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# *Flucuation of Great Lakes Levels*

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*THE ROCHESTER COMMITTEE FOR SCIENTIFIC INFORMATION*
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## Summary

Great Lakes levels fluctuate largely in response to natural factors, the most important ones being precipitation, evaporation and wind. The lakes have also experienced small changes in levels due to several man-made factors that affect the outflows, including navigation channel improvement, dredging, diversion and consumptive use of water. For Lake Ontario, the total range between the highest and lowest levels during the past century has been 6.6 feet (2.01 meters). Man rarely benefits from lake level fluctuations, and has attempted to lessen them through regulating the outflows of Lake Superior and Lake Ontario. Through man's regulation, the maximum range of stage (seasonal, daily, etc levels) has been reduced by only 16% for Lake Superior and 7% for Lake Ontario. The socio-economic problems which are used in determining lake levels are not considered in this bulletin.

## Background

(1) The Importance of Great Lakes Levels. "The lakes are used intensively by the large concentrations of people living in both the Canadian and the United States portions of the region. Economic activity depends heavily on the use of the lake system for commercial navigation and the generation of hydroelectric power. Many people live on the lakeshore and many more depend on the lakes for recreation, as well as for domestic water supply.

"The many uses of the lake system depend critically on the magnitude of lake levels and outflows. Commercial navigation depends on maintenance of adequate depths. The power entities need adequate flows to meet electric demands. Shore interests desire to avoid either extreme high levels, which will damage their property, or extreme low levels, which will interfere with recreational uses of the lakes. There is also increasing public concern for the environment and recognition of the value of the Great Lakes as an important natural resource." (2)

(2) Study of Lake Levels. Low lake levels that occured in the early 1960's prompted the governments of the United States and Canada to undertake a joint study of Great Lakes water levels**(4). The problem of fluctuation of lake levels was referred to the International Joint Commission (established by the Boundary Waters Treaty of 1909 to resolve problems along the lake and river boundary between the U.S. and Canada) (2, 3). The I.J.C. was to study

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** An outline of regulation studies made prior to this is presented in Regulation of Great Lakes Water Levels, Appendix B.

the factors that affected lake levels; the feasibility of their regulation; and the benefits that would accrue from regulation of lake levels (4). The I.J.C. established the Great Lakes Levels Board in December of 1964 to undertake the investigation of these matters (2,3,4). The final report of the Great Lakes Levels Board, entitled Regulation of Great Lakes Water Levels, appeared in 1973.

Why Lake Levels Fluctuate

The level of each of the Great Lakes represents a balance between inputs of water received by the lake, and outputs of water removed from the lake. Inputs include: A) Runoff from tributaries of the lake, including inflow from the lake immediately upstream, and from man-made diversions into the lake; B) Precipitation falling on the lake surface; C) Subsurface groundwater flowing into the lake. Outputs include: A) Evaporation from the lake surface; B) Outflow of water from the lake through its natural outlet or through man-made diversions out of the lake; C) Subsurface groundwater flowing out of the lake.

If the inputs of water into the lake exceed the outputs, the volume of water in the lake will increase and the lake levels will rise. Outflow from the lake will increase and the excess supply of water will be slowly distributed to the lakes downstream (1,2,5,6).

Natural Regulation of the Great Lakes

As a result of the relationship between the size and capacity of the lake basins and the size and capacity of the rivers connecting them, the Great Lakes comprise to a large degree a self-regulating natural system.

