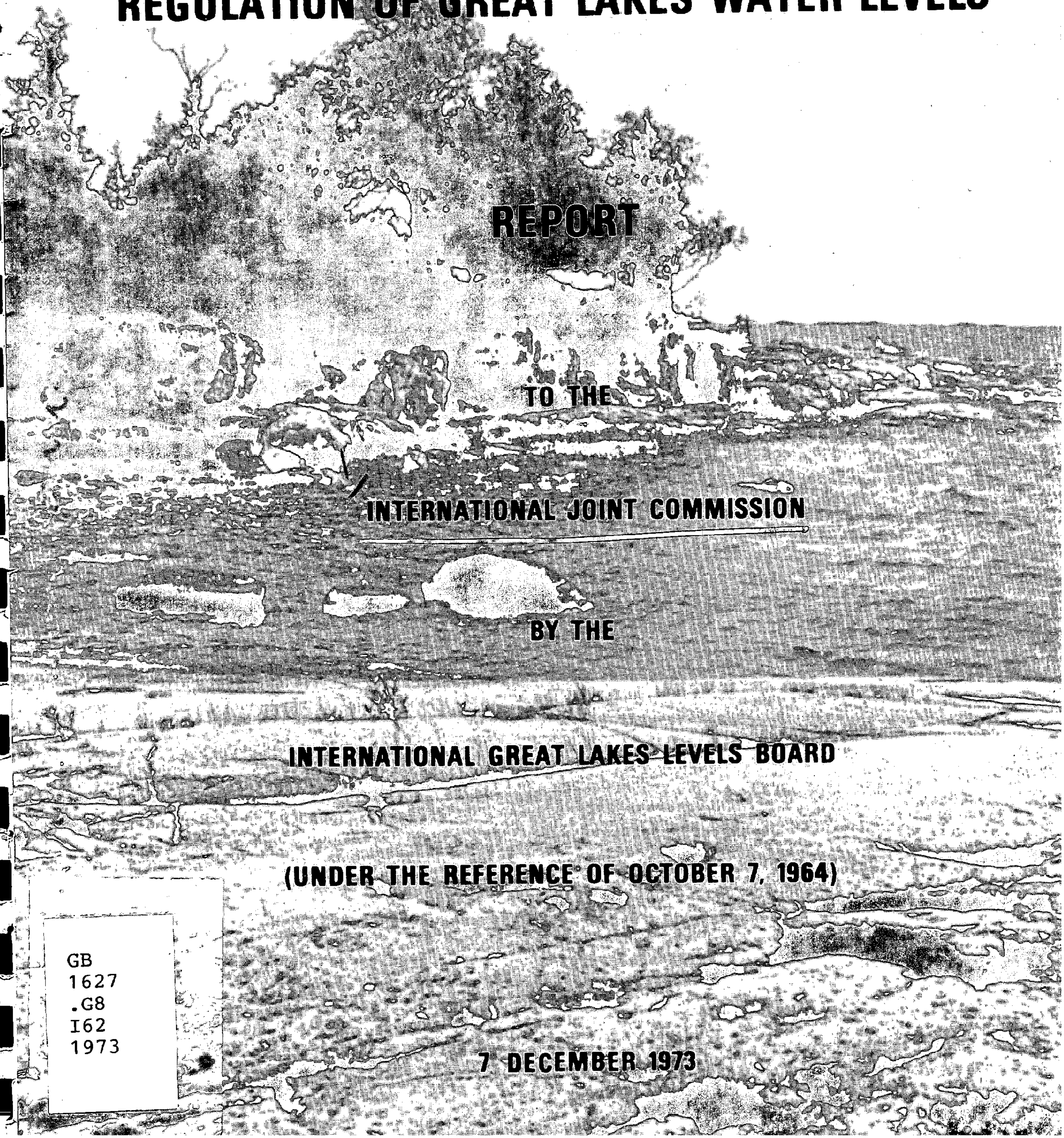
REGULATION OF GREAT LAKES WATER LEVELS



REPORT

TO THE

INTERNATIONAL JOINT COMMISSION

BY THE

INTERNATIONAL GREAT LAKES LEVELS BOARD

(UNDER THE REFERENCE OF OCTOBER 7, 1964)

7 DECEMBER 1973

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DECEMBER 7, 1973

INTERNATIONAL GREAT LAKES LEVELS BOARD
Offices of the Chairmen
Ottawa, Ontario
Chicago, Illinois

December 7, 1973

International Joint Commission
Washington, D. C. and
Ottawa, Ontario

Gentlemen:

The International Great Lakes Levels Board is pleased to submit herewith its Report on the Regulation of Great Lakes Water Levels under the assignment given to it under the Reference of October 7, 1964. The Findings and Conclusions reached by the Board are summarized in Section 14 of the Report while Section 13 elaborates on areas requiring further study.

The details of the studies and investigations carried out by the Board are contained in seven appendices to the main report. These appendices are under preparation and will be forwarded to the Commission as they are completed.

Respectfully submitted,

MEMBERS FOR CANADA	MEMBERS FOR THE UNITED STATES
C. K. HURST, CHAIRMAN	MG E. GRAVES, CHAIRMAN
R. H. SMITH	B. T. JOSE
N. H. JAMES	M. ABELSON

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A detailed description of the hydrology and hydraulics of the Great Lakes system, including an outline of the "state of knowledge" of the various factors which govern its water supply and affect the response of the system to its supply.

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APPENDIX D - FISH, WILDLIFE AND RECREATION

A documentation of the methodology developed to assess the effects on fish, wildlife and recreation of changes in water level and outflow regimes and of the detailed evaluations of the effects of selected regulation plans on these interests.

APPENDIX E - COMMERCIAL NAVIGATION

A documentation of the methodology applied in the assessment of the potential benefit or loss to shipping, using the Great Lakes-St. Lawrence navigation system, as a consequence of changes in lake level regimes and the evaluation of the economic effects on navigation of regime changes that would take place under selected regulation plans.

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APPENDIX G - REGULATORY WORKS

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Section 1

INTRODUCTION

1.1 Authority

The water levels of the Great Lakes fluctuate under the influence of a variety of natural and artificial factors. When they are extremely high, such as in the early 1950's, and currently, or extremely low, as in the mid-1960's, public and private interests suffer serious adverse effects. On October 7, 1964, as a result of wide-spread public concern, the Governments of Canada and the United States submitted the following Reference to the International Joint Commission (IJC) 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."

Pursuant to this Reference, the Commission established the International Great Lakes Levels Board on December 2, 1964, to undertake the necessary studies and investigations and to give advice on the foregoing matters. The Directive to the Board is reproduced as Annex A.

1.2 The Nature of the Problem

The water in the Great Lakes comes from the rain and snow falling on the lakes and on the lands draining into them. A large portion of this precipitation is lost through evaporation. With their large areas the lakes are normally able to store the net supply with relatively small changes in their levels. However, the capacities of the rivers connecting and draining the lakes are quite small compared to the storage volumes. The relation between storage volume and outflow capacity is such that, if precipitation persists above or below normal, water levels and flows vary significantly above or below their long-term averages.

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

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

Over time, people have adjusted their many uses of the lakes to the normal range of levels and flows, with limited flexibility to cope with extreme conditions. The construction of control works at the outlet of Lake Superior early in the century was aimed at using some of the outflow for the generation of power without significantly disturbing the historical lake regime. The construction of navigation and power facilities on the St. Lawrence River in the 1950's was carried out in such a way as to permit reducing the range of stage on Lake Ontario and improving the distribution of outflows without changing the regime to the detriment of downstream interests. This approach was based upon the experience that a change in favor of one interest or lake tended to be disadvantageous to others. Therefore, it was deemed best to make only small changes from conditions to which everyone had adapted his activities and to make such changes only when there were significant advantages to be gained and minimal disadvantages to any interest or to any lake. Under this approach Canada and the United States have sought gradually to optimize their use of the Great Lakes. However, except for Lake Ontario, man has not succeeded in regulating the levels and flows of the lakes within a significantly narrower range in the face of the natural variation in the supply of water received as rain and snow. The overall purpose of the current study is to determine whether it is practicable to improve the regulation of the Great Lakes so as to alleviate this basic problem.

1.3 Purposes and Scope of Study and Report

The purposes of this study are: (1) to review the various factors affecting the fluctuations of the water levels of the Great Lakes; (2) to determine the feasibility of regulating further the water levels in the Great Lakes and connecting channels so as to bring about a more beneficial range of stage and other improvements for the purposes enumerated in the Reference; (3) to determine the changes in existing works or other measures within the basin needed to accomplish such regulation that would be practicable and in the public interest; (4) to provide an estimate of the costs of such measures; and (5) to indicate the probable effects, beneficial or adverse, in each country of any regulation plans or measures proposed. The study considers all major interests affected by the water levels of the Great Lakes.

To meet the foregoing purposes, the scope of the study, as required by the Reference, deals only with further regulation of the Great Lakes based on the available supplies of water within the basin as modified by current diversions into or out of it.

This report presents the results of the studies undertaken by the International Great Lakes Levels Board.

1.4 Findings and Conclusions

Section 14 of this report discusses the Board's findings and conclusions which are listed briefly hereunder:

1.4.1 Summary of Findings

(1) There are three categories of water level fluctuations on the Great Lakes: short period, seasonal and long term.

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

(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.

(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.

(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.

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

(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.

(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.

(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.

(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.

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

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

1.4.2 Summary of 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.

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

(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.

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

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

1.5 Study Method

One of the first steps in the investigation involved the use of historical data and certain assumed conditions to calculate the levels and flows which would have occurred during the selected period from 1900 to 1967 if current regulation plans had been in effect over that period. Section 5 of this report describes the "basis-of-comparison" used in evaluating regulation plans.

Studies were made concurrently to determine the economic effect of changes in levels and flows on the major interests - shore property*, commercial navigation and power. As part of the requirement for base line data, a detailed inventory survey of existing conditions and developments on the entire Great Lakes-St. Lawrence River shoreline was carried out. Section 7 describes how the dollar values of benefits or losses were estimated. To facilitate preliminary evaluation of trial regulation plans, economic factors were combined into "generalized loss functions", from which the economic effect of any regime of levels and flows on any major interest on any lake could be calculated rapidly by computer.

Trial regulation plans based on various objectives were prepared and evaluated. Section 6 describes the selection of objectives and the preparation of trial plans. These plans were applied to the historical sequence of basin water supplies to determine the levels and flows which would have occurred from 1900 to 1967 had each trial plan been in effect. Computer calculations, using the generalized loss functions, determined the approximate net annual benefit or loss to each major interest on each lake by comparing the results of application of each trial plan with the effects of current regulation plans had they been in operation for the same period.

The results of trial plans were reviewed, and refined plans based on selected objectives were developed and evaluated in detail for hydrologic, economic and environmental effects.** The economic evaluation considered the estimated dollar value of benefits and losses under the new plan compared to the basis-of-comparison for a 50-year project period. Since we have no way of forecasting the weather 50 years into the future, the Board used the calculated results of the new plan and basis-of-comparison as an indicator of future variations in levels and flows. Applying these data to the projected conditions for navigation, power and shore property gave the projected average annual benefit or loss to each interest in each country for each lake. The economic evaluation included determination of the benefit-to-cost ratio in cases involving the construction of additional regulatory works. The environmental evaluation examined the effects of the changes in levels and flows under new plans on such aspects as the Great Lakes fisheries, wildlife, hygiene, aesthetic appreciation and social well-being.

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* Including fish, wildlife and recreation.

** For the purposes of this report, "hydrologic evaluation" of a regulation plan means appraisal of its effects upon the levels and flows of the lakes and their connecting channels; "economic evaluation" means estimation of dollar benefits and losses accruing to the various interests; and "environmental evaluation" means assessment of non-quantifiable or intangible effects such as upon aquatic ecosystems, aesthetics and man's social well-being.

Sections 8, 9, 10 and 11 describe the development and evaluation of new regulation plans for the following combinations of Lakes: Superior-Ontario (SO); Superior-Michigan-Huron-Ontario (SMHO); Superior-Erie-Ontario (SEO); and Superior-Michigan-Huron-Erie-Ontario (SMHEO). The plans selected by the Board are compared and discussed in Section 12. Section 13 of this report deals with areas requiring further study.

The detailed engineering, economic and environmental data and procedures developed during this investigation are compiled in seven separately bound appendices to this report:

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

1.6 Interim Reports

Three previous reports have been submitted by the Board to the Commission:

(a) "Interim Report on the Regulation of Great Lakes Levels," February 1968, which described the study procedures and the progress to that date.

(b) "A Survey of Consumptive Use of Water in the Great Lakes Basin," September 1969.

(c) "Interim Report on Lakes Superior and Ontario Regulation," March 15, 1973, which presented the results of the study of improved regulation of Lake Superior without major construction.

The substance of all three reports is included herein.

1.7 Public Hearings

The International Joint Commission held public hearings on the October 7, 1964 Water Levels Reference as follows:

Toronto, Ontario	May 10, 1965
Sault Ste. Marie, Michigan	May 11, 1965
Windsor, Ontario	May 25, 1965
Chicago, Illinois	May 26, 1965

The hearings were for the purpose of receiving testimony and evidence relevant to the investigation which was being initiated and to provide a convenient opportunity for interested persons to submit pertinent information and opinions to the Commission. The information submitted to the Commission at these hearings provided additional background to the Board for the formulation of regulation criteria.

During the progress of the study the lakes entered a period of extremely high water levels. On January 15, 1973, the Commission instructed the Board "to report prior to March 1, 1973, its interim findings and conclusions with respect to possible modified operations at Sault Ste. Marie." Further public hearings were held in 1973, as follows, to obtain public reaction to the Board's "Interim Report on Lakes Superior and Ontario Regulation":

Rochester, New York	May 3, 1973
Toronto, Ontario	May 4, 1973
Detroit, Michigan	May 8, 1973
Sault Ste. Marie, Ontario	May 10, 1973

A public meeting was also held in Duluth, Minnesota, on June 18, 1973, to explain the proposed regulation plan. Testimony presented at these hearings indicated mixed reactions to the plan. Opinions for or against it varied according to geographic locations in the Great Lakes and to the various interests expressing them.

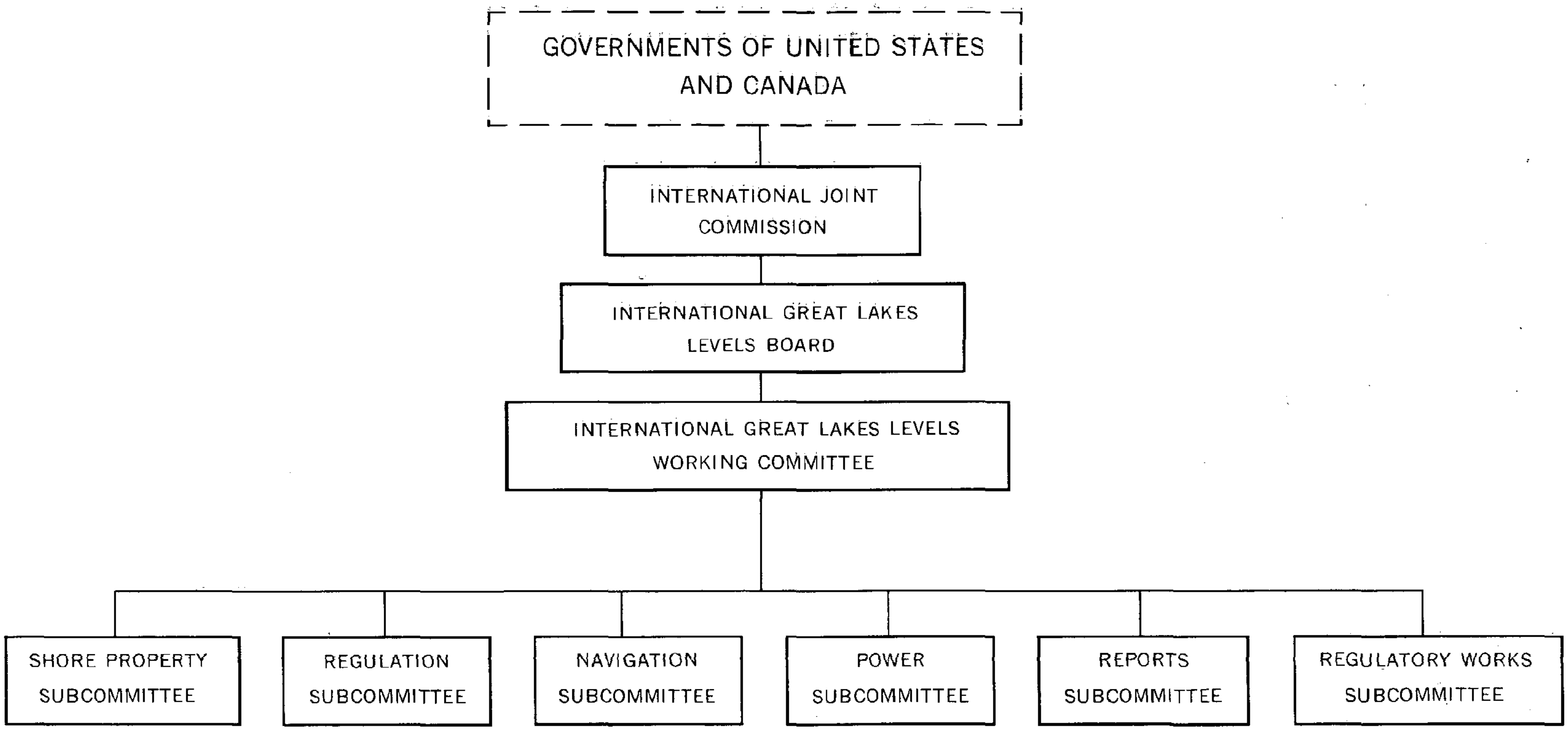
1.8 Study Organization

The United States Section of the Board is composed of a representative from each of the U. S. Army Corps of Engineers, Department of the Interior and Department of Transportation. The Canadian Section of the Board is made up of a representative from each of the Department of Public Works, Ministry of Transport and Department of the Environment.

