John Glenn Great Lakes Basin Program
Biohydrological Information Base

In response to Public Law 106-53, Water Resources Development Act of 1999,

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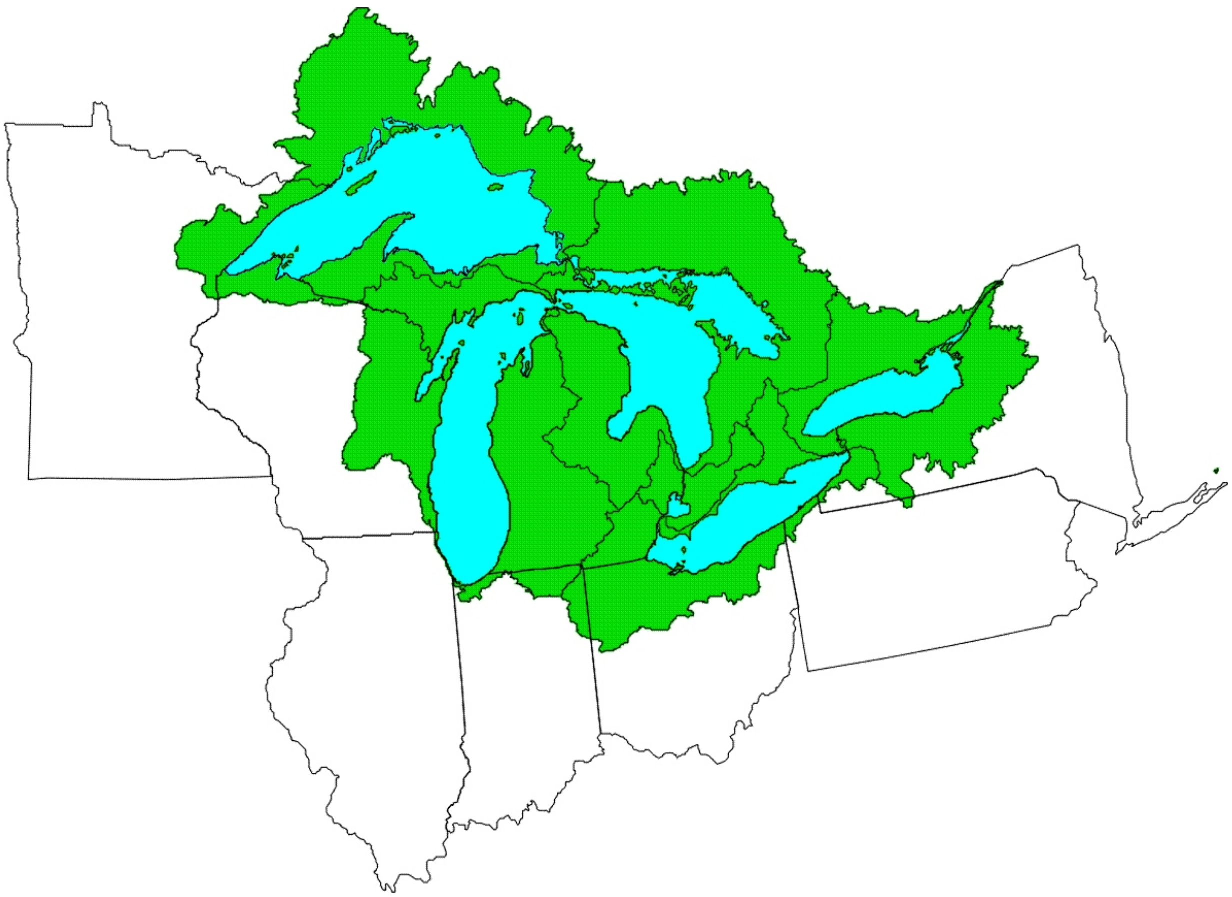

September 2007

US Army Corps
of Engineers®

Appendix A:

Physical Overview of the Great Lakes - St. Lawrence River System

Measurement Converter Table

U.S. to Metric

Length
feet x 0.305 = 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
meter 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

Appendix A: Table of Contents

APPENDIX A

Physical Overview of the Great Lakes - St. Lawrence River System

Introduction

Covering more than 94,000 square miles and draining more than three times as much land, the Great Lakes hold an estimated 6 quadrillion[1] gallons of water and constitutes the largest concentration of unfrozen fresh surface water in the western hemisphere (U.S. Army Corps of Engineers et al, 1999). The lakes, rivers, streams and aquifers that make up the Great Lakes - St. Lawrence River basin are important sources of water for all organisms that live within the Great Lakes - St. Lawrence River region. Water is used every day by humans for public, industrial and agricultural uses. The region's lakes, rivers and streams also provide recreational opportunities such as boating, fishing and wildlife viewing. Consequently, the economic and social well-being of humans within the Great Lakes - St. Lawrence River basin is closely linked to the quality and quantity of the water resources of the basin and the services they provide. The Great Lakes - St. Lawrence River basin is inhabited by over 36 million people - one in every nine Americans and one in every three Canadians. The Great Lakes are home to a great diversity of plants, animals and other biota.