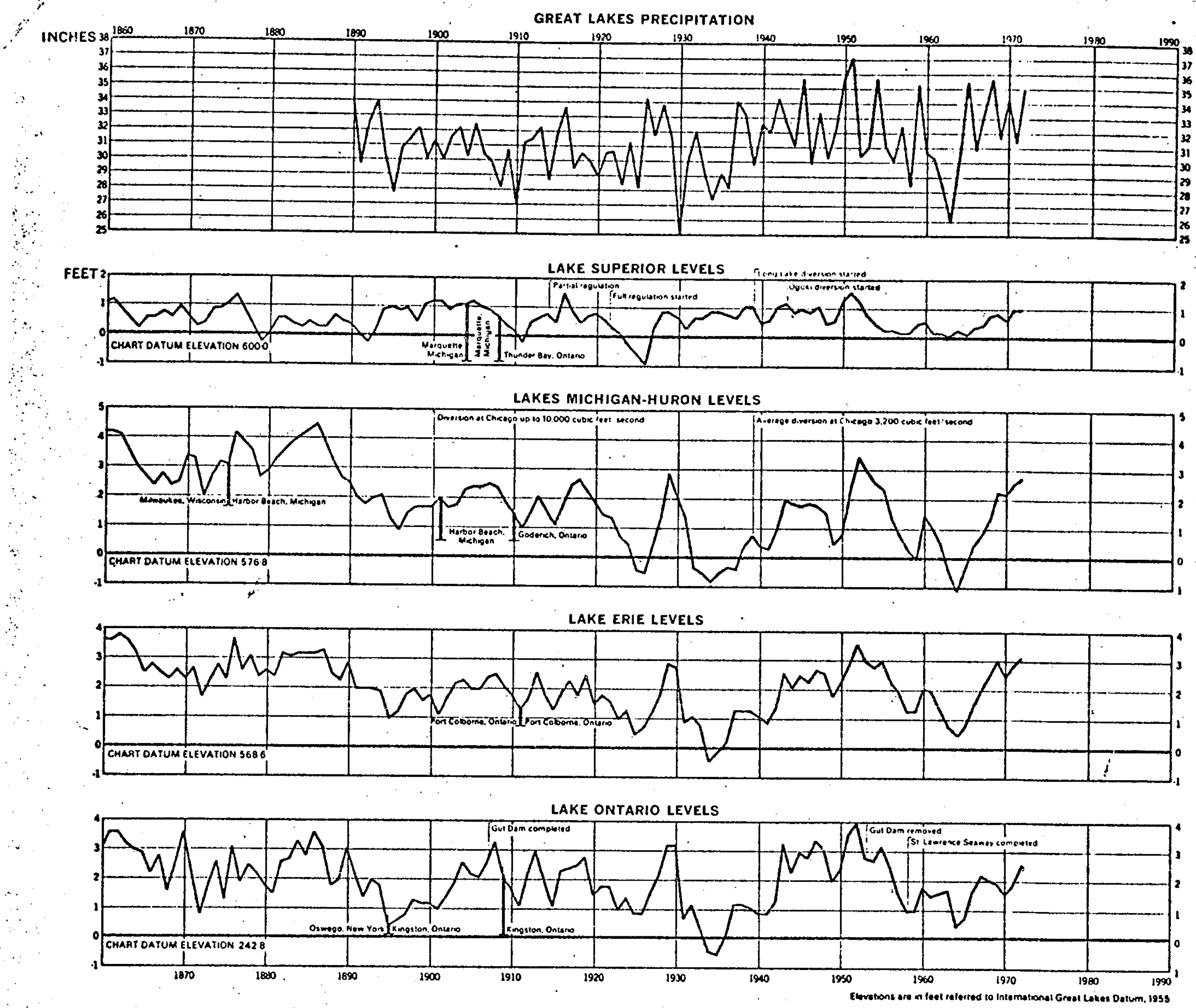
The Great Lakes contain one fifth of the earth's fresh surface water, or about 5,470 cubic miles (22,810 cubic kilometers) of water (1). Their surface area alone comprises 94,600 square miles (245,014 square kilometers) or almost one third of their entire drainage basin. As a result of their immense storage capacity and surface area, the Great Lakes require huge inputs or outputs of water before a change in lake storage will be manifested in a change in lake levels. To illustrate this, it has been estimated that the total amount of water stored in one foot over all the Great Lakes would be equal to the average flow of the St. Lawrence River for about four months. As a consequence, the magnitude of lake level fluctuation is not very great. During the period 1860 to 1972, the range between the recorded extreme high level and the recorded extreme low level was 3.8 feet (1.16 meters) for Lake Superior; 5.3 feet (1.62 meters) for Lake Erie; and 6.6 feet (2.01 meters) for Lakes Michigan, Huron and Ontario (2).

Seasonal variations in lake levels, which reflect the annual inputs and outputs of the hydrologic cycle also tend to be small, averaging 1 foot (.30 meters) for Lakes Superior, Michigan and Huron; 1.5 feet (.46 meters) on Lake Erie; and 1.9 feet (.58 meters) on Lake Ontario (2).

In comparison, however, to the size and capacity of the Great Lakes basins, the capacity of the rivers that connect and drain them is rather tiny (2). These rivers restrict the outflows from the Great Lakes, and their inability to quickly convery large changes in lake storage downstream has two important consequences for lake levels.

