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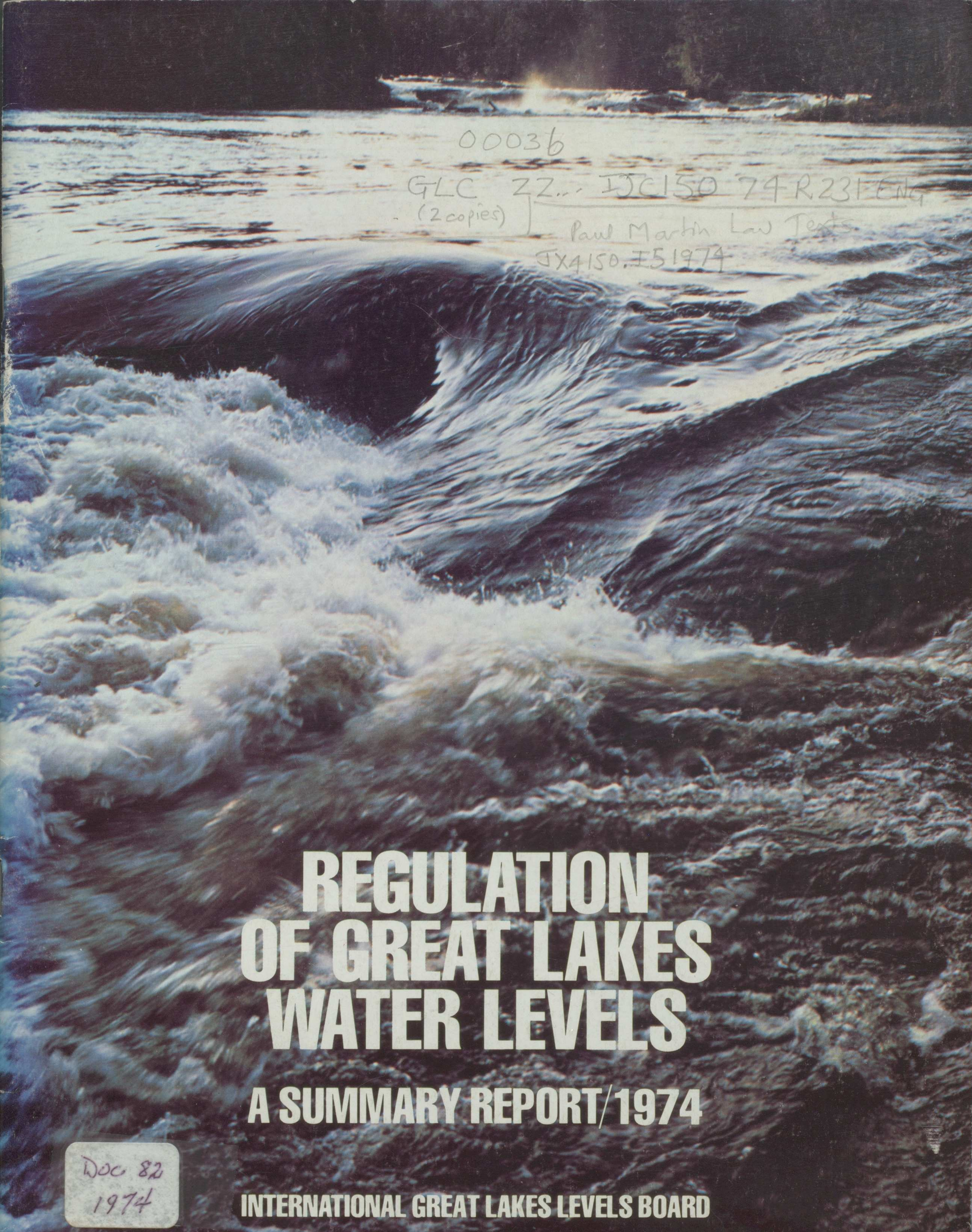

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REGULATION OF GREAT LAKES WATER LEVELS

A SUMMARY REPORT/1974

DOC 82
1974

INTERNATIONAL GREAT LAKES LEVELS BOARD

INTRODUCTION

The Great Lakes:

☐ *are a body of fresh water bigger in area than the states of New York and Pennsylvania combined.*

☐ *contain almost 1/5 of the world's fresh, liquid, surface water—so much that it could cover the whole of North America to a depth of three feet.*

☐ *are a shipping route for more than 350,000,000 tons of cargo every year.*

☐ *have a shoreline that could stretch nearly half-way around the world.*

☐ *are the source of 70% of the water used by 600 communities in Ontario alone.*

☐ *provide a total of more than 50 billion kilowatt hours of power each year.*

☐ *moderate the climate of the entire centre of the continent.*

☐ *have almost 1,000 miles of international boundary between Canada and the U.S.A.*

☐ *provide a playground for many millions of people of both countries.*

The Great Lakes are an international resource and an international responsibility. No other body of fresh water in the world is so important to the standard and style of living of so many people.

In 1964, in view of the then prevailing extreme low lake levels and the highs of 1952, the governments of Canada and the U.S. decided upon a joint study of the water levels in the lakes to determine answers to three fundamental questions. What good, or harm, results from high or low water levels? Can the range between high and low be reduced? What can be done to regulate those levels for the greatest benefit of the public in terms that cover every aspect of living, from power requirements to shipping to cottage ownership to ecology to every other consideration?

This enormous study took nine years to complete. It took the cooperation of 12 governments (including 8 lake states and 2 provinces) and experts from disciplines of many kinds.

The book you are now reading is a summary of the study. It touches upon all the points found in the main report, and features some of the main statistics, the problems, alternative methods of regulating the water levels, the resulting benefits, and findings and conclusions.

Study Terms of Reference:

On October 7, 1964, the Governments of Canada and the United States submitted the following Reference to the International Joint Commission (IJC — established by the Boundary Waters Treaty of 1909) concerning Great Lakes water levels:

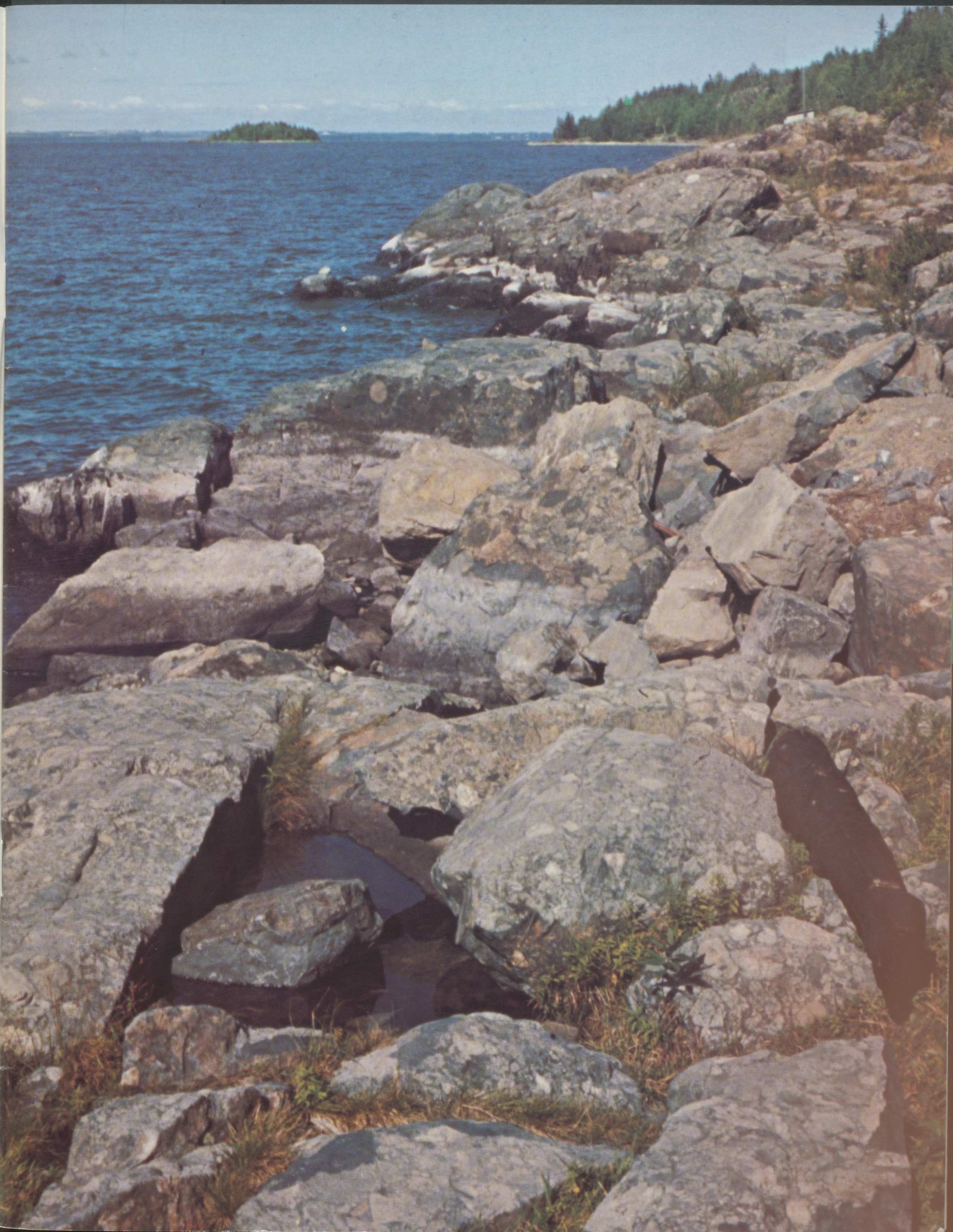
"In order to determine whether measures within the Great Lakes basin can be taken in the public interest to regulate further the levels of the Great Lakes or any of them and their connecting waters so as to reduce the extremes of stage which have been experienced, and for the beneficial effects in these waters described hereunder, the Governments of Canada and the United States have agreed to refer the matter to the International Joint Commission for investigation and report pursuant to Article IX of the Boundary Waters Treaty of 1909.

"It is desired that the Commission study the various factors which affect the fluctuations of these water levels and determine whether, in its judgment, action would be practicable and in the public interest from the points of view of both Governments for the purposes of bringing about a more beneficial range of stage for, and improvement in: (a) domestic water supply and sanitation; (b) navigation; (c) water for power and industry; (d) flood control; (e) agriculture; (f) fish and wildlife; (g) recreation; and (h) other beneficial public purposes.

"In the event that the Commission should find that changes in existing works or that other measures would be practicable and in the public interest in light of the foregoing purposes, it should indicate how the various interests on either side of the boundary would be benefited or adversely affected thereby. The Commission should estimate the cost of such changes in existing works or of such other measures and the cost of any remedial works that might be found to be necessary and make an appraisal of the value to the two countries, jointly and separately, of such measures. For the purpose of assisting the Commission in its investigations and otherwise in the performance of its duties under this Reference, the two Governments will, upon request, make available to the Commission the services of engineers and other specially qualified personnel of their governmental agencies and such information and technical data as may have been acquired or as may be acquired by them during the course of the investigation.

"The two Governments have agreed that when the Commission's report is received they will consider whether any examination of further measures which might alleviate the problem should be carried out, including extending the scope of the present Reference.

"The Commission is requested to submit its report to the two Governments as soon as may be practicable."



SYNOPSIS

"If we don't have 27 feet in the channels we can't take on a full load. The whole lake commerce system could be slowed down."

"We need the water high enough to maintain a good flow at peak load times."

"If the water leaves the marshland you're going to see a significant drop in wild fowl population. And fish spawning grounds will lose out as well."

"When the level is too low our intakes get exposed. We need a good depth of water."

"I don't want the lake coming in my front door. I want the water just low enough that we get a proper beach for the kids."

Not all Great Lakes water levels satisfy all the people, all the time. But with regulation (both of the lake levels and of the people who use them) and legislation, levels to satisfy most needs can be effectively achieved.

The water levels in the Great Lakes rise or fall in direct proportion to the amount of rain and snow falling on the basin. The only way water gets into the Lakes is through precipitation and run-off from the surrounding land. The only natural ways for it to get out are through evaporation or through escape down the connecting river system, through the St. Lawrence River and out to the ocean.

The whole system is a natural reservoir of remarkable efficiency. The outlet rivers are quite constant in their flow with the maximums only two or three times as great as the minimums. This is in contrast to a maximum/minimum flow ratio of about 30:1 in the Mississippi River and as high as 60:1 for the Saskatchewan River—two mighty rivers of North America. High water tends to remain in the Lakes, escaping only slowly and a low water situation takes time to build up to average.

When excessive precipitation continues over extended periods, as in the early 1970's and in the 1950's the Lakes are high, marshes important to wildlife are flooded, and cottage owners begin to lose their property to flood water.

When precipitation is low, as it was in the early 1930's and mid-1960's, the levels fall and commercial shipping interests, recreational boat-owners and hydro-electric power purchasers are in trouble.

What can be done to reconcile the different needs of the different sections of the public? Can a way be found to maintain the water level of the Great Lakes in a balance that will satisfy everybody?

There are already some regulatory works in use on the Great Lakes. Lake Superior and Lake Ontario have dams at their outlets. As well, the St. Clair has been dredged for navigational purposes and there are four major diversions of water which affect the levels to a limited extent.

However, the effects of these are dwarfed by the natural forces affecting the levels of the Lakes. The problem remains that a few years of heavier than average precipitation can push the levels of some lakes by as much as 6.6 feet above their low water marks. When you add the further effects of wind which can push the water up about eight feet at the downwind end of the lake, the problems of control become complicated. Indeed, under some weather conditions, the problems of control are greater than any regulatory work can accommodate.

Different Methods of Control Were Studied

The International Great Lakes Levels Board was given the task of finding out all the factors which affect water levels in the Great Lakes by the International Joint Commission. It was then to work out ways of controlling these levels. The investigation was to include the creation of new ideas and a review of existing methods. The Board was also to estimate the costs of putting these ideas into operation and to assess the probable effects of the resulting hydrological, economical, environmental and aesthetic changes, both beneficial and adverse.

The Board was comprised of: for the U.S., a representative of the Army Corps of Engineers, the Department of the Interior, and the Department of Transportation; for Canada, a representative of the Department of Public Works, the Ministry of Transport, and the Department of the Environment.

The Board set up a working committee which then brought together experts from every relevant discipline.

This committee began its work on January 6th, 1965 and completed its report nine years later.

The study started with the collection and comparison of physical measurements of every kind. Precipitation records, flow rates, even the minute effects of the movements of the Earth's crust were considered. The public was heard from in meetings convened on both sides of the border. Through computerized mathematical models the effects of a number of proposed plans were studied from every aspect, every discipline.

The completed report and its seven appendices (listed on page 37) add up to about 2000 pages.

GREAT LAKES PHYSICAL AND HYDROLOGICAL DATA
(from historical record: 1860-1973)

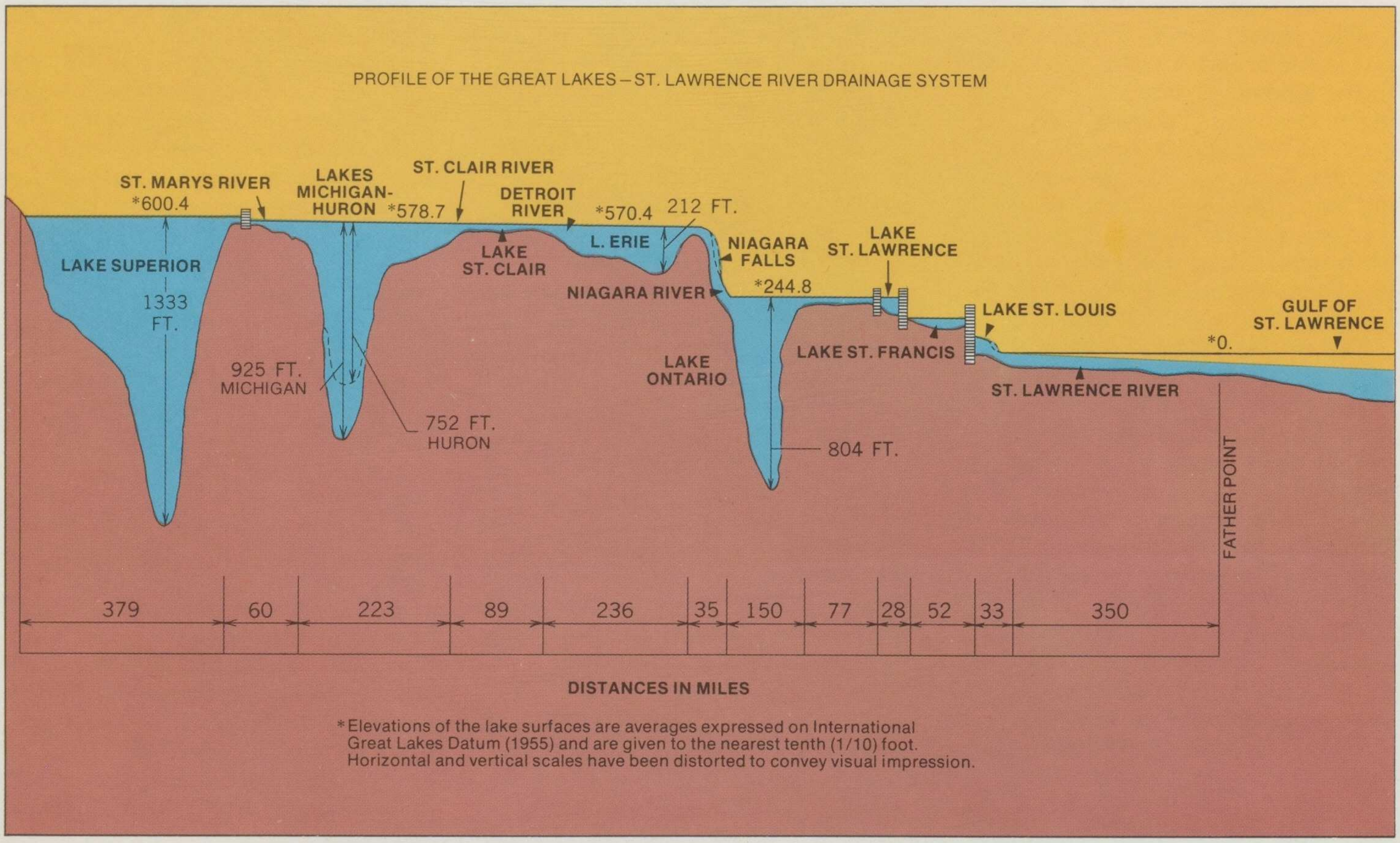
	Drainage Area; sq. mi.		Recorded Elevations			Range of Recorded Elevations				Recorded Outflows		
Lake	Land	Water Surface	Max.	Min.	Average	Long Term	Seasonal Max.	Seasonal Min.	Seasonal Ave.	Max.	Min.	Ave.
Superior	49,300	31,700	602.06	598.23	600.40	3.8	1.9	0.4	1.1	127,000	40,900	75,300
Michigan-Huron	97,400	45,300	581.94	575.35	578.71	6.6	2.2	0.1	1.1	245,000*	99.000	188.200
Erie	29,700**	10,300	573.51*	567.49	570.42	6.0	2.7	0.5	1.5	265,000*	116,000	202,600
Ontario	27,200	7,600	248.06	241.45	244.78	6.6	3.6	0.7	1.9	350,000*	154,000	240,300

*Maximums established in 1973
**Includes Lake St. Clair and its local drainage area

Note: Elevations in feet, International Great Lakes Datum (1955)
Outflows in cubic feet per second

A TOURIST'S GUIDE TO THE LAKES

The lakes are like a series of bowls, one above the other, connected by narrow channels.