The Physical Setting

The Great Lakes - St. Lawrence River basin covers about 302,000 square miles and 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. The Great Lakes - St. Lawrence River basin spans over 900 miles from east to west and about 700 miles from north to south. Fifty-nine percent of the surface area of the Great Lakes - St. Lawrence River basin is in the United States; 41 percent is in Canada (Great Lakes Commission, 2003). This includes all land, rivers and streams from which waters drain into any of the Great Lakes. The Great Lakes - St. Lawrence River system is comprised of lakes Superior, Michigan, Huron, Erie and Ontario; their connecting waterways, St. Mary's River, St. Clair River, Lake St. Clair, Detroit River and Niagara River; and the St. Lawrence River, which carries the waters of the Great Lakes to the Atlantic Ocean (Figure A-1). The system includes several man-made waterways and control structures that either interconnect Great Lakes or connect the Great Lakes to other river systems. The Great Lakes - St. Lawrence River basin consists of 109 watersheds[2] in the U.S. and 67 watersheds[3] in Canada. Because of the size of the system, it responds slowly to environmental and hydraulic changes (Rankin, 2002).

Figure A-1 The five Great Lakes.

[1] One quadrillion equals 1 x 10^{15}.
[2] U.S. Geological Survey 8-digit hydrologic unit code (HUC)
[3] Canadian tertiary divisions, Ontario Hydro EDSS Digital Database Map

Hydrology, sediment transport and other fluvial processes work together to shape stream channels, lake shorelines and floodplains throughout the basin. Bedrock, relief and weather also help to determine the physical, chemical and biological qualities of the basin. To the north, the climate is cold and the terrain is dominated by granite bedrock called the Canadian (or Laurentian) Shield consisting of Precambrian rocks under a generally thin layer of acidic soils. In the southern areas of the basin, the climate is much warmer. The soils are deeper with layers or mixtures of clays, silts, sands, gravels and boulders deposited as glacial drift or as glacial lake and river sediments. The lands are usually fertile and can be readily drained for agriculture. About 52 percent of the basin is forested; 35 percent is in agricultural uses; 7 percent is urban/suburban; and 6 percent is in other uses. (Great Lakes Commission, 2003).

The Great Lakes and their Connecting Waterways and Diversions

Lake Superior

Although part of a single system, each lake is different. In volume, Lake Superior is the largest (Figure A-2). It is also the deepest, coldest and highest in elevation of the Great Lakes. Superior could contain all the other Great Lakes plus three times Lake Erie's capacity. Because of its size, Superior has a retention time of 191 years. Retention time is a measure based on the volume of water in the lake and the mean rate of outflow. Lake Superior borders Minnesota, Wisconsin, Michigan and Ontario. 335 tributary rivers and streams drain into Lake Superior including large in-flows from the Long Lac and Ogoki diversions. Ninety-five percent of Lake Superior's drainage basin is forested, and the remaining five percent is split between agriculture, urban and industrial land uses. Approximately two percent of the entire population of the Great Lakes, or about 740,000 residents, live within the Lake Superior basin. (Rankin, 2002)