(1) High lake levels, which represent conditions of high supply, may persist long after the original input of water occurs. Note, in figure 1, that high levels persist for several years after periods of high precipitation.

Figure 1. Great Lakes Precipitation and Level (Annual Means).




SOURCE: THE CANADIAN HYDROGRAPHIC SERVICE
MARINE SCIENCES DIRECTORATE
DEPARTMENT OF THE ENVIRONMENT, OTTAWA

(2) Dissipation of changes in storage from upstream lakes to downstream lakes is slowed down. It takes several years for a change in Lake Superior's storage to be fully manifested in a change in the flow of the St. Lawrence River. Note, in Figure 1, that the levels are not always in phase on all lakes (2, 10).

## Natural Factors That Influence the Fluctuation of Lake Levels

Even though the fluctuations of the Great Lakes levels are not very great, they are critical to the various uses made of the lakes. Variations in the amount of precipitation and evaporation are the most important factors influencing the seasonal and long term fluctuations of lake levels. Wind and meteorologic disturbances can cause drastic short term changes in levels. Other factors that exert only a small influence on lake levels include the retarding effects of winter ice buildup in channels, the effects of tides and movement of the earth's crust (2).

(A) Precipitation, falling as rain or snow on the lake surface and tributary land areas, is the original source of water reaching the Great Lakes, and comprises the major input (7). Small seasonal variation in precipitation characterizes the Great Lakes Basin. On the average, Lake Superior's precipitation varies from about 3 to 4 inches (7.62 to 10.16 cm) on its surface during the summer and fall months to about 2 inches (5.08 cm) during the winter months (8). From Lake Superior southeastward to Lake Ontario, the proportion of winter precipitation increases and the seasonal variation lessens (1, 8). On the average, Lake Ontario receives about 3 inches (7.62 cm) in all months.

Periods of several months of high or low precipitation that occur for several successive years lead to long term fluctuations in lake levels (8,2,4,). High precipitation during 5 of the 6 years preceeding 1952 led to extreme high levels in 1951 and 1952 (2, 7). Low precipitation in the early 1960's led to low lake levels in 1964 and 1965 (7).

Precipitation averaged 8% higher than the mean during the period of 1967 to 1972 (2). As a result of these high supplies, all of the lakes except for Lake Superior rose above their normal levels in 1973 (4). Lakes Michigan and Huron reached their highest levels since 1886. Lake Erie and Lake St. Clair reached record highs(2).

(B) Evaporation, from the lake surface and tributary land areas is an important output of water from the Great Lakes Basin (8). On the average, most of the water reaching the lakes in the form of precipitation is later returned to the atmosphere by evaporation.

Table 1. Relationship Between Evaporation and Precipitation on the Surface of the Great Lakes (Based on data for the period of Oct. 1950 - Sept. 1960) (3).

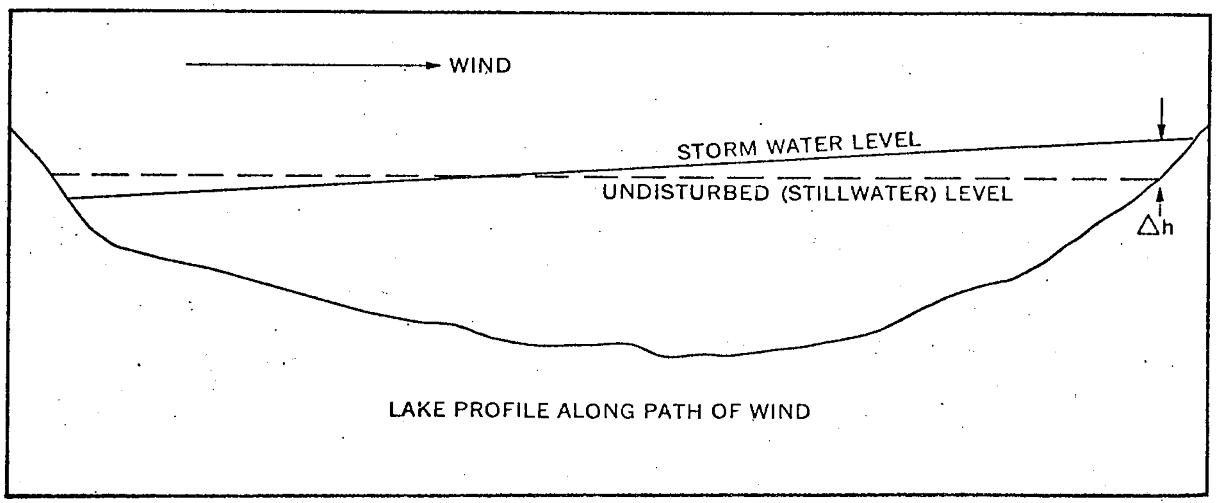
| Lake(s) | Approx. Average Annual Evaporation from Lake Surface (inches) | (cms.) | Average Annual Precipitation on Lake Surface (inches) | (cms.) | Average Annual Evaporation as a Percentage of Average Annual Precipitation on Lake Surface |
|---|---|---|---|---|---|
| Superior | 22 | 56 | 32 | 81 | 69 |
| Michigan-Huron | 26 | 66 | 33 | 84 | 79 |
| Erie | 36 | 91 | 36 | 91 | 100 |
| Ontario | 25 | 64 | 34 | 86 | 74 |