Lake Superior and St. Marys River

Lake Superior is the uppermost and largest of the Lakes, discharging through the St. Marys River into Lake Huron.

The first 14 miles of the river fall less than three inches. Then, in the St. Marys Rapids it drops about 20 feet in a distance of about ¾ of a mile. The remaining two-foot fall takes place over the 48 miles between the foot of the rapids and Lake Huron.

Because of the smallness of this drop, water levels at Sault Ste. Marie, at the foot of the rapids, are affected by the level of Lake Huron. To compensate for the effect on Lake Superior levels of hydroelectric power diversions around the St. Marys Rapids, a control dam was completed in 1921. Since that time the discharge from Lake Superior has been regulated under the supervision of the International Joint Commission (IJC) through its International Lake Superior Board of Control.

The natural supply to Lake Superior has been increased by diversions from the Albany River Basin, a tributary of James Bay.

Lakes Michigan-Huron and St. Clair-Detroit Rivers

The two Lakes (Lake Michigan

being entirely within the U.S.) are connected by the broad, deep Straits of Mackinac so they stand at virtually the same level and, for the purposes of this study, are treated as one. The water flows out through the St. Clair River into Lake St. Clair, then to the Detroit River and on into Lake Erie, eight feet lower in level than Michigan-Huron.

The water surface slopes gradually from Michigan-Huron to Lake Erie, with no rapids.

Sand and gravel have been removed from the St. Clair River for commercial purposes. This work, plus dredging of both the St. Clair and Detroit rivers to increase the depth of navigation channels, has caused an increase in their discharge capacity.

Dredging in the St. Clair River.

Lake Erie and Niagara River

This system is the most dynamic of all. Lake Erie is the shallowest of the Great Lakes and is extremely sensitive to the effects of winds. The natural outlet from Lake Erie is the Niagara River.

Lake Ontario lies about 326 feet lower than the level of Erie. Approximately 310 feet of this difference occurs in the reach of the Niagara River from the head of the Cascades, upstream from the Falls, to the lower end of the Lower Rapids, six and a half miles below the Falls. About half the difference occurs in the spectacular drop of the Falls themselves.

There are several diversions at the Falls for hydroelectric purposes.

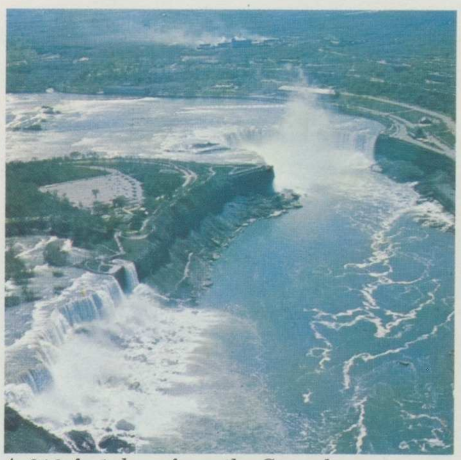
A structure on the Canadian side of the river, extending almost to Goat Island serves to maintain the level in the Chippawa-Grass Island pool providing proper flow over the Falls for scenic purposes while allowing water to be diverted for power production purposes.

The Niagara Treaty of 1950 between Canada and the United States requires a minimum flow of 100,000 cubic feet per second during daylight for the tourist season. A minimum flow of 50,000 c.f.s. is required at other times.

Water from Lake Erie also reaches Lake Ontario through the Welland Canal, and DeCew Falls power plant tailrace and from the Niagara River through the New York State Barge Canal at Tonawanda, New York.

Lake Ontario and the St. Lawrence River

Lake Ontario is the lowest and smallest of the Great Lakes. Since 1958, when the St. Lawrence Seaway and Power Project was completed, the outflows from Lake Ontario have been regulated under the direct su-



A 310 foot drop from the Cascades.

pervision of the IJC's International St. Lawrence River Board of Control.

From the outlet of Lake Ontario at Kingston, Ontario to Father Point, Quebec, the beginning of the Gulf of St. Lawrence, the St. Lawrence River falls about 245 feet.

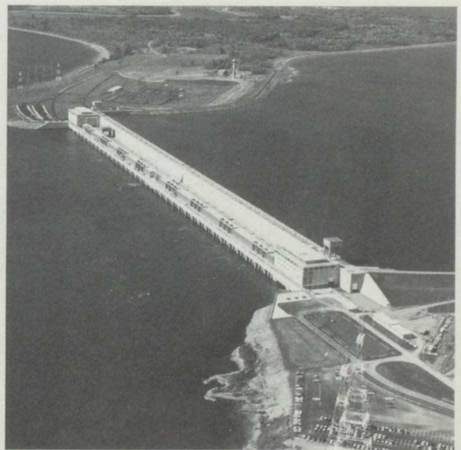
For the first 67 miles, the River is dotted with many rocky islands and reefs giving the area the familiar name, "The Thousand Islands".

With the completion of the Seaway and Power Project, the features of the St. Lawrence, farther downstream, have been changed considerably. 105 miles downstream from Lake Ontario, at Barnhart Island, stand the large Moses-Saunders powerhouses. These are operated by the Power Authority of the State of New York and Ontario Hydro. At the upstream end of Barnhart Island is Long Sault Dam, used to pass excess flows during times of high supply or of turbine shutdown.

The artificial lake formed by impounding the river behind these structures is called Lake St. Lawrence. Fluctuations in the levels of this lake are moderated by the operation of Iroquois Dam, about 27 miles upstream. Below the powerhouses, the river divides in two to pass around Cornwall Island. It then widens to form Lake St. Francis. The river, from Kingston to Lake St. Francis (about 110 miles) is bounded by Canada and the U.S.

The remainder of the river (about 430 miles) is entirely within Canada. From Lake St. Francis it flows through the Beauharnois Power and Navigation Canal and the Cedars development into Lake St. Louis.

At the lower end of the Canal stands the Beauharnois Powerhouse. It came into operation in 1932, was enlarged during 1951-1953 and again



Moses/Saunders powerhouses.

in 1959-1961.

At the outlet of Lake St. Louis the river drops through the Lachine Rapids, the LaPrairie Basin, through a swift section near Victoria Bridge and into Montreal Harbour, a fall of about 50 feet.

In the 169 miles of river between Montreal and Quebec City the low tide fall is about 25 feet with the tides at Quebec City averaging about 16 feet. Extreme high spring tides exceed 21 feet. The tidal effect diminishes upstream, down to about 1.5 feet maximum at Trois-Rivières and 0.5 foot at Lake St. Peter but even very small variations can be detected at Montreal Harbour.

The navigation channel in the river at and below Montreal is called the St. Lawrence Ship Channel with an advertised depth of 35 feet at low water. Downstream from Quebec City the present controlling depth is 30 feet at low tide. These channels are currently being deepened to 41 feet.

WHAT THE LAKES ARE LIKE

Together, the Lakes take up an area slightly larger than the whole of the States of New York and Pennsylvania combined. They also drain a land area about twice as big again. When they are at their low water datum they contain 5,473 cubic miles of water, which means they hold almost one-fifth of all the fresh, liquid, surface water in the world.

So a study of a natural phenomenon this large must be undertaken very carefully, beginning with all the known facts about the Lakes, under all aspects that concern the study. To begin:

The Geography of the Lakes Basin

The Great Lakes/St. Lawrence River system is bordered by eight states and two provinces. These are: Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania and New York, and the provinces of Ontario and Quebec.

The total length of the shoreline, including islands, equals almost half the earth's circumference, some 11,200 miles.

The land area drained by the Great Lakes belongs to two broad physiographic regions: the Laurentian Shield and The Central Lowlands. East and south of Lake Ontario, and southeast of Lake Erie, the Lakes basin is set in hilly country.

The Great Lakes basin, like much of the rest of North America, was once covered by massive ice sheets. The glaciers melted in the general area of the Lakes leaving a mixture of silt, soil, sand, gravel, clay and boulders.

From a farmer's point of view the land in the Laurentian Shield, north and west of Lake Superior, is poor because of the sheet-ice action of over fifty centuries ago. The bedrock is visible in much of the area and there are many lakes and swamps filled with the debris of the centuries since the Ice Age. The overburden not scoured away by the ice is thin. The area is poor farmland and is covered mostly with natural forest.

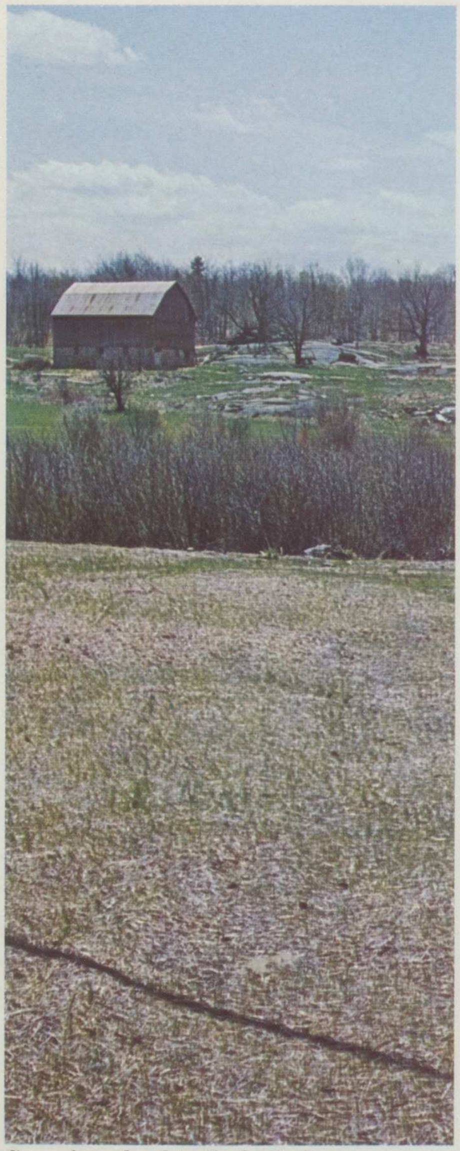
The Central Lowlands, by contrast, are much richer. The whole area is covered by deposits left behind by the melting glaciers with the overburden running from a few feet to hundreds of feet thick. The land varies from flat to gently rolling and includes the rich dairylands of Wisconsin and Ontario. In fact, the area alone generates 7% of the U.S. and 25% of Canada's total farm production. West and south of Lake Michigan, the land is so flat that the divide between the Great Lakes basin and the Mississippi system is only ten feet higher than the level of Lake Michigan itself.

The Climate of the Region

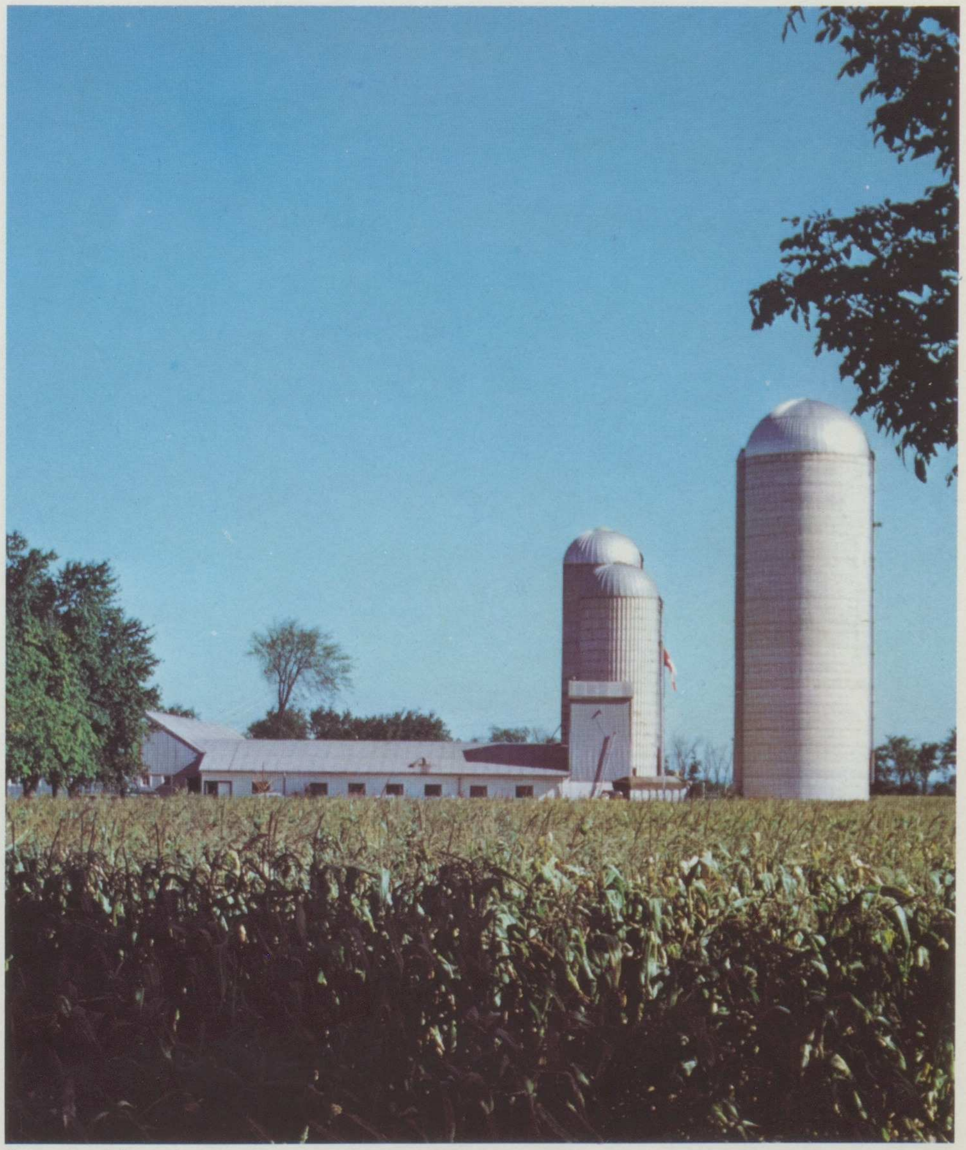
The climate of the Great Lakes region is moderate. The Lakes are the reason. What happens, in fact, is that the Lakes act like a hot water bottle in winter, and like an air-conditioner in summer, keeping temperatures all year round far more even than is the case in similar latitudes elsewhere in the world.

The climate of the Lakes has these significant features: four distinct seasons; a variety of precipitation types and sources; not too much month-to-month variation in amount of precipitation; and marked temperature contrasts over the 750 miles of latitude occupied by the Lakes.

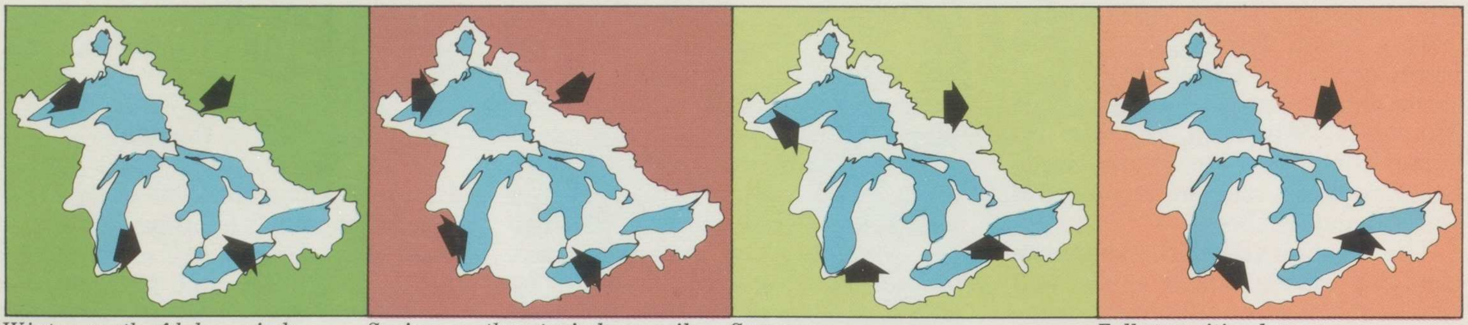
The winds over the Lakes have great importance, especially in their effects on local water levels. In winter the winds are generally westerly. In



Some farm land in the basin is poor.



Some is rich.



Winter: north of lakes, winds blow generally from the west and northwest.

Spring: southwest winds prevail in lower lakes. Northwesterlies prevail in higher latitude.

Summer: winds more variable.

Fall: transition between summer and winter with higher mean wind speeds.