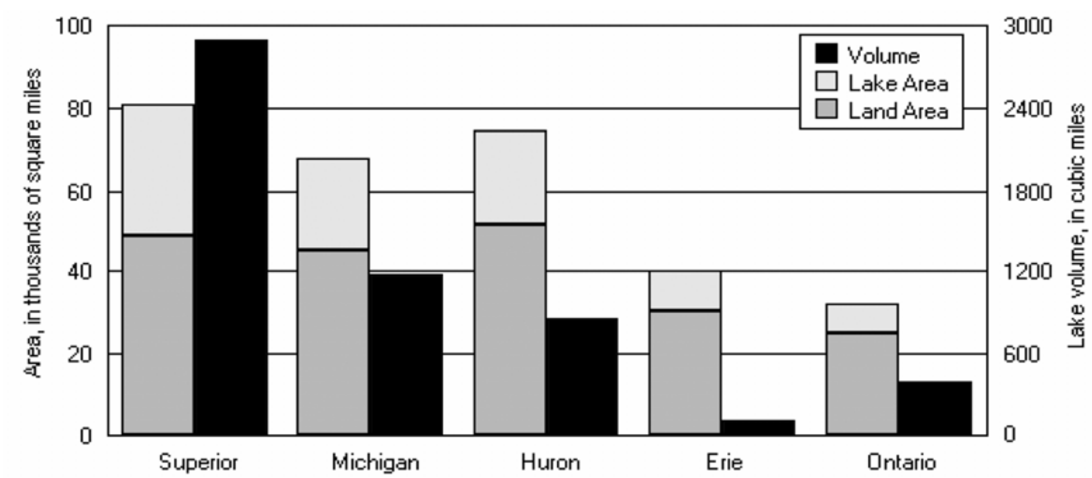

Figure A-2 Volumes and areas of the Great Lakes.

The majority of water entering Lake Superior, some 49 percent, is groundwater transported to the lake via the network of tributary rivers and streams. The surface runoff carried by these same tributaries accounts for just 17 percent of the water that enters the lake each year. The net contribution of over-lake precipitation (after evaporative losses are considered), accounts for 28 percent of new water each year. The remaining 6 percent of the water that refreshes

Lake Superior each year comes from the diversions into the system from the Hudson Bay drainage at Long Lac and Ogaki. Water exits Lake Superior through the St. Mary's River (Figure A-3). The average outflow rate in the St. Marys River is approximately 78,000 cubic feet per second (cfs). (Rankin, 2002)