Under authority of the Directive from the Commission, the International Great Lakes Levels Board set up a Working Committee on January 6, 1965, to assemble the data, organize field activities and conduct the studies necessary to provide the information requested by the Commission. In view of the extensive nature of the investigation and its multi-disciplinary nature the Working Committee established subcommittees for each of the major phases of the study. Ad hoc working groups, listed in Annex B, were convened to investigate significant problem areas.

The structure of the Board's organization is shown in Figure 1.

In the appointment of the Board by the Commission and in the setting up of the Working Committee, the various subcommittees and ad hoc groups, full advantage was taken of the offer of the two federal governments to "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." This has provided access to a broad coverage of public and private professional talent, data, experience and investigatory skills in the disciplines necessary to the Commission's assignments. Annex B lists all participants and the capacities in which they served in the study.



Note: See Annex B for list of participants.

Figure 1
STRUCTURE OF STUDY ORGANIZATION

State and provincial agencies were consulted and contributed materially to the study. Coordination was maintained with the Commission's Boards concerned with the water quality of the Great Lakes.

1.9 Prior Regulation Studies

Some thirty studies relating to the regulation of one or more of the Great Lakes are known to have been made. Some of these studies were in the nature of investigations of the feasibility of lake regulation, while others were to develop operational regulation plans for Lake Superior and Lake Ontario. These major studies are outlined in Appendix B.

Section 2

GREAT LAKES REGION

2.1 Geographic Description

The Great Lakes have a total water area of about 95,000 square miles and drain a land area approximately twice as large. They are among the largest bodies of fresh water in the world and contain an estimated 5,473 cubic miles of water when their levels are at low water datum. A map of the Great Lakes drainage basin is shown on Figure 2. Physical data and principal hydrologic features for each of the Great Lakes are presented in Table 1.

The Great Lakes-St.Lawrence River system is bordered by eight states--Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania and New York--and by the Provinces of Ontario and Quebec. The Province of Ontario forms the entire Canadian shoreline of the Great Lakes, as well as the north shore of the St.Lawrence River from Lake Ontario to the Ontario-Quebec border midway along Lake St.Francis. From this point, the St.Lawrence flows north-eastward through the Province of Quebec into the Gulf of St.Lawrence and the Atlantic Ocean. The total length of Great Lakes shoreline above the outlet of Lake Ontario, including islands, is some 11,200 miles.

In large part, the land tributary to the Great Lakes is included within the areas of two broad physiographic regions: the Laurentian Uplands and the Central Lowlands. East of Lake Ontario, the limit of the basin is in the foothills of the Adirondack Mountains; the limit southeast of Lake Erie and south of Lake Ontario is also in very hilly country.

Areas of the Great Lakes basin north and west of Lake Superior and north of Lake Huron are in the Laurentian Uplands and are dominated by hills, a few low mountains with summit elevations up to about 1,700 feet above sea level, and many lakes and swamps. In general, the bedrock has a shallow overburden. The region is not cultivated to any great extent and much of it consists of forest lands.

In the Central Lowlands portion of the basin, the physiographic relief varies from gently-rolling to relatively flat topography. West and south of the southern end of Lake Michigan, the divide between the drainage tributary to the Mississippi and that tributary to Lake Michigan is, in places, only about ten feet higher than the level of Lake Michigan. The overburden in these portions of the basin varies from a few feet to several hundred feet in depth. The area is covered by glacial deposits which, in many localities, consist of rather heterogeneous mixtures of silt, clay, sand, gravel and boulders.

Table 1

GREAT LAKES PHYSICAL AND HYDROLOGIC DATA
(Historical Record: 1860-1972)
All Elevations in feet IGLD (1955)

	LAKE SUPERIOR	LAKE MICHIGAN	LAKE HURON	LAKE ST. CLAIR(a)	LAKE ERIE	LAKE ONTARIO
Elevation of Low Water Datum	600.0	576.8	576.8	571.7	568.6	242.8
Monthly Elevations						
-Average	600.39	578.70	578.70	573.09	570.41	244.77
-Maximum	602.06	581.94	581.94	575.70(b)	572.76(b)	248.06
-Minimum	598.23	575.35	575.35	569.86	567.49	241.45
-Range of Stage	3.8	6.6	6.6	5.8	5.3	6.6
Range, Winter Low to Summer High (Monthly)						
-Average	1.1	1.1	1.1	1.8	1.5	1.9
-Maximum	1.9	2.2	2.2	3.3	2.7	3.5
-Minimum	0.4	0.1	0.1	0.9	0.5	0.7
Recorded Monthly Outflows (c) (cfs) Outlet	St. Marys	Str. of Mackinac	St. Clair	Detroit	Niagara	St. Lawrence
-Average	75,400	52,000(d)	187,900	188,900	202,300	239,700
-Maximum	127,000	-	242,000(b)	- (e)	256,000(b)	314,000(b)
-Minimum	40,900	-	99,000	100,000(e)	116,000	154,000
Average Outflow in Inches on Total Drainage Basin (f)	12.4	11.1	11.1	11.1	10.2	10.5
Drainage Areas (Sq. Mi.)						
-Land Area (g)	49,300	45,600	51,800	6,100	23,600	27,200(i)
-Water Surface Area (h)	31,700	22,300	23,000	400	9,900	7,600(i)
Storage Capacity Per Ft. Depth (CFS-months)	337,000	481,000		5,000	105,000	80,000

(a) Lake St. Clair elevations are available only for the period 1898 to date.
(b) New maximums set in 1973: Lake St. Clair 576.23 (June), Lake Erie 573.51 (June).
Outflows: St. Clair River 245,000; Niagara River 265,000; St. Lawrence River 350,000.
(c) Outflows include the effects of diversions.
(d) Approximate.
(e) Insufficient records available.
(f) Drainage basin includes land and water surface areas.
(g) Land areas include the total drainage area to the outlet of the upstream lake.
(h) Water areas do not include areas of connecting channels.
(i) Includes area down to the St. Lawrence Power Project at Cornwall.

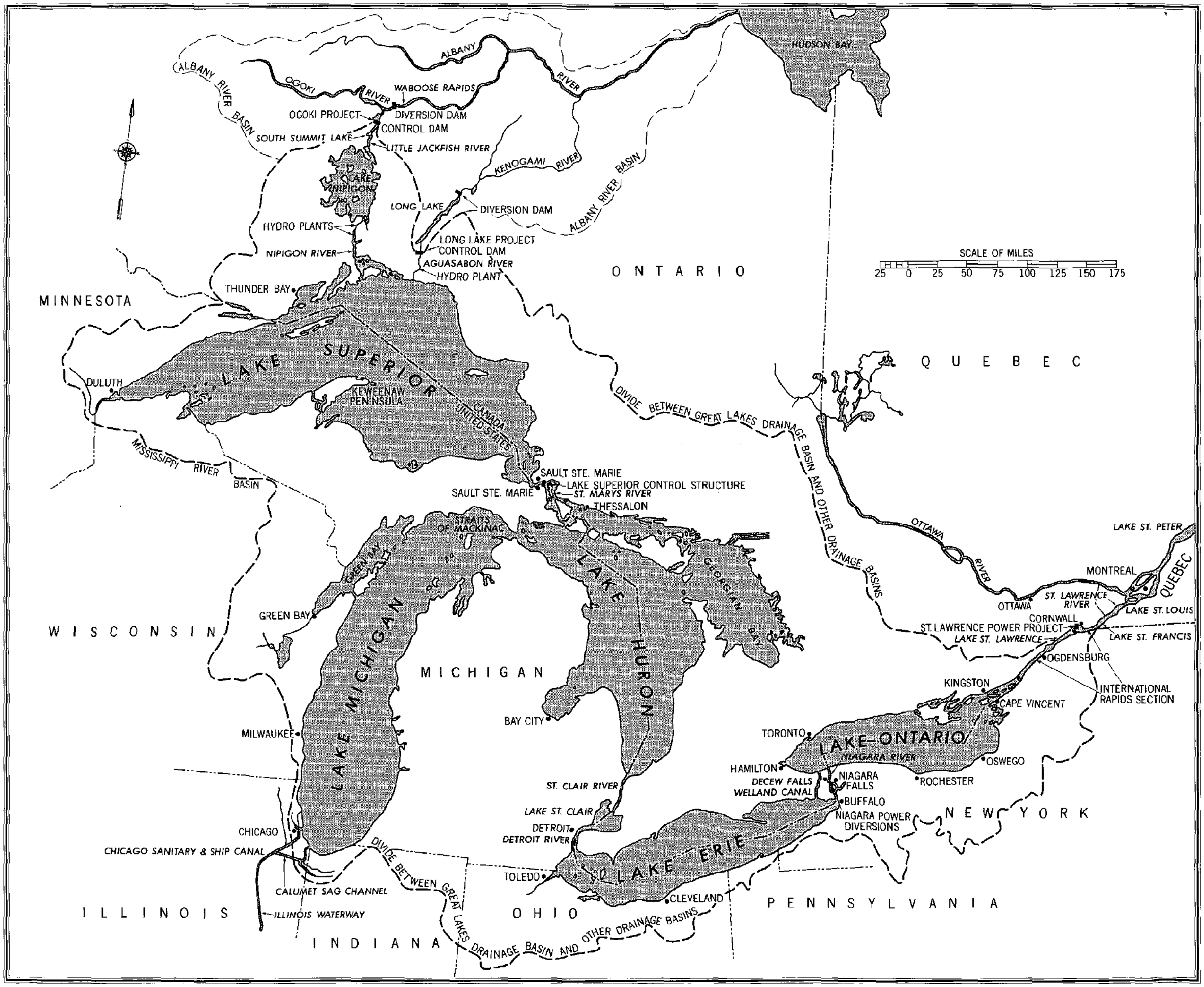


Figure 2

GREAT LAKES-ST. LAWRENCE RIVER DRAINAGE BASIN

2.2 Climate

The unique features of the climate of the Great Lakes basin are: four distinct seasons; a variety of precipitation types and sources; but with almost no month to month variation in precipitation amount; marked temperature contrasts over only 750 miles of latitude; and the influence of the Great Lakes in modifying continental air.

Temperatures decrease from south to north. This latitudinal contrast is 20-25° greater in winter than in summer (see Figure 3). The basin has warm summers with frequent uncomfortable periods of hot, humid, tropical air from the Gulf of Mexico. In winter, arctic air dominates the region with mean daily temperatures below freezing from 3 to 6 months. During spring and autumn, the passage of storms through the basin causes considerable change. From June through October hurricane remnants can pass close to the basin, producing heavy rain and strong wind. Annual precipitation averages between 26 and 52 inches with a slight summer maximum. About 20 to 30 percent of the annual total occurs as snowfall with large regional differences depending on the proximity of open lakes.

The lakes act as a vast reservoir for the storage and subsequent exchange of heat energy with the atmosphere. The lakes significantly moderate the temperature regimes over adjacent land areas. The annual lake surface temperature range is only half that of the air due to the freezing of water at 32° F. During autumn and winter, surface water temperature is usually warmer than the air temperature due to the transfer of heat upward from warmer, deeper waters. In spring, cold subsurface water maintains the surface water at near-freezing. By late summer the surface waters have warmed to their maximum--a lag of one or more months with respect to air temperature.

It is of interest to compare the surface temperature cycle of Lakes Superior and Erie, since they provide maximum contrast in latitude and thermal regime. Erie, the shallowest and most southerly of the Great Lakes, has an average surface temperature of 72° F in summer and 33° F in winter. Lake Superior, in July, is 26° F cooler than Erie, and reaches its maximum temperature of 53° F in late August and early September. The annual range of surface water temperature between the warmest and coolest month is 40° F for Erie and only 21° F for Superior.

Annual radiation totals generally increase from north to south.

There is a greater tendency for winds to have a westerly component in winter. In January over the middle and upper lakes regions, winds blow from the west and northwest 40 to 50 percent of the time, with northwest winds prevailing. South of the lakes, winds from the west and southwest direction predominate 30 to 40 percent of the time. Wind speeds average between 6 and 19 miles per hour.

Winds are generally strongest in early spring with mean speeds from all directions over 8 miles per hour and highest mean speeds above 13 miles per hour, and usually from the prevailing direction. Stronger speeds are associated with increased cyclonic activity and less surface retardation since the ground is either snow covered or thawing, and with little vegetative growth.

In summer, south winds prevail as the flow is often controlled by a high pressure area extending over the southeastern United States from the Atlantic Ocean. In July the direction in the upper lakes is west and southwest about 40 percent of the time. Over the lower lakes, winds blow from the south and southwest more than half the time. Summer winds are generally more variable in direction and less variable in speed than winter winds.

Winds in October reflect the transition between summer and winter conditions in both speed and direction. The increase in cyclonic activity and the large thermal differences between air and water contribute to the high mean wind speed.

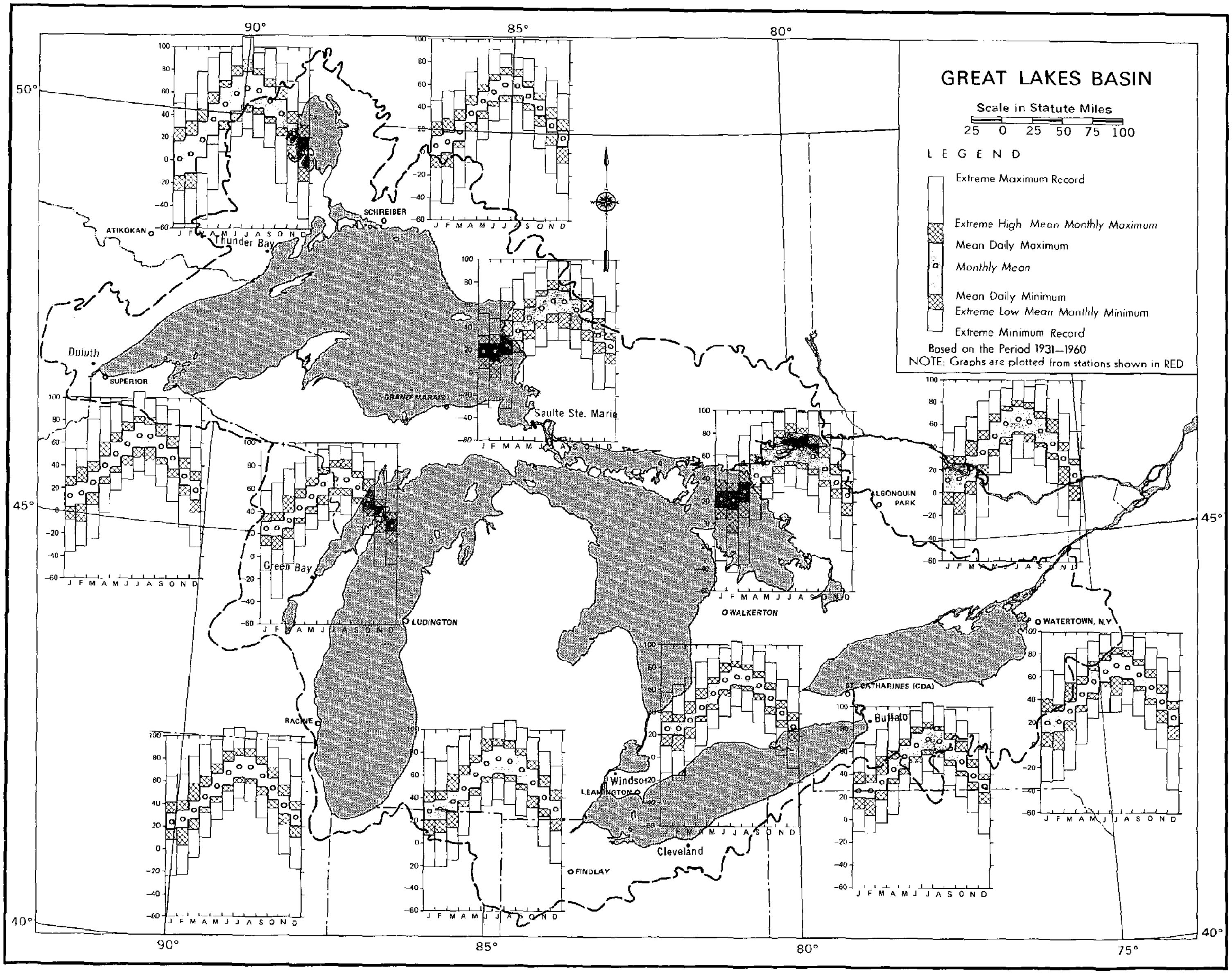
2.3 Socio-economic Description

Both in the United States and Canada the Great Lakes basin contains major concentrations of population and economic activity. The concentration of human activity in the basin can be directly related to the advantages provided by the Great Lakes.