January over the middle and upper region, winds blow from west or northwest 40% to 50% of the time. South of the Lakes, winds blow largely from west or southwest 30% to 40% of the time. Wind speeds average from 6 to 19 miles per hour.

In early spring, winds are stronger. These high winds aggravate the problem of high water levels in flooding and eroding lakeshore properties.

In summer, the Lakes usually have westerly or southerly winds. By October the winds are stronger again, because of increased cyclonic activity and the large temperature differences between air and water.

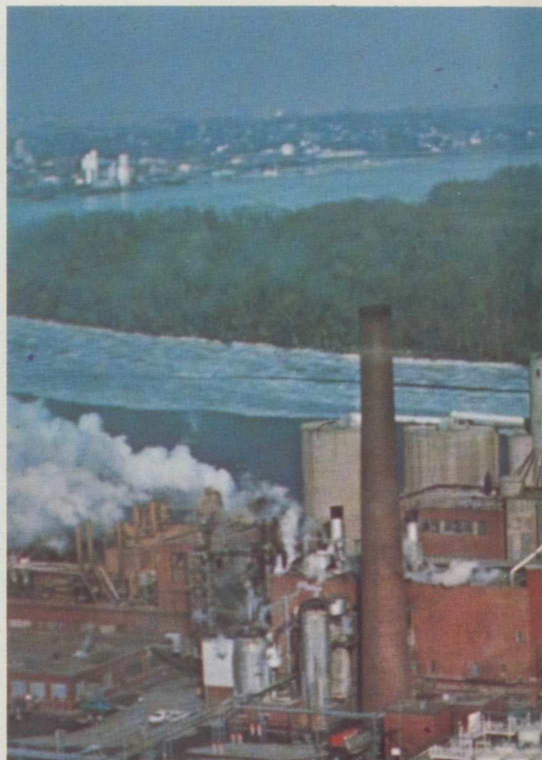
Water Quality — Good

The quality is generally good but there are local areas, near large urban areas where quality is seriously degraded. In particular, Lakes Erie and Ontario and the international section of the St. Lawrence River are being polluted to a point that is likely to cause injury to health and property.

The Great Lakes Water Quality Agreement signed by Canada and the U.S. on April 15th, 1972 sets out specific objectives for water quality in the lower Lakes. At this writing a program of remedial works and regulations is being enacted.

Lakes Huron and Superior are the object of a separate study aimed at

One seventh of the U.S. population and one third of Canada's live in the Great Lakes Basin.



The Great Lakes have a powerful effect on our economy.

preventing their degradation from present high quality standards.

Large Populations Live in the Great Lakes Area

In the United States, the Great Lakes basin contains one-seventh of the total U.S. population. These people produce one-sixth of the national income and live, many of them, in four of the twelve largest cities in the nation (Chicago, Detroit, Cleveland, Milwaukee).

In Canada, the figures are even more dramatic with about one in three living in the region, producing nearly one-half of the national income. If the Canadian section of the St. Lawrence basin is included, then the figures jump to an astonishing 60%, both of population and of national income. The area includes the country's two largest population centres, Toronto and Montreal.

Population of the region has increased from 10 million in 1900 to 35 million in 1970.

The population density (average 113 people per square mile) varies widely, from the sparsely settled areas of the Superior and northern Huron basins with their 20 people per square mile to 500 persons per square mile in the southern Michigan, Erie and Ontario basin. Densities in the U.S. are generally higher than those in Canada.

The highest concentrations of all are along the shorelines, particularly in the Chicago, Milwaukee, Detroit, Cleveland, Buffalo, Hamilton-Toronto, and Montreal metropolitan regions.

The Great Lakes Influence Our Economy

In his famous poem, Carl Sandburg called Chicago "Hog-butcher for the world" and "The Nation's freight handler". It was true then, in 1916, and still is. Chicago, Detroit, Toronto and the other cities of the Great Lakes region have an importance that extends the world over.

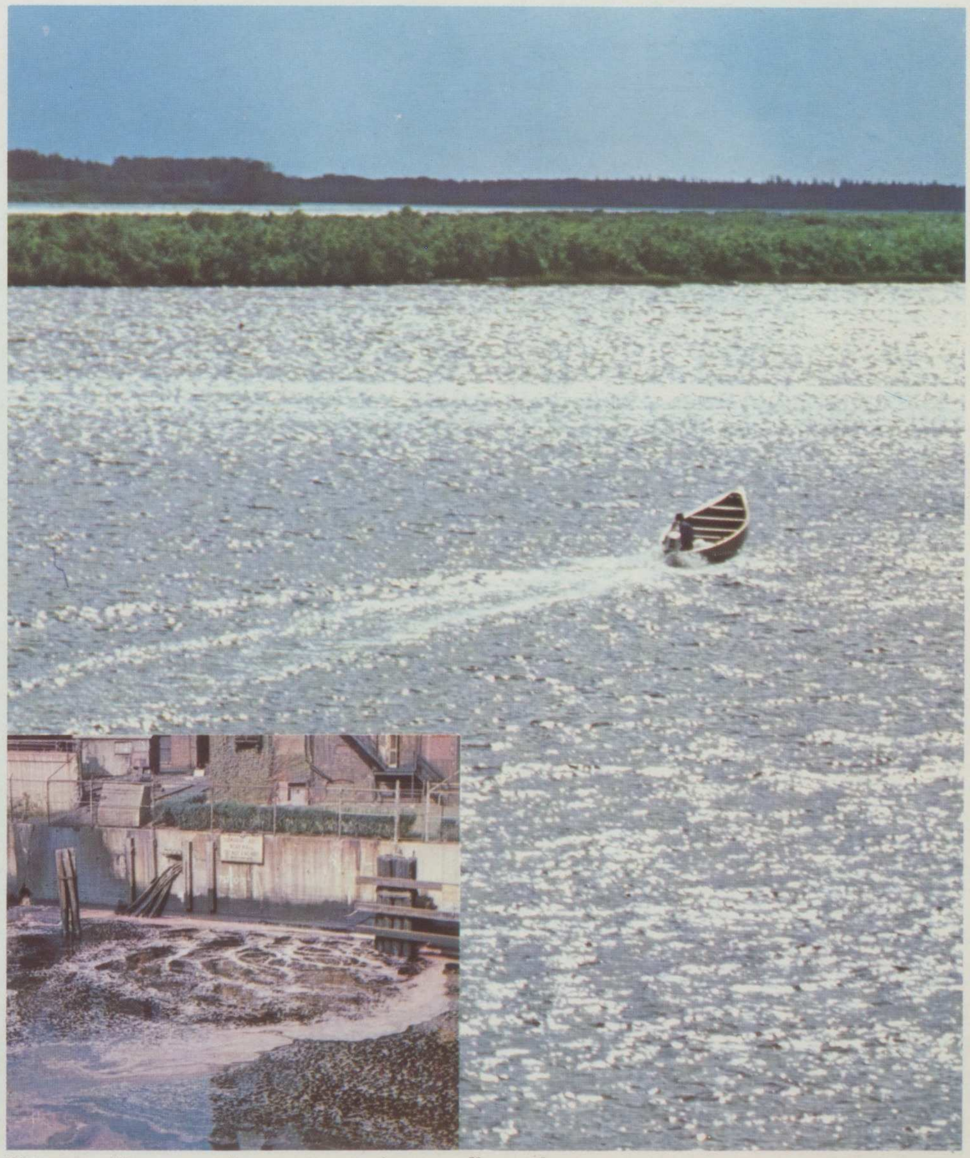
In the United States, more than 20% of the manufacturing employees and capital expenditures, are within the Great Lakes basin. In Canada, over one-half the national manufacturing employees, and capital expenditures, are within the basin.

The region is the primary focus of the iron and steel industry in both nations. 40% of U.S. and 80% of Canadian production occurs here. The region also contains other industries, including chemicals, paper, food products, machinery, transportation equipment and fabricated metal products.

Despite the weight of industrial effort in the basin, a major portion of the farming in both Canada and the U.S. is carried out here.

There are also 59,000 square miles of commercial forest in the U.S. and 70,000 in Canada's portion of the

omy.



Water quality, except in some areas, is generally good.

basin. Minerals are produced here, too, mostly iron ore and limestone.

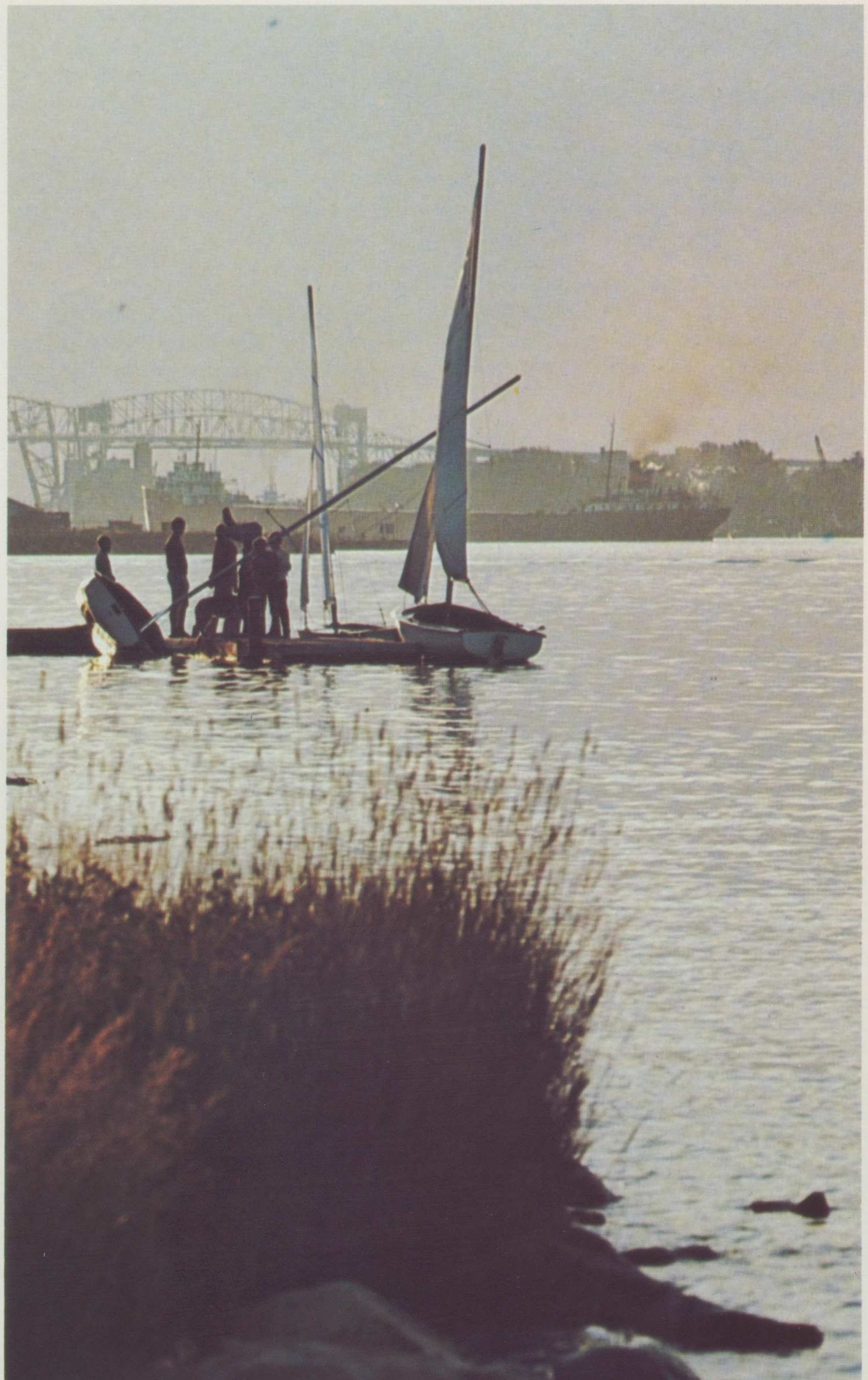
A major industry in the area is tourism. Even if the Lakes had no beaches, millions of people would still travel here to view the Niagara Falls. As it is, the extensive sandy beaches and scenic shorelines of the Great Lakes, along with the cottage and summer resort areas of northern Michigan, northeastern Wisconsin, Georgian Bay, and The Thousand Islands area of the St. Lawrence hold out an appeal which adds up to a total of 800 million dollars annually in tourist expenditures in the region; 300 million in the U.S. and 500 million in Canada.

The Great Lakes System is Important to Transportation

Part of the reason the area is so heavily industrialized is the efficient and economical transportation offered by the Lakes.

More than 100 billion ton-miles of freight are carried through the system every year. The St. Lawrence Seaway has opened many Great Lakes' cities to ocean-going shipping making inland cities like Duluth as much ocean ports as Montreal is. While ocean shipping on the Lakes and down to Montreal is limited by the 27-foot depth of channels, the St. Lawrence River between Montreal and Quebec City is 35 feet deep at low water.

In the U.S. the eight Lake states and eleven other contiguous states use the Lakes waterways to move a total of 25% of the U.S. general cargo export traffic.



In Canada, almost half of the wheat export shipments pass through Great Lakes/St. Lawrence ports. Approximately one-third of all Canadian ship cargoes are handled in this system.

As well as shipping routes there are huge railroad, motor transportation concerns, airlines, barge companies and pipelines serving the area, but the effectiveness of the shipping system means these other methods are usually employed in conjunction with it, transporting goods to and from the Great Lakes' ports.

The Lakes' System is a Source of Abundant Hydroelectric Power

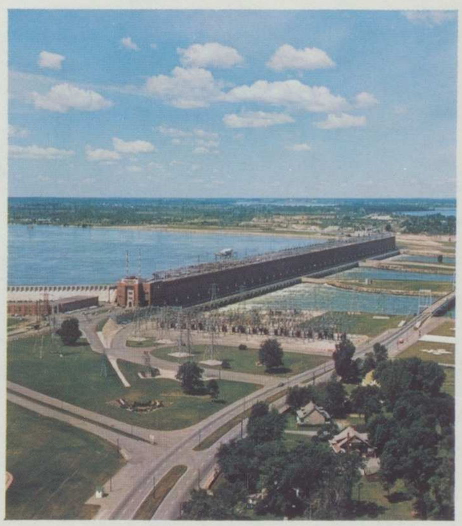
In Ontario and Quebec electricity is called "Hydro". This shows the importance which has been placed upon the massive power resources of the Lakes.

In the U.S. the Power Authority of the State of New York generates electricity from the U.S. share of the flows of the Niagara and the St. Lawrence rivers. About 355 electric utilities operate within the U.S. portion of the basin, representing all segments of the power industry: private, cooperative, and federal, municipal, and other public systems. At Sault Ste. Marie, Michigan there are two small plants developing power from the St. Marys river, one privately and the other federally owned. The generating capacity of the utilities in the region in 1970 was about 32.8 million Kw (around 10% of the national total).

On the Canadian side of the border, the Ontario Hydro generates electricity from the Canadian share of the flows of the Niagara and St. Lawrence rivers. The Quebec Hydro-Electric Power Commission uses the full flow of the St. Lawrence River at its Beauharnois-Cedars developments. There is also a small private power plant located at Sault Ste. Marie in Ontario.

Altogether about 15% (nearly 5,000,000 Kw) of Canada's hydroelectric generating capacity is located on the Great Lakes outflow rivers. Almost one half of the steam generating capacity in Canada (4,474,000 Kw) is located on the Lakes or the outlet rivers. Thermo-nuclear plants also draw water from the Lakes.

The existing (1972) hydroelectric installations affected by regulation of the Great Lakes have a total installed capacity of 7,969,000 Kw. Since the unit cost of power generated at these stations is lower than power from fueled installations, it pays to use the hydro sources as much as possible. Besides, there is no pollution from the use of water-driven turbines.

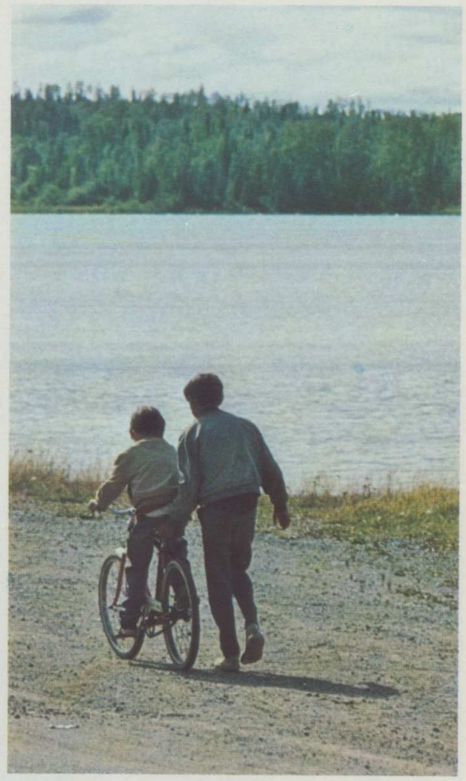


The Use of Waterfront Property is Changing

The shoreline of the Great Lakes is a valuable asset. In the southern part of Lake Michigan and around Lakes Erie and Ontario, urban uses of the shoreline predominate. In both countries most of the shoreline is privately owned.

During the last few decades forestry and agricultural uses of the shore have declined while recreational, industrial, as well as residential, uses have grown.

The change in use and the influence of the water levels on the users is the focus of attention of a significant part of this study.



WHY THE LAKE LEVELS FLUCTUATE

The level in each of the Lakes varies like a bank balance. When more is put in than is taken out, the level rises. When more is taken out than is put in, the level drops.

Three Natural Factors Affect Fluctuations

Three major factors and many small ones affect the fluctuation of the Lake levels. The major influences are: precipitation, evaporation, winds.