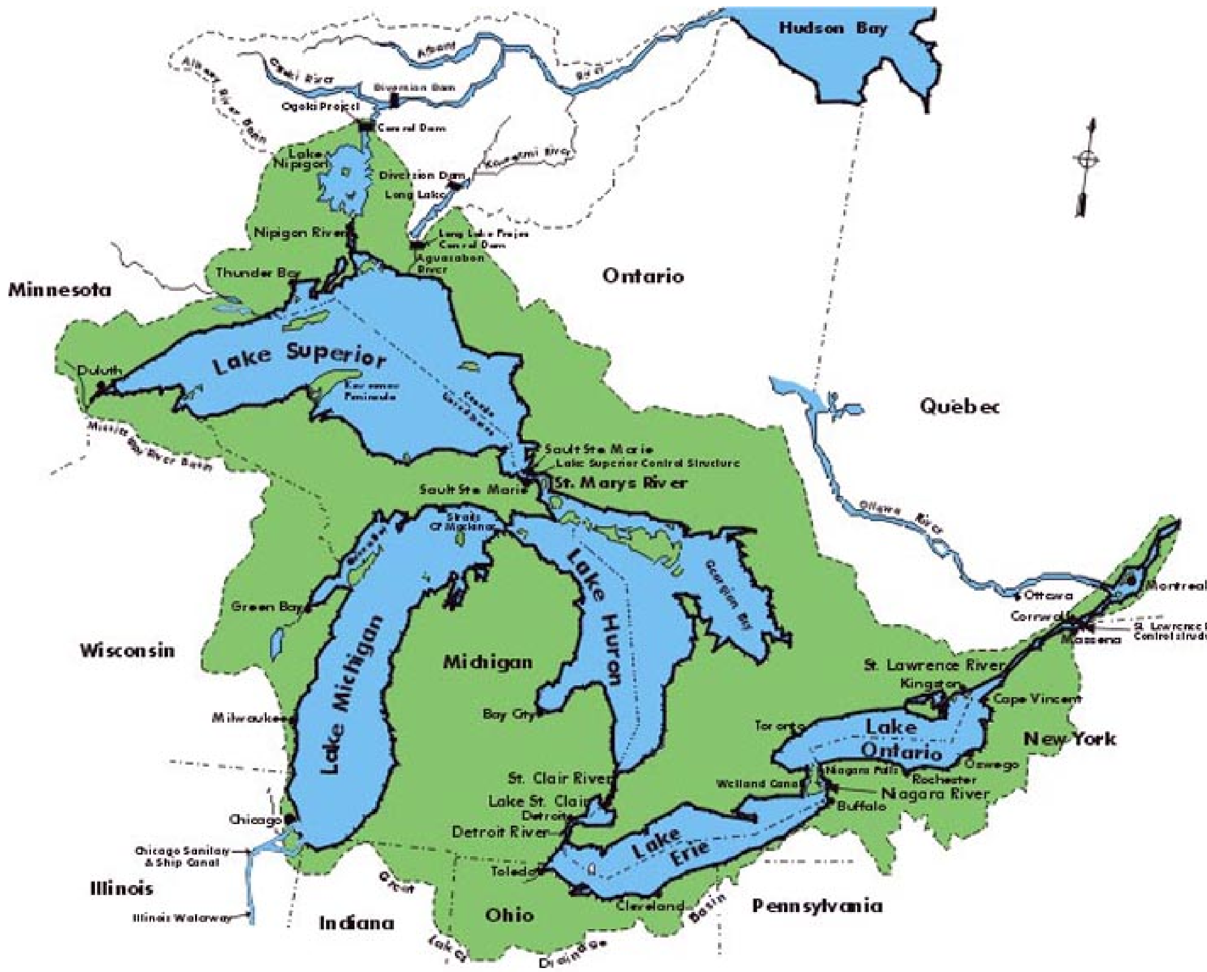

Figure A-3 Great Lakes system and its connecting waterways. (International Joint Commission)

Lakes Michigan and Huron
Lakes Huron and Michigan are described here as a single hydraulic system because they share a common outlet to the lower lakes and posses the same long-term water level.

Lake Michigan, the second largest by volume, is the only Great Lake entirely within the United States and borders Wisconsin, Illinois, Michigan and Indiana (Figure A-2). Its retention time is 99 years. The northern part is colder and less populated, except for the Fox River Valley, which drains into Green Bay. This bay has one of the most productive Great Lakes fisheries but receives the wastes from the world's largest concentration of pulp and paper mills. Due to the small population and limited water consumption within the northern portion of the watershed, many northern tributaries are dammed for industrial and public power production. The more temperate southern basin of Lake Michigan is one of the most urbanized areas in the system, with significant industrial, agricultural and domestic water use. (U.S. Environmental Protection Agency, 1995)

Lake Huron, which includes Georgian Bay, is the third largest of the lakes by volume (Figure A-2). It has a retention time of 22 years. The U.S.-Canada border divides Lake Huron almost in half. The Canadian portion of the lake is wholly within Ontario; the U.S. portion is located entirely within Michigan. Many Canadians and Americans own cottages on the shallow, sandy beaches of Huron and along the rocky shores of Georgian Bay. The Saginaw River basin is intensively farmed and contains the Flint and Saginaw-Bay City metropolitan areas. Saginaw Bay, like Green Bay, contains a very productive fishery. (Rankin, 2002; U.S. Environmental Protection Agency, 1995)

The Lake Huron-Michigan system is dominated by the flow from Lake Superior, which provides an estimated 42 percent of the year's water input. The contribution of groundwater reaching the system totals 35 – 20 percent in Lake Huron and 15 percent in Lake Michigan. Surface runoff transmitted through tributaries totals 12 percent of the annual average amount of water entering the system – 8 percent in Lake Huron and 4 percent in Lake Michigan. The net contribution of precipitation is 22 percent of the annual water budget – evenly divided between the two lakes. The system drains into the St. Clair River at about 187,000 cfs (5,295 cms). (Rankin, 2002)

Lake Erie

Lake Erie is the smallest of the lakes in volume and is exposed to the greatest effects from urbanization and agriculture (Figure A-2). Because of the fertile soils surrounding the lake, the area is intensively farmed. Lake Erie borders Michigan, Ohio, Pennsylvania, New York and Ontario. The lake also receives surface and ground waters for the northeast portion of the state of Indiana. Seventeen metropolitan areas with populations over 50,000 are located within the Lake Erie basin. It is the shallowest of the five lakes and therefore warms rapidly in the spring and summer and frequently freezes over in winter. It also has the shortest retention time of the lakes, 2.6 years. Fifty-nine percent of the basin is agricultural land, 17 percent is forested, 15 percent is industrial and urban, and the remaining 9 percent is used for other purposes. Thirteen million people live within the Lake Erie basin, 86 percent of them in the U.S. Despite its small size, the Lake Erie basin is the most populated of the Great Lakes and has the most agriculture. Lake Erie has also historically suffered significant damage from pollution. (Rankin, 2002; U.S. Environmental Protection Agency, 1995)

Eighty-eight percent of the water entering Lake Erie comes from the upper lakes via the Detroit - St. Clair rivers. The remaining 12 percent is evenly divided between surface runoff and ground water recharge from the lakes' tributaries. The precipitation falling on the lake is equivalent to the amount that evaporates from its surface. Lake Erie flows into Lake Ontario through the Niagara River and Welland Canal at an average rate of 212,000 cfs (6,000 cms). (Rankin, 2002)

Lake Ontario

Lake Ontario, although slightly larger in volume, is much deeper than its upstream neighbor, Lake Erie, with an average depth of 283 feet and a retention time of about 6 years (Figure A-