The amount of evaporation depends on several factors including "the characteristics of the air masses passing over the lake, the available energy, ice cover, and the heat storage capacity of the lake (2). There is a pronounced seasonal variation in the amount of evaporation that occurs. In general, evaporation from the lake surface is least in the spring and early summer when the lakes are cold in relation to the air above them (1,7,8). Evaporation from the lake surface is greatest in the fall and winter when the lakes are warm in contrast to the cold dry air above them (1,7,8). Lake Erie, which becomes ice covered in the winter, experiences the greatest evaporation in the fall (8).

Long periods of high precipitation that lead to long term rises in lake levels tend to be reinforced by low evaporation to the extent that the two factors occur simultaneously: the cloud cover associated with heavy precipitation reduces the amount of solar energy available for evaporation. Periods of low precipitation tend to be likewise reinforced by high evaporation to lead to low levels (7,2,1,). Brazel and Phillips noted the high proportion of days with measurable precipitation, and low numbers of hours of sunshine for stations around the lower Great Lakes during the high levels of 1972 (9).

(C) High winds and differences in barometric pressure, that occur when a storm passes over the lakes, can have temporary but dramatic effects on lake levels (6). Persistent strong winds blowing along the length of a lake build up the water level on the downwind shore of the lake, and reduce the water level on the upwind shore (11). This phenomenon, called "wind set-up", lasts for as long as the high winds persist (6). The difference in levels between the downwind and upwind shores that result from wind set-up may be as much as 7 feet (2.13 meters) (2). Wind set-up is temporary, lasting usually less than one day, and does not cause a change in the volume of water contained in the lake; rather it simply "tilts" the surface (1,2) (see figure 2). When pressure over the lake becomes equalized, and winds die down as the storm passes, the levels quickly change, sometimes resulting in oscillations of over a foot in magnitude known as "seiches" (6). Set up and seiche phenomena are greatest on long shallow water bodies such as Lake Erie (6).

Figure 2. Diagram of Storm Effects on Water Levels (2)




The passage of a high or low pressure system over the lakes, alone, can result in a change in water level of up to 6 inches (15.24 cms.)(10). While these disturbances due to wind and pressure differences are only temporary, they are the major cause of flood damage and shore erosion. Damage from wind set-up and seiche would occur even if the lakes could be maintained at their average levels (4).

(D) Ice cover and ice jams: the formation of cover ice and of ice jams in the channels of the outlet rivers of the Great Lakes reduces their winter outflows. Insofar as lake levels are concerned, the ice jams on the St. Clair River are most important (2).

The ice cover on Lake Huron begins to form in January, and during a normal winter, 60% of the lake surface becomes ice covered (8). Predominant northwest winds break up the ice cover and the floes form ice jams in the St. Clair River (2). The winter outflows of this river are reduced by 10% on the average but have been reduced by as much as 50%. As a result, the levels of Lakes Michigan and Huron are raised and the levels of Lake St. Clair and Lake Erie are lowered. When the spring break-up occurs, outflows from Lake Huron are higher than normal, and the seasonal lowering of Lakes St. Clair and Erie is gradually reversed, those lakes reaching their normal levels by the following winter (2). It is estimated, however, that the effects of ice retardation on the outflows of Lake Huron is to raise the average level of Lakes Michigan and Huron by 4.8 inches (12.192 cm.)(2).