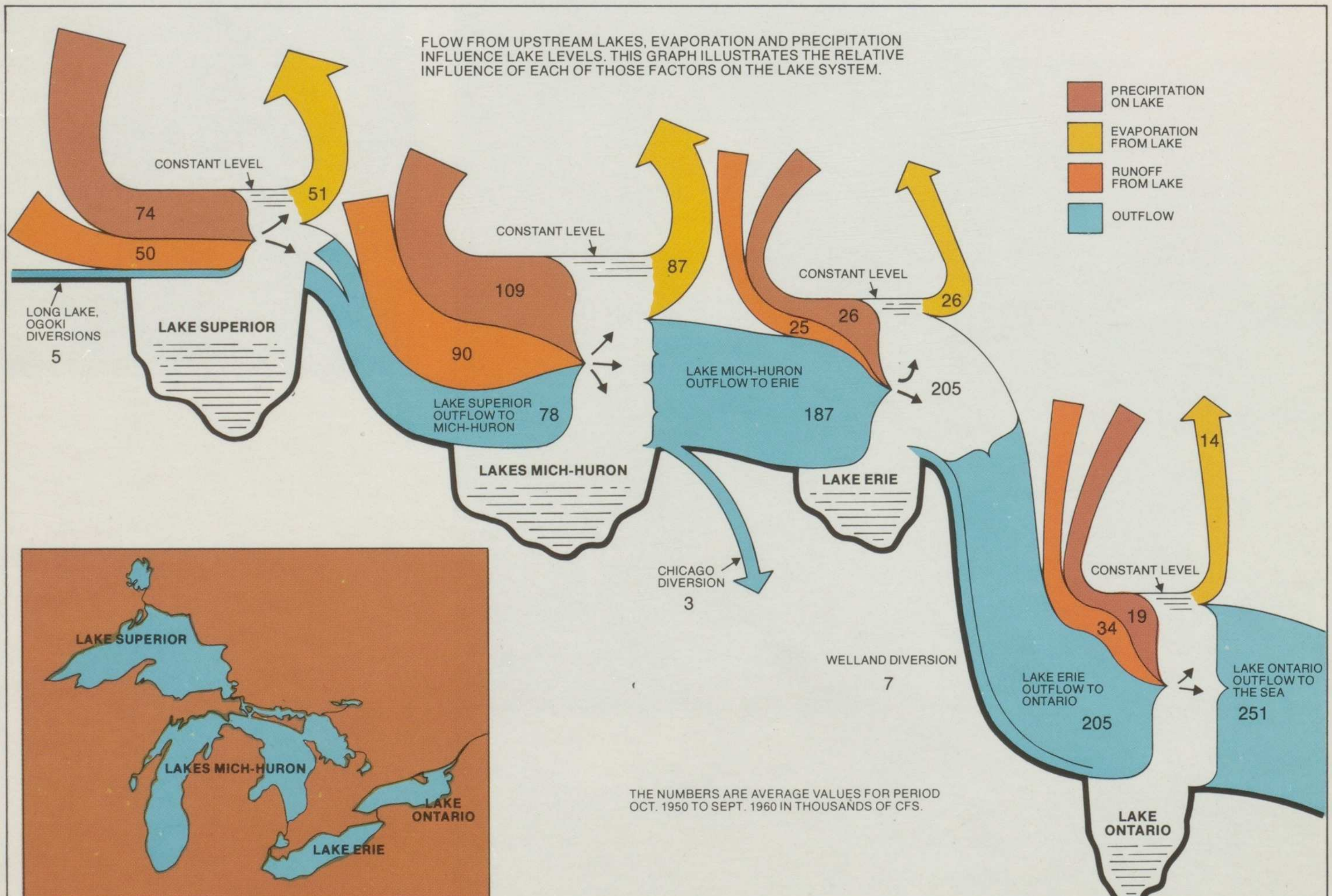
The whole cycle begins with rain and snow falling upon the Lakes and the areas they drain. Records of average precipitation are gathered in the U.S. by the National Weather Service and in Canada by the Atmospheric Environment Service. Here are the long-term average, maximum and minimum annual figures in inches over each of the five basins for the period 1900-1972.

	Average	Max.	Min.
Lake Superior...	29.7	38.0	24.0
Lake Michigan..	31.2	37.8	22.2
Lake Huron	31.3	39.0	25.8
Lake Erie	33.8	42.6	24.5
Lake Ontario ...	34.3	43.7	27.6

The second major influence of level changes is evaporation. A little or a lot of evaporation usually accompanies a lot or a little of precipitation. They reinforce each other in producing long-term variations in Lake levels.

The third and most familiar cause of level change is wind. The wind can tilt the whole surface, raising the levels of the downwind end of the lake by as much as 8 feet. The other end of the lake is naturally lowered since wind has no effect upon the volume of water in the lake.

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



Long-term variations are the result of persistent high or low precipitation. In the mid-1960's on Lakes Michigan-Huron there was low precipitation and low levels. In 1972-73 there was higher precipitation and extreme high levels on all lakes except Lake Superior.

A hundred years of record-keeping has indicated no regular, predictable cycles of levels. The interval between periods of high and low water can vary widely. Maximum recorded ranges of levels have varied from 3.8 feet on Lake Superior to 6.6 feet on Lakes Michigan-Huron and Ontario. Lake Ontario's high range of levels results from fluctuation in both its own supply and the fluctuations in inflow from Lake Erie.

Seasonal fluctuations reflect the normal hydrologic cycle, more input during spring and early summer than during the rest of the year, owing to spring run-off and low evaporation. This kind of fluctuation is quite small, averaging about one foot on Lakes Superior and Michigan-Huron, and 1.5 feet on Lake Erie. Lake Ontario, the lowest, takes up some of the slack from the other Lakes and has the largest seasonal fluctuation, 1.9 feet.

Short-period fluctuations are caused by meteorological events and can last from a few hours to several days.

Wind, combined with barometric pressure differences, can cause unusual local water level changes. It must be remembered that these short-period changes do not cause alteration in the total volume of the Lakes.

The effects of winds and the waves they generate are the *major* cause of damage due to flooding and shore erosion. Even if the levels of the lakes were held to their long-term average, flood damage would still occur in periods of extremely high winds.

Some other factors which have some slight effect on lake levels are: the minute tides on the lakes, crustal movement of the earth and, in the outflow rivers, aquatic growth, and ice jams during spring breakups.

The Great Lakes are Mainly Self-Regulating

There are two major factors which make the Great Lakes an efficient natural reservoir. First is their vast area. One cubic mile of water over the whole Lake system would amount to about six tenths of an inch rise in levels.

The second factor is the stability of the outflows. The maximums are only two to three times the minimums, preventing rapid loss of high supplies. This is in contrast with such rivers as the Mississippi with a factor of 30:1, the Columbia at 35:1 and the Saskatchewan at nearly 60:1.

To illustrate the limiting effect of the outflow rivers, it takes 2½ years for half the effect of a continuous supply change to Michigan-Huron to be reflected in the outflows of Lake Erie.

With their larger areas, the levels of both Superior and Michigan-Huron are slower to respond to outflow changes than Erie and Ontario. This means that any regulation of the levels of Superior and Michigan-Huron would require greater flexibility than would be needed for Erie and Ontario if all Lakes are to enjoy a comparable degree of level stabilization.

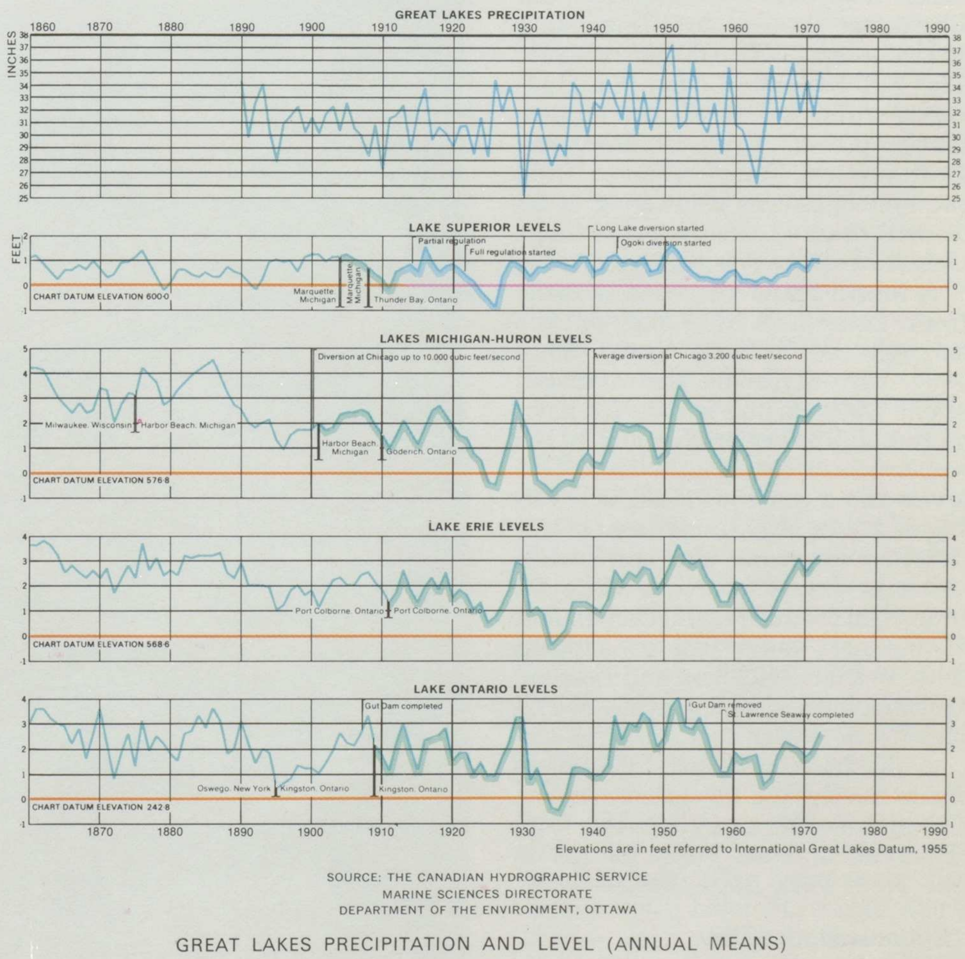
Man's Part in Causing Fluctuations in the Great Lakes

The Great Lakes capacity to store water is largely governed by the size of the rivers flowing out from them, so any increase in the flow of the rivers will lower the levels of the upstream Lakes.

Since the beginning of the century, dredging has been carried out in the St. Clair and Detroit Rivers. Some of this was for commercial extraction of gravel, some was for enlargement of navigation channels for shipping.

When channels were dredged for navigation projects, some of the material was returned to the river in areas where it does not impede navigation. In this way the effect of the channel dredging was partly offset. The dredging for navigation channels between 1933 and 1962 has

Great Lakes Precipitation and Levels (Annual Means)



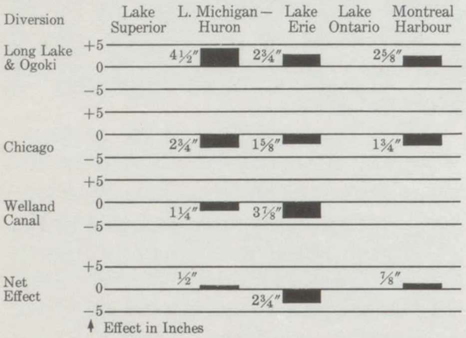
SOURCE: THE CANADIAN HYDROGRAPHIC SERVICE
MARINE SCIENCES DIRECTORATE
DEPARTMENT OF THE ENVIRONMENT, OTTAWA

GREAT LAKES PRECIPITATION AND LEVEL (ANNUAL MEANS) lowered Lakes Michigan-Huron by 0.59 foot.

(a) Diversions

There are only four major diversions in the system. Two of these bring water into Lake Superior from the Albany River Basin, part of the James Bay drainage, via Long Lake and Ogoki diversions. They account for an average 5,000 cfs and have caused a raising of all Lake levels except Lakes Superior and Ontario which are regulated.

Ultimate Effect of Diversions on Water Level



The third diversion started in 1948 with water being taken out of Lake Michigan at Chicago and released into the Mississippi drainage system. Until 1900 this was only 500 cfs. Thereafter it grew to a maximum annual average of 10,000 cfs in 1918. The U.S. Supreme Court, in a number of rulings, has limited outflow to the present figure of 3,200 cfs. However, the water removed from the system caused a lowering of all downstream Lake levels except Ontario because it is regulated.

A fourth major diversion is made from Lake Erie to Lake Ontario through the Welland Canal. Since 1950, the diversion has averaged about 7,000 cfs and is used for navigation and power production. It has resulted in a lowering in Lake Erie levels and a consequent slight lowering of Lakes Michigan-Huron levels.

Minor diversions also occur when water is drawn from one Lake for municipal use and returned as effluent to the next lower lake as happens with Detroit, Michigan and London, Ontario, both of which return Michigan-Huron water to Lake Erie.

A diversion of about 1,000 cfs is made during the navigation season, from the Niagara River at Tonawanda, New York, for use in the New York State Barge Canal.

(b) Consumptive Use

Under this heading comes all water incorporated into manufactured products, consumed by man or livestock, used in industrial processes, thermal-electric power generation, irrigation, and municipal and rural water supplies, and not returned to the system.

Consumptive use of water results in a lowering of the lake from which it was taken and a consequent lowering of all unregulated lakes farther down the system.

Use is not constant year by year. In 1965 it was estimated at 2,300 cfs. By the year 2,000 it is expected to reach 6,000 cfs or about twice the effect of the Chicago diversion.

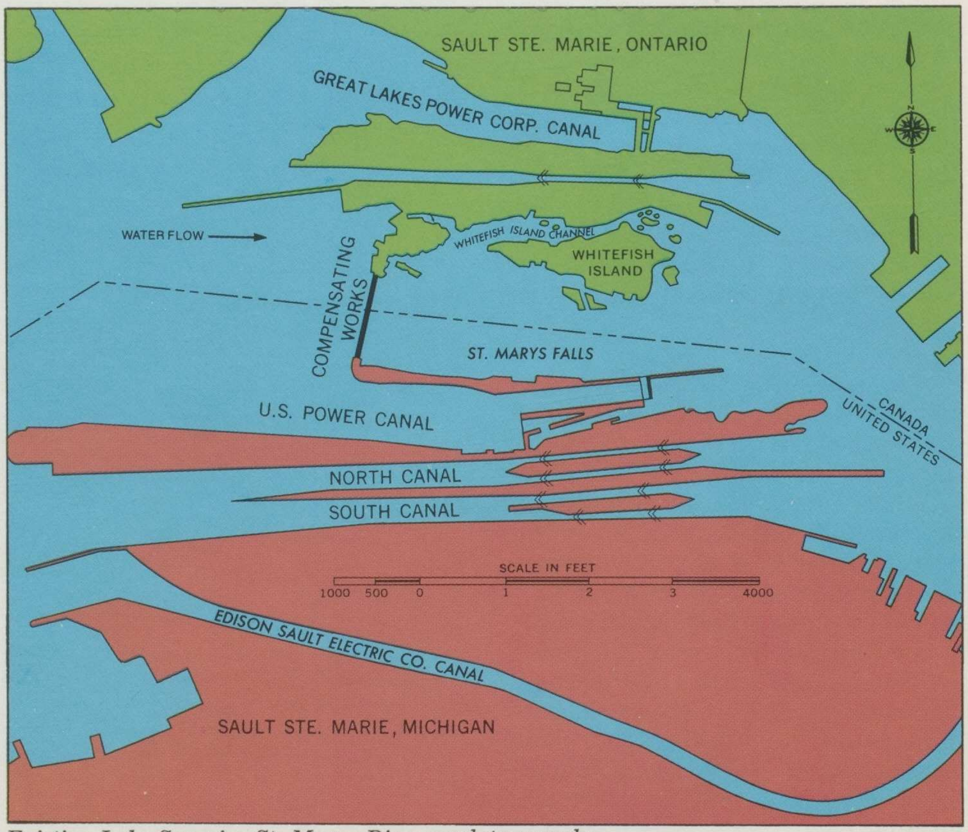
The Lakes are Regulated, in Part, Already

Regulation of Great Lakes levels is no novelty. The outflow from Lake Superior has been controlled completely since 1921 (the present regulation plan is called the September 1955 Modified Rule of 1949). Lake Ontario outflows have been controlled since 1958 (the regulation plan now in use is called Plan 1958-D).

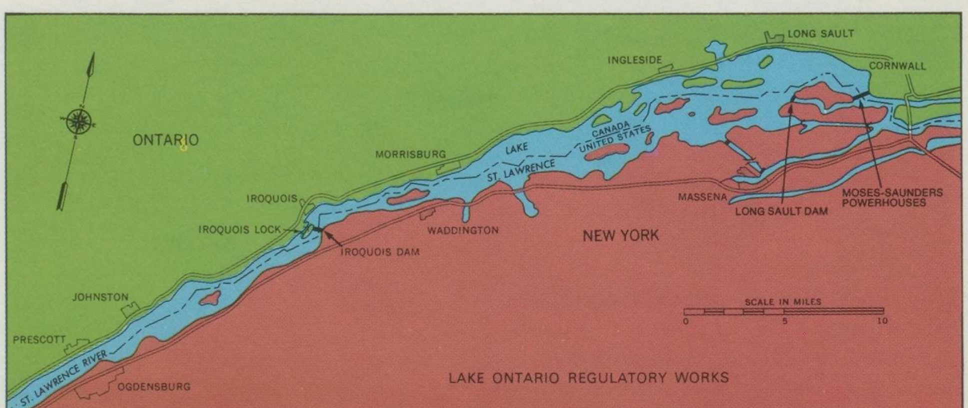
A Close Examination of the Regulatory Works

Lake Superior: The work of regulating Lake Superior was begun in 1901 when construction began on a 16-gate dam across the St. Marys River above the Rapids. This was completed in 1916 and is known as the "Compensating Works".

By August 1921 these works had been extended to close off the St. Marys River completely. The current plan provides for a monthly setting



Existing Lake Superior-St. Marys River regulatory works.