2). Lake Ontario borders New York and Ontario. Major urban industrial centers, such as Hamilton and Toronto, are located on its shore. The U.S. shore is less urbanized and is not intensively farmed, except for a narrow band along the lake (U.S. Environmental Protection Agency, 1995). Forty-nine percent of the basin is forested, 39 percent is used for agriculture, 7 percent is urbanized or industrialized land, and the remaining 5 percent is used for other purposes. Lake Ontario suffers from agricultural runoff and pollution. (Rankin, 2002)

Like Lake Erie, the majority of water entering Lake Ontario is from the upper lakes – about 85 percent of the average annual amount. Some 9 percent of the new water entering Lake Ontario is from groundwater carried to the lake by tributaries. Five percent is surface runoff carried in tributaries. The net contribution of precipitation accounts for nearly 2 percent. On an average basis, approximately 251,000 cfs (7,100 cms) leaves Lake Ontario via the St. Lawrence River. (Rankin, 2002)

Diversions
There are five diversions on the Great Lakes: the Long Lac and Ogoki diversions into Lake Superior, the Lake Michigan diversion at Chicago[4] 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 system, 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 one inch, had no measurable effect on lakes Michigan-Huron, lowered Lake Erie by almost four inches and raised Lake Ontario by less than one inch. (USACE and GLC, 1999)

Elevation Changes

Four of the five Great Lakes are at different elevations, leading like a series of steps toward the Atlantic Ocean (Figure A-4). The five individual lakes are connected to each other through waterways, 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.

[4] *The Lake Michigan diversion at Chicago is outside of the Great Lakes system.*

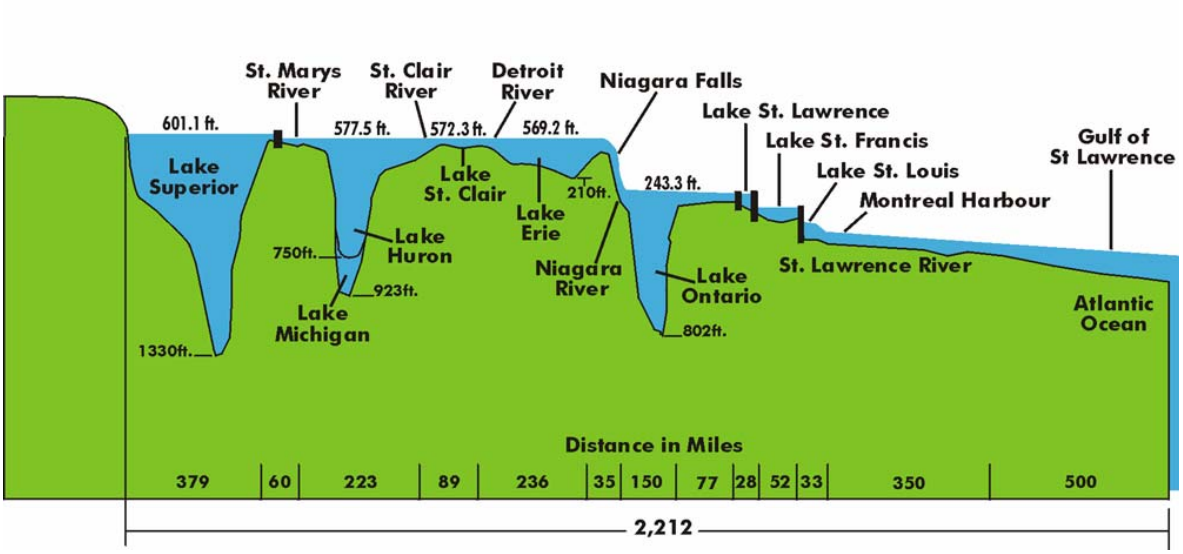

Figure A-4 Profile of the Great Lakes – St. Lawrence River System (U.S. Army Corps of Engineers)

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. (USACE and GLC, 1999)

Crustal Rebound

Beginning about 12-14,000 years ago, the last ice age concluded and the glaciers covering the Great Lakes began to recede northward. The glaciers were completely gone over the region about 6,000 years ago. 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 - St. Lawrence River basin continues to rise (Figure A-5). 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. (USACE and GLC, 1999)

