbacks with minimum requirements for both movable and permanent structures;
- flood setbacks and elevation requirements for new structures;
- requirements/guidelines for shoreline alteration to ensure that updrift and downdrift impacts are considered and mitigated for;
- real estate disclosure requirements to ensure that a prospective buyer is fully informed as to whether the property is within a mapped or known flood or erosion hazard area; and
- adoption of hazard insurance programs that provide for mapping of hazard zones, establishing setbacks for new construction, and denying subsidized insurance for new construction or major renovations within the flood or erosion hazard area.

An additional nonstructural option available to both public and nongovernmental agencies and organizations is the implementation of conservation practices including the purchase of developed and undeveloped property in hazard areas for recreational use, habitat enhancement or other purposes.

Selecting the best options

Lake level fluctuations, storm events and related natural processes continuously reshape the coastal zone through flooding and erosion. These processes are an integral part of the ecosystem; it is neither economically feasible nor environmentally desirable to severely limit these processes.

Stakeholders in the Great Lakes need to be aware of long-term water level history; knowledge of the past can help to minimize future losses.

Shoreline property owners should be cognizant of long-term lake level history so they will not be surprised by what happens in the future. While various private protective structures can be effective in temporarily protecting shorelines and associated buildings, none will be permanent. Ownership of shore property and structures has many benefits, but does require a thorough understanding and acceptance of the risks involved.

"Let the buyer beware" is sound advice to any prospective shore property owner. Every aspect of the property's history should be investigated thoroughly, particularly past flooding or erosion patterns and structural and nonstructural shoreline protection measures that either need to be maintained or possibly installed on the property. Selecting and implementing one or more management measures will be one of the most significant decisions shoreline communities and their citizens can make. Careful planning, including assistance from public agencies and reputable professionals, is advised.

States and Provinces

Points of Contact

Illinois

Illinois Dept. of Natural Resources
Division of Water Resources
310 South Michigan Avenue, Room 1606
Chicago, IL 60604
Phone: 312-793-3123
Fax: 312-793-5968
http://dnr.state.il.us/waterresources/

Illinois State Emergency Management Agency
110 East Adams
Springfield, IL 62701-1109
Phone: 217/782-2760
Fax: 217/782-2589
http://www.state.il.us/iema/

Indiana

Indiana Dept. of Natural Resources
Division of Water
402 West Washington, Room W264
Indianapolis, IN 46241
Phone: 317-232-4160
Fax: 317-233-4579
http://www.state.in.us/dnr/water/

Indiana State Emergency Management Agency
Recovery Division
402 West Washington, Room W046
Indianapolis, IN 46204
Phone: 317-233-4626
Fax: 317-232-4987
http://www.state.in.us/sema/

Illinois-Indiana Sea Grant College Program
Purdue University
1200 Forest Products Building
West Lafayette, IN 47907-1200
Phone: 765-494-3573
http://ag.ansc.purdue.edu/il-in-sg/

Michigan

Michigan Department of Environmental Quality
Land and Water Management Division
P.O. Box 30458
Lansing, MI 48909-7958
Phone: 517-373-1170
Fax: 517-373-9965
http://www.deq.state.mi.us

Michigan State Police
Emergency Management Division
4000 Collins Road
P.O. Box 30636
Lansing, MI 48909-8136
Phone: 517-336-6198
Fax: 517-333-4987
http://www.msp.state.mi.us

Michigan Sea Grant College Program
2200 Bonisteel Boulevard
Ann Arbor, MI 48109-2099
Phone: 734-763-1437
http://www.engin.umich.edu/seagrant/

Minnesota

Minnesota Department of Natural Resources
Division of Water
DNR Building, 3rd Floor
500 Lafayette Road
St. Paul, MN 55155
Phone: 651-296-4800
Fax: 651-296-0445
http://www.dnr.state.mn.us/waters/

Minnesota Board of Water & Soil Resources
One West Water Street, Suite 200
St. Paul, MN 55107
Phone: 612-296-3767
Fax: 612-297-5615
http://www.bwsr.state.mn.us/

University of Minnesota Sea Grant Program
2305 East 5th Street
Duluth, MN 55812-1445
Phone: 218-726-8715
Fax: 218-726-6556
http://www.d.umn.edu/seagr/