2.3.1 Demography

The United States portion of the basin contains one-seventh of the national population, produces one-sixth of the national income and is the location of four of the twelve largest cities (Chicago, Detroit, Cleveland and Milwaukee). The relative importance of the basin is even greater in Canada. In 1971, the Ontario portion alone contained almost one-third of the total population of Canada and produced nearly one-third of the national income. If the Canadian portion of the St.Lawrence River basin is included, then the proportion of total population and economic activity is much higher, rising to over 60 percent of the Canadian national total and including the two largest concentrations of population in the country, the Toronto and Montreal regions.

The population within the basin has increased considerably in this century, from 10 million in 1900 to 35 million in 1970. The Canadian portion of the total population has remained at 17 percent in the intervening 70 years. The average population density is 113 persons per square mile, but it varies considerably from less than 20 persons per square mile in the Superior and northern Huron basins to around 500 persons per square mile in the southern Michigan, Erie and Ontario basins. Densities are higher in general in the United States. The highest concentrations are along the shoreline, particularly in the Chicago-Milwaukee, Detroit, Cleveland, Niagara, Hamilton-Toronto, and Montreal metropolitan areas.



SOURCE: THE CLIMATE OF THE GREAT LAKES BASIN BY D. W. PHILLIPS AND J. A. W. McCULLOCH.

Figure 3
MONTHLY MEAN AND EXTREME TEMPERATURE RECORDS FROM THE PERIOD 1931-60

2.3.2 Economic Activity

The Great Lakes basin economy is basically industrial, utilizing the transportation and power advantages offered by the Great Lakes-St. Lawrence River system. In addition, there is significant agricultural, mining and forestry production. Fishing, historically one of the oldest activities, has declined in commercial importance.

Economic activity is greater and more intensive in the United States portion of the basin, but the proportion of total Canadian activity in the basin, compared with the national total, is much higher. The economic-industrial structures are generally similar in the two countries, with some important differences in the relative share of some industrial groups.

In the United States more than one-fifth of the manufacturing employees, value added and capital expenditures are within the Great Lakes basin; in Canada, over one-half the national manufacturing employees, value added and capital expenditures are within the basin. The region is the primary focus of the iron and steel industry in North America, accounting for 40 percent of the U.S. production and 80 percent of the Canadian output. The Great Lakes ports serve an additional one-third of the U.S. steel industry. The region also contains high proportions of other industries, including chemicals, paper, food products, machinery, transportation equipment and fabricated metal products.

Despite this predominance of manufacturing in the economic structure, primary production activities are still important. The farms in the basin produce 7 percent of all U.S. farm output. In Canada, the proportion of agricultural activity is higher, with farms in the basin accounting for at least 25 percent of the agricultural production of the country. There are 59,000 square miles of commercial forest in the United States portion of the basin and over 70,000 square miles in the Canadian portion. Mineral production is also important, particularly iron ore and limestone.

Finally, the basin has a major recreation and tourist industry. The extensive sand beaches and scenic shorelines of the Great Lakes, with water-related recreational opportunities, attract many users. Typical are the cottage and summer resort areas of northern Michigan; northeastern Wisconsin; Georgian Bay, Ontario; and the Thousand Islands reach of the St. Lawrence River. Major tourist attractions include the Soo Locks, Niagara Falls and the Welland Canal.

The value of tourism in the U.S. portion of the Great Lakes basin has been estimated at $300 million annually. Canadian figures indicate that international tourism expenditures in the Great Lakes basin totalled over $500 million in 1971. The value of Canadian inland waters in all aspects of water-based recreation was about $1.5 billion in 1972 and is increasing annually at a 16% growth rate, with a major part ascribed to the Great Lakes and its tributary areas. Water-based recreation on the U. S. side is also growing rapidly.

2.3.3 Transportation

The region occupies a location strategic to the highly industrialized and well-populated north central United States and south central Canada, and is astride the transcontinental link between the major agricultural production regions of the west and midwest and the consuming areas of the east. The Great Lakes-St.Lawrence system provides 27-foot deep navigation channels from Duluth-Superior to Montreal and 35-foot channels from Montreal to Quebec City. Over 100 billion ton-miles of waterborne freight are carried by this system each year.

The region can be considered tributary to Great Lakes harbors for shipment of overseas general cargo. In the United States, it includes the eight lake states and eleven additional contiguous states which generate about 25 percent of the U.S. general cargo export traffic. The tributary areas for overseas shipments of U.S. grain produce 79 percent of U.S. grain with the six midwest states bordering the Great Lakes producing 37 percent. The share of U.S. grain exports through Great Lakes harbors was 18 percent in 1971 and is projected to increase to 20 percent in 1980. Almost half of the Canadian wheat export shipments pass through Great Lakes-St.Lawrence ports and approximately one-third of all Canadian ship cargoes are handled in the system.

The railroads, motor carriers, airlines, barge companies and pipelines serving the region tributary to the Seaway system are extremely active competitors for much of the cargo tonnage which moves or could move through the Great Lakes-St.Lawrence Seaway system. However, such carriers assume a complementary service role for most of the domestic and overseas traffic actually moving through the system. As partners in the total physical distribution process, they transport freight to and from Great Lakes ports and inland origins or destinations.

2.3.4 Power

There are about 355 electric utilities operating totally or partially within the U.S. part of the Great Lakes basin, representing all segments of the power industry--private, co-operative, and federal, municipal, and other public systems. The electric power requirements of the U.S. Great Lakes region in 1970, aggregating 161.3 billion kilowatt-hours, were approximately 11 percent of the national total. The total generating capacity was 32.8 million kilowatts, representing 10 percent of the national total.

The Hydro-Electric Power Commission of Ontario generates electricity from the Canadian share of the flow in the Niagara River and in the St.Lawrence River in its International Rapids Section. The Quebec Hydro-Electric Power Commission utilizes the full flow of the St. Lawrence

River at its Beauharnois-Cedars developments. In addition, there is a small private power plant located at Sault Ste. Marie, Ontario. Approximately 15% of the total hydroelectric generating capacity in Canada is located on the outflow rivers of the Great Lakes and amounts to 4,807,000 kilowatts. Almost one-half of the steam generating capacity in Canada (4,474,000 kilowatts) is located on the lakes and outlet rivers.

The total installed hydroelectric capacity located on the United States side of the outflow rivers is 3,162,000 kilowatts. The principal power producer is the Power Authority of the State of New York, which utilizes the United States portion of the flows of the Niagara River and of the St.Lawrence River in the International Rapids Section. There are also two small hydro plants on the St.Marys River.

The existing (1972) hydroelectric installations affected by regulation of the Great Lakes have a total installed capacity of 7,969,000 kilowatts. Since the unit cost of power generated at Great Lakes hydroelectric installations is cheaper than power produced at fossil or nuclear fueled installations, maximum utilization of the hydroelectric power capacity is economically advantageous.

2.3.5 Riparian Property and Development

The shoreline of the Great Lakes is not only a valuable asset, but also the most intense interface between the population of the basin and the lakes. In the southern part of Lake Michigan and around Lakes Erie and Ontario, urban uses of the shoreline are predominant. During the last twenty years, forestry and agricultural uses of the shoreline have declined in comparison with the recreational, industrial and residential uses serving the expanding urban populations. Table 2 shows the distribution of shoreline land use on each of the Great Lakes.

In both Canada and the United States, the majority of the shoreline is privately owned.

2.4 Great Lakes and Their Outflow Rivers

The Great Lakes system comprises a chain of lakes and connecting channels, the excess waters from one lake being discharged through its connecting channel into the next lake downstream in the system. The water level profile of the Great Lakes-St.Lawrence system is illustrated on Figure 4.

2.4.1 Level Datum

The present water level datum in use on the Great Lakes is known as the International Great Lakes Datum-1955 (IGLD-1955). It measures the difference in elevation between sea level at Father Point, Quebec, and any point in the basin. This was developed to provide Canadian and U.S. agencies with an official datum, acceptable to both countries, on

Table 2

PERCENTAGE DISTRIBUTION OF SHORELINE LAND USE 1970
(including islands)

	Superior		Michigan	Huron		Erie		Ontario	
	U.S. %	Canada %	U.S. %	U.S. %	Canada %	U.S. %	Canada %	U.S. %	Canada %
Recreation	8	9	11	6	21	18	41	10	18
Industry & Commercial	5	7	6	4	5	15	8	8	7
Residential	18	*	33	48	2	42	4	44	15
Agriculture	7		20	16		21	24	38	52
Forest & Undeveloped	62	84	30	26	72	4	23	*	8
Total	100	100	100	100	100	100	100	100	100

Source for U.S. Data: Great Lakes Region Inventory Report, National Shoreline Study, Department of the Army, Corps of Engineers, North Central Division, August 1971

Source for Canadian Data: Canada Centre for Inland Waters, Department of Environment, 1970

* less than one percent

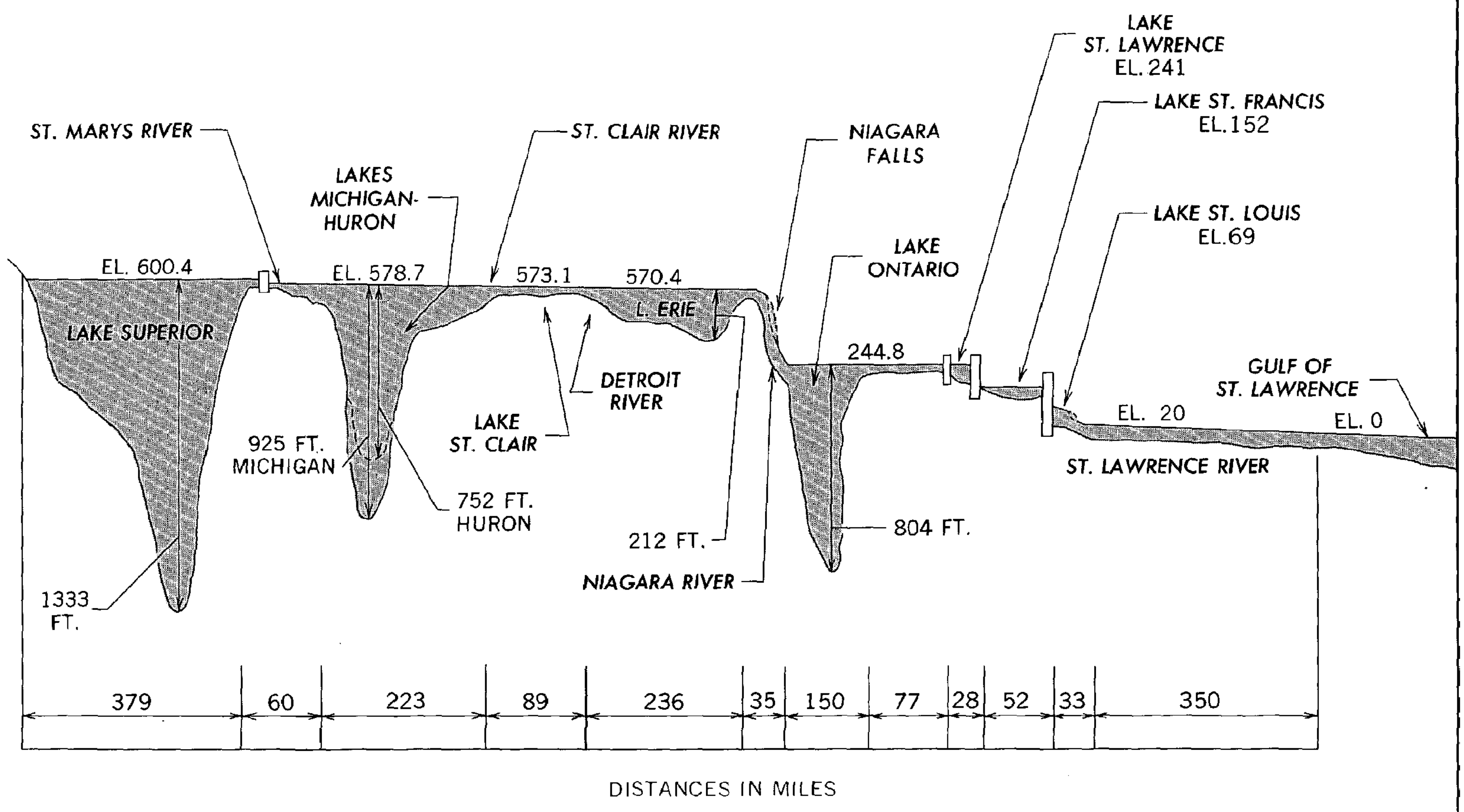


Figure 4
PROFILE OF THE GREAT LAKES—ST. LAWRENCE RIVER DRAINAGE SYSTEM

which design and operation of the St.Lawrence Seaway and Power Project could proceed. Because, over a period of time, there is a differential movement of the earth's crust in the Great Lakes region (discussed in Subsection 3.2.9) which affects the relationship between the actual water level at a given place and the elevation indicated by the reading of a gage at the same location, it is important to show the year in which the datum elevations are assigned. With the passage of time it may become necessary to adjust the reference elevation at the gage to allow for its movement with respect to Father Point during the intervening period.

Low water datum (LWD) on each lake is the water level to which depths on navigation charts and harbor and channel improvements on the Great Lakes are referred. The elevations of LWD for the Great Lakes are shown in Table 1.

Several other reference datum planes are commonly used in the Great Lakes basin mainly for establishing vertical control for producing topographic maps. The 1935 Datum plane, referred to mean tide at New York City, was used in the Great Lakes prior to the establishment of the International Great Lakes Datum (1955) and it was in use until 1961. The difference between IGLD (1955) and the 1935 Datum varies from place to place.

2.4.2 Lake Superior and St.Marys River

Lake Superior, the uppermost and largest of the Great Lakes, discharges through the St.Marys River into Lake Huron. In the upper 14 miles the river falls approximately 0.2 foot; then in the St.Marys Rapids, a distance of 3/4 mile, it falls approximately 20 feet. The remaining fall, about 2 feet, takes place in the 48 miles between the rapids and Lake Huron. Because of this very mild slope to Lake Huron, the water levels at the foot of the rapids in the vicinity of Sault Ste.Marie are affected by the levels of Lake Huron. To compensate for the effect on Lake Superior levels of power diversions around St.Marys Rapids, a gated dam was constructed across the St.Marys River at the head of the rapids. Since the completion of this dam in 1921, the discharge from Lake Superior has been completely controlled under the supervision of the International Joint Commission through its International Lake Superior Board of Control. The natural supply to Lake Superior has been increased by diversions from the Albany River basin through the Long Lake and Ogoki Projects in Canada which together average about 5,000 cfs (refer to Subsection 3.3.2 for furth details of these diversions). The present Lake Superior regulation plan accommodates these diversions.

2.4.3 Lakes Michigan-Huron and St.Clair-Detroit Rivers

Lakes Michigan and Huron stand at virtually the same level since they are connected by the broad and deep Straits of Mackinac and they are usually treated as one lake in hydrologic and hydraulic considerations.

The natural outlet for the discharge from these lakes is through the St.Clair River, Lake St.Clair and the Detroit River into Lake Erie, approximately eight feet lower than the level of Lakes Michigan and Huron. The slopes of water surface profiles along the St.Clair and Detroit Rivers are relatively uniform and there are no rapids or falls. Removal of sand and gravel for commercial purposes, together with dredging to increase depths in navigation channels in these rivers, has increased their discharge capacity (see Subsection 3.3.1). During the latter dredging program in the St. Clair River, excavated material was placed in the river to compensate partially for the lowering effects caused by this program. Compensating dikes have been constructed on the lower Detroit River to offset partially the lowering of water levels due to past authorized navigation improvements.

The average rate of diversion from Lake Michigan at Chicago is limited to 3,200 cfs by a United States Supreme Court decree. Further details on the Chicago diversion are presented in Subsection 3.3.2.

The difference in elevation between Lakes Huron and Erie is only about eight feet and the flow out of Lake Huron is a function of both lake levels, i.e., the levels of Lake Erie have an effect on the levels of Lake Huron.