(E) Tides: solar and lunar tides have only minor effects on Great Lakes levels. The largest or spring tide is less than 2 inches (5.08 cm.) on Lake Superior, the largest lake (2,4).

(F) Movement of the earth's crust has a very minute influence on lake levels. Slow uplift of the earth's crust due to post-glacial isostatic rebound is still taking place in the Great Lakes basin. This occurs at different rates, tending to be a little greater for Lakes Superior, Ontario and northern Lake Huron, less for Lakes Michigan, Erie and southern Lake Huron. The entire basin may be thought of as being slowly tilted several inches per century upward to the northeast. Thus, the shorelines of the northeastern parts of the lake basins are slowly emerging with respect to those of the southwestern parts of the lake basins, which are slowly being submerged (1,2,11). The total supply of water to the lakes is not changing due to crustal movement (4).

## Man-Made Influences on Lake Levels

Man has caused small fluctuations in lake levels through engaging in certain activities that affect the magnitudes of inflow and outflow of the lakes. These activities include the improvement of channels for navigation, dredging of material from the channel bottoms, diversions of water into and out of the lakes, consumptive use of water for industrial, agricultural and domestic water supplies, and the intentional regulation of water levels and outflows (1). Further control of the winter ice cover of the lakes will have some small, long term effect in lowering their levels (1). "Increased urbanization, industrialization, intensified agricultural practices and the use of phosphate-based detergents in recent decades" in the Great Lakes basin has led to increased nutrient pollution of the lake water (12). The International Great Lakes Levels Board has reported that the increased nutrient content of the Great Lakes surface waters has resulted in increased growth of aquatic vegetation in the channels of the connecting rivers. During the summer, this vegetation can reduce the outflows of the Niagara River by about 5%. The effects of this summer decrease in outflows on lake levels have not been confirmed (1,2). Gradual changes in the hydrology of the Great Lakes Basin have occured during the past 150 years due to man's activities of clearing, irrigating or draining the land, of controlling the hydrologic regimes of the tributary waters, and of creating widespread urban and suburban environments (1). The effects of these progressive changes on Great Lakes levels are difficult to quantify. Most man-made influences on lake levels are insignificant when compared to natural influences.

(A) Regulation of levels and outflows: The Level and outflows of Lake Superior have been controlled by regulatory works in the St. Mary's River since 1921. It has been calculated that under the current regulation plan, the "1955 Modified Rule of 1949", the range of levels on Lake Superior is decreased by about 7 inches (17.78 cm.); the range of levels on Lakes Michigan and Huron is increased by about 2 inches (5.08 cm.); and the range of levels on Lake Erie hardly affected (2). Lake Ontario is not affected because its level and outflows have been controlled since 1958 by regulatory works in the St. Lawrence River. It has been calculated that under its current regulation plan, "Plan 1958-D", Lake Ontario's range of levels has been decreased by about 5 inches (12.7 cm.) (2). Through regulation, the range of levels that occurs due to natural factors has been reduced by only 16% for Lake Superior and 7% for Lake Ontario.

(B) Improvement of channels for navigation: From the earliest use made of the Great Lakes-St. Lawrence River system as a water route by settlers, man has been making changes in the river channels to improve navigation (1,2). Since the outflows from Lake Ontario are controlled, recent channel enlargements have not increased the outflows from the whole system (1). However, channel changes in the St. Clair and Detroit Rivers, completed in 1962, are estimated to have lowered the unregulated levels of Lakes Michigan and Huron by about 7 inches (17.78 cm.). Lake St. Clair was lowered by about 1.5 inches (3.81 cm.). The inflow to Lake Erie was increased and the level of this lake temporarily rose, but the effect had become negligible by 1969 (2).

(C) Dredging of material from channel bottoms: Most dredging in channels has been done to facilitate regulation of a lake or to improve navigation, and the effects of these have already been discussed. In addition, indiscriminate commercial dredging of gravel in the St. Clair River between 1908 and 1925 is reported to have caused a lowering in the levels of Lakes Michigan and Huron by about 4 inches (10.16 cm.)(1,2).

(D) Diversions: There are four major diversions in the Great Lakes system. These have some effect on the levels of unregulated lakes, but the levels of Lake Superior and Lake Ontario are not affected because their outflows are regulated, and compensate for the effects of diversion (2).