New York

New York State Department of Environmental Conservation
Bureau of Flood Protection
50 Wolf Road, Room 388
Albany, NY 12233
Phone 518-457-3157
Fax 518-485-7786
http://www.dec.state.ny.us

New York State Emergency Management Office
1220 Washington Avenue
Building 22 - Suite 101
Albany, NY 12226-2251
Phone: 518-485-1797
Fax: 518-457-7528
http://www.nysemo.state.ny.us

New York Sea Grant Institute
115 Nassau Hall
SUNY at Stony Brook
Stony Brook, NY 11794-5001
Phone: 516-632-6905
Fax: 516-632-6917
http://www.seagrant.sunysb.edu/

Ohio

Ohio Dept. of Natural Resources

Ohio Coastal Management Program
Div. of Real Estate & Land Management
Fountain Square, Bldg C, 4th Floor
Columbus, OH 43224
Phone: 888-644-6267
or 614-265-6384
Fax: 614-267-4764
http://www.dnr.state.oh.us/odnr/relm/

Division of Water
Fountain Square, Building E
Columbus, OH 43224
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Fax: 614-447-9503
http://www.dnr.state.oh.us/odnr/water/

Division of Geological Survey
P.O. Box 650
Sandusky, OH 44870
Phone: 419-626-4296
Fax: 419-626-8767
http://www.dnr.state.oh.us/odnr/geo_survey/

Division of Engineering
Fountain Square, Bldg F, 3rd Floor
Columbus, OH 43224
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Fax: 614-262-2197
http://www.dnr.state.oh.us/odnr/engineering/

Ohio Sea Grant College Program
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Columbus, OH 43212-1194
Phone: 614-292-8949
Fax: 614-292-4364
http://www.sg.ohio-state.edu/

Ohio Emergency Management Agency
2855 West Dublin-Granville Road
Columbus, OH 43235-2206
Phone: 614-889-7150
Fax: 614-889-7183
http://www.state.oh.us/odps/division/ema/

Pennsylvania

Pennsylvania Department of Environmental Protection

Bureau of Watershed Conservation
Watershed Support Division
Coastal Zone Management, 10th Floor
Rachel Carson State Office Building
P.O. Box 8555
Harrisburg, PA 17105-8555
Phone: 717-787-5259
Fax: 717-787-9549
http://www.dep.state.pa.us

Coastal Zone Management Program
Northwest Regional Office
230 Chestnut Street
Meadville, PA 16335-3481
Phone: 814-332-6942
Fax: 814-332-6121
http://www.dep.state.pa.us

Pennsylvania Emergency Management Agency
P.O. Box 3321
Harrisburg, PA 17105-3321
Phone: 717-651-2009
Fax: 717-651-2040
http://www.pema.state.pa.us

Pennsylvania Sea Grant Project
Penn State - Erie
5091 Station Road
Erie, PA 16563-0101
Phone: 814-898-6420
Fax: 814-898-6462
http://www.pserie.psu.edu/seagrant/

Wisconsin

Wisconsin Dept. of Natural Resources
Bureau of Watershed Management
P.O. Box 7921
Madison, WI 53707
Phone: 608-267-7694
Fax: 608-267-7664
http://www.dnr.state.wi.us

Wisconsin Dept. of Administration
Coastal Management Program
P.O. Box 7868
Madison, WI 53707
Phone: 608-261-6349
Fax: 608-267-6931
http://www.doa.state.wi.us/deir/coastal.htm

University of WI Sea Grant Institute
University of Wisconsin - Madison
1975 Willow Drive
Madison, WI 53706-1103
Phone: 608-262-0905
Fax: 608-262-0591
http://www.seagrant.wisc.edu/

Ontario

Ontario Ministry of the Environment
Water Policy Branch
40 St. Clair Avenue West, 12th & 14th Floors
Toronto, ON M4V 1M2
Phone: 416-314-3923
Fax: 416-314-4128
http://www.ene.gov.on.ca/envision/org/iepd.htm

Ontario Ministry of Natural Resources
Peterborough Regional Office
4th Floor, 300 Water St., P.O. Box 7000
Peterborough, ON K9J 8M5
Phone: 705-755-2500
Fax: 705-755-1267
http://www.mnr.gov.on.ca/mnr/