2.4.4 Lake Erie and Niagara River

The natural outlet from Lake Erie is through the Niagara River into Lake Ontario, which is about 326 feet lower than the level of Lake Erie. See Figure 4. Approximately 310 feet of the difference in elevation between Lakes Erie and Ontario occurs in the reach of the Niagara River extending from the head of the Cascades upstream from Niagara Falls to the lower end of the Lower Rapids six and one-half miles downstream of the Falls; about half of the difference occurs in a sheer drop at the Falls.

Diversions from the Niagara River above the Falls for power purposes commenced in the late 1880's and in the year 1900 totaled about 6,000 cfs. By 1921, the amount diverted was approximately 50,000 cfs. With the completion of the first of the high-head plants, the Sir Adam Beck No. 1, in 1926, a further 14,000 cfs bypassed the Falls. During the Second World War, increased diversion by Canada was permitted and in 1954 the units of the Sir Adam Beck No. 2 Plant came into service. This plant reached full capacity in 1958, bringing the maximum diversion through the Beck developments to 66,000 cfs. The Robert Moses Niagara Plant on the United States side of the river, immediately upstream of the Sir Adam Beck Plants, came into service in January 1961 and reached full capacity in 1962. It has a design capacity of 83,000 cfs, but on occasion has diverted up to 105,000 cfs.

There is a structure which is located immediately upstream of Niagara Falls extending from the Canadian shoreline part way to Goat Island. This structure serves to maintain the levels in the Chippawa-Grass Island Pool so as to provide proper flows over the Falls while allowing for diversion for power purposes. This structure is not used to control the level of Lake Erie, being located 16 miles downstream of Lake Erie at a point where the river level is about 9 feet lower than the level of Lake Erie.

The Niagara Treaty of 1950 between the Governments of Canada and the United States requires a minimum flow over the Falls of 100,000 cfs between the hours of 8:00 a.m., E.S.T., and 10:00 p.m., E.S.T., from April 1 through September 15, and between the hours of 8:00 a.m. and 8:00 p.m. from September 16 through October 31 (tourist hours). A minimum flow of 50,000 cfs is required at all other times (non-tourist hours). In 1973, the governments agreed to use Eastern Daylight Savings Time (EDST) when in effect in either country at Niagara Falls.

Water from Lake Erie also reaches Lake Ontario by way of the Welland Canal and DeCew Falls power plant tailrace. This flow has averaged about 7,000 cfs since 1950. Between 700 and 1,000 cfs is diverted from the Niagara River through the New York State Barge Canal. This water is diverted from the Niagara River at Tonawanda, New York, and is returned to Lake Ontario via the Oswego River, Genesee River, Oak Orchard Creek and Eighteen Mile Creek, all in New York State.

The Niagara River Treaty of 1950 provides that "water made available for power purposes by the provisions of this treaty shall be divided equally between the United States of America and Canada." Not included as a part of the water so allocated by the Treaty is 5,000 cfs of the diversions into the basin through the Ogoki and Long Lake diversion projects. The allocation to Canada of this diverted water at Niagara Falls was authorized in 1940 by an exchange of notes between the two countries. This diversion is utilized at the Ontario Hydro DeCew Falls plant and is part of the 7,000 cfs Welland Canal diversion mentioned in the preceding paragraph.

2.4.5 Lake Ontario and St.Lawrence River

Lake Ontario, the lowest in the Great Lakes chain, is also the smallest. Since 1958, with the completion of the control works in the St. Lawrence River for the Seaway and Power Project, the outflows from Lake Ontario have been regulated. A map of the St.Lawrence River from Lake Ontario to Lake St.Peter is shown on Figure 5.

From the outlet of Lake Ontario, at Kingston, Ontario, to Father Point, Quebec, which marks its transition to the Gulf of St.Lawrence, the St.Lawrence River falls approximately 245 feet. Throughout the first 67 miles of its length, the river is characterized by numerous rocky islands and reefs from which the name Thousand Islands reach is derived. With the construction of the St.Lawrence Seaway and Power Project, the physical features of the St. Lawrence further downstream have been changed considerably. Situated 105 miles downstream from Lake Ontario at Barnhart Island, New York, just west of Cornwall, Ontario, are the large Moses-Saunders Powerhouses, operated by the Power Authority of the State of New York and Hydro-Electric Power Commission of Ontario. At the upstream end of Barnhart Island is Long Sault Dam, which is used to pass excess flows during periods of high supplies or shut-down of turbines in the powerhouses. The man-made lake formed by impounding the river behind these structures has been named Lake St.Lawrence. The fluctuations in levels of this lake are moderated by operation of Iroquois Dam, about 27 miles upstream. Below the powerhouses, the river divides into two channels around Cornwall Island and then widens to form Lake St.Francis.

The remainder of the river is entirely within Canada. From Lake St. Francis, the river flows to Lake St.Louis through the Beauharnois Power and Navigation Canal and the Cedars developments. At the lower end of the ca is situated the Quebec Hydro-Electric Power Commission's large Beauharnois Powerhouse, which commenced operation in 1932 and which was enlarged during the periods 1951-53 and 1959-61. At the outlet of Lake St.Louis the river drops through the Lachine Rapids into the Laprairie Basin and thence through the short, swift-flowing section near Victoria Bridge to Montreal Harbour, dropping about 50 feet. In the 169 miles of river between Montreal and Quebec City the fall is about 25 feet at low tide. The range of tide at Quebec City averages about 16 feet, but the extreme high spring tides exceed 21 feet. The tidal effect diminishes upstream until the range is only about 1-1/2 feet maximum at Trois-Rivières, Quebec, and 1/2 foot maximum at the upper end of Lake St.Peter. Very small variations can be detected in Montreal Harbour. Below Quebec City, the river gradually widens into the St.Lawrence estuary and finally the Gulf of St.Lawrence. The navigation channel at and below Montreal is referred to as the St.Lawrence Ship Channel with an advertised depth of 35 feet at low water datum. Downstream of Quebec City, the present controlling depth is 30.0 feet LNT (Lowest Normal Tide) and these channels are currently being deepened to 41.0 feet (LNT).

2.5 Water Quality

Although the water quality of the Great Lakes is generally good, there are local areas near major population centers where water quality is seriously degraded. A lake-wide problem exists in Lakes Erie and Ontario where the abundance of plant nutrients is causing accelerated eutrophication. Recent pollution studies on the lower Great Lakes indicate that Lake Erie, Lake Ontario and the International Section of the St.Lawrence River are being polluted to an extent that is causing and is likely to cause injury to health and property.

In general, water quality decreases as one moves downstream through the lake system to the St.Lawrence River. With the exception of conservative pollutants such as chlorides, most other pollutants degrade near their point of entry and thus only contribute to a local problem.

The Great Lakes Water Quality Agreement signed by Canada and the U.S. on April 15, 1972, identifies general and specific water quality objectives for the lower lakes, and a program of remedial works and regulation is currently being implemented. Lakes Huron and Superior are the object of a separate study Reference similar to the Reference on pollution of the lower lakes. One significant difference is the fact that water in the upper lakes is still of high quality and therefore non-degradation of existing quality is a major objective.

Section 3

FLUCTUATION OF WATER LEVELS AND FLOWS

3.1 General

The level of each of the Great Lakes depends on the balance between the quantities of water received and the quantities of water removed. If these quantities are exactly the same, the general lake level is constant. If the quantities received are larger than the quantities removed, the volume of water in the lake increases and the lake level rises and, with no control, its outflow increases. The amount of lake level and outflow fluctuation which will occur in the system depends on the magnitude of water supply change and the timing of the passage of water supply through the Great Lakes system. These, in turn, are the result of the interaction of the natural and artificial factors which affect the supply and discharge of water to and from the system. The range of fluctuation of water levels and outflows is also directly affected by the relationship between the area of the lake and the discharge capacity of its outlet river.

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

Long-term fluctuations are the result of persistent low or high water supply conditions within the basin which culminate in extremely low levels such as were recorded in the mid-60's on Lakes Michigan-Huron or in extreme high levels such as in 1972-73 on all the lakes except Lake Superior.

A century of record in the Great Lakes basin indicates that there are no regular, predictable cycles such as one might expect. The intervals between periods of high and low levels, and the length of such periods can vary widely and erratically over a number of years. Maximum recorded range of levels, from extreme high to extreme low, have varied from 3.8 feet on Lake Superior to 6.6 feet on Lakes Michigan-Huron and Lake Ontario. Lake Ontario's range in levels reflect not only the fluctuations in supplies from its own basin but also the fluctuations from the upstream lakes.

Seasonal fluctuations of Great Lakes levels reflect the annual hydrologic cycle. This is characterized by higher net supplies during the spring and early summer with lower net supplies during the remainder of the year. The magnitude of seasonal fluctuations are quite small, averaging about one foot on Lake Superior and Lakes Michigan-Huron, 1.5 feet on Lake Erie and with Lake Ontario, the lowest in the chain of lakes, having the largest average seasonal value, 1.9 feet.

Short-period fluctuations, lasting from a few hours to several days, are caused by meteorological disturbances. Wind and differences in barometric pressure over the surface of a lake create temporary imbalances in the water levels at various locations on the lake. Although the range of fluctuations from these causes has reached 8 feet in some locations, there is no change in the volume in the lake, which is the fundamental difference between the short-period, and the seasonal and long-term fluctuations.

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

3.2 Natural Factors Affecting Fluctuations

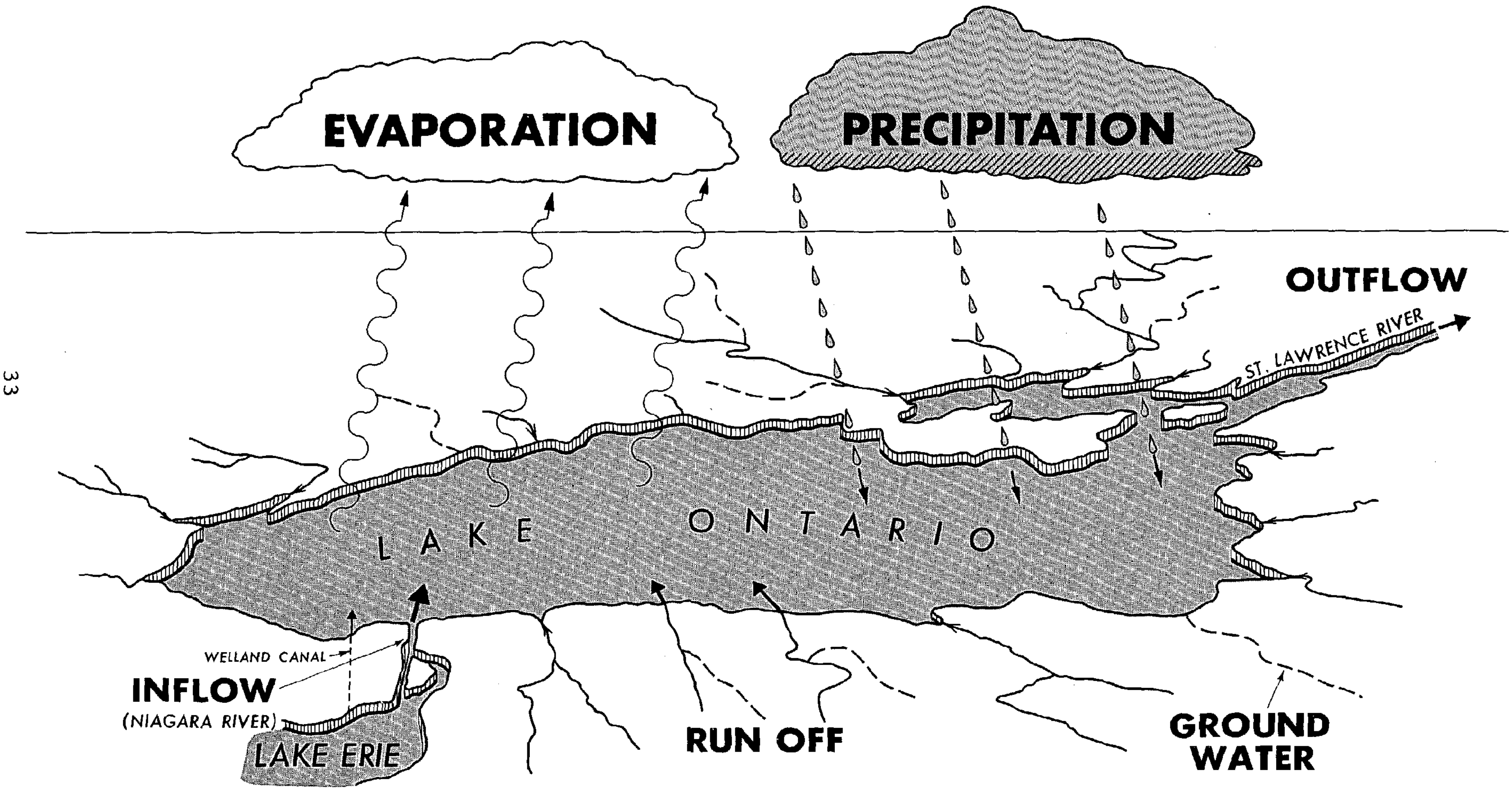
The factors which affect short-period, seasonal and long-term fluctuations of the Great Lakes levels can be separated into two categories - natural and artificial. The natural factors, which are discussed in the following subsections, include precipitation, evaporation, runoff, groundwater, ice retardation, aquatic growth, meteorological disturbances, tides and crustal movement. A pictorial representation of the principal factors is shown in Figure 6. Artificial factors are discussed in Subsection 3.3.

3.2.1 Precipitation

The original source of water reaching the Great Lakes is precipitation, both rain and snow, on the lakes and their tributary land areas. Protracted excesses or deficiencies in precipitation are largely responsible for the long-term variations in lake levels. This effect is evident from Figure 7, which shows the historical variations in precipitation and lake levels. Record high precipitation in the early 1950's (5 of the 6 years prior to 1952 had above-normal precipitation) with resultant high lake levels was followed only 12 years later by below-normal precipitation. These small precipitation amounts in the '60s continued for 5 years and resulted in record low lake levels. These events are illustrative of the close association between precipitation and lake levels.

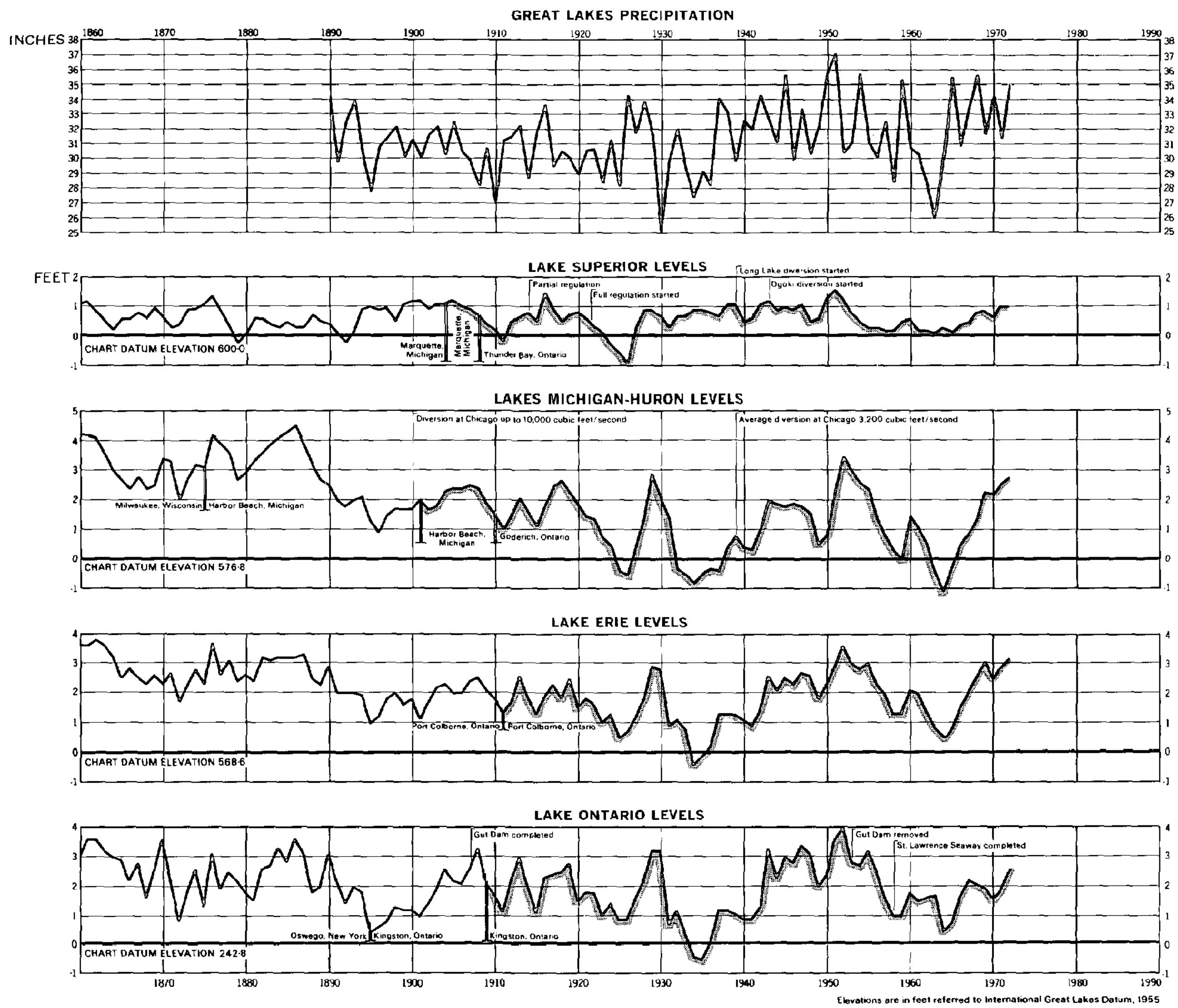
Data on monthly and annual precipitation on the drainage basins of each of the lakes are taken from records of the U.S. National Weather Service and the Atmospheric Environment Service of the Department of the Environment, Canada, as compiled by the Lake Survey Center, Department of Commerce. The present network of precipitation stations in the Great Lakes basin is composed of about 400 stations in the United States and about 190 in Canada. The distribution of stations over the land area of the basin varies from an average of one station for every 160 square miles in parts of the Lake Erie basin to one for every 1,100 square miles in parts of the Lake Superior basin. The long-term maximum, minimum and average annual precipitation in inches over the basin, recorded for each of the five lake drainage basins has been determined to be:

FACTORS AFFECTING THE LEVELS OF THE GREAT LAKES



SOURCE: THE GREAT LAKES WATER LEVELS PROBLEM BY B. G. DE COOKE, LIMNOS 1968

Figure 6
FACTORS AFFECTING THE LEVELS OF THE GREAT LAKES



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

Figure 7
GREAT LAKES PRECIPITATION AND LEVEL (ANNUAL MEANS)

(Period of Record 1900-1972)

	Average	Maximum	Minimum
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

Because the lakes occupy such a large portion of the total catchment area of the Great Lakes basin, precipitation directly on the lake surface constitutes a factor of major importance in hydrologic studies of this basin. However, a quantitative determination of actual precipitation over the lakes is not possible, although the few measurements that are available indicate that it is slightly more than that over land areas. In the studies herein the precipitation over the lake areas was interpolated from the land-based stations.