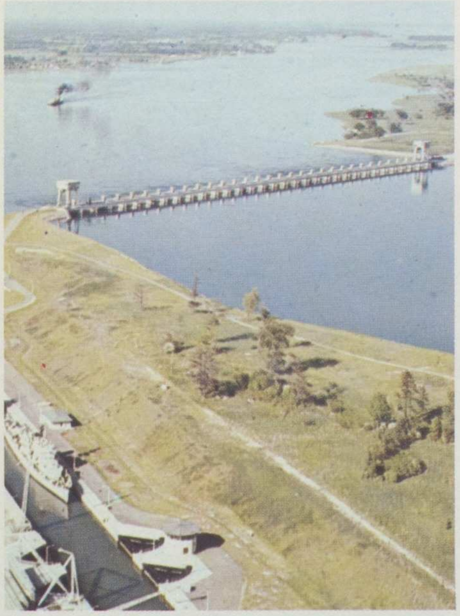
Existing Lake Ontario-St. Lawrence River regulatory works.

of the gates of the control works, from May 1st to December 1st. Gate changes may be made between December and April depending upon the supply situation.

In order to pass shipping around the St. Marys Rapids, five locks have been built, four on the U.S. side, one on the Canadian side. In addition, navigation channels have been excavated throughout the length of the St. Marys River. Three hydroelectric plants are located on the St. Marys River; one in Sault Ste. Marie, Ontario, two in Sault Ste. Marie, Michigan. The Great Lakes Power Corporation plant in Ontario is rated at 21,500 Kw, the U.S. Government Plant at 18,300 Kw, and the Edison Sault Power Plant at 41,300 Kw.

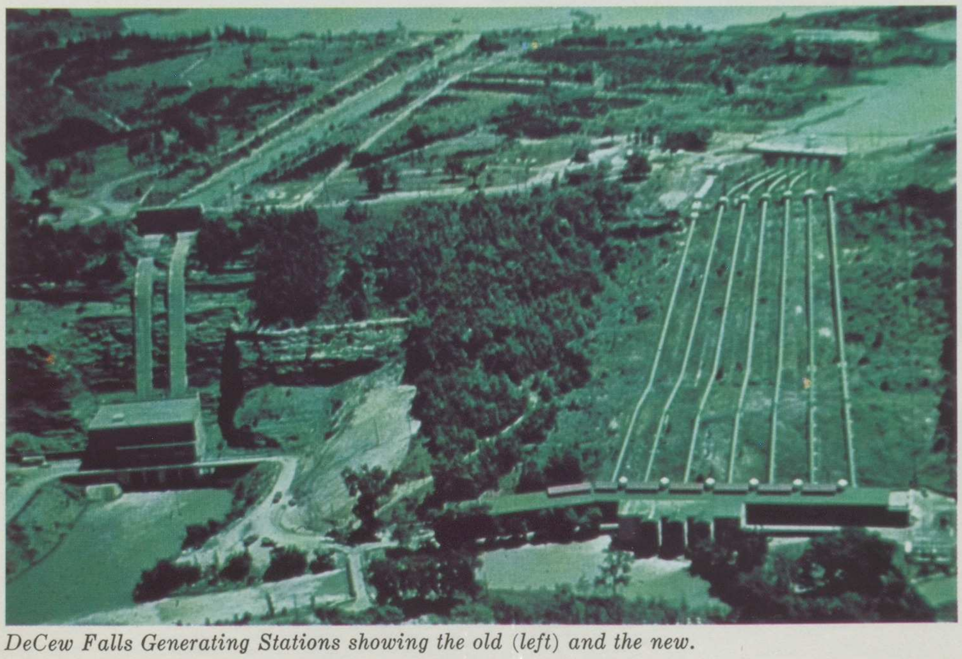
The waters of Lake Superior (excluding the waters of the Ogoki and Long Lake diversions) are equally divided between Canada and the U.S. and since the U.S. plants use more than half the water available for power generation, their outputs are curtailed during periods of low supply.

Lake Ontario: Regulation of Lake Ontario began in July 1958 and is determined by a plan based on the International Joint Commission's Orders of Approval, and under the direct supervision of the International St. Lawrence River Board of Control. It attempts to provide the best possible compromise among the needs of the power entities, of shipping and of the need to keep Lake Ontario at a level which benefits the property owners along the shore and yet protect those same interests downstream.



Iroquois control works.

Robert Moses/Lewiston Generating Station.



DeCew Falls Generating Stations showing the old (left) and the new.

The outlet from Lake Ontario is regulated by a series of structures and channel enlargements. Between Lake Ontario and Lake St. Louis there are structures at Point Rockway-Point Iroquois, at Massena-Cornwall, (both circumnavigated by locks and canals) at Coteau Landing and at Beauharnois. The Moses-Saunders Power Dam and Long Sault Dam at Massena-Cornwall normally control the levels of Lake Ontario while the series of dams near Coteau Landing, together with the Beauharnois power plant, control the levels of Lake St. Francis.

The 1,980-foot Iroquois Dam is capable of passing and controlling the full discharge from Lake Ontario. Long Sault Dam is located 25 miles downstream, below the foot of Long Sault Island and lies entirely within the United States. Usually, the gates are operated only under very high river flow conditions or when flow through the powerhouses is restricted for the maintenance of generating units.

About 2 miles downstream from Long Sault Dam, the Saunders Generating Station of Ontario Hydro and the Moses Power Dam of the Power Authority of the State of New York, span the river. Together they form one of the largest hydroelectric generating stations in the western world. Their 32 generators, each rated at 57,000 Kw produce a total of 1,824,000 Kw divided equally between Canada and the U.S. Impounded behind the powerhouses is the water of Lake St. Lawrence.

At the lower end of Lake St. Francis, about 32 miles east of Cornwall, Ontario, the major part of the St. Lawrence flow is diverted through a 15-mile long navigation and power canal to Hydro-Quebec's generating station at Beauharnois which has 36 main generating units with a total capacity of 1,574,000 Kw. The remainder of the St. Lawrence flow leaves Lake St. Francis through the Coteau Control Dams and is used by the 162,000 Kw Hydro-Quebec generating station in the natural channel of the St. Lawrence at Cedars.

The navigation channel, 27 feet deep and 600 feet wide, is situated along the north bank of the Beauharnois Canal. Two locks at its confluence with Lake St. Louis allow ships to enter and leave the canal.

WHEN WATER LEVELS FLUCTUATE PROBLEMS RESULT

Three major groups of people are interested in lake regulation. They are: riparian (waterfront) property owners, ship operators, hydroelectric power producers.

Riparian users want moderate levels at all times. This is natural. Shore property damage is the biggest single problem caused by fluctuation of lake levels. The thousands of persons who have experienced flood damage or loss are understandably outspoken in their demand for "better" control of levels. However, it must be understood that simply lowering the lake levels by regulation will not automatically solve the problem.

Damage resulting from fluctuation in water levels may be caused by simple flooding, by wind generated waves or by a combination of both. The intensity of the damage varies with these factors.

1. The 'still-water' level.
2. The temporary increase in that level (set-up) at a specific location as a result of wind or of differential barometric pressures.
3. The duration and size of wind-generated waves.
4. The extent of wave 'run-up' on shore.

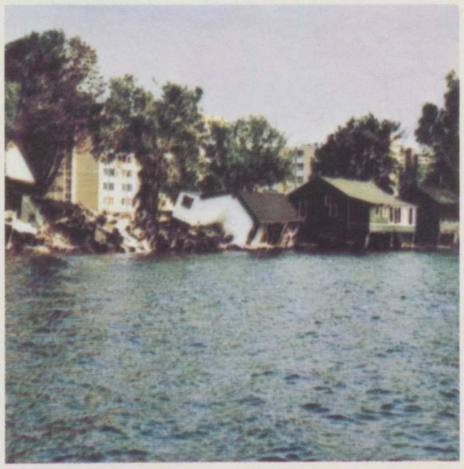
These various conditions overlap one another. The storm-water level is the height to which wind can 'tilt' the still-water level and force it up the beach at the downwind end of a lake. Above this is the ultimate water level. This includes the distance to which wind-generated waves will push water up the beach and is the water level which causes the most shore damage.

A number of other factors contribute to a damaging effect. These include the nature of shore materials, exposure to on-shore winds, off-shore and on-shore slopes, berms, backshore elevations and widths. All of these affect the way in which the shore can absorb the energy of the storm. The effects of these factors are continuous and for that reason are usually overlooked.

Ice has also damaged the Great Lakes shorelines. However, the damage, while dramatic, has usually been local.

Navigation interests usually benefit from higher, rather than lower, water levels. The past fifty years' experience shows that shipping will always take advantage of high water levels to load vessels to the fullest. This, naturally, results in more cargo being carried in fewer trips with a direct economic benefit.

Power interests prefer a fairly wide



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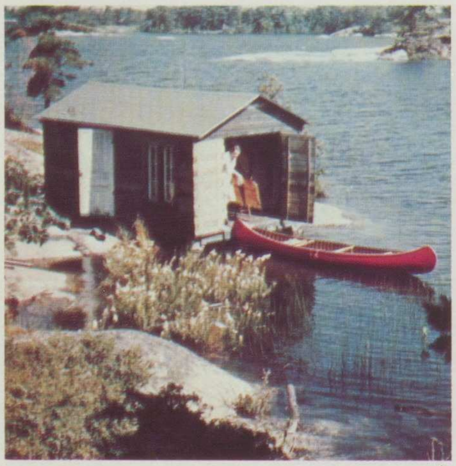

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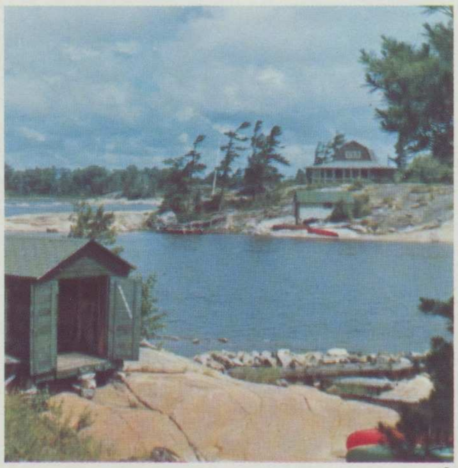

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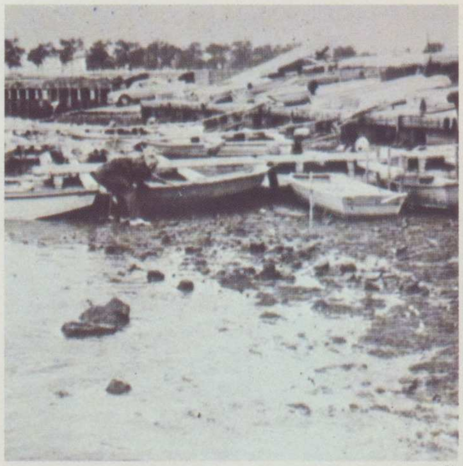
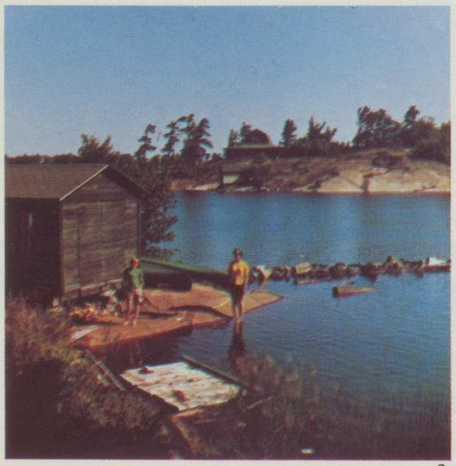


7.

Variation in levels on the east shore of Georgian Bay.
(1) 1952 (2) 1964 (3) 1969 (4) 1973
(5)(6) High water can cause considerable damage.
(7) Low water can cause inconvenience.
(8) This protective wall is cut from behind by Lake Huron waters.(page 23)



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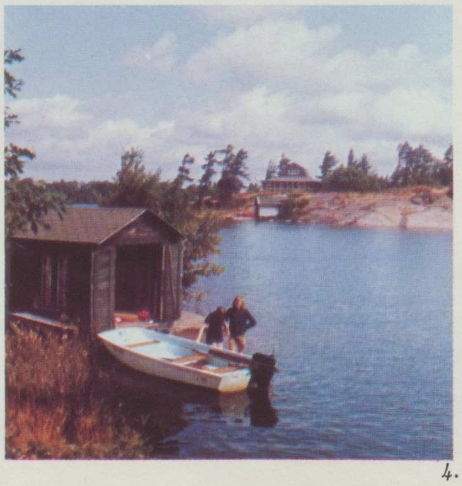


4.

range of levels in order to have enough storage to give them all the water they need to operate their turbines. They also want flexibility of operation, the ability to increase flows through their turbines, hence increasing their power output during peak load periods.

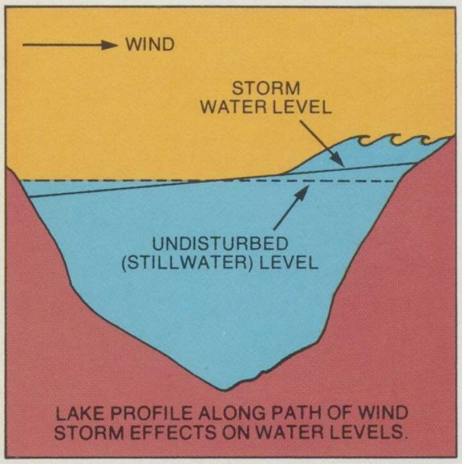
During the winter, when demands for electricity are greatest, power interests want minimum flows to be greater than in the summer, but not too high to cause ice jamming in the rivers or the clogging of the turbine intakes.

A variety of other interests also are effected by the change in levels of the Great Lakes, including marina operators who are affected in much the same way cottage owners are (if I build my dock this high, will the water be too high or too low next year?). And municipalities and industries whose water intakes and sewer outfalls can be affected. The fluctuation of water levels subtracts or adds to beaches to the chagrin or joy of bathers.

The lake levels are of vital importance to an enormous wildlife population. High or low Lake levels which cause flooding or drying up of marshlands have an effect upon wildlife and upon the quality of life of everyone who enjoys the outdoors. The ecology is therefore a fourth imp ortant member of the major interests.

A look at the requirements of the major interests shows that the best regulation plan will be one which:

1. Cuts down the variances of levels about the average.
2. Cuts down the variances of flow.
3. Changes the average level only to a limited degree.



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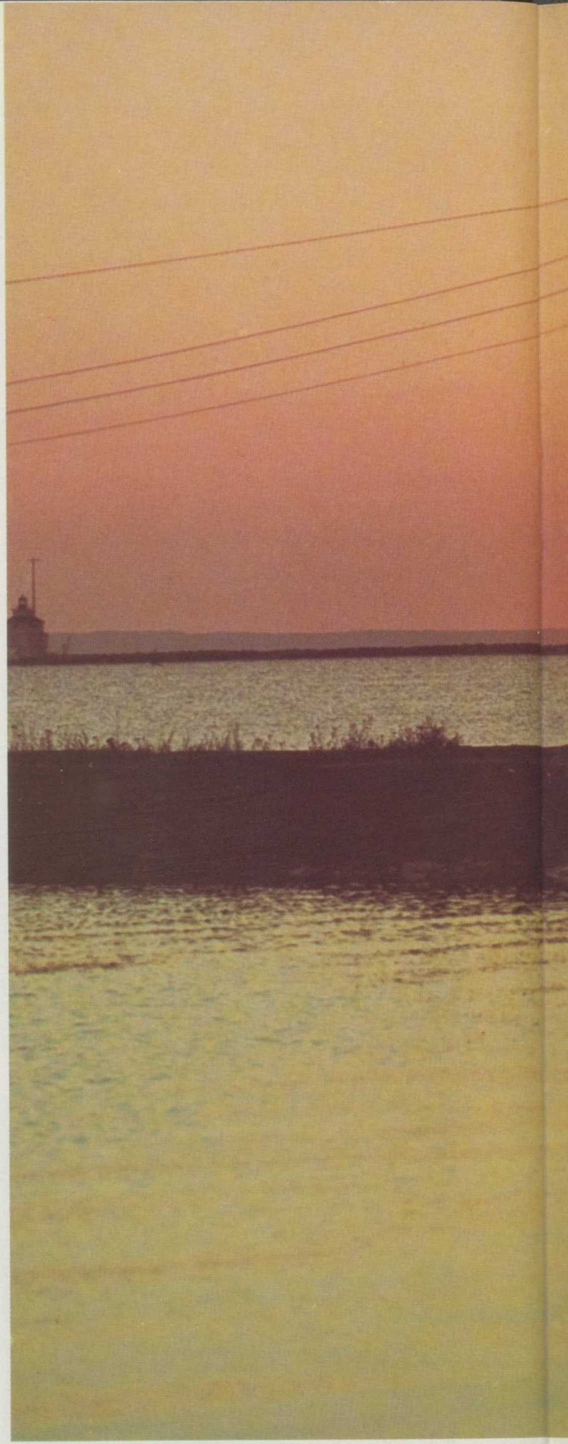
HOW THE PROBLEM WAS TACKLED

The study began with a broad examination of all theoretical possibilities. As more knowledge was gained of the hydrologic and economic factors involved it became apparent that not every idea was practicable.



It is very difficult to put a price on a sunset.

The study began to narrow its scope to a consideration of those plans which showed the greatest potential for overall improvement. One of the objectives introduced at this point was that plans should produce benefits without significant loss to any of the major interests throughout the system.