U.S. federal agencies

U.S. Army Corps of Engineers
Great Lakes Regional Office
111 North Canal Street, Suite 1200
Chicago, IL 60606
Phone: 312-353-6310
Fax: 312-353-5233
http://www.lrd.usace.army.mil/gl/gl.htm
Buffalo District
1776 Niagara Street
Buffalo, NY 14207
Phone: 716-879-4104
http://www.lrb.usace.army.mil
Chicago District
111 North Canal Street
Chicago, IL 60606-7206
Phone: 312-353-6400
http://www.usace.army.mil/lrc
Detroit District
477 Michigan Avenue
Detroit, MI 48226
Phone: 313-226-6440
Fax: 313-226-2398
http://www.lre.usace.army.mil

U.S. Coast Guard - Ninth District
Marine Safety Division, 1240 East Ninth St.
Cleveland, OH 44199-2060
Phone: 216-902-6045
Fax: 216-902-6059
http://www.uscg.mil/d9/uscgd9.html

U.S. Department of Agriculture
Natural Resources Conservation Service (NRCS)
Midwest Regional Office
2820 Walton Commons W., Suite 123
Madison, WI 53716
Phone: 608-224-3001
Fax: 608-224-3010
http://www.mw.nrcs.usda.gov/
Farm Service Agency (FSA)
1400 Independence Avenue, S.W.
3086 SAG
Washington, DC 20250
Phone: 202-720-3467
Fax: 202-720-9105
http://www.fsa.usda.gov

U.S. Department of Commerce
National Oceanic and Atmospheric Administration (NOAA)
Great Lakes Environmental Research Laboratory (GLERL)
2205 Commonwealth Boulevard
Ann Arbor, MI 48105-1593
Phone: 734-741-2235
Fax: 734-741-2003
http://www.glerl.noaa.gov/

U.S. Department of the Interior
Fish & Wildlife Service
Great Lakes-Big Rivers Region
1 Federal Drive, BHW Federal Building
Fort Snelling, MN 55111
Phone: 612-713-5360
http://www.fws.gov/r3pao/
U.S. Geological Survey
Biological Resources Division
Great Lakes Science Center
1451 Green Road
Ann Arbor, MI 48105
Phone: 734-994-3331
Fax: 734-994-8780
http://www.glsc.usgs.gov/

Federal Emergency Management Agency (FEMA)
Region II
26 Federal Plaza
Suite 1337
New York, NY 10278
Phone: 212-225-7209
Fax: 212-225-7281
http://www.fema.gov/reg-ii/regii.htm
Region III
One Independance Mall, Sixth Floor
615 Chestnut Street
Philadelphia, PA 19106-4404
Phone: 215-931-5608
Fax: 215-931-5621
http://www.fema.gov/reg-iii/regiii.htm
Region V
536 South Clark Street, 6th Floor
Chicago, IL 60605-1521
Phone: 312-408-5501/5503
Fax: 312-408-5234
http://www.fema.gov/reg-v/regv.htm

U.S. Environmental Protection Agency
Great Lakes National Program Office
77 West Jackson Boulevard
Chicago, IL 60604
Phone: 312-353-2117
Fax: 312-353-2018
http://www.epa.gov/glnpo
U.S. EPA Region 2
290 Broadway
New York, NY 10007
Phone: 212-637-3000
http://www.epa.gov/region2/
U.S. EPA Region 3
1650 Arch Street
Philadelphia, PA 19103-2029
Phone: 215-814-2300
http://www.epa.gov/region3/
U.S. EPA Region 5
77 West Jackson Boulevard
Chicago, IL 60604
Phone: 312-353-2000
http://www.epa.gov/region5/water/

Canadian federal agencies

Environment Canada
Great Lakes Water Level Communication Centre
867 Lakeshore Road
Burlington, ON L7R 4A6
Phone: 905-336-4580
Fax: 905-336-8901

Great Lakes - St. Lawrence Regulation Office
111 Water Street East
Cornwall, ON K6H 6S2
Phone: 613-938-5725
Fax: 613-937-1302

Department of Fisheries and Oceans
Canadian Hydrographic Service
867 Lakeshore Road, P.O. Box 5050
Burlington, ON L7R 4A6
Phone: 877-247-5465
Fax: 905-336-8916
http://chswww.bur.dfo.ca/danp/

Binational agencies

Great Lakes Commission
Argus II Building, 400 Fourth Street
Ann Arbor, MI 48103-4816
Phone: 734-665-9135
Fax: 734-665-4370
http://www.glc.org