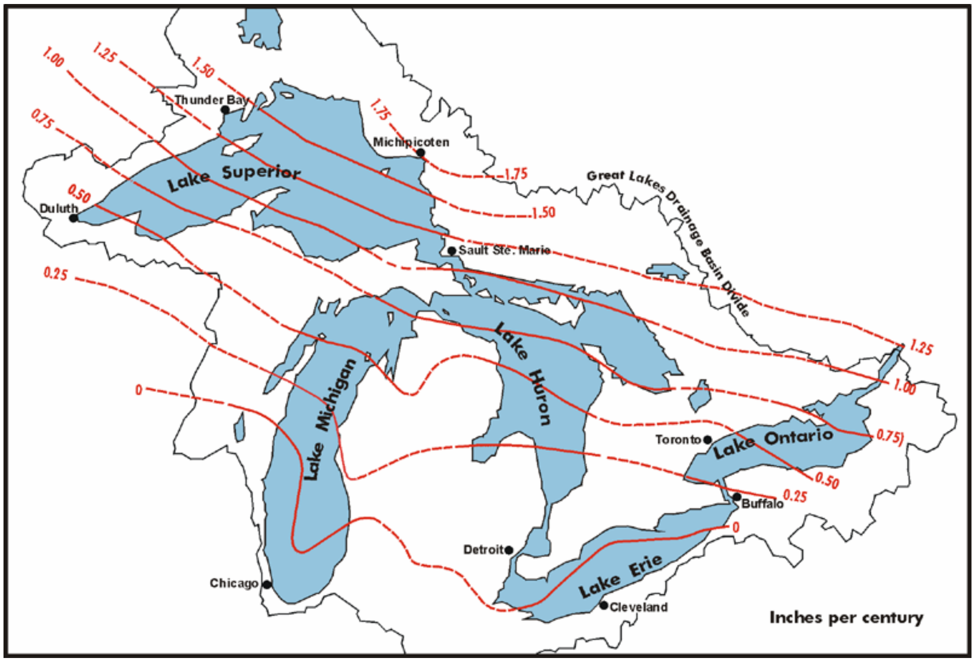

Figure A-5 Rate of crustal rebound for the Great Lakes - St. Lawrence River region (U.S. Army Corps of Engineers)

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. This tipping phenomenon is particularly significant for Lake Superior, and somewhat lesser for lakes Michigan, Huron, 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. (USACE and GLC, 1999)

Natural Forces that Shape the Great Lakes - St. Lawrence River Basin

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. (USACE and GLC, 1999)

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. Natural areas, such as wetlands, have evolved as a result of variations in water levels. Consequently, reducing these variations can have significant environmental consequences. (USACE and GLC, 1999)

The Hydrologic Cycle

The waters of the Great Lakes are, for the most part, a nonrenewable resource. They are composed of numerous aquifers that have filled with water over the centuries, waters that flow in the tributaries of the Great Lakes and waters that fill the lakes themselves. Lake levels are determined by the combined influence of precipitation (the primary source of water supply to the Great Lakes), upstream inflows, groundwater, surface runoff, evaporation, diversions into and out of the system, consumptive use, dredging and water level regulation. (IJC, 2000)

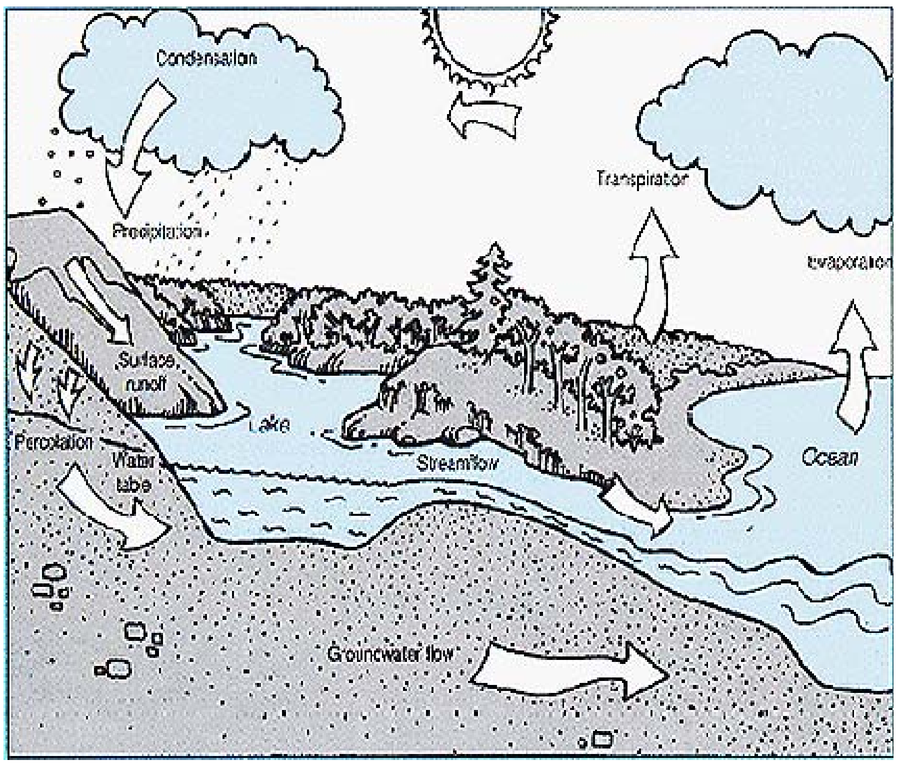

Figure A-6 The hydrologic cycle.