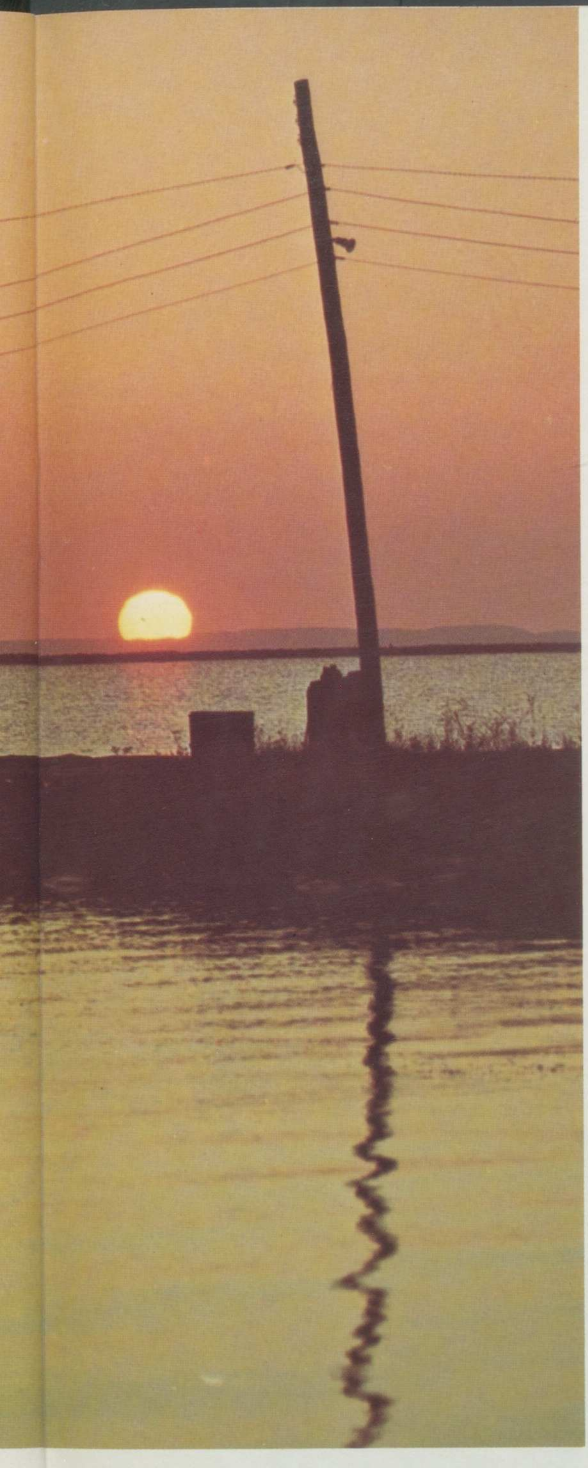
The study found that this objective could best be fulfilled by concentrating on plans which maintained the lakes at the same relative position with respect to their mean levels.

The study dealt with a succession of regulation plans. For brevity, these have been coded with the initials of the lakes involved in each plan. The prefix SO means that a plan deals with combined regulation of Lakes Superior and Ontario. SMHO means a plan dealing with combined regulation of Lakes Superior, Michigan-Huron and Ontario. SMHEO indicates combined regulation of Lakes Superior, Michigan-Huron, Erie and Ontario. SEO means combined regulation of Lakes Superior, Erie and Ontario.

The numerals on each of the plans are for cataloguing purposes and do not indicate the number of trials to arrive at a selected plan (eg—Plan SO-901 means the first plan in the 900 series).

The best plans for each combination of lakes were evaluated in detail. The SO and SEO plans looked the most promising and the study concentrated the greatest effort upon them.

In order to have a common basis on which to compare the effects of the various plans, a set of lake levels and flows was developed which reflected a fixed regimen in the Great Lakes—St. Lawrence River system over the study period. These basis-of-comparison data took into account the changes in the amount of diversion into and out of the Great Lakes basin, alterations in the configuration of the connecting channels and the existing control structures at the outlets of Lake Superior and Lake Ontario.



The figures were obtained by using the longest available period of reliable recorded figures as a base. This period of record-keeping runs from 1900 to 1967 and contains periods of droughts and periods of high supply.

The Measurement of Success

Change in lake levels will affect each of the interests in different ways. Riparian owners may find they have a wider beach in front of their property. Shipowners may find they need more trips to carry the same amount of cargo. Power systems may have less flow than they need. How can these different effects be compared, meaningfully?

The answer to this question is not simple. You can compare the different effects in dollars or you can compare them hydrologically.

If dollar values are put on each of the results then a simple addition or subtraction should show whether the plan provides gains or losses.

However, while dollar values are the usual measurements, they are not always the easiest to apply.

In the case of shipping and hydroelectric systems, dollar values are easily calculated. Even the loss or gain to shoreline property is not impossible to reckon. Example: evaluation of recreation beaches was carried out by computing the area of a beach, its use, the potential extra use that would result if the beach were made larger by lower levels, or lesser use if the beach were made smaller by higher levels. Costs were then worked out for seasonal attendance at the beach.

The loss to shoreline property by erosion and inundation is infinitely more difficult to evaluate and the techniques presently available are somewhat inexact.

The important point is that the effects of all plans were evaluated using the same yardstick—dollars—and one that was adequate for the calculations that were made.

One real problem area in the calculations was the effect of water level fluctuations on the environment. This is the total of all factors which affect the life and growth of an organism. Human environment includes not only the physical factors, but such influences as beauty, aesthetics and human sensitivity and the quality of life.

Yet how can a price be put upon a sunset? Or upon the unpleasantness of having water polluted with algae? Or upon the loss of good fishing? It soon became apparent that considerations of the environment could not be closely calculated. Therefore, the study took notice of them in a qualitative way only. Where plans require more detailed costing of effects, a note was made that full environmental studies should be completed before a decision could be made to make changes.

If a hydrologic evaluation is used some interesting comparison possibilities arise. These would involve a look at the regime of levels and flows the lakes would have under the various regulation plans.

The analysis of these factors includes consideration of maximum, average and minimum values month by month and of their range, duration and seasonal distribution. Various criteria, expressed in these hydrologic terms, have been developed for the purposes of regulation. Evaluating them involves finding out the degree to which any new regulation plan meets the criteria. In some cases this requires a comparison between regulated data and the basis-of-comparison data which were established when the study began.

The two evaluation approaches are complementary and both were used for the purpose of the study.

Assessment of Some of the Plans Indicated Good and Poor Returns

Once the guidelines had been established, the assessment of the plans was begun. All possible combinations of lakes were considered. As it turned out the plans showing promise were from the SO series, particularly SO-901.

Even the unskilled eye will pick out the problems in any attempt to regulate Lakes Superior, Michigan-Huron, Erie and Ontario together (Plan SMHEO-38) or Lakes Superior, Michigan-Huron, and Ontario together (Plan SMHO-11). The difficulty lies in the complexity of regulating Lakes Michigan-Huron in concert with the other lakes.

To execute either of those plans nine or ten control structures would be needed in the St. Clair-Detroit rivers: (a) in the St. Clair River at Point Huron, Stag Island, St. Clair, North and Middle Channels and Fawn Island; (b) in the Detroit River at; the head of the Detroit River, north and south of Peach Island, Belle Isle', Zug Island, East Fighting Island (Grassy Island), and Trenton Channel.

These would cost hundreds of millions of dollars, far more than could ever be recouped in benefits. Both the construction and the subsequent changes in flows and levels would cause harm to the environment.

With the advent of the extreme high water supplies in 1972 and since complete regulation of Lake Erie outflows was determined to be not feasible, a partial regulation of Lake Erie, affecting high levels only, was conceived. This plan, called SEO-42P was tested in initial form and was singled out as promising enough to deserve further study.

TWO PROMISING REGULATION PLANS SO-901 and SEO-42P

The natural balance of the Great Lakes, created over the years, is delicate. To disturb it is to affect lakeshore properties, water supply intakes, navigation, power production and the environment.

Therefore, the water levels of the lakes which are already controlled follow the natural water level patterns quite closely.

Significant changes occur only when it is obvious that high inflow or low outflow will continue for some time in the future.

What Happens when Lakes Superior & Ontario are Regulated Together?

This was an obvious first choice for investigation since both lakes already have works at their outlets which completely control their flow. A number of different plans were created and tested. One of them, with the code number SO-901 was found to be functional. It calls for only slight modification to the St. Marys control works so they can be operated swiftly and surely during the winter.

This scheme would cost about $70,000 a year. In return the plan would give annual benefits of $2.37 million spread over power, shipping and shoreline interests. At the same time, the plan does not cause significant damage to the environment.

With this plan, Lake Ontario was found to be a vital partner. As the ultimate outlet for the lakes, the regulation of Lake Ontario is essential. It was also found that when tested over the selected study period the present Lake Ontario regulation plan could accomodate the new outflow regime from Lake Superior.

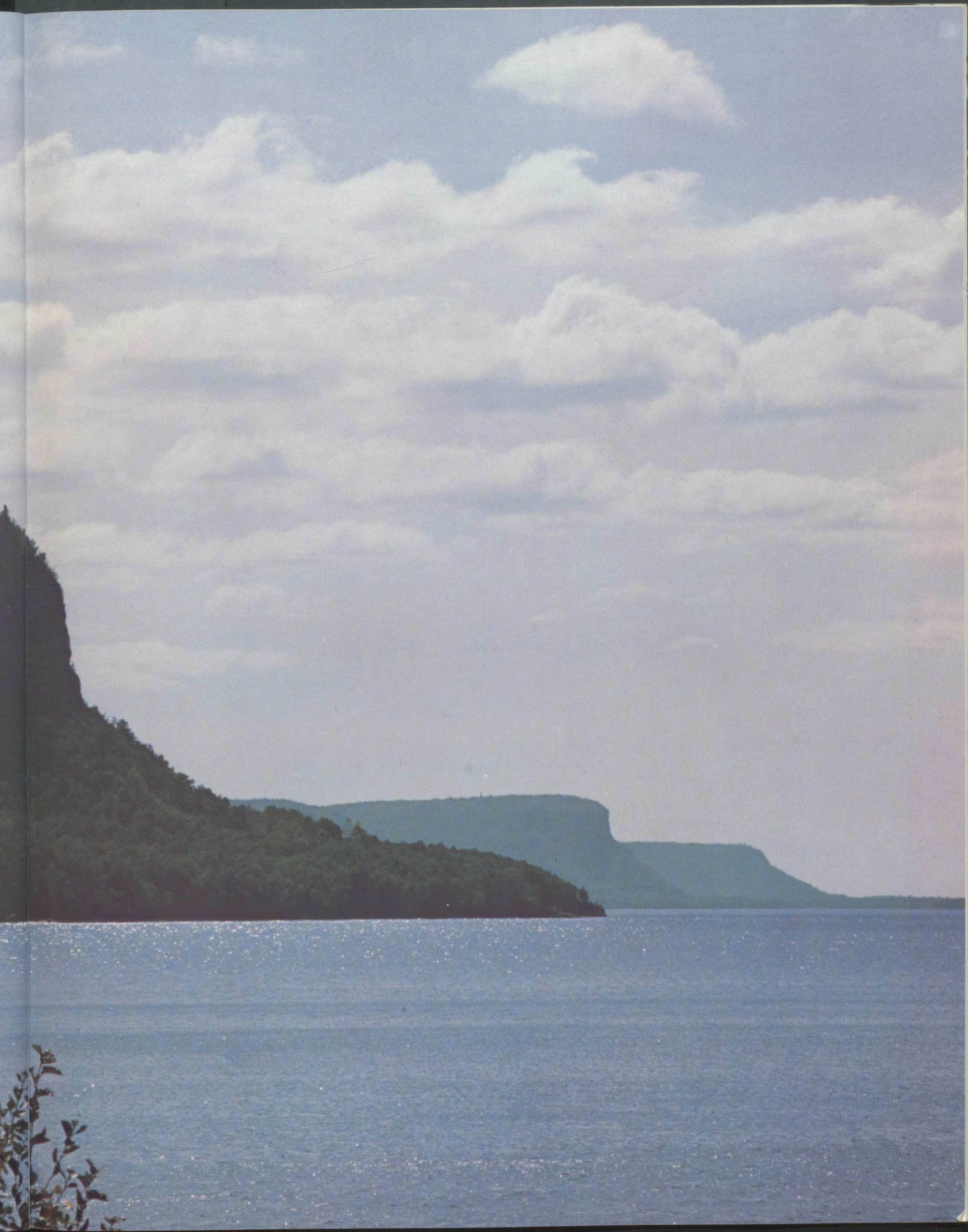
Since Plan SO-901 was developed, there has been a period of very high supply and the regulation plan for Lake Ontario is being re-assessed to see if it can be adapted to releasing some of these record supplies in time of serious flooding.

Plan SO-901 in Detail

With this plan:

- ☐ the same minimum outflow specified by the present Lake Superior regulation plan would be maintained.
- ☐ the levels of Superior, Michigan-Huron would be kept at relatively the same position with respect to their mean levels, tending to moderate extreme levels on both lakes.
- ☐ minimum levels on Lake Superior would be raised slightly.
- ☐ a slight raising of mean levels on all lakes would occur.
- ☐ the frequency of occurrence of highs on Lake Erie would be reduced.
- ☐ frequency of levels above the mean would be about the same on Lake Ontario.

The plan was designed to balance the water levels in Lake Superior and Lakes Michigan-Huron. When Superior is high, water can be released. When Michigan-Huron levels are high, water can be retained in Lake Superior. Under this system, nearly half of the total net supply to Michigan-Huron would be regulated on the basis of the levels of these lakes as well as those of Lake Superior.



Hydrologic Effects

The 1st table below shows computed water levels and outflows for Plan SO-901 if the supplies during the 1900-1967 study period were to reoccur in exactly the same sequence.

As you will see, it would raise Lake Superior water level slightly. This will benefit shipping. The minimum flows would be increased slightly to the benefit of hydro production at Niagara and on the St. Lawrence.

There would be slight losses to Lake Superior riparian interests, but a gain to shore property interests on Lakes Michigan-Huron and Erie. Lake Ontario would experience very little change in frequency of above-average levels.

Economic Effects of Plan SO-901

Annual benefits to commercial navigation under Plan SO-901 amount to $927,000.

There would also be an annual net benefit of $640,000 to power interests. This includes a loss of $160,000 to the Upper Michigan system (a high figure in relation to the small size of the local power system). The total annual benefits of $460,000 to New York State, $260,000 to Ontario and $80,000 to Quebec are small in rela-

HYDROLOGIC EVALUATION

Summary of Stages in Feet and Outflow in thousands of cubic feet per second

	Basis of Comparison		SO-901		SEO-901		SEO-42P		Basis of Comparison		SMHO-11		SEO-33		SMHEO-38	
	Stage	Flow	Stage	Flow	Stage	Flow	Stage	Flow	Stage	Flow	Stage	Flow	Stage	Flow	Stage	Flow
Lake Superior																
Mean	600.38	77	600.41	77	600.41	77	600.37	77	600.38	77	600.38	77	600.39	77	600.41	77
Max	601.91	123	602.00	123	602.00	123	601.95	123	601.91	123	602.09	123	602.01	123	602.19	124
Min	598.36	55	598.81	55	598.81	55	598.76	55	598.36	55	598.73	55	598.79	55	598.74	55
Range	3.55	68	3.19	68	3.19	68	3.19	68	3.55	68	3.36	68	3.22	68	3.45	69
Lake Michigan-Huron			(1962 outlet conditions)								(1933 outlet conditions)					
Mean	577.95	183	577.96	183	577.89	183	577.86	183	578.54	183	578.48	183	578.48	183	578.38	183
Max	580.91	233	580.64	227	580.57	227	580.52	227	581.50	233	581.20	236	581.20	227	581.26	220
Min	575.15	107	575.46	113	575.39	113	575.39	113	575.74	107	576.03	132	576.02	111	575.90	130
Range	5.76	126	5.18	114	5.18	114	5.13	114	5.76	126	5.17	104	5.18	116	5.36	90
Lake Erie																
Mean	570.60	204	570.61	204	570.42	204	570.36	204	570.60	204	570.63	204	570.45	204	570.17	204
Max	573.01	258	573.04	259	572.85	259	572.69	259	573.01	258	572.99	257	572.90	266	572.89	259
Min	567.95	149	568.14	152	567.95	152	567.97	149	567.95	149	568.36	160	568.02	154	567.39	165
Range	5.06	109	4.90	107	4.90	107	4.72	110	5.06	109	4.63	97	4.88	112	5.50	94
Lake Ontario																
Mean	244.53	238	244.55	238	244.55	238	244.48	238	244.53	238	244.56	238	244.41	238	244.51	238
Max	246.95	310	246.92	310	246.92	310	246.89	310	246.95	310	246.96	305	247.05	310	247.02	308
Min	241.31	176	241.53	188	241.53	188	241.29	188	241.31	176	241.86	200	241.75	179	241.35	210
Range	5.64	134	5.39	122	5.39	122	5.60	122	5.64	134	5.10	105	5.30	131	5.67	98

1933 outlet conditions: this represents the condition referred to in the Exchange of Notes between Canada and the United States in 1961-62 with regard to the construction of sills in the St. Clair River to compensate for the 25 and 27-foot navigation channel in the St. Clair and Detroit Rivers. It is the condition existing in the St. Clair and Detroit Rivers before the start of the 25-foot navigation channel dredging.
1962 outlet conditions: this represents the current Lake Huron outlet condition which has existed since the completion of the 27-foot navigation channel dredging.

Summary of Average Annual Economic Benefits of Plan SO-901 ($1,000)

LAKE	COUNTRY	NAVIGATION*	POWER		SHORE PROPERTY					TOTAL
			Energy	Capacity**	Erosion and Inundation	Marine Structures	Water Intakes and Sewer Outfalls	Recreation Beaches	Sub-total	
Superior	U.S.		− 130		− 109	− 2	0	− 5	− 116	
	Canada		0		− 6	− 2	0	0	− 8	
Michigan	U.S.		—		+ 156	+ 6	0	+ 82	+ 244	
Huron	U.S.		—		+ 89	+ 3		+ 17	+ 109	
	Canada				+ 12	0	0	+ 56	+ 68	
St. Clair	U.S.				+ 10			0	+ 10	
	Canada				+ 63			0	+ 63	
Erie	U.S.		+ 170		+ 348	+ 4	0	+ 18	+ 370	
	Canada		+ 120		+ 38	+ 1	0	+ 56	+ 95	
Ontario	U.S.		+ 50		− 43	+ 1	0	+ 4	− 38	
	Canada		+ 100		+ 5	+ 1	0	0	+ 6	
Great Lakes	U.S.	+ 708	+ 90	+ 210	+ 451	+ 12	0	+ 116	+ 579	+ 1,587
	Canada	+ 219	+ 220	+ 120	+ 112	0	0	+ 112	+ 224	+ 783
	TOTAL	+ 927	+ 640		+ 563	+ 12	0	+ 228	+ 803	+ 2,370

*Navigation benefits are computed for traffic routes, not for individual lakes.
**Capacity benefits are computed for power systems, not for individual lakes.

tion to the size of these power systems.