Great Lakes Fishery Commission
2100 Commonwealth Blvd., Suite 209
Ann Arbor, MI 48105
Phone: 734-662-3209
Fax: 734-741-2010
http://www.glfc.org

International Joint Commission
http://www.ijc.org
U.S. Section
1250 23rd Street N.W., Suite 100
Washington, DC 20440
Phone: 202-736-9000
Fax: 202-736-9015
Canadian Section
100 Metcalfe Street, 18th Floor
Ottawa, ON K1P 5M1
Phone: 613-995-2984
Fax: 613-993-5583
Great Lakes Regional Office
100 Ouellette Ave. 8th Floor
Windsor, ON N9A 6T3
Phone: 313-226-2170
Fax: 519-257-6740

Additional Resources

Online and video resources

Great Lakes - St. Lawrence River Hydrology, Great Lakes Information Network (GLIN):
http://www.great-lakes.net/envt/water/hydro.html
Includes links to current, forecasted and historical data on water levels, water flows, and weather and climate. Also features overviews of hydrology concepts written by experts in the Great Lakes region; and comprehensive lists of agencies and organizations, datums, laws, newsletters and related FAQs. Created under the guidance of the binational Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data and the U.S. Army Corps of Engineers, Detroit District.

Great Lakes Hydraulics & Hydrology Home Page, U.S. Army Corps of Engineers/Detroit District:
http://huron.lre.usace.army.mil/hmpghh.html
Includes current and forecasted water levels, key water level updates and newsletters, and multi-media resources.

Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data:
http://huron.lre.usace.army.mil/coord/cchome.html
Includes information and data coordinated between the U.S. and Canada used for the management of Great Lakes resources.

Evaluating Your Coastal Property (Video, VHS format), University of Wisconsin Sea Grant Institute; advises on shoreline property construction and building placement.

Living on the Edge (Video, VHS format), U.S. Army Corps of Engineers, Detroit District; explores the many influences on levels and flows of the Great Lakes system; ***preview at http://huron.lre.usace.army.mil/levels/vidpromo.html***

The ADVISOR, Great Lakes Commission: ***http://www.glc.org/docs/advisor/advisor.html***
Bimonthly newsletter of the GLC, providing regular updates on policy positions and programs, regional events and binational Great Lakes issues.

Focus, International Joint Commission: ***http://www.ijc.org/focus***
Quarterly newsletter of the IJC contains regular updates on Commission and Board activities and emerging Great Lakes water quality and quantity issues.

LEVEL News, Environment Canada, Great Lakes Water Level Communication Centre:
http://www.cciw.ca/glimr/data/level-news/intro.html
Includes monthly updates on weather conditions, levels and flows, public meetings and Great Lakes facts.

For further reading

An Introduction to Michigan's Water Resources, Institute for Water Resources, Michigan State University

Beaches are Shore Protection, Ohio Sea Grant College Program

Bluff Slumping & Stability: A Consumer's Guide, Michigan Sea Grant College Program

Coastal Erosion and the Residential Property Market, Ohio Sea Grant College Program

Coastal Processes Manual, 2nd Edition, University of Wisconsin Sea Grant Institute

Erosion Abatement Tips, Assessment and Assistance, Ohio Sea Grant College Program

Great Lakes-St. Lawrence River Regulation: What it Means and How it Works, Environment Canada and U.S. Army Corps of Engineers, North Central Division

Great Lakes Water Levels, Environment Canada

Guide to Lake Erie Bluff Stabilization, Ohio Sea Grant College Program

How to Use Fill Material in Stabilizing Shoreline Bluffs or Banks, University of Wisconsin Sea Grant Institute

Identify Your Shoreline Erosion Problems (Fact Sheet), Ohio Sea Grant College Program

Low Cost Shore Protection...a Property Owner's Guide, U.S. Army Corps of Engineers

Methods of Alleviating the Adverse Consequences of Fluctuating Water Levels in the Great Lakes-St. Lawrence River Basin, A Report to the Governments of Canada and the United States, 1993, International Joint Commission

Questions to Ask Before You Buy Great Lakes Shoreline Property (Fact Sheet), Ohio Sea Grant College Program

Shoreline Erosion: Questions and Answers, Revised 1986, Michigan Sea Grant College Program

Vegetation and its Role in Reducing Great Lakes Shoreline Erosion, Michigan Sea Grant College Program

Great Lakes Commission

US Army Corps of Engineers

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