Water moves within the basin in accord with the hydrological cycle – the dominant physical process at work in the basin (Figure A-6). Air carries water vapor over the basin and deposits it on the land, where it eventually enters the lakes by way of direct precipitation, surface runoff into streams, or through the subsurface groundwater system. Once in the lakes, water moves by currents, is pushed by winds and storms and eventually flows out of each of the Great Lakes through their connecting waterways and the St. Lawrence River to the Atlantic Ocean.

The water that replenishes the Great Lakes comes from precipitation, which is driven by the region's climate. Rain and snow fall directly on the lakes and on the lands drained by tributary rivers and streams. The majority of water that enters the system falls as rain or snow on the watershed, becomes groundwater and is discharged to the lakes through tributaries. It has been estimated that approximately 53 percent of the water entering the Great Lakes takes this groundwater pathway.

The second largest category, about 24 percent of water on a system-wide basis, is surface runoff that drains into tributaries and, ultimately, to the lakes themselves. Over-lake precipitation, subtracting evaporation losses, accounts for about 20 percent of the water entering the lakes. The remaining 3 percent of inputs to the lakes are diversions into the system from the Hudson Bay drainage that enter Lake Superior (Long Lac and Ogaki Diversions) (Rankin, 2002).

Although the total volume in the lakes is vast, on average less than one percent of the waters of the Great Lakes are renewed annually by precipitation, surface water runoff and inflow from groundwater sources[5]. 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. (USACE and GLC, 1999)

Fluctuations in Lake Levels

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 (USACE and GLC, 1999).

Three types of water-level fluctuations occur on the Great Lakes. Short-term changes in outflows are usually a result of storm surge or seiches. Seasonal and annual fluctuations of the Great Lakes levels are caused by variability in hydrologic factors. Long-term or multi-year fluctuations result from persistent low or high water supplies.

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. 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. (USACE and GLC, 1999)

[5] The Great Lakes Information Network. "An Overview of Flows." Great Lakes - St. Lawrence Water Flows. (2000)

Sustained high winds from one direction can push the water level up at the downwind end of the lake and make the level drop by a corresponding amount at the windward 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. (USACE and GLC, 1999)

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. (USACE and GLC, 1999)

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 southern lakes usually occurring in June or July. Lake Superior, the northernmost lake, is generally the last lake to peak, usually in August or September. (USACE and GLC, 1999)

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. (USACE and GLC, 1999)

Global change could cause significant changes in long-term lake levels. Although debatable, most predictions indicate that climate change 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 - St. Lawrence River 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. (USACE and GLC, 1999)

Channelization and Outlet Controls

The water of the lakes and the many resources of the Great Lakes - St. Lawrence River basin have played a major role in the history and development of the United States and Canada. For the early European explorers and settlers, the lakes and their tributaries were the avenues for penetrating the continent, extracting valued resources and carrying local products abroad.

Dredging, control structures, locks, dams, hydroelectric facilities, canals and diversions have altered the hydrology of the Great Lakes - St. Lawrence River system. Of these, dredging and outflow control have been the most significant. Dredging has had a major permanent impact on water levels on the middle Great Lakes. Dredging in the St. Clair and Detroit rivers began as early as 1855. Further improvements were made incrementally to deepen these navigation channels, with major dredging projects occurring in the 1930s and 1960s. In addition, sand mining occurred in the St. Clair River from 1909 through 1926 to support local manufacturing. From 1880 to 1965, dredging and/or sand mining in the St. Clair River caused a permanent lowering of Lake Michigan-Huron by about 14 inches. (GLC, 2003)

Outflow control structures at the outlets of Lake Superior and Lake Ontario keep the levels of these lakes regulated within a range that is smaller than the range of levels that would occur under natural outflow conditions. The outflow from Lake Superior has been affected by human modifications beginning in 1822, with subsequent expansions occurring over time. The current outflow control structures have been in place since 1921. Outflows are adjusted monthly under the direction of the International Joint Commission (IJC) with an objective of maintaining the water levels on lakes Superior and Michigan-Huron in relative balance to their long-term seasonal averages. The St. Lawrence Seaway and Power Project, opened in 1960, incorporates outflow control structures to regulate Lake Ontario water levels, maintain hydropower operations, provide adequate depths for commercial navigation and protect the lower St. Lawrence River from flooding. (GLC, 2003)