The minor changes in lake levels would not affect the value of the Canadian shoreline on Lake Superior, owing to its rocky nature and generally higher terrain, however, the plan would cause an annual loss of $109,000 to the lower and easily erodible U.S. shore, while providing benefits totalling about $720,000 on all other lakes.

It appears that, should Plan SO-901 be put into effect, U.S. beaches would benefit to the tune of $116,000 annually and Canadian beaches about $112,000 annually. Lake Superior would experience a small loss of beach use.

Environmental Effects Would Be Small

Plan SO-901 has a relatively minor effect upon sport fishing. Reductions in flow through the St. Marys Rapids would result in some decrease in fish population in the area. In July 1973 the International Joint Commission called for a study of ways to prevent this.

Plan SO-901 is moderately beneficial to marshlands and hence to wildlife, particularly during times of low water supplies. The plan does not perform as well at times of high level. When this happens there will be some loss of marshlands in all the lakes except Superior.

The plan will not cause any drop in quality of life in the region. The only possible adverse aesthetic effect could result from an increase in erosion in the red clay area of Wisconsin's Superior shore.

(A version of Plan SO-901, called SEO-901 was tested. Additionally, it would involve the dredging of the Niagara River which would lower the mean level of Lake Erie. This plan would not involve any regulation of the levels of Lake Erie. It would, however, cause irreversible harm to the environment. Also, under periods of low supplies there would be no way of raising the levels.)

What Happens When Superior, Erie & Ontario are Regulated Together?

This was a most interesting proposition. The Board studied it by way of a number of plans. It soon became apparent that one of them would offer far more advantages than the others. This plan, coded SEO-42P, would provide a benefit of $8.8 million annually at a cost of only $450,000 annually.

Plan SEO-42P, having been developed toward the end of the study, is still only a trial plan and needs further development. It could be refined to yield even more worthwhile benefits than are indicated here.

The plan presupposes the regulation of Lake Superior according to Plan SO-901 with the current regulation plan for Lake Ontario modified to deal with the change in outflow regime from Lake Erie but still meet the criteria and requirements for the regulation of Lake Ontario as laid down by the International Joint Commission.

The basis of the plan is the partial control of Lake Erie's outflow by the building of a controlled diversion through Squaw Island in the Niagara River. This would be used to divert up to 8,000 cfs during times of above normal supply.

The channel would be 35 feet wide and approximately 1,500 feet long. The flow through would be controlled by a 35-foot wide tainter gate.

Total capital cost would be $4.9 million, with a total annual cost of $380,000 including amortization.

The Superior regulatory works would require the same modification as those required for Plan SO-901.

With this plan:

- ☐ the range of monthly mean outflows from Lake Superior would be unchanged but there would be more frequent low flows.
- ☐ maximum levels would be lowered on Michigan-Huron and Erie.
- ☐ maximum level on Lake Ontario would be slightly lowered.
- ☐ maximum level on Lake Superior would be slightly raised.
- ☐ minimum levels on Lakes Superior and Michigan-Huron would be raised.

Summary of Average Annual Economic Benefits of Plan SEO-42P ($1,000)

LAKE	COUNTRY	NAVIGATION*	POWER		SHORE PROPERTY					TOTAL
			Energy	Capacity**	Erosion and Inundation	Marine Structures	Water Intakes and Sewer Outfalls	Recreation Beaches	Sub-total	
Superior	U.S.		− 130		+ 150	− 3	0	+ 1	+ 148	
	Canada		0		+ 3	− 1	0	0	+ 2	
Michigan	U.S.				+ 926	− 5	− 21	+ 850	+ 1,750	
Huron	U.S.				+ 300	− 3	0	+ 168	+ 465	
	Canada				+ 16	− 1	+ 4	+ 156	+ 175	
St. Clair	U.S.				+ 157			+ 8	+ 165	
	Canada				+ 248			0	+ 248	
Erie	U.S.		+ 60		+ 3,165	− 16	− 23	+ 319	+ 3,445	
	Canada		+ 70		+ 344	− 7	0	+ 222	+ 559	
Ontario	U.S.		− 50		+ 644	− 2	− 2	+ 63	+ 703	
	Canada		− 40		+ 105	+ 2	0	+ 389	+ 496	
Great Lakes	U.S.	+ 479	− 120	+ 80	+ 5,342	− 29	− 46	+ 1,409	+ 6,676	+ 7,115
	Canada	+ 151	+ 30	+ 20	+ 716	− 7	+ 4	+ 767	+ 1,480	+ 1,681
	TOTAL	+ 630	+ 10		+ 6,058	− 36	− 42	+ 2,176	+ 8,156	+ 8,796

*Navigation benefits are computed for traffic routes, not for individual lakes.
**Capacity benefits are computed for power systems, not for individual lakes.

☐ minimum levels on Lakes Ontario and Erie would remain about the same.

☐ the range of levels would be reduced on all lakes.

In almost all instances, Plan SEO-42P would generate benefits. To shipping, the annual benefit would be about $630,000 while hydroelectric generation would benefit in New York State by $120,000 annually and in Ontario by $60,000.

There would be an annual loss to the Upper Michigan System of $160,000 and to the Quebec System, $10,000.

Since this plan generally would lower the range of levels on all lakes there would be a benefit to the shoreline on both sides of the border—$5,342,000 to the U.S. and $716,000 to Canadian shores.

Beaches, too, would benefit under this plan by an estimated $1,409,000 in the U.S. and $767,000 to Canada.

As far as quality of life, ecology, fish and wildlife are concerned, Plan SEO-42P offers mixed benefits.

The plan calls for a canal to be dug, bisecting Squaw Island and fitted with control works. For a short time, owing to dredging and blasting to construct the canal and control works, sport fishing could suffer because the Caddis fly population would be disturbed and the water quality could be lowered. The plan also calls for the same modifications to the Lake Superior control structure in the St. Marys River as Plan SO-901, so unless some kind of mitigating measures can be taken, there could be some adverse effects to sport fishing in the St. Marys Rapids. The plan does not benefit wildfowl. Dredging in the Niagara River might temporarily discourage the wildfowl which use the area as a stopover. Acreage of wetland on all Lakes would be reduced.

On the plus side, the plan does not cause any drop in the quality of life in the region. No adverse effects are foreseen to hygiene, aesthetics, or social well-being.

Summary of the Benefits of Both Plans, by Interest, Country & Costs

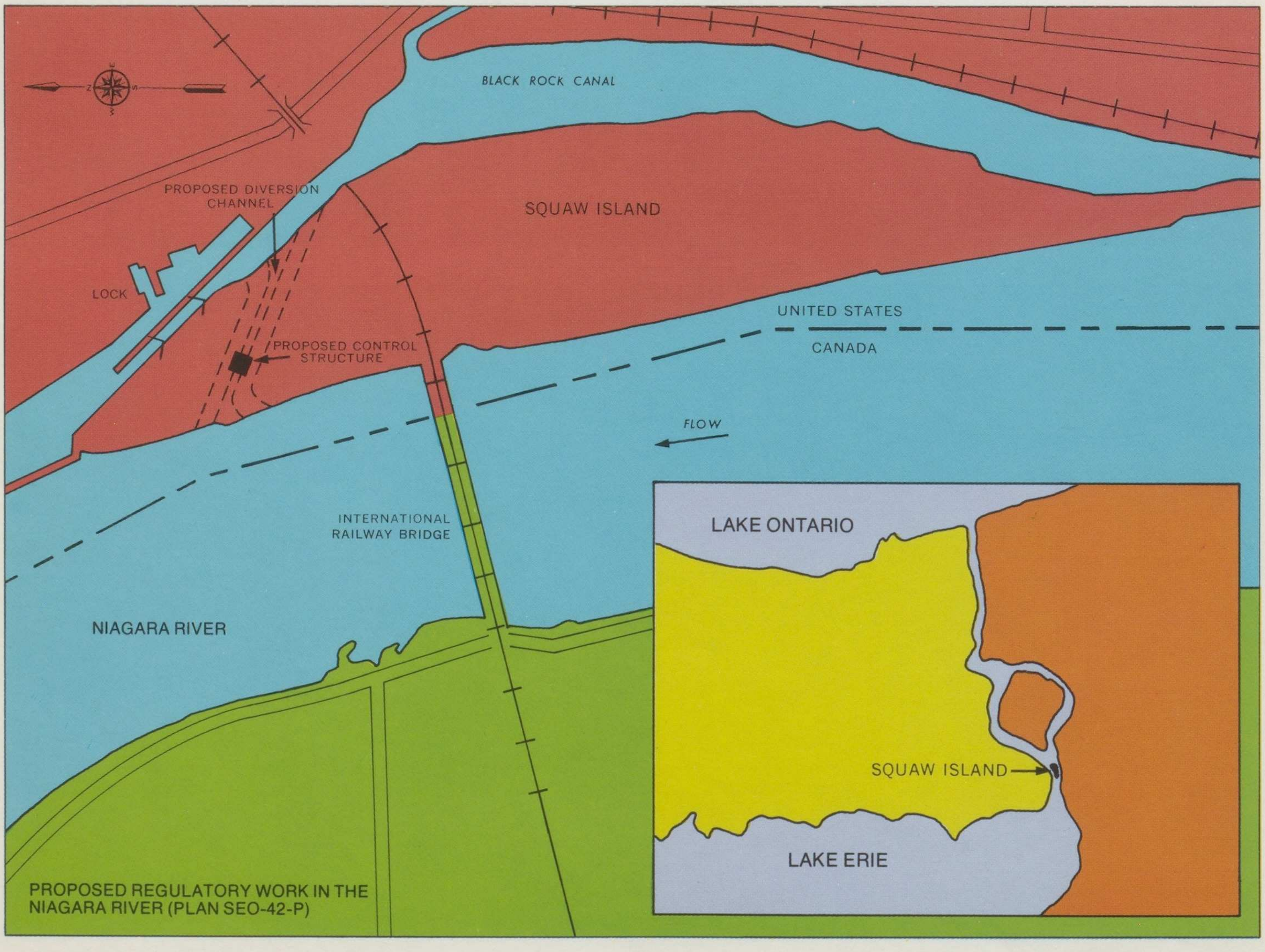
While both countries benefit, Plans SO-901 and SEO-42P provide net annual benefits two to four times greater for the U.S. than for Canada.

These plans provide a net shipping benefit three times greater for the U.S. than for the Canadian fleet.

Plan SO-901 provides equal power benefits to each country while Plan SEO-42P produces a small loss to U.S. and a small benefit to Canadian power interests.

Plans SO-901 and SEO-42P produce higher net benefits to shore property owners in the U.S. than in Canada. Plan SEO-42P provides a lower total benefit-cost ratio (19.5:1) than Plan SO-901 (33.9:1). It does, however, provide a favourable incremental benefit-cost ratio over SO-901 of 16.9.

Essentially, all major interests benefit equally from Plan SO-901. Plan SEO-42P would provide large benefits to shore property interests and it would produce less benefit to



PROPOSED REGULATORY WORK IN THE NIAGARA RIVER (PLAN SEO-42-P) navigation than Plan SO-901, generating a loss, compared with Plan SO-901, of $297,000 annually. The benefits to power interests under Plans SEO-42P would be about $630,000 less compared with Plan SO-901.

Expected Results Could be Altered

Three factors could change the indicated benefits of the plans.

1. *Departure from the supply sequences used in the evaluation.* As this report has mentioned from time to time, there is no way of forecasting precipitation so there is no way of forecasting supplies of water to the lakes far enough into the future.

While the likelihood of the seasonal supply sequences remaining essentially the same is very high, there is no guarantee the annual sequence will follow past performance. In fact, it is a pretty safe bet it will not.

2. *Growth in consumptive use of Great Lakes' water.* Increased population and economic growth in the region will undoubtedly call for greater consumptive use of the waters of the Great Lakes. If present trends continue it is estimated that the 1965 figure of 2,300 cfs will grow to 4,000 cfs in 1985, 6,000 cfs by 2000 and 13,000 cfs by the year 2030. This growing use ultimately will call for revised regulation of the Lakes.

3. *Changes in shoreline development.* The benefits to shore property interests will be reduced if development is not regulated by proper land use controls. The demand for waterfront property has resulted in development of low-lying shoreline. This occurred during the low-water periods as recently as the 1960's, even though the land had been flooded only a few years before.

Some beach and bluff areas which were stable in the low-water periods have also been developed, even though they suffer visible erosion during high-water periods.

At this writing, all these areas are experiencing damage from high lake levels.

Summary of Average Annual Benefits and Costs ($1,000)

Annual Benefits	SO-901	SEO-901	SEO-42P	SEO-33	SMHEO-38	SMHO-11
Navigation						
U.S.	708	745	479	236	204	207
Canada	219	205	151	88	69	88
	927	950	630	324	273	295
Power						
U.S.	300	300	– 40	80	– 30	440
Canada	340	340	50	230	120	– 450
	640	640	+ 10	310	90	– 10
Shore Property						
U.S.	579	4,006	6,676	5,395	7,204	665
Canada	224	1,171	1,480	1,523	2,461	882
	803	5,177	8,156	6,918	9,665	1,547
Total Benefits						
U.S.	1,587	5,051	7,115	5,711	7,378	1,312
Canada	783	1,716	1,681	1,841	2,650	520
	2,370	6,767	8,796	7,552	10,028	1,832
Incremental Benefits Over SO-901						
U.S.		3,464	5,528	4,124	5,791	– 275
Canada		933	898	1,058	1,867	– 263
		4,397	6,426	5,182	7,658	– 538
Annual Costs						
Total Costs	70	169	450	8,159	27,854	18,003
Incremental Costs Over SO-901		99	380	8,089	27,784	17,933
Benefit-Cost Ratios						
Total Benefits and Costs	33.9	40.0	19.5	0.93	0.36	**
Incremental Benefits and Costs Over SO-901		44.4	16.9	0.64	0.28	**

*Annual benefits and costs are based on project period 1972-2022 for SO-901 whereas the project period 1980-2030 is used for all other plans.

**The Board estimates that the total benefits of a refined SMHO plan, developed from the basis of preliminary Plan SMHO-11 would be about $3 million. This would yield an overall benefit-cost ratio of 0.17 and an incremental benefit-cost ratio of 0.03.

It is interesting to note that the range of levels on the Great Lakes averages about six feet over periods of decades. This relatively small differential has caused great loss and hardship to users of property along the shores.

By contrast, the rise and fall of the Atlantic in the Bay of Fundy is over 40 feet *twice daily* and the people respect this range. The Bay users have adjusted their requirements to the fluctuations, and because they are reminded daily of the oncoming water, they do not use the shoreline in such a way that the water can get at them.

If the same philosophical approach were applied along the Great Lakes' shores, riparian problems would be vastly reduced.

Zoning will be Important

At the time the study was made, it was calculated that 80% of any expected flood or erosion damage would occur to residential property. Some of this property was developed during the mid-sixties, when lake levels were at their lowest on record. Because of the high value of lakeshore land, the building was carried out down to the lowest possible level *even for that historically low-period.* Obviously a return to even average levels for the lakes could only result in flood damage to these properties. Given the record highs of the 1973 season, flood damage was inevitable and extensive. The lesson to be drawn from this example is that building should not follow the fluctuations of lake levels but should be maintained at a safe height above the lakes.

FINDINGS

After all the measurements were taken, the calculations made, the plans prepared and assessed, what did we find out? And what can be done with the information?

1. There are Three Categories of Water Level Fluctuations on the Great Lakes: Short-Period, Seasonal and Long-Term.

Short-period fluctuations, lasting from a few hours to several days, are caused by: meteorological disturbances, by wind and by differences in barometric pressure. Although the level of a lake at a particular location may change as much as eight feet from such causes, there is no change in the *volume* of water in the lake. Short-term fluctuations cannot be reduced by operation of a regulatory structure at the outlet of the lake. They are superimposed on the seasonal and long-term fluctuations of the water levels.

Seasonal fluctuations of Great Lakes levels result from the annual hydrologic cycle: i.e. higher supplies during spring and early summer, lower supplies during the remainder of the year. The magnitude of seasonal fluctuations is quite small, averaging about one foot on Lake Superior and Lakes Michigan-Huron, 1.5 feet on Lake Erie, and 1.9 feet on Lake Ontario. Such seasonal fluctuations are only about one-quarter of the long-term fluctuations and are superimposed on the latter.

Long-term fluctuations are the result of persistent low or high water supply conditions within the basin which culminate in extreme low levels, such as were recorded in 1964-65, or in extreme high levels, such as were recorded in 1972-73. A century of record-keeping in the Great Lakes basin indicates that there are no regular, predictable cycles. The intervals between periods of high and low levels and the length of such periods vary widely.

Superimposed upon all three categories of water level fluctuations are wind-induced waves.

2. The large storage capacities and restricted outflow characteristics of the Great Lakes are highly effective in providing a naturally regulated system.

The vast surface areas of the Great Lakes, which are equal to about half the land areas contributing run-off to them, constitute a unique feature of this waterway. Small differences in lake level represent enormous quantities of water.

The level of each of the Great Lakes depends on the balance between the quantity of water supplied to the lake and the quantity of water removed from it. The source of supply is precipitation on any part of the basin above a lake's outlet. This reaches the lake as inflow from the lake next upstream in the series, runoff from the precipitation falling on the drainage area directly contributing to the lake, and precipitation falling directly on the lake. Water leaves the lake by evaporation and by flow through its outlet river. If the quantity of water received by a lake is larger than the quantity removed, the volume of water in the lake increases, the lake level rises, and its outflow increases. The more limited the outflow capacity, the greater will be the rise in water level for a given volume of total inflow. The supply to a lake in one month has been as much as three times the volume of water that could be discharged through its outlet river during the month.

Because of the size of the Great Lakes and the limited natural discharge capacities of the outflow rivers, extreme high or low levels and flows persist for some considerable time after the factors which caused them have changed or ceased. Under natural conditions it would take two and one-half years for only half of the full effect of a supply change to Lakes Michigan-Huron to be realized in the outflow from Lake Erie. Therefore, the result of a change in outflow from Lake Superior may

manifest itself in Lake Ontario and be translated into flows in the St. Lawrence River at a time when such supplies aggravate an extreme condition in the lower river.

The only way to eliminate the natural time lag would be to have major control works and channel enlargements at the outlets of all the lakes and down the St. Lawrence River and to operate all the works simultaneously. Under such conditions the effect of a supply change could be translated almost immediately from the upper end of the basin to the lower river by adjustment of the regulatory works at the outlet of all the lakes.

3. The mean levels and outflows of the Lakes will change progressively with time as a result of:

(*a*) *The steadily increasing consumptive use of water in the basin, and*

(*b*) *The nearly imperceptible movement of the earth's crust in the region of the Great Lakes' basin.*

(a) The increasing consumptive use of water will gradually decrease the net supply to the lakes. The effect of this will be to decrease the mean water elevation of an unregulated lake and its outflow. If the present growth trend in consumptive use continues, this problem will require careful and serious study.

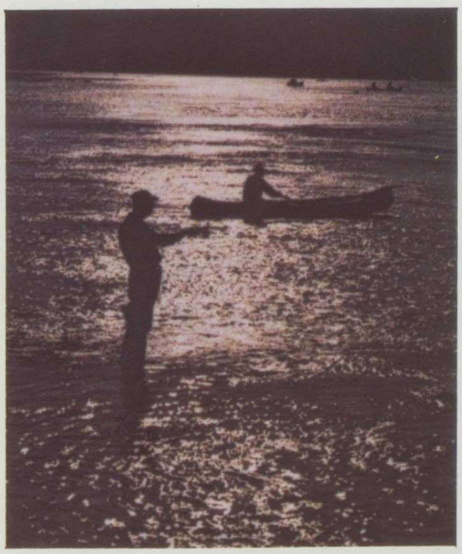
(b) The "tilting" of the earth's crust in the region is gradually raising the northeastern limits of the Great Lakes' basin relative to its southwestern limits. This effect is detectible on individual lakes after a period of years; for example, on Lakes Michigan-Huron, land on Thessalon on the northeastern shore is rising with respect to land at Milwaukee on the southwestern shore at a rate of about 1.2 feet per century.

The net effect of the "tilting" is to increase gradually the mean water elevation of unregulated lakes. For regulated lakes, the effect can be ameliorated by adjustment of the regulation regime at least until such compensation begins to affect the regulation capability. Crustal movement does not change the supply of water to the lakes.

4. To the extent that the lakes already possess a high degree of natural regulation and are artificially regulated by means of the works at the outlets of Lake Superior and Lake Ontario, only small improvements are practicable without costly regulatory works and remedial measures.

Further regulation could be obtained: (a) by revising the current plans for regulation of Lake Superior and Lake Ontario without making major changes to the existing regulatory structures in their outlet rivers; (b) by devising new kinds of regulation with concommitant major construction changes to existing regulatory works; (c) by constructing regulatory works in the outlet rivers of Lakes Michigan-Huron and Lake Erie; or (d) by various combinations of these measures.

A limited reduction in the range of levels of a lake could be obtained by a redistribution of its outflows during the year. A further compression of the range, reducing the effective storage, could only be achieved by increasing the variation of the flows of its outlet river. This, in turn, would increase the range of levels and outflows of the downstream lakes, which could be economically detrimental to them. By regulating the downstream lakes, such hydrologic and economic effects could be eliminated, but the result would be to transfer these variations to the St. Lawrence River, where significant physical constraints exist. Consequently, only minor reductions in the range of levels would be possible without costly remedial measures to avoid significant adverse downstream effects.



5. A new regulation plan for Lake Superior, SO-901, can be expected to yield small long-term average annual net benefits to the system at minimal cost.

The limited outlet capacities of the lakes mean that significant reductions in extremes of levels cannot be achieved for all lakes. However, the maximum range of levels determined from the long-term fluctuations can be reduced on two large lakes in series, if the upper one can be regulated, by balancing the storage between the two lakes.

The economic evaluation of the plan indicates that it could provide an overall average annual net benefit to the system in the order of $2 million shared by the United States in the ratio of about 2:1. The net effects of Plan SO-901 on aquatic wildlife would be minor and other ancillary effects would be unmeasurable.

6. Two preliminary plans for the combined regulation of Lakes Superior, Erie and Ontario exhibit favourable benefit-cost ratios.

(a) Permanently lowering the mean level of Lake Erie by channel enlargement in the upper Niagara River and use of Plan SO-901 for the regulation of Lakes Superior and Ontario (Plan SEO-901): Annual benefits in the order of $6.3 million would be obtained from such a plan at an estimated annual cost of $169,000. The permanent lowering of Lake Erie under this plan would result in irreversible harm to the environment.

(b) Increasing the outflow of Lake Erie during periods of above-average supply by controlled diversion through the Black Rock Canal, which parallels the upper Niagara River, regulation of Lake Superior in accordance with Plan SO-901, and use of a modified Plan 1958-D for the regulation of Lake Ontario (Plan SEO-42P): Annual benefits in the order of $8.8 million would be obtained from such a plan at an estimated annual cost of $450,000.

7. Regulation of Lakes Michigan-Huron by construction of control works and dredging of channels at their outlet, combined with the regulation of Lakes Superior and Ontario, would not provide benefits commensurate with costs.

This plan would require regulatory works in the St. Clair and Detroit Rivers at a cost of about $150 million and Detroit River Channel enlargement at a cost of about $50 million. The estimated upper limit of annual benefits from this plan is only $3 million.

8. Regulation of all five lakes, employing existing control works for Lakes Superior and Ontario and newly constructed works for Lakes Michigan-Huron and Lake Erie, would not provide benefits commensurate with costs.

This plan would require regulatory works in the St. Clair, Detroit and Niagara Rivers at a cost of $266 million and Detroit and Niagara Rivers Channel enlargements at a cost of $105 million. The estimated upper limit of annual benefits from this plan is only $15 million.

9. The physical dimensions of the St. Lawrence River are not adequate to accommodate the record supplies to Lake Ontario received in 1972-73 and at the same time satisfy all the criteria and other requirements of the IJC Orders of Approval for the regulation of Lake Ontario.

Based upon water supplies for the study period 1900-1967, the existing regulatory works and channel capacities of the St. Lawrence River were judged to be adequate for the regulation of Lake Ontario under the existing Orders of Approval of the International Joint Commission. However, even with extraordinary discretionary deviation from Plan 1958-D, it was not possible to accommodate the record high supplies of 1972-73 and meet all the regulation criteria and other requirements of the Orders. Recent studies of the International St. Lawrence River Board of Control have confirmed that it is not practicable within existing physical constraints to design a plan which will meet all such criteria and other requirements under the maximum supplies received to date.

10. Construction of works in the St. Clair and Detroit Rivers to compensate hydraulically for the remaining effect of the 25 and 27- foot navigation projects would result in increased shoreline damage from higher lake levels.

The navigation projects in the St. Clair-Detroit River system were authorized with the provision that compensatory works would be constructed in the rivers to prevent the ultimate lowering of Lakes Michigan-Huron from the increased channel capacity of these rivers. Some hydraulic compensation was effected during construction by placement of excavated material so that it would retard river flow. However, full compensation has not been achieved. The average annual economic benefit to shore property due to the resulting 0.59-foot lowering of Lakes Michigan-Huron is $12 million, compared to a loss of $1.3 million to navigation.

11. Better and faster determination of basin hydrologic response will allow improvement in regulation.

Studies indicate that accurate forecasts of water supplies four months in the future could increase the benefits of regulation by as much as one-third. However, there is very little promise for forecasting precipitation more than a few weeks. Improvement is possible in the forecast of runoff into the lakes from precipitation which has already fallen on tributary land areas. Such forecasts would allow partial prediction of supplies and hence improved regulation.

12. The most promising measures for minimizing future damages to shore property interests are strict land use zoning and structural setback requirements.

The shoreline surveys and damage evaluations for this study have indicated that a significant portion of the shore property damage is due to flooding and wave attack on existing shore structures. The surveys also indicate that shoreline development is proceeding at an accelerating rate. In the future, damages will continue in developed areas where existing structures are too close to the lake. Loss of unprotected shoreline through erosion will also continue. However, total future damages can be reduced by judicious provision and enforcement of land use zoning to limit development and by-laws requiring proper setback of structures from the lake where development is permitted. If such measures are not taken, future development will continue to follow the general lake levels and total shoreline damage will continue to increase.

CONCLUSIONS

1. Small net benefits to the Great Lakes system would be achieved by a new regulation plan for Lake Superior which takes into consideration the levels of both Lake Superior and Lakes Michigan-Huron.

The new plan (SO-901) would employ the existing control works for Lake Superior and Lake Ontario, would incorporate the existing plan (1958-D) for the regulation of Lake Ontario, and would satisfy the existing criteria and requirements for Lake Ontario regulation to the same extent as 1958-D. The ratio of the long-term average annual benefits to the cost of the modifications is in the order of 34 to 1. Geographically, Lakes Michigan, Huron and Erie would be the main beneficiaries, with shore property, navigation and power interests sharing the total benefits. The United States and Canada would share them in the ratio of about 2 to 1. There would be no significant adverse environmental effects.

2. Regulation of Lakes Michigan-Huron by the construction of works in the St. Clair and Detroit Rivers does not warrant any further consideration.

To regulate the outflow of Lakes Michigan-Huron and at the same time maintain close to the natural profile of the 89-mile St. Clair-Detroit River system would require at least nine control structures. The cost of constructing as many works as this far exceeds any benefits to be expected from regulating Lakes Michigan-Huron outflows.

3. Further study is needed of the alternatives for regulating Lake Erie and improving the regulation of Lake Ontario, taking into account the full range of supplies received to date.

Such studies should (1) examine all constraints on regulation of these lakes downstream to Trois-Rivières on the St. Lawrence River and alternative means by which such constraints may be met or modified, (2) estimate the benefits and costs of the alternatives, and (3) appraise other factors which could affect the acceptability of the alternatives, including their environmental effects.

4. The hydrologic monitoring network of the Great Lakes basin should be progressively improved.

The responsible national agencies of Canada and the United States should co-operate in studying the benefits and costs of specific alternatives for expanding hydrologic monitoring, then adopt a step-by-step expansion program incorporating those measures within the improving state-of-the-art which are feasible and desirable.

5. Appropriate authorities should act to institute land use zoning and structural setback requirements to reduce future shoreline damage.

The power to institute such measures resides at different levels of government in Canada and the United States and even from one jurisdiction to another within each country. Without necessarily affecting such existing powers, there should be a concerted program of zoning and setback requirements based upon the realities of natural lakeshore processes. The Great Lakes are a dynamic natural system. Their water levels will fluctuate even with regulation. In periods of high-water storm-driven waves will flood and erode vulnerable shorelands. To live in harmony with his environment and avoid continual losses, man must keep development out of the danger zone.

POST SCRIPT

The study was conducted on a set of flow and level figures provided by the records for the years 1900-1967. In 1973, the lakes experienced the highest supplies ever recorded. Because of these conditions and the attendant problems, the Board decided that further study should be undertaken to see if regulatory methods could be found to accommodate such record high supplies if and when they occurred again.

Two specific areas were singled out for more study.

1. Finding ways to meet, or modify, existing upstream and downstream constraints on regulation to reduce damage to the riparion sector during periods of extreme supplies.
2. Finding ways to determine the hydrologic response of the lake basins, better and faster than at present in order to improve regulation.

Effects of the recent high supplies

Since 1967 the annual precipitation on the Great Lakes basin has averaged 8% more than the 31.4 inches averaged over the study period of 1900-1967. As a result, all the lakes rose to above normal levels.

In 1973, Lakes Michigan and Huron reached the highest levels since 1886, and Lakes St. Clair and Erie exceeded any previous highs.

Inclusion of the recent higher than normal supplies with the study period figures will help test the plan's performance against supplies that might occur in the future.

All lakes exceeded the 1900-1967 levels during the 1972-1973 period except Lake Superior, which received less extreme supplies than the lower lakes, and as a result experienced a maximum level about 0.2 foot lower than the maximum for 1900-1967.

To alleviate problems of flooding on the lower lakes the IJC instructed its International Lake Superior Board of Control to deviate from the modified Rule of 1949. The Superior outflow was reduced beginning February 1st, 1973.

This emergency action continued through 1973, using the objective of Plan SO-901 as a guide. As a result, in mid-August, Lake Superior was eight inches higher and Lakes Michigan-Huron were five inches lower than they would have been if the regulation plan under normal use had been followed.

During the first week of September 1973, Lake Superior reached a peak elevation of 601.9 feet, 0.1 foot below the prescribed upper limitof regulation.

The mid-August peak of Lakes Michigan-Huron was 581.0 feet, the highest since 1886.

Lake Ontario received record high supplies during 1972 and 1973. The International St. Lawrence River Board of Control began deviating from the established regulation plan in late 1972.

Even with increased outflows during the early months of 1973 it was not possible to avoid exceeding the upper limit of 246.77 feet specified in the IJC Orders of Approval.

The St. Lawrence Board continued to release higher flows than the regulation plan called for. Throughout June and July the outflow was 350,000 cfs. This exceeded by 32,000 the maximum flow ever recorded before the St. Lawrence Seaway and Power Project was built. It also exceeded by 13,000 cfs the peak flow that could have occurred *without* the Project. These excessive outflows kept Lake Ontario at least one foot lower than it would have been if the Project had never been built.

Computed Performance of the Two Selected Regulation Plans during the recent High Water.

If Plan SO-901 or SEO-42P could have been put into operation when the Lake levels had returned to normal levels (1968) from their previous extreme lows (1964) the plans would have lowered the 1973 maximum levels for all the Lakes.

That observation excludes the effects of the extraordinary deviation carried out in 1973 from the usual Lake Ontario regulation. If the same deviation were applied in the operation of either Plan SO-901 or SEO-42P, the result would have been a further lowering of Lake Ontario in the 1968-1973 period to a maximum of 247.3 feet, about 7 inches below what was actually recorded.

Downstream Physical Constraints on Improved Regulation of Lake Ontario

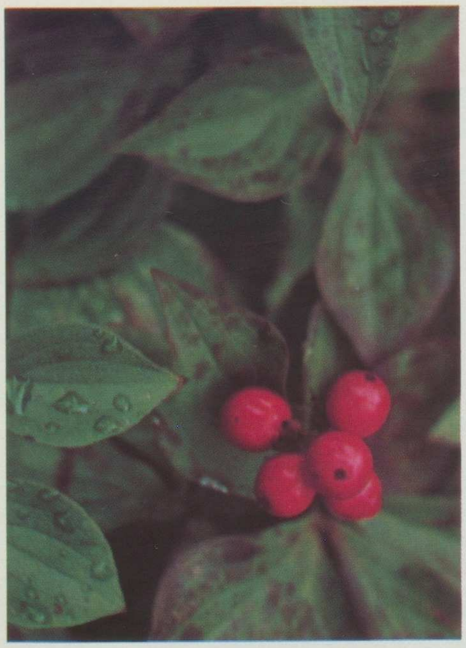
The power and navigation facilities built on the St. Lawrence River in the 1950's were designed to allow reduction of the high levels on Lake Ontario while improving the distribution of the outflows. This was to be done without changing the regime to the detriment of downstream interests. The calculations were based on supplies recorded from 1860 to 1954.

With the record supplies of 1973, it was found that the river is too narrow, or too shallow, in certain places to accommodate the excessive flows of extreme supply conditions so as to meet the criteria and other requirements of the IJC's Orders.

The most logical way of resolving this problem is to determine what changes in the physical character of the river are needed to handle the excess flows, then analyze the costs of making them and the new regulation plan which would be required.

The Need for Continuing Study

The practical experience of the last few years has shown the limitations of the present system for dispersing quickly, supplies which greatly exceed normal.



This points out the need for continued studies which will help us broaden our gross experience with level control and help us better cope with extremes which are sure to come.

As reported earlier, the Board has developed and evaluated a plan (SEO-42P) for the combined regulation of Lakes Superior, Erie and Ontario, that has a favourable benefit-cost ratio. However, the plan needs further refinement and examination before any final judgment is made.

In the development of Lake Erie plans, benefits tend to be limited by the amount of water which could be discharged into Lake Ontario. The refinement of these plans is therefore dependent upon further study of the regulation of Lake Ontario.

These studies should consider all the benefits on all the lakes which could be obtained through regulation of Lake Erie and further regulation of Lake Ontario.

The benefit-cost ratio of any Niagara River control works and changes in the St. Lawrence River would reflect total system benefits so further study of combined regulation of Lakes Superior, Erie and Ontario are warranted.

If Better Hydrologic Forecasting were Possible, Improvement in Regulation would be Possible

The essence of regulation is timely storage or release of supplies. If the amount of future supplies were known in advance, better regulation decisions could be made. In order to determine the effects of such knowledge, the Board analyzed the improvement in regulation under a plan similar to SO-901 assuming perfect foreknowledge of water supplies, for period ranging from 1 to 12 months.

Results indicate that significant benefits could come only from forecasts of at least four months and would increase benefits by about a third.

How can this forecasting be done? Long range weather forecasts of even a few weeks are not accurate. However, there is a potential for improving our knowledge of future run-off to the lakes from precipitation which has already fallen on the land areas. This hydrologic lag is a significant factor in seasonal fluctuation in the Great Lakes.

Present regulation decisions are based on actual lake levels and outflows. Factors which should also be studied for inclusion in the calculations are: recent precipitation, tributary streamflow, soil moisture content, air and water temperatures.

Present instrumentation and communications do not provide enough area coverage or timely information to permit this kind of analysis. Expansion of meteorological and hydrologic networks would be costly. The investment would be justified only if the ensuing benefits measure up to costs.

The Board has made a preliminary examination of the potential benefits and feel they will justify expansion of the meteorological and hydrologic networks. The responsible agencies in Canada and the United States should co-operate in studying the benefits and costs of such a program.

The foregoing is a summary of the report of the International Great Lakes Levels Board. The complete report is composed of several parts as follows:

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

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