Two of these diversions, the Long Lake and Ogoki projects, divert water from part of the James Bay Drainage into Lake Superior (1). The amount of water added to the Great Lakes from these two diversions has averaged about 5,000 cfs, ultimately raising the levels of Lakes Michigan and Huron by about 4.5 inches (11.43 cm.); of Lake Erie by about 3 inches (7.62 cm.) and the level of the St. Lawrence River at Montreal Harbor by about 3 inches (7.62 cm.)(1).

Water has been diverted out of the Great Lakes at Chicago into the Mississippi River since 1848. The amount of water diverted out of the Great Lakes through the Chicago Diversion now averages about 3,200 cfs, but this has been as high as 10,000 cfs in the past. The Chicago Diversion lowers the levels of Lakes Michigan and Huron by about 3 inches (7.62 cm.), and the levels of Lake Erie and the St. Lawrence at Montreal Harbor by about 1.8 inches (4.53 cm.)(1).

The fourth major diversion is from Lake Erie to Lake Ontario, bypassing the Niagara River through the Welland Canal. This diversion has averaged about 7,000 cfs since 1950 and has lowered Lake Erie levels by about 4 inches (10.16cm.) and Lake Michigan and Lake Huron levels by about 1 inch (2.54 cm.)(1).

(E) Consumptive use of water: Water is removed from the lakes for use in industry, power generation, agriculture and domestic water supplies and some of it is not returned to the lakes. The amount of water removed for consumption is expected to gradually increase in the future, but at the present, lowers the levels of unregulated lakes by only about 1.8 inches (4.57 cm.)(1).

## Conclusions

The Great Lakes respond with changes in level to a variety of natural factors, and to a lesser extent, to man-made factors. While most changes in levels are not very great, they can be detrimental to man's activities, and damaging to shoreline property. In an attempt to lessen the adverse effects of lake level fluctuations, man has brought the outflows of Lakes Superior and Ontario under some control. The extent to which man has been successful may be judged by comparing the magnitude of fluctuation that occurs due to natural factors with the magnitude of reduced fluctuation that results from regulation of lake outflows. The range in long term fluctuations of lake levels due to natural factors varies from 6 to 15 times greater than the amount by which man can control or reduce them. The largest and most damaging lake level fluctuations are a result of short term meteorological disturbances. Man is powerless to control these fluctuations.

The fluctuations of Great Lakes levels and complexities of lake level regulation have been and continue to be intensively studied by the International Joint Commission. It has thoroughly explored the possibilities for further regulations of the lakes, and the benefits and adverse effects for all uses of the lakes that would result from further regulation. In addition, studies made on the data collected during the International Field Year on the Great Lakes (IFYGL, 1972-1973) should make important contributions to the better understanding of processes of the hydrology of the Great Lakes and the factors that influence their levels (13).

One fact, however, becomes clear: In terms of reducing the damage from lake level fluctuations to shoreline property and structures, changes in the zoning and land use of lake shore land will be far more important than any further regulation of lake levels and outflows.

## References


(1) *Regulation of Great Lakes Water Levels, Appendix A: Hydrology and Hydraulics,* Report to the International Joint Commission by the International Great Lakes Levels Board, December 7, 1973

(2) *Regulation of Great Lakes Water Levels,* Report to the International Joint Commission by the Great Lakes Levels Board, December 7, 1973

(3) *I.J.C. International Joint Commission,* Department of State Publication 8750, Washington D.C. U.S. Government Printing Office, January 1974