3.2.2 Evaporation

Protracted deficiencies or excesses in evaporation generally accompany excesses or deficiencies, respectively, in precipitation. These conditions reinforce each other in producing long-term variations in lake levels. The magnitude of the evaporation over a 10-year period from each of the Lakes and its relationship to precipitation on the Lakes during that period are shown in Table 3.

3.2.3 Runoff

The land area contributing runoff to the Great Lakes consists of essentially a peripheral band around the lake shores, which varies in width from less than 10 miles to about 100 miles. The stream systems, collecting the land drainage and discharging it into the lakes, consist of many perennial and some intermittent streams, a large number of which are small in terms of area drained.

Stream-gaging stations are operated on many of the tributary streams. In the United States, this operation is carried out principally by the U.S. Geological Survey, Department of the Interior, and in Canada, principally by the Water Survey of Canada, Department of the Environment. Records from the stream-gaging stations are available for various periods, some extending back for 60 years or more, but many for only a few years. The percentages of the land areas of the lake basins for which runoff records are available range from 72% for Lake Erie to 53% for Lake Superior.

3.2.4 Groundwater

Groundwater movement may take place away from a lake as well as towards it. However, data are not available to determine the magnitude of groundwater flows to or from any of the Great Lakes.

Table 3

RELATIONSHIP BETWEEN EVAPORATION AND PRECIPITATION
ON THE SURFACE OF THE GREAT LAKES
(Based on Data for the Period Oct. 1950 - Sept. 1960)

Lake(s)	Approx. Average Annual Evaporation from Lake Surface (Inches)	Average Annual Precipitation on Lake Surface (Inches)	Average Annual Evaporation as a Percentage of Average Annual Precipitation on Lake Surface
Superior	22	32	69
Michigan-Huron	26	33	79
Erie	36	36	100
Ontario	25	34	74

Table 4

EFFECTS OF ICE RETARDATION ON WINTER FLOWS (JAN. THROUGH MAR., INCL.)
IN THE GREAT LAKES CONNECTING CHANNELS AND ST. LAWRENCE RIVER

Outlet River	Average annual Flow (cfs) (1860-1967)	Estimated Average Ice Retardation (cfs)	Percent Retardation
St. Marys	74,500	3,000*	4*
St. Clair	187,000	19,000	10
Detroit	190,000	4,000	2
Niagara	202,000	4,000	2
St. Lawrence	239,000	7,000*	3*

*Prior to regulation.

3.2.5 Ice Retardation

The flows in the outlet rivers of the lakes during the winter season are often retarded materially by ice formation and by ice jamming. These conditions are not predictable for any specific winter, either as to their severity or the exact timing of their occurrence. Average reductions in the outflow rates, for the period January through March, are indicated in Table 4.

The natural retardation of flows under ice conditions causes the levels of unregulated lakes to be higher at the time of the spring breakup than the levels would be if there were no ice, and this increases the storage on the lake. Such increased storage causes higher outflows following the breakup and the seasonal effect is gradually dissipated. However, in the case of Lakes Michigan-Huron the long-term effect is to raise the average level by an estimated 0.4 foot higher than it would have been without ice retardation.

During the winter months of December-April the flow rate of the St.Clair River is reduced due to ice cover in the lower reaches and periodic ice jams. Historical data indicate that during an ice jamming situation the outflow rate has been reduced by as much as 50 percent. The major portion of the ice is contributed to the river from Lake Huron where large volumes of ice are produced during the winter months. The Detroit River is not subjected to a large degree of flow retardation due to the protective ice cover on Lake St.Clair which generally remains intact through the winter, and as a result, prevents ice from entering the Detroit River in large enough quantities to cause ice jams. The flow retardation in the Detroit River results from the in situ ice cover in the lower channels. Consequently as the ice retards the outflow from Lakes Michigan-Huron, their level is raised and the levels of Lakes St.Clair and Erie are lowered. This change on Lake St.Clair and Erie is dissipated before the following ice season, but on the average about 34% of the effect remains on Lakes Michigan-Huron.

Ice retardation on the Niagara River has been significantly reduced since the installation of the Lake Erie-Niagara River ice boom commencing in the winter of 1964-65. The boom is installed in the fall of each year by the Niagara Power Entities and has successfully reduced ice jamming conditions, which affect power generation and damage shoreline properties.

3.2.6 Aquatic Growth

Aquatic growth in the rivers during the summer also creates outflow retardation which varies from river to river. In the Niagara River, for example, comparison of discharge curves developed during periods of both minimum and maximum aquatic growth indicates that such retardation could reduce outflows by as much as 10,000 cfs during the months of June to September. This retardation generally starts in May, averaging about 1,900 cfs, increasing to its maximum in July. There is a drastic reduction of this retardation in the fall, and it becomes insignificant by November.

3.2.7 Meteorological Disturbances

Other factors may create large short-term fluctuations of lake levels which last for periods of from minutes to several days. Sustained high winds along the axis of a lake may cause the surface of the lake to tilt, rising as much as 7 feet at one end and falling a like amount at the other. Cessation of such conditions may result in oscillations, with a rapid change in lake level. Buffalo Harbor, at the east end of Lake Erie, has experienced a rise of about 8 feet due to meteorological disturbances.

Atmospheric pressure changes also produce sudden temporary lake level fluctuations. One such event occurred on Lake Michigan on June 26, 1954, causing a sudden and unexpected rise in lake level in Chicago's Montrose Harbor and resulting in several drownings.

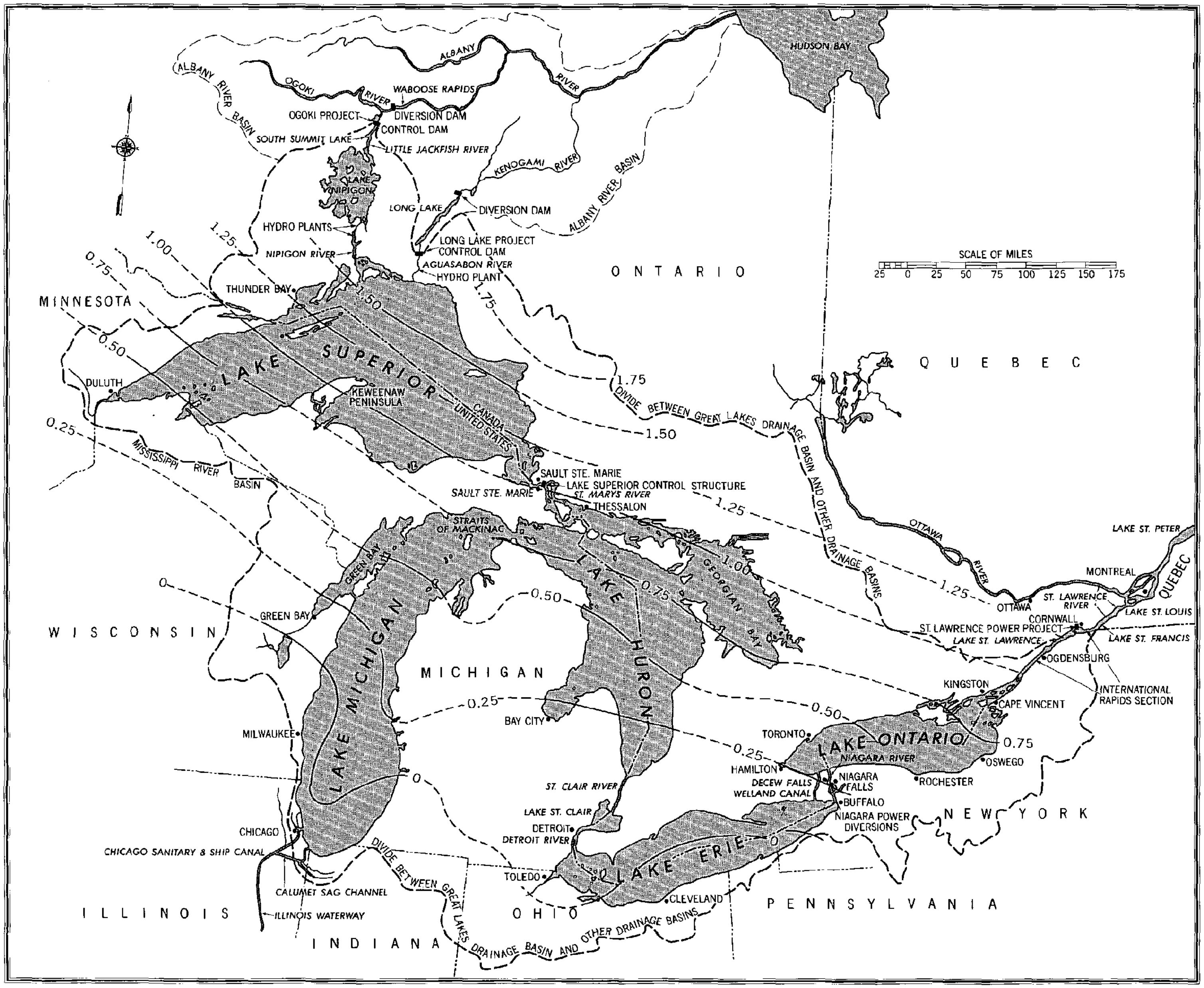
3.2.8 Tides

True tides, both solar and lunar, occur on the Great Lakes and have been observed and studied for many years. However, their magnitudes are small. The U.S. National Ocean Survey, Department of Commerce, reports that the spring, or combined lunar and solar tide, is less than two inches on the largest lake, Lake Superior.

3.2.9 Crustal Movement

Geologists, in their study of the Great Lakes basin, have discovered that uplift of several hundred feet has occurred in some places in the area during the thousands of years since glacial times. About the turn of the century the late Dr. G. K. Gilbert, U.S. Geological Survey, was convinced that this uplift of the earth's crust was continuing, that it was measurable, and that it should be considered in any studies of levels in the area. The effects of this phenomenon on the water level regime of each of the Great Lakes has been determined by the Canada-United States Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data and documented in reports of that Committee. The effect of differential crustal movement is not uniform; generally, the rates around Lakes Superior and Ontario are greater than those around Lakes Michigan-Huron and Erie. Since vertical movement studies are usually carried out by water level records comparison, factors which may affect the accuracy of computed movement rates include: changes in gaging sites; unstable vertical control survey points; limitation of gaging and vertical control measuring instruments and procedures; and local subsidence. Figure 8 shows estimated rates of upward differential movement in the Great Lakes basin.

The effects on water levels of differential crustal movement may be better understood if the lakes are visualized as basins which are being tilted by a gradual raising of their northeastern rims. As time goes on, the water levels along shores that are situated south and west of a lake outlet are rising higher on these shores for a given water level elevation. Similarly, water levels along the shores at localities north and east of the outlet are receding with respect to the land.



SOURCE: CLARK R.H., AND PERSOAGE, N.P., SOME IMPLICATIONS OF CRUSTAL MOVEMENT IN ENGINEERING PLANNING, CANADIAN JOURNAL OF EARTH SCIENCE, VOLUME 7, NUMBER 2, 1970.

Figure 8

DIFFERENTIAL CRUSTAL MOVEMENT WITHIN THE GREAT LAKES BASIN. ESTIMATED RATES OF UPWARD MOVEMENT IN FEET PER CENTURY

The regulation plans developed in the current studies use lake levels as part of the operating criteria and, since crustal movement will cause the water level to land relationship around the lakes to change with time, any regulation plan should be reassessed at some future period.

3.3 Artificial Factors Affecting Fluctuations

The artificial factors affecting fluctuations of the Great Lakes levels are discussed below. They include dredging, diversions, consumptive use, and current regulation.

3.3.1 Dredging

Dredging to increase a lake's outflow capacity is often an integral part of the works to provide full control of the levels and outflows. However, through operation of the control structure, the levels can be manipulated in accordance with a predetermined policy. Since the levels of Lakes Michigan-Huron and Lake Erie are not controlled, dredging of their outflow rivers will increase their discharge capacity and permanently lower the level of these lakes.

The levels of Lake Erie have not been affected by any dredging which has been carried out in the Niagara River.

The levels of Lakes Michigan-Huron have, however, been lowered by commercial dredging for gravel and by dredging operations undertaken to improve the St.Clair and Detroit Rivers and Lake St.Clair for navigation.

The 1926 report of the Joint Board of Engineers, entitled "St.Lawrence Waterway," attributes about 0.3 foot of lowering of Lakes Michigan-Huron levels to commercial dredging of gravel from the reach of the St.Clair River in the vicinity of Point Edward, Ontario, between 1908 and 1925.

The material dredged in deepening the channels for navigation projects was, in large part, deposited in the river in areas where it does not impede navigation, offsetting some effects of channel enlargements. The uncompensated lowering of Lakes Michigan-Huron levels due to dredging after 1933 for the 25-foot navigation project, plus the uncompensated lowering due to dredging for the 27-foot project completed in 1962, is estimated to be 0.59 foot. Similarly the effect on Lake St.Clair was a 0.14-foot lowering.

The effect of the channel enlargements in the St.Clair and Detroit Rivers was to temporarily increase the inflow to Lake Erie. This caused a rise in the Erie levels which in turn, was reflected by increased outflow from this lake. The transitory effect caused by 27-foot deepening became negligible in 1969.

3.3.2 Diversions

There are four diversions in the system; two increase the supply to the Great Lakes, one decreases the supply and the other by-passes the natural outlet river.

Waters are diverted from the Albany River basin, part of the James Bay drainage, via the Long Lake and Ogoki Diversion Project into the Lake Superior basin. These projects commenced operation in 1939 and 1943 respectively and have increased the water supply of the Great Lakes system and thus its water levels. During the period 1943 through 1970 the sum of these diversions has averaged about 5,000 cfs.

Since 1848, water has been diverted at Chicago from Lake Michigan into the Mississippi River basin, averaging about 500 cfs until 1900 and thereafter increasing progressively until the maximum annual average of about 10,000 cfs was reached in 1928. The diversion then decreased progressively to an average of 3,100 cfs by 1938, in accordance with a 1930 decree of the United States Supreme Court. From 1939 to 1952 the diversion was maintained at an annual average of about 1,500 cfs which with domestic pumpage, averaging about 1,600 cfs, resulted in a total mean annual diversion of about 3,100 cfs. From 1953 to 1970, with few exceptions, the mean annual diversion has been about 3,300 cfs. Effective March 1, 1970 by a decree of the United States Supreme Court dated June 12, 1967, the maximum allowable diversion from Lake Michigan at Chicago is 3,200 cfs, including domestic pumpage. The accounting period is a 12-month term ending on the last day of February. A period of 5 years consisting of the current annual accounting period and the four previous accounting periods is permitted, when necessary, for computing the average diversion. The average diversion in any one annual accounting period shall not exceed 110% of the maximum diversion permitted in the decree. This diversion reduces the supply to the lower Great Lakes system and thus lowers the water levels in the system except for those in Lake Superior.

A fourth major diversion, which occurs within the system, is made from Lake Erie to Lake Ontario through the Welland Canal. This diversion for navigation and power purposes has averaged about 7,000 cfs since about 1950 and has lowered Lake Erie levels and slightly lowered Lakes Michigan-Huron levels, since the latter have a minor dependence on the former.

The effect of the four major diversions on each of the lakes and Montreal Harbour is shown in Table 5.

Within the Great Lakes system, minor lowerings result from withdrawals for municipal water supply when the effluent is returned to the next lower lake. For example, minor lowerings of Lakes Michigan-Huron result from withdrawals for domestic water supply for the Detroit, Michigan and London, Ontario areas, since these withdrawals by-pass the St.Clair and Detroit Rivers, but are discharged into Lake Erie. A minor diversion of about 1,000 cfs from the Niagara River at Tonawanda, New York, primarily for navigation purposes on the New York State Barge Canal, has caused an insignificant lowering of Lake Erie.

Table 5

MAJOR DIVERSIONS (AS OF 1970) AND THEIR ULTIMATE EFFECTS ON THE LEVELS OF THE GREAT LAKES AND MONTREAL HARBOUR

Diversion	Average Amount (cfs)	Ultimate Effects in Feet				
		Lake Superior*	Lakes Michigan-Huron	Lake Erie	Lake Ontario*	Montreal Harbour
Long Lake and Ogoki	5000	0	+0.37	+0.23	0	+0.22
Chicago	3200	-	-0.23	-0.14	0	-0.15
Welland Canal	7000	-	-0.10	-0.32	0	0

*Regulation plans for these lakes have been designed to accommodate the diversions.

3.3.3 Consumptive Use of Great Lakes Water

The term "consumptive use" refers to that portion of the water withdrawn or withheld from the Great Lakes and not returned.* It includes water utilized by crops, incorporated into manufactured products, used in industrial processes, consumed by man or livestock, or otherwise expended. The water so consumed in any of the separate lake basins constitutes a reduction in the net supply to that lake and therefore subsequently to each of the downstream lakes. Generally the major portion of consumption results from increased evaporation which takes place during use. Consumptive use of water has been estimated under four withdrawal categories: thermal-electric power generation, irrigation, industrial, and municipal and rural water supply.

Consumptive use of water, in effect, reduces the water supply to a lake and, in turn, has an effect on the water levels of that lake and all lakes downstream. If the consumptive use were at a constant rate, the downstream lake levels and outflows would eventually stabilize at reduced values. The ultimate effects of the 1965 estimated rate of consumptive use on Great Lakes water levels, if stabilized at that rate, are presented in Table 6. There is no sustained effect on the levels of Lakes Superior and Ontario, because they are artificially regulated within given stage limits. To operate within these limits, with a reduced water supply, would require an average reduction in the outflow from each lake equal to the accumulated consumptive use of water above its outlet. Thus, the effects of consumptive use apply equally to regulated and unregulated flows.

The rate of consumptive use of water within the Great Lakes watershed is not constant from year to year. It is expected, based on projected land uses, industry and power growths, and population increases, that rates of consumptive use will increase from a total basin consumptive use of 2,300 cfs in 1965, to 6,000 cfs in 2000 and to 13,000 cfs in 2030.

3.3.4 Current Regulation

Lake Superior outflows have been under complete control since 1921. The current regulation plan is known as the 1955 Modified Rule of 1949. Lake Ontario outflows have been controlled since 1958. The plan currently in use is Plan 1958-D.

Regulation of Lake Superior has changed the sequence and magnitude of the releases from that lake. This change has affected the levels and outflows of the downstream lakes. Table 7 shows that if regulation of Lake Superior had been conducted under the current plan of operation

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* For the purposes of this study the diversion of water from Lake Michigan at Chicago is excepted from this definition.

Table 6

EFFECTS OF 1965 RATE OF CONSUMPTIVE USE OF WATER

Lake(s)	Consumptive Use: Individual Basin (cfs)	Consumptive Use: Cumulative (cfs)	Ultimate Effect on Levels to Nearest 0.1 Foot
Superior	40	40	0*
Michigan-Huron	1,250	1,290	-0.1
Erie	680	1,970	-0.1
Ontario	300	2,270	0*
Montreal Harbour	-	2,270	-0.1

* Due to these lakes being regulated (See Subsection 3.3.3)

Table 7

CALCULATED EFFECTS OF LAKE REGULATION
SUMMARY OF RANGES OF STAGE IN FEET
AND OUTFLOW IN THOUSANDS OF CUBIC FEET PER SECOND
1900-1967

A. LAKE SUPERIOR REGULATION

	Lake Superior regulated (1)		Lake Superior unregulated (2)	
	Stage	Outflow	Stage	Outflow
Lake Superior				
Mean	600.38	77	600.04	77
Max.	601.91	123	602.02	119
Min.	598.36	55	598.02	39
Range	3.55	68	4.00	80
Lakes Michigan-Huron*				
Mean	578.54	183	578.56	183
Max.	581.50	233	581.28	229
Min.	575.74	107	575.70	110
Range	5.76	126	5.58	119
Lake Erie				
Mean	570.60	204	570.61	204
Max.	573.01	258	572.88	255
Min.	567.95	149	567.85	147
Range	5.06	109	5.03	108
Lake Ontario				
Mean	244.53	238	244.52	238
Max.	246.95	310	246.94	310
Min.	241.31	176	241.19	188
Range	5.64	134	5.75	122

B. LAKE ONTARIO REGULATION

	Lake Ontario regulated (1)		Lake Ontario unregulated	
Lake Ontario				
Mean	244.53	238	244.54	238
Max.	246.95	310	247.58	304
Min.	241.31	176	241.53	168
Range	5.64	134	6.05	136

(1) For assumed system conditions, see Subsection 5.5.

(2) 1887 Lake Superior outlet conditions and using average computed ice retardation.

* 1933 outlet conditions

1955 Modified Rule of 1949 over the entire period, 1900-67, the long-term mean level would have been raised and the range of levels reduced when compared to unregulated conditions. The table also shows that the long-term mean levels of the other lakes would not have been materially affected although the extreme stages would have been raised. Since 1960 any minor effects of Lake Superior regulation on Lake Ontario and the St. Lawrence River have been absorbed by the regulation of Lake Ontario. Table 7 also shows that if Lake Ontario had been regulated over the entire period 1900-1967 under the current plan of operation, the range would have been reduced when compared to unregulated conditions.

3.4 Supply and Diversion Summary

The relative proportions of average annual values of the several previously discussed supply factors and the inflow from the upstream lake, where applicable, together with the lake outflows and the existing diversions, are shown diagrammatically on Figure 9 in terms of equivalent average flow rates, in thousands of cfs. The diagram is drawn as though there were no change in the storage within the lakes from the beginning to the end of the period used, October 1950 to September 1960. It thus indicates the relative proportions of the inputs and outputs to each of the lakes in a state of storage equilibrium with the sum of the inputs to each lake being exactly equal to the sum of the outputs.

3.5 Regulative Characteristics

The vast water surface areas of the Great Lakes constitute a feature unique to the Great Lakes-St.Lawrence River system. Small changes in the levels of the lakes account for large quantities of water.

The immense storage capacities of the lakes in combination with their restricted outflow capacities already make them a highly effective naturally-regulated water system. The effectiveness of the natural regulation is shown by the relatively small variations in levels from summer to winter, and from extreme low to extreme high, as shown in Table 1.

Natural regulation of a lake exists when its outflows are uniquely related to the lake levels and can be expressed in terms of a stage-discharge relationship. In the Great Lakes the outflows from Lakes Superior and Ontario are fully controlled, and may be varied widely at any given water level. The outflow from Lakes Michigan-Huron is through the St.Clair and Detroit Rivers into Lake Erie, and depends basically on the levels of the upstream and downstream lakes. Lake Erie discharges through the Niagara River and Welland Canal. The major portion of the outflow from Lake Erie occurs through the Niagara River. Only a relatively small portion is diverted to Lake Ontario through the Welland Canal. Therefore, the major portion of the outflow depends on Lake Erie levels. Stage-discharge relationships for uncontrolled outflow channels may be expressed in terms of lake level alone, or lake level and slope in the river.

Large variations in supplies to the lakes are absorbed and modulated to maintain outflows which are remarkably steady in comparison with the range of flows observed in other large rivers of the world. The maximum flows of the outlet rivers are only about two to three times their minimum flows. (See Table 1). However, such stability is in marked contrast to the wide ranges of flow of several other major North American rivers; for example, the ratio of maximum to minimum flow for the Mississippi River is about 30 to 1; for the Columbia River, about 35 to 1; and for the Saskatchewan River, nearly 60 to 1.

By the nature of the Great Lakes system, the relatively steady outflow from a lake, in comparison with the fluctuating nature of the local supply to that lake, constitutes a continuous source of supply to the next lake downstream. While the local supply is an unknown variable, the storage available on a lake is a nearly predictable source of supply to the next lake downstream.

The lake levels at any time are a measure of the amounts of water in storage at that time; rises or recessions in lake levels from beginning to end of any time interval are a measure of the quantity of water added or removed during that interval. When the net supply to any one of the lakes exceeds the outflow, its level rises. When the net supply is less than the outflow, its level falls. For example, a large monthly net supply of water to Lakes Michigan-Huron may be more than twice the discharge capacity of the St.Clair River. During such a month, at least half of the net supply would be added to the water stored in the lake. The resulting rise in the water surface during the month could be about four inches, with a corresponding continuous increase in the rate of discharge through the St.Clair River, from beginning to end of the month, of about three percent.

The magnitude of the reservoir effect of a lake, a significant factor in lake regulation, is much greater in Lakes Superior and Michigan-Huron than in Lakes Erie and Ontario. (See Table 1). This effect involves lake outlet capacity as well as lake storage capacity. Because of their larger areas, the levels of Lakes Superior and Michigan-Huron respond to changes in outflow much more slowly than do the levels of Lakes Erie and Ontario. On the basis of difference in surface areas only, regulation of the levels of Lakes Superior and Michigan-Huron would require a greater range of flexibility in discretionary control of outflows than would be the case for Lakes Erie and Ontario, in order to obtain for both the larger and the smaller lakes a comparable degree of lake level stabilization.

Because of the size of the Great Lakes and the limited discharge capacities of their outflow rivers, extreme high or low levels and flows persist for some considerable time after the factors which caused them have changed or ceased. Some measure of the importance of this may be gaged from the fact that it takes two and one-half years for only half of the full effect of a continuous supply change to Lakes Michigan-Huron to be realized in the outflows from Lake Erie.

As described above, the Great Lakes system is already relatively well regulated, both naturally and under existing regulation plans employed on Lakes Superior and Ontario.

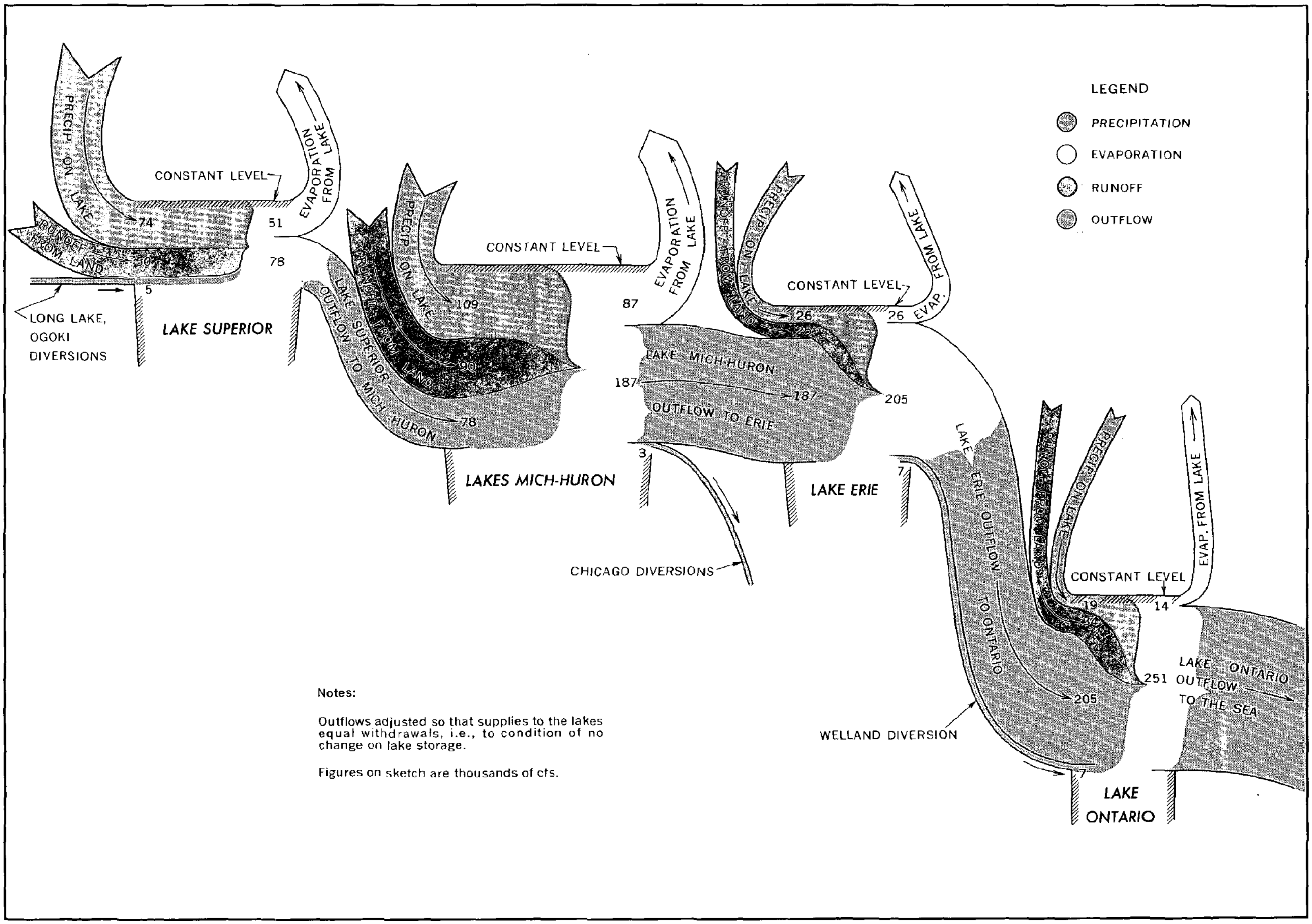

Figure 9

FACTORS OF WATER SUPPLY TO THE LAKES. AVERAGE VALUES FOR PERIOD OCT. 1950 TO SEPT. 1960

Section 4

CURRENT REGULATION

4.1 General

In order to achieve control of the levels of and outflows from a lake, regulatory works are required. These works are essentially of two types: (a) excavation to increase channel capacity so that at times more water can be released, and (b) structures capable of reducing the outflows when required. The amount of excavation and the retarding capability of structures depend on the degree of control which any regulation plan is designe to achieve. A higher degree of control, offering greater benefits, would mean more extensive works and hence greater costs.

Apart from the need to design works which are the most efficient and least expensive, there are other inherent inter-related factors to be considered. Manipulation of the flows in an outlet river changes its water level profile. For example, closing some of the gates of a dam to cut back the flow could, if not otherwise compensated, reduce the available depths of water in the downstream navigation channels to the detrimen of shipping. Upstream of the dam, raised water levels could cause inundation and accelerated erosion of shore properties. An increase in the slop of the water surface profile - the result of higher flows - may produce excessive current velocities from the navigation point of view. For example, the dredged channels in the International Rapids Section of the St.Lawrence River have been designed so that a maximum average velocity of 4 feet per second is not exceeded. The existing or future potential use of the river for power generation is another important factor to be considered. Flow manipulation will also affect the winter ice regime of a river.

Regulatory works exist in the outlet rivers of Lakes Superior and Ontario to control the levels of these lakes. The effects of these controls on downstream lakes and their outflow rivers are discussed in Subsection 3.3.4 and summarized in Table 7. There are no control facilities in the St.Clair and Detroit Rivers, the outlet of Lakes Michigan-Huron, or in the Niagara River, the outlet of Lake Erie.

4.2 Lake Superior

The history of various Lake Superior plans used from 1921 to date, existing regulatory works and water usage are described in this subsection.

4.2.1 Regulation Plan History

Subsequent to completion in August 1921 of the control works in the St.Marys River at Sault Ste.Marie, the outflows from Lake Superior have been controlled. The regulation of the lake is in accordance with the Orders of 26 and 27 May 1914 of the International Joint Commission approving diversions of water around the St.Marys rapids for production of power. The control structure in the river above the rapids at Sault Ste. Marie, consisting of 16 gates each about 52 feet wide, was completed in 1916, except for a closure to flow at the southern end of the structure. The flow through this open section, about 250 feet in width, remained uncontrolled until the closure was completed in August 1921.

The primary purpose of the control structure is to compensate for the increased outflow capacity from Lake Superior through the power canals. The Orders provide that the works be so operated as to maintain the lake levels within a specified range and in such a manner as not to interfere with navigation. Further, they provide safeguards against extremely high and low regulated lake levels, and high levels on the St. Marys River. The operation of the river control works and the amounts of the diversions through the side channels are under the direct supervision of the International Lake Superior Board of Control established by the Commission in accordance with the terms of its 1914 Orders.

The plan of regulation first used in actual regulation of any of the Great Lakes was that developed in 1916 for controlling the outflows of Lake Superior. This plan is referred to as the Sabin Rule since it was developed by Mr. L. C. Sabin, then Senior Engineer at the U.S. Army Corps of Engineers Office at Sault Ste.Marie, Michigan, and advisor to the U.S. Member of the International Lake Superior Board of Control. It provided a basis for operating the regulating gates before closure of the open section south of the structure; and its use was continued after such closure until 1941. The rule was not closely adhered to at all times, but it was at all times used as a guide. A plan designated Rule P-5 increased minimum flows for power to the extent possible without detriment to navigation and other interests. A plan designated the Rule of 1949 was developed primarily in recognition of the increased supplies to Lake Superior resulting from the diversions of water into the lake by means of the Ogoki and Long Lake Projects. The Rule of 1949 has been used since 1951. It was modified in 1955 to obtain improved results.

Under this plan, the monthly regulated discharge from Lake Superior is derived from a rule curve showing the outflow as a function of the mean Lake Superior level for the prior month. This flow can vary from 55,000 cfs to 125,000 cfs. This rule provides for a monthly setting of the gates of the control works from May 1 to December 1. Alterations to the December gate settings are contemplated between December 1 and April 30 only when the Lake Superior monthly mean lake levels move from the normal or intermediate range to the maximum or minimum range, or when they move from the maximum or minimum range to the normal or intermediate range. Further details of the regulation procedures are given in Annex C. The criteria governing regulation are given in Section 8.

4.2.2 Existing Regulatory Works

The 16-gate Lake Superior regulatory structure (see Figure 10), constructed between 1901 and 1916, and alternatively known as the "Compensating Works," controls the flow over the St.Marys Rapids. It has a maximum discharge capacity of about 65,000 cfs. Together with the adjacent hydroelectric facilities, it is used to regulate the outflows from Lake Superior.

In order to pass shipping around the St.Marys Rapids, five locks have been constructed, four on the United States side of the river and one on the Canadian side. In the St.Marys River between the locks and Lake Huron, many large islands exist. Several channels passing these islands provide parallel routes for the flow of the river to its discharge points in Lake Huron. Navigation channels have been excavated throughout the length of the St.Marys River. Much of the excavation has been through ledge rock, boulder and gravel areas, although some short reaches are through soft materials. Minimum width for two-way traffic is 600 feet and minimum width for one-way traffic is 300 feet. Depths vary from 27 to 30 feet.

Three hydroelectric power plants are located in the St.Marys River at Sault Ste. Marie, one in Sault Ste.Marie, Ontario, and two in Sault Ste.Marie, Michigan. Since the average gross head on these plants is approximately 20 feet, all are classed as low head plants.

The Great Lakes Power Corporation plant, located between the Canadian lock and the mainland, was constructed between 1918 and 1931. It has 28 generators, having a total rated capacity of 21,500 kilowatts. Output from this plant is fed into the utility system which serves the needs of Sault Ste.Marie, Ontario, and surrounding areas. Because of the characteristics of the utility system, the plant is generally operated at full capacity. Water requirements are approximately 18,000 cfs.

The United States Government's hydroelectric plant is located between the United States locks and the rapids. It consists of two separate structures having a common forebay and convergent tailraces. This plant has five units with a total rated capacity of 18,300 kilowatts. Power from the plant is used to supply the requirements of the United States locks, the city of Sault Ste.Marie, Michigan, and surrounding areas. Because of the ever-increasing demands for more electrical energy, this plant, too, is operated at full capacity. Water requirements are approximately 12,700 cfs.

The Edison Sault Electric Company hydroelectric power plant, constructed in 1902, is served by a two and one-half mile long canal which diverts water from a point just above the United States locks and delivers it to the plant which is located about one-half mile below the locks. This plant is one-quarter mile in length, has 78 generators horizontally mounted, with a combined rated capacity of 41,300 kilowatts. Water requirements are approximately 30,500 cfs. The power is used to provide for the needs of the eastern half of the Upper Peninsula of Michigan. The plant is generally operated at full capacity.

4.2.3 Water Usage - Lake Superior Outflow

Although the Orders note the agreement of Canada and the United States to divide the waters of the St. Marys River equally, the present usage of the Lake Superior outflow is estimated as follows:

<u>Canadian Water Usage</u>

Great Lakes Power Corporation	18,000 cfs
Canadian Navigation Lock (during navigation season)	200 cfs

<u>U.S. Water Usage</u>

Edison Sault Electric Company	30,500 cfs
U.S. Power Plant	12,700 cfs
U.S. Navigation Locks (during navigation season)	1,300 cfs

Each month the difference between the navigation and power requirements for water and the outflow prescribed by the rule curve is discharged through the control structure gates at the head of the rapids. The minimum gate setting is 1/2 gate open in the control structure. Since the U.S. plants use more than half the water available for power generation, their diversions are curtailed during periods of low supply in order to adhere to rule curve outflow requirement.

4.3 Lake Ontario

The regulation of Lake Ontario began in July 1958. From July 1958 to April 1960 the Project was regulated to maintain preproject conditions, i.e., the level and flow regime that would have existed under outlet conditions in March 1955. Thereafter, regulation was in accordance with a specific plan.

4.3.1 Regulation Plan History

The regulation of Lake Ontario is in accordance with the International Joint Commission's Order of Approval of October 29, 1952 and the Supplementary Order of July 2, 1956, and is under the direct supervision of the Commission's International St.Lawrence River Board of Control. The Orders provide that, during the navigation season, the lake is to be regulated

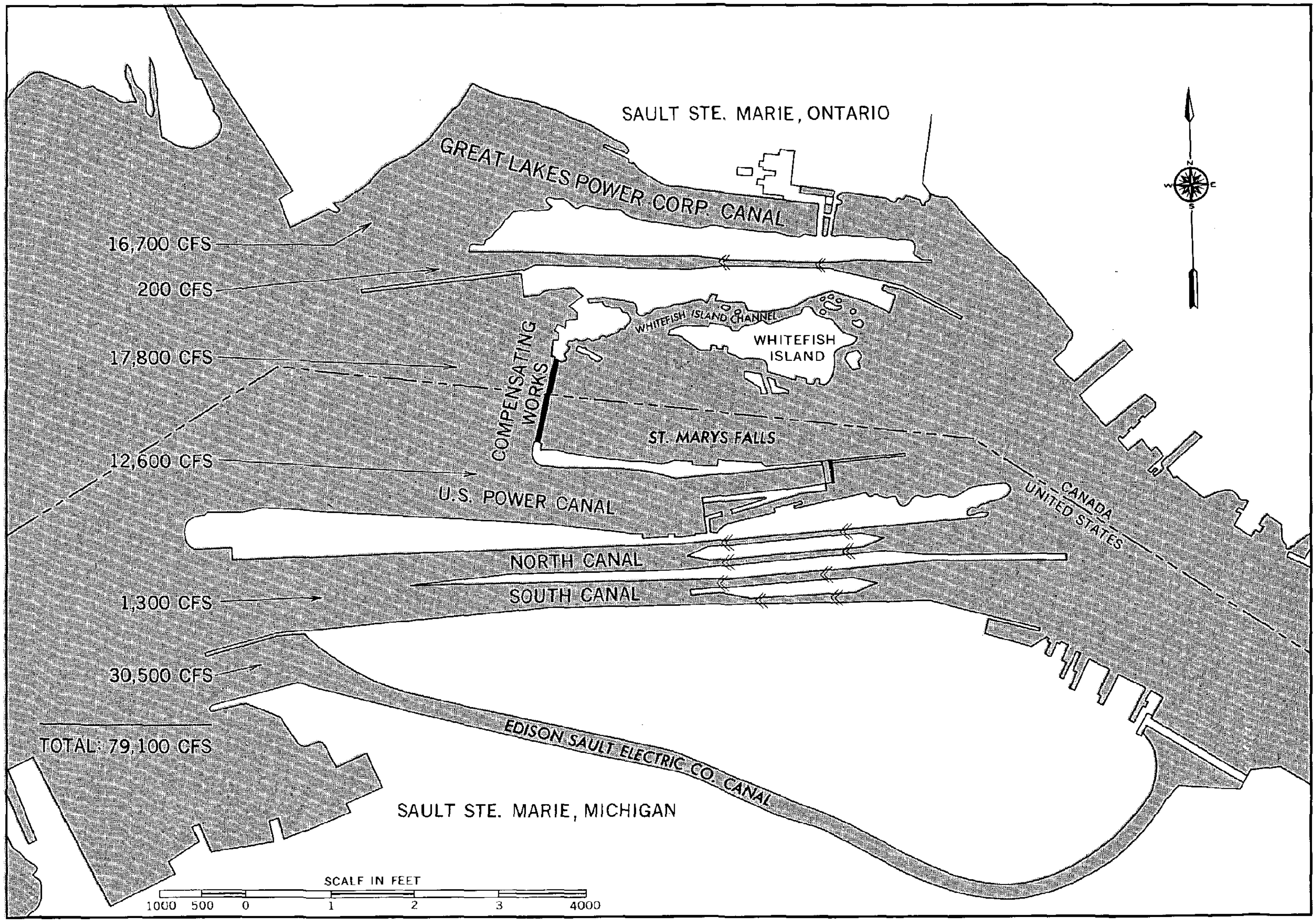

Figure 10
DISTRIBUTION OF MONTHLY FLOW AT ST. MARYS RAPIDS FOR SEPTEMBER 1970

within a certain range of levels; in addition, certain requirements relating to downstream power and Lake Ontario interests must be satisfied. The criteria governing regulation are given in Section 8. Plan 1958-A was in use from April 1960 until January 1962, when it was replaced by Plan 1958-C. The current plan, 1958-D, was put into effect in October 1963. It is described briefly in Annex D.

4.3.2 Existing Regulatory Works

The flows in the St.Lawrence River, the natural outlet of Lake Ontario and the Great Lakes, are regulated by a series of structures and associated channel enlargements (See Figure 11). Between Lake Ontario and Lake St.Louis, where part of the Ottawa River joins the St.Lawrence, there are structures at Points Rockway-Iroquois, at Massena-Cornwall, 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 (see Figure 5), while the series of dams near Coteau Landing, together with the Beauharnois power plant, control the levels of Lake St.Francis.

The Iroquois Dam, which extends 1,980 feet from Point Rockway, in the United States to the Canadian shore near Iroquois, was designed with the capability to pass and control, as required, the full discharge from Lake Ontario. Two 350-ton travelling gantry cranes operate the 32 steel, roller-type, sluice gates. Elevation of the top of sills is 200.0 feet. The gates can be dipped to prevent excessive build-up of water levels in Lake St.Lawrence during periods of strong westerly winds. The pattern of gate settings for the dam was developed from hydraulic model tests, and has been selected so as to minimize adverse currents in the navigation channel at the lower approach to Iroquois Lock. The gates are also used during ice formation to assist in promoting a stable ice cover.

Long Sault Dam is located below the foot of Long Sault Island, about 25 miles downstream of the Iroquois Dam, and lies entirely within the United States. It is capable of discharging a flow of up to 450,000 cfs. It measures 2,960 feet along its curved axis and comprises a sluiceway section and a non-overflow section. Thirty 50-foot sluiceways, formed between 10-foot piers, discharge flows in excess of requirements at the Moses-Saunders plants and effect control of river flows and water levels within specified ranges. Eighteen of the thirty sluice gates are equipped with fixed electric hoists, while the other twelve are handled by service cranes on the deck. Two 275-ton electric travelling gantry cranes, running on tracks the length of the deck, provide hoisting service The spillway crest elevation is 217.0 feet. The gates of this dam are operated only under very high river flow conditions or when flows are restricted through the powerhouses for maintenance of generating units.

Located about three and one-half miles downstream from Long Sault Dam and two miles west of Cornwall, Ontario, the Saunders Generating Station of the Hydro-Electric Power Commission of Ontario, and the Moses Power Dam of the Power Authority of the State of New York form contiguous power plants spanning the St.Lawrence from Barnhart Island in the United States to the Canadian shore. Bisected by the International Boundary Line, the semi-outdoor plants have a combined length of 3,300 feet with a rated head of 81 feet, and a total flow capacity of approximately 325,000 cfs. With thirty-two 57,000 kilowatt capacity generators, equally divided between Canada and the United States, the combined power plants have a total rated capacity of 1,824,000 kilowatts, making the installation one of the largest hydroelectric power producing plants in the western world. Impounded behind the concrete gravity dam of the power plants is the water of manmade Lake St.Lawrence with a volume of 750,000 acre-feet at the normal lake level elevation of 241.0 feet. The lake has an area of 37,500 acres and extends upstream to Iroquois Dam. It is confined by a system of earth embankments at the lower end totalling about 16 miles in length.

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 navigation and power canal to Hydro-Quebec's generating station at Beauharnois. Constructed in three stages over a period of thirty years, the Beauharnois Power House has 36 main generating units with a total capacity of 1,574,000 kilowatts at a head of 80 feet of water. The length of the structure is 2,836 feet and has a maximum discharge capacity of 270,000 cfs. The remainder of the flow leaves Lake St.Francis through the Coteau Control Dams which have a maximum discharge capacity of 435,000 cfs and is utilized by the 162,000-kilowatt Hydro-Quebec generating station in the natural channel of the St.Lawrence River at Cedars. The navigation channel is situated along the north bank of the Beauharnois Canal and has a minimum depth of 27 feet, over a width of 600 feet. Two locks at its confluence with Lake St.Louis allow ships to enter the canal.

An integral part of the St. Lawrence Seaway-Power Project was the St. Lawrence River channel dredging and excavations carried out for the following purposes: (1) to provide a channel depth, width, alignment and water velocity for 27-foot depth navigation; (2) to reduce velocities to induce ice cover over most of the river thus minimizing operational problems and enhancing the channel carrying capacity of the river subsequent to the ice forming period; (3) to distribute the flow in such a way as not to interfere with navigation; and (4) more important from the standpoint of lake regulation, to reduce head losses at specific points in order to increase the channel capacity and to maximize the head available for hydroelectric power generation. For the most part, channel enlargements carried out for one interest were beneficial to the other interests.

The International Joint Commission, in its Orders of Approval, specified that the power entities were required to undertake channel enlargements which would ensure that acceptable velocities are provided through the Galop

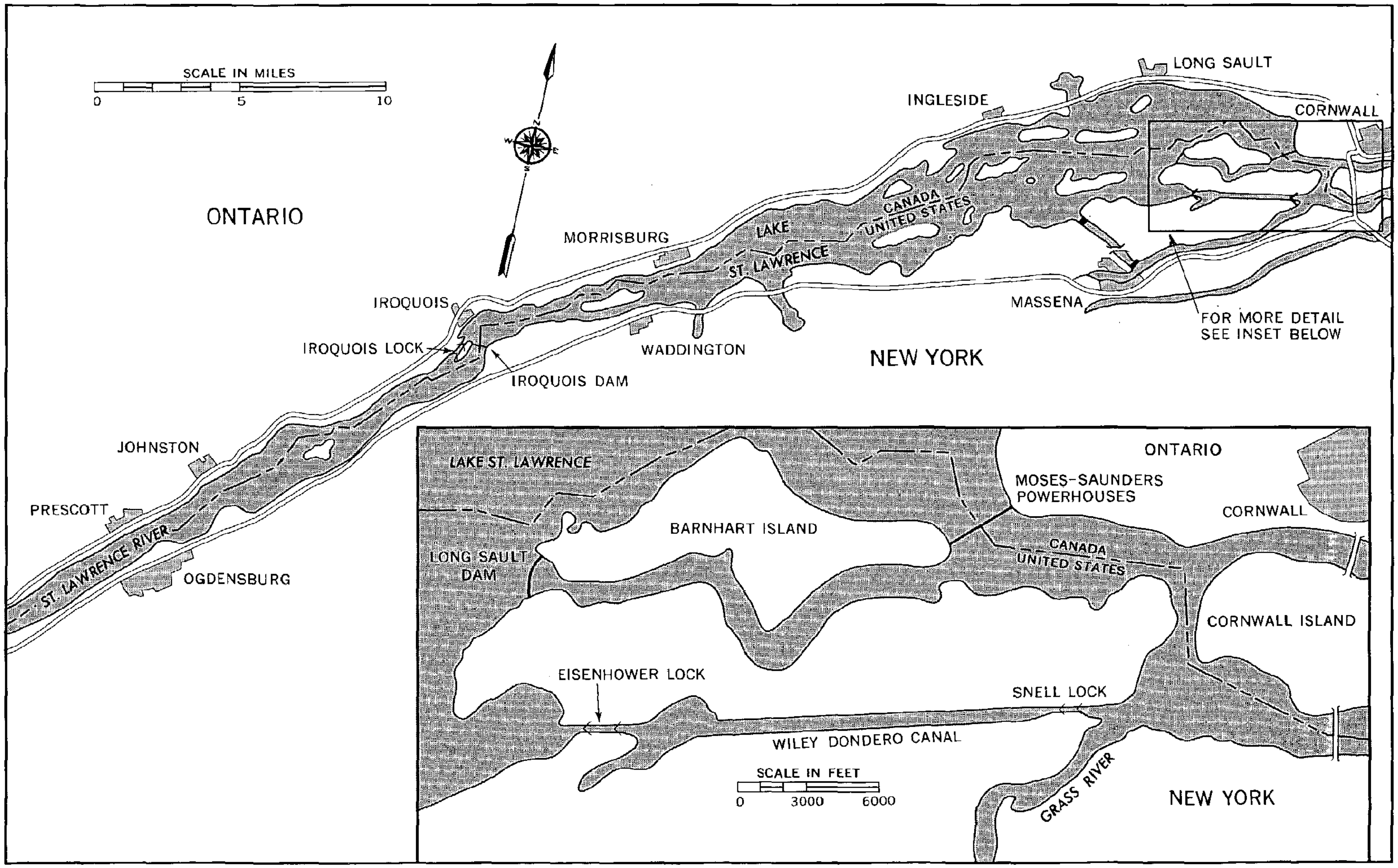

Figure 11
LAKE ONTARIO REGULATORY WORKS

Rapids, particularly below Galop to Morrisburg. These velocities were not to exceed 2.25 feet per second in order to form an ice cover during the winter. Additionally, minimum depths required upstream and downstream of Iroquois were 29.5 feet and 28.5 feet respectively. The power entities carried out channel enlargements in ten areas while the navigation agencies carried out dredging in four locations. The principal locations of channel enlargements carried out by the power entities were at Chimney Island, Galop Island, Lalone-Lotus Islands, Sparrowhawk Point - Toussaints Island, Iroquois, Pt. Rockway, Point Three Points, Ogden Island, the headrace of Long Sault Dam and the tailrace of the Moses-Saunders Dam. The principal locations of channel improvements carried out specifically for navigation were at the Thousand Islands Section and in the International Rapids Section at Iroquois Lock, Wiley-Dondero Ship Channel, including Eisenhower and Snell Locks, and in the North and South Channels, adjacent to Cornwall Island.

A total of approximately 107 million cubic yards of material was excavated. The excavations carried out by the power entities totaled 63 million cubic yards; the major locations being in the vicinity of Sparrowhawk Point - Toussaints Island (12 million), Galop Island (16 million) and Point Three Points - Ogden Island (11 million). The excavations carried out by the navigation agencies totalled 44 million cubic yards, with the principal locations being Wiley-Dondero Channel (25 million), and north and south of Cornwall Island (15 million).

Section 5

SELECTION OF LEVEL AND FLOW REGIME FOR COMPARISON PURPOSES

5.1 General

In order to have a common basis on which to compare the effects of various regulation plans, a set of lake levels and flows was developed which reflected a constant or fixed regimen in the Great Lakes - St. Lawrence River system over the study period. This set of data was an adjustment of the recorded data for the entire study period to account for changes in the amount of diversion into and out of the Great Lakes basin, alterations in the configuration of the connecting channels and construction of control structures at the outlets of Lake Superior and Lake Ontario.

Monthly or quarter-monthly water supplies were determined for each lake for a hydrologically significant time period. Using these supplies, a basis-of-comparison regime was computed for each lake assuming certain diversions and lake outlet conditions. The levels and flow regime that would result from further regulation was then evaluated with respect to this basis-of-comparison. Since future water supplies to the lakes will differ in magnitude and sequence from those of the historic period, a number of simulated sequences of supplies were generated and used in evaluating plan performance.

5.2 Selected Study Period

Although observations of the water levels of the Great Lakes have been taken almost continuously since about 1860, few discharge measurements of the outflows from the Lakes were made prior to the turn of the century. In order to use as uniformly consistent and reliable observations as possible for each of the lakes and their outlet rivers, and also to have a reasonably long record for developing and evaluating regulation plans, the period from January 1900 to December 1967 was selected. This 68-year period is known as the "study period" throughout this report. For purposes of the study, which commenced in 1965, it was considered appropriate to end the period in December 1967, at which time the lakes had returned to about normal elevations. This period contains basin-wide drought periods, such as those of the mid-1930's and mid-1960's as well as several very high supply periods, such as those centered on the years 1928-29 and 1951-52. This 68-year study period provides an adequate basis for assessing the effects of a plan as well as defining the statistical characteristics of water supplies to develop simulated sequences for further evaluation of plan performance.

Implications of water supplies since the end of 1967 are discussed in Section 13.

5.3 Recorded Data

The basic data employed in developing the water supplies are mainly from records of levels, flows and diversions maintained by the United States in the Lake Survey Center of the National Oceanic and Atmospheric Administration, Department of Commerce and by the Water Survey of Canada of the Department of the Environment. The values of levels and flows developed by the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, and agreed to by Federal agencies of both countries, were employed. Since the Committee had not yet developed a set of co-ordinated St.Clair-Detroit River flows, these were, of necessity, developed by the International Great Lakes Levels Board for the purposes of this study.

5.4 Derived Data

Data required for the lake regulation studies were determined by employing the available records as described in this subsection.

5.4.1 Net Basin Supplies

Net basin supply is a term used to describe the net water supply to a lake resulting from: precipitation on the lake surface; runoff from the tributary drainage area; groundwater flow into or out of the lake; and evaporation from the lake. Although available techniques do not permit the accurate determination of these factors separately, the net basin supplies can be computed quite accurately by employing reliable lake level, flow and diversion records for the required monthly and quarter-monthly periods. The relationship used is as follows:

$$NBS = S + O - I \pm D$$

where:

NBS = Net basin supply

S = Change in storage on lake from beginning to end of period

O = Average outflow from lake through outflow river

I = Average inflow to lake from inflow river

D = Total diversions into or out of lake (positive if out of lake, negative if into lake)

All terms are expressed in units of cubic feet per second for the period.

5.4.2 Simulated Supplies

Although the study period supplies (i.e., the magnitude and sequence of supplies for the period 1900-1967) were used to develop regulation plans, it is certain that future supplies will occur in a different sequence, as well as with different magnitudes. Accordingly, a number of simulated supply sequences were generated, against which a regulation plan could be tested to determine its flexibility under a variety of possible future supply conditions and its ability to meet regulation objectives.

5.5 Basis-of-Comparison

The recorded data reflect the effects of changes in the regime of the lakes and their connecting channels which have occurred over the study period (1900-1967). The principal changes to the system have been man-made and consist of changes in the amount of diversion into and out of the Great Lakes basin, alterations in the configuration of the connecting channels and the construction of control structures at the outlets of Lake Superior and Lake Ontario. In addition to these man-made changes, the relative movement of the earth's crust within the Great Lakes basin, a natural phenomenon, has been progressively and unevenly tilting the basin with resultant gradual changes in the elevation of individual lake outlets with respect to points on the shoreline of each lake. This phenomenon has been discussed in Subsection 3.2.9.

In order to have a common basis on which to compare the effects of various regulation plans, a set of lake levels and flows was developed which reflected a constant or fixed regimen in the Great Lakes - St. Lawrence River system over the study period. The conditions selected for the basis-of-comparison are as follows:

(1) A constant diversion of 5,000 cfs into Lake Superior by way of the Long Lake and Ogoki Diversions. These diversions were the subject of an exchange of notes, dated October 14 and 31 and November 7, 1940, between the Governments of the United States and Canada.

(2) Lake Superior regulated in accordance with the September 1955 Modified Rule of 1949, which is currently used by the International Lake Superior Board of Control.

(3) A constant diversion of 3,200 cfs out of Lake Michigan at Chicago. This is the maximum allowable diversion at Chicago by decree of the U.S. Supreme Court, dated June 12, 1967.

(4) Outlet conditions for Lake Huron:

(a) 1933 outlet condition. 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, or

(b) 1962 outlet condition. This represents the current Lake Huron outlet condition which has existed since the completion of the 27-foot navigation channel dredging.

(5) A constant diversion, by way of the Welland Canal, of 7,000 cfs out of Lake Erie and into Lake Ontario. This is the approximate average diversion through the Welland Canal in recent years.

(6) 1953 outlet conditions for Lake Erie. In its 1953 report on the Preservation and Enhancement of Niagara Falls, the International Joint Commission considered it essential that the relationship existing at that time between the Niagara River flow and the Chippawa-Grass Island Pool level be maintained following the commencement of operation of the Chippawa-Grass Island Pool Control Structure and power diversions as permitted by the 1950 Niagara Treaty.

(7) Lake Ontario regulated during the period 1900-1960 in accordance with Plan 1958-D as designed and, thereafter, as operated (i.e., with discretionary authority).

With respect to the two alternatives for the outlet condition for Lake Huron outlined in (4) above, it should be noted that the 1933 outlet condition for Lake Huron was utilized for certain plans of regulation studied not only because of its "Exchange of Notes" basis, but also because such plans would involve costly major construction works requiring a number of years to build. Hence, bearing in mind the possibility that these plans would have difficulty in producing a benefit-cost ratio greater than unity, the emphasis was on maximizing the benefits. Utilizing the 1933 outlet condition, as opposed to the 1962 outlet condition, accomplishes this. Conversely, for other plans studied, which involved only low cost construction works for their implementation, such as some SO and SEO plans, the emphasis was on avoiding overstatement of benefits since such plans would in all likelihood indicate a benefit-cost ratio somewhat greater than unity. Additionally, any of these low cost plans, involving relatively little construction, might be implemented at an early date before final resolution of the question of compensating works. The economic significance of the two alternative Lake Huron outlet conditions is discussed more fully in Subsection 7.5.

The monthly mean level and outflow for each lake to be used as the basis-of-comparison were obtained by routing through the system the net basin supplies, assuming a regime defined by the foregoing conditions. The effect of changes in diversions and regulation thus have been removed from the data. No adjustments were made in the data for the progressive effects of crustal movement and regulation of tributaries, variations in winter retardation and increasing rates of consumptive use. The effects of these factors during the study period are not considered large enough to affect significantly the results of the regulation studies.

Section 6

APPROACH TO DEVELOPMENT OF REGULATION PLANS

6.1 General

The word "regulate" is defined by Webster as "to govern or direct according to a rule"; also, "to fix the time, amount, degree, or rate of, by adjusting, rectifying, etc." As understood in this study, the word implies a capability, through adjustable works constructed by man, for discretionary control of lake inflow or outflow. Full control of the Great Lakes system requires such works at the outlet of each of the lakes. For partial control such works are required only at selected points in the system. In the latter case these works may control the total outflow from the lake or only a part thereof.

Traditionally, regulation plans have been developed on the basis of the supplies which had occurred in the past. A regulating rule which would benefit one or more interests was devised and the effects determined by computing the resulting levels and outflows that would occur if supplies that were received during a short critical period of the historical supply sequence were repeated. If the rule did not satisfy the objectives or regulation criteria over this short period, it was adjusted and retested over the same critical period. This process of adjustment and test continued until the criteria had been satisfied over the entire test period of record. This trial method results in plans which are tailored closely to the sequences and magnitudes of past supplies.

The ability to forecast the weather and, therefore, the water supply for extended periods of time, would enable the adoption of a more flexible regulation plan. Forecasts of dry or wet periods could be dealt with more effectively by such a plan provided the lead time of such events was sufficiently long to enable appropriate adjustments to be made. Unfortunately, accurate weather forecasts, including precipitation, for periods of more than a few weeks would not seem to be in the realm of possibility.

Recognizing the limitations of traditional approaches to regulation and the infeasibility of long-range hydrologic forecasts, the Board sought improved approaches which would better provide for the public interest under possible future variations in the sequence and magnitude of supplies. Using modern computer techniques, the Board examined and tested the consequences of a wide range of objectives and criteria, explored the maximum benefits that might be obtained without constraints, and tested several hundred trial plans over the entire sequence of historical supplies. Selected plans were further tested over several simulated supply sequences.

6.2 Objectives and Criteria

Two goals of good water resource management are to optimize the return from the use of the resource and to allocate the return wisely among the various interests. If the return, or benefit, for each of the interests could be measured in precise economic terms, and if hydrologic inputs were known in advance, an exact mathematical formulation could be devised to achieve these goals. Such "formulation" would, in effect, be the "best" regulation plan.

There are three reasons why this is not possible. First, our knowledge of the hydrologic processes is so imperfect that future inflows cannot be estimated with certainty. Second, all benefits cannot be expressed in economic terms. For example, the aesthetic value of recreational uses of the lakes cannot be expressed in precise economic terms. The third problem, which is perhaps the most difficult to overcome, is that of equity; that is, even if an overall benefit is obtainable from a resource, certain sectors of society may be obliged to accept some losses.

In order to obtain a partial solution to the second and third problems, constraints or regulation criteria are usually introduced to protect the various interests. Certain of these criteria have been established over the years in connection with the regulation of Lakes Superior and Ontario. Aside from the criteria already being imposed on the system in day-to-day operation, a number of additional constraints have evolved during the course of this study. In general, these constraints are designed to ensure that no major interest on any individual lake will incur a substantial detrimental effect.

In any reservoir system such as the Great Lakes, the ability to respond to any hydrologic condition of either flood or drought depends on where the water can be stored in the system. If a large reservoir is at the upstream end of a system, the remainder of the system can be better regulated (smaller variations in outflow) because the upper reservoir can be used to store water to minimize downstream flooding and as a water supply in time of downstream drought. Since the major portion of the Great Lakes system is downstream from Lake Superior, it is logical that benefits could be achieved for the downstream Great Lakes if the storage potential of this lake were used more fully. However, its use for such a purpose is limited by the needs of the riparian interests on Lake Superior. As a reservoir, the range of level fluctuations on Lake Superior would be increased over that which has been experienced.

Hydroelectric power, commercial navigation, erosion and inundation, beaches, marinas, fish and wildlife habitat, water intakes and sewer outfalls are all affected by regulation, but in different ways. Generally speaking, shore property interests would be best served by lowering extreme high levels and raising extreme low levels, navigation interests benefit most from higher lake levels and hydroelectric power generation requires the maintenance of minimum flows as large as feasible, particularly during periods of high power load on the system.

In order to provide an indication of the effect on these interests of a different regime of levels, an evaluation was made of the consequences of raising or lowering the entire regime (mean, maximum and minimum levels) of all the lakes by increments up to one foot. The results obtained, employing the generalized loss functions, are shown in Table 8. The table shows that shore property interests are benefited by a general lowering of lake levels. However, the benefits so derived are off-set by losses to the navigation and power interests. The reverse is true when all lakes are raised. These tables do not include the costs associated with carrying out any lowering or raising of lake levels or any assessment of the environmental or resource depletion implications. It will be seen that, geographically, the largest dollar values would accrue to Lakes Michigan-Huron and, of the three interest groups, the largest values accrue to shore property.

The Board began its examination of objectives and criteria with the assumption that the existing International Joint Commission Orders would not constitute a constraint to the development of further regulation plans. However, the Board recognized the wisdom of the existing requirements and criteria and reviewed their application at every stage of plan development. The current regulation plans for Lakes Superior and Ontario, described in Annexes C and D, were developed to meet criteria specified in Orders of Approval of the International Joint Commission. These criteria, which are listed in Subsection 8.3.1, relate to specific problems associated with each lake and its outlet river.

The present study involving re-regulation of the system raises the important question of distribution of the resulting benefits among all the lakes. After review of the several initial plans, the Board adopted the view that the benefits obtainable from new plans should be distributed to the overall advantage of the Great Lakes region so that, if possible, each major interest and each lake should have a net benefit.

6.3 Plan Evaluation

Of the three elements of plan evaluation described in Section 7 - hydrologic, economic and environmental - the first two played the greatest role in initial plan development. Detailed economic evaluation required such costly and time consuming computer calculations that an abbreviated technique had to be developed to allow the rapid testing of many alternatives. Accordingly, simplified benefit-loss functions, otherwise known as "generalized loss curves" were developed. The simplification essentially consisted of combining groups of functions,

Table 8

ECONOMIC EVALUATIONS OF LOWERING OR RAISING THE MEAN LEVELS OF THE GREAT LAKES
($ Millions)

A. LOWERING THE MEAN LEVELS

	0.00	-0.25	-0.50	-0.75	-1.00 foot
Approximate Annual Benefits					
Power	0.0	-0.7	-1.4	-2.1	-2.9
Navigation	0