The Great Lakes - St. Lawrence River Basin as a Physical and Economic Resource

The freshwater seas of the Great Lakes have made a vital contribution to the historical settlement, economic prosperity, culture and quality of life and to the diverse ecosystems of the basin and surrounding region. Today, about 36 million people reside in the basin itself. The basin is home to more than one-ninth of the population of the United States and one-third of the population of Canada. Some of the world's largest concentrations of industrial capacity are located in the Great Lakes - St. Lawrence River region. Nearly 25 percent of the total Canadian agricultural production and 7 percent of the American production are located in the basin. The United States considers the Great Lakes a fourth seacoast, and the Great Lakes - St. Lawrence River region is a dominant factor in the Canadian industrial economy. (USEPA, 1995)

Drinking water

Municipalities throughout the Great Lakes - St. Lawrence River 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. Millions of people in the Great Lakes - St. Lawrence River basin rely on groundwater for their sole supply of water. (USACE and GLC, 1999)

Agriculture

Agriculture in the Great Lakes - St. Lawrence River 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. West Michigan provides excellent conditions for orchards and vineyards. About one-third of the land in the basin is used for agriculture, supporting 25 percent of Canadian agricultural production and 7 percent of U.S. production. Irrigation represents a modest but growing consumptive use of regional water. (USACE and GLC, 1999)

Although agriculture contributed much to the economic prosperity of the region, the impacts on the system should be noted. The rapid, large-scale clearing of land for agriculture increased the movement of sediments into the lakes. As a result, tributaries and river deltas have been clogged, destroying fish habitats and spawning areas. Greater surface runoff led to increased seasonal fluctuation in water levels and the creation of more flood-prone lands along the waterways. Agricultural development has also contributed to Great Lakes pollution chiefly in the form of eutrophication. Agricultural chemicals used to control crop pests have found their way into the rivers and lakes, affecting plants, animals and human health. (USEPA, 1995)

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. Half of Canadian manufacturing and one-fifth of U.S. manufacturing is based within the region. The binational Great Lakes - St. Lawrence River 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 being returned after treatment. (USACE and GLC, 1999)

All industrial activities produce waste. Many of the dangers of industrial pollution to the Great Lakes and to human and environmental health were not recognized until recently in part due to the difficulty in detecting their presence and impacts. This is evident in the aging industrial disposal sites that are leaking chemical into the environment and in the sediments contaminated by long-standing industrial activities. Because pollutants tend to persist in the environment, levels must continue to be reduced. Pollution-prevention measures are being combined with cleanup initiatives across the Great Lakes. (USEPA, 1995)

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. (USACE and GLC, 1999)

Recreational Boating, Sport Fishing and Commercial Fishing

The Great Lakes offer outstanding tourism and recreation opportunities, ranging from wilderness areas such as the U.S. Isle Royale National Park to waterfront parks in major cities. A distinct four-season climate supports many types of recreation, from ice fishing and skiing in winter to boating, swimming and fishing in summer. There are about 911,000 registered recreational boats that use the Great Lakes; Michigan and Minnesota are near the top in U.S. boat registrations, and six Great Lakes states rank in the U.S. top ten. The commercial and sport fishing industry collectively exceeds $4 billion annually. (USACE and GLC, 1999)

Hydroelectric power

Hydroelectric power generation is by far the largest instream use of Great Lakes water. Hydroelectric power plants on the St. Marys, Niagara and St. Lawrence rivers are 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 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 region. (USACE and GLC, 1999)

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. (USACE and GLC, 1999)

References

American Fisheries Society, Ohio Chapter. 2001. A Guide to Ohio Streams.

Grannemann, N.G., R.J. Hunt, J.R. Nicholas, T.E. Reilly, and T.C. Winter. 2000. The

Importance of Ground Water in the Great Lakes Region. U.S. Geological Survey. Water-Resources Investigations Report 00-4008.

Great Lakes Commission. 2003. Toward a Water Resources Management Decision Support System.

International Joint Commission. 2000. Protection of the Waters of the Great Lakes.

Rankin, D. 2002. Freshwater Ecosystems and Human Populations: Great Lakes Case Study. Yale School of Forestry and Environmental Studies. Bulletin Series 107. URL: http://www.yale.edu/environment/publications/bulletin/107pdfs/107Rankin.pdf

U.S. Army Corps of Engineers (Detroit District) and Great Lakes Commission. 1999. Living with the Lakes: Understanding and Adapting to Great Lakes Water Level Changes.

U.S. Environmental Protection Agency. 1995. The Great Lakes: An Environmental Atlas and Resource Book.