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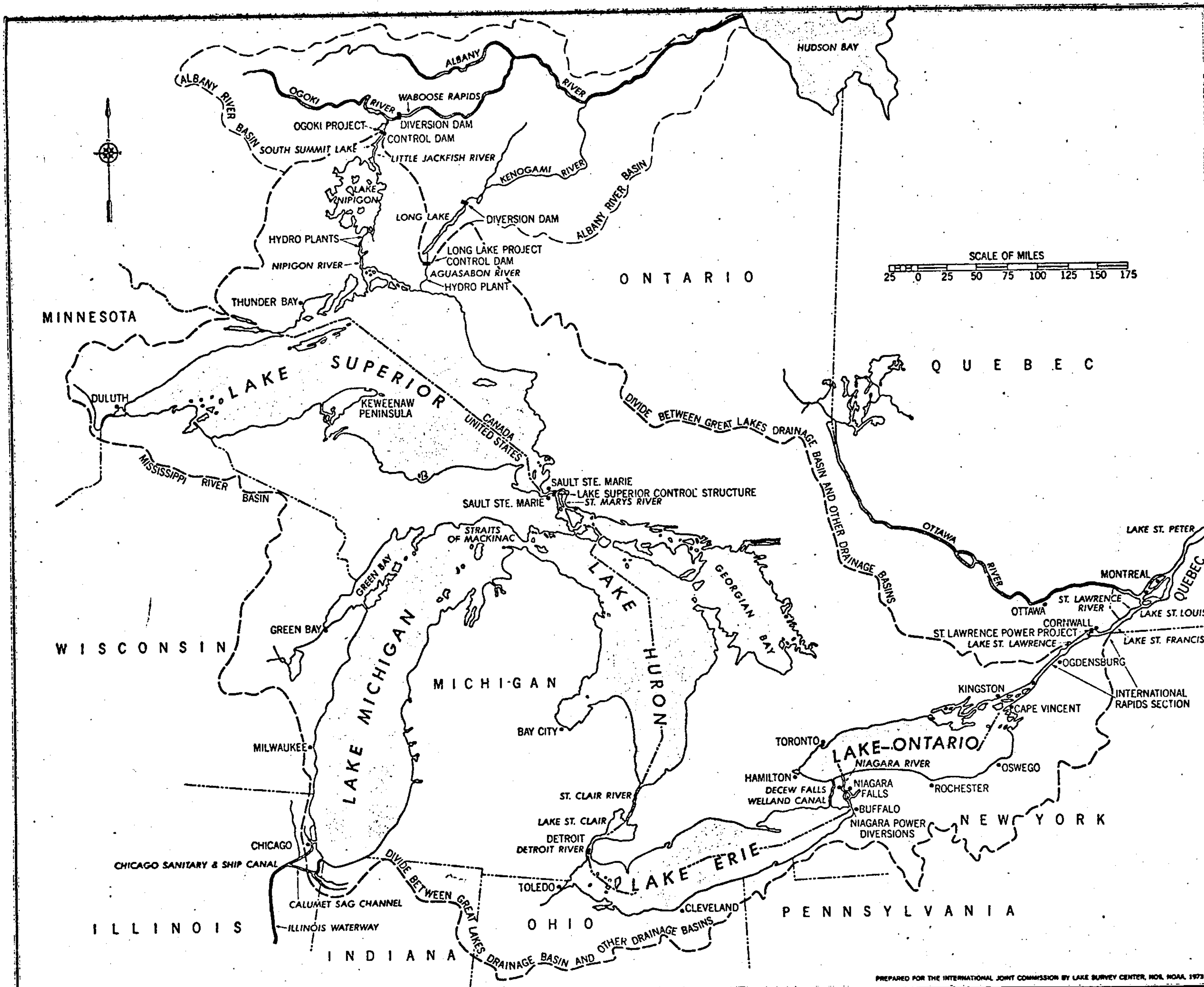


GREAT LAKES—ST. LAWRENCE RIVER DRAINAGE SYSTEM[1]

## SOURCES FOR FURTHER INFORMATION

Regulation of Great Lakes Water Levels, Report to the International Joint Commission by the International Great Lakes Levels Board, December 7, 1973.
Appendix A - Hydrology and Hydraulics
Appendix B - Lake Regulation
Appendix C - Shore Property
Appendix D - Fish, Wildlife and Recreation
Appendix E - Commercial Navigation
Appendix F - Power
Appendix G - Regulatory Works
(Appendices A-G bound separately)

### SUMMARY REPORTS:

Regulation of Great Lakes Water Levels: A Summary Report/1974, International Great Lakes Levels Board.

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### WATER LEVELS DATA:

Monthly Bulletins and Annual Compilations of Daily Water Levels Data are available from: U.S. Department of Commerce
NOAA-National Ocean Survey
Lake Survey Center
630 Federal Building and U.S. Courthouse
Detroit, Michigan 48226

Information on water levels and depths in connecting channels is available from: Department of the Army
Detroit District
Corps of Engineers
P.O. Box 1027
Detroit, Michigan 48226

Water Levels Data are also available from the Canadian Government through:
Tides and Water Levels
Canadian Hydrographic Service
Marine Sciences Directorate
Department of the Environment
Ottawa, Canada

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**FILMS:**

"Not Man's to Command" from Public Relations Unit<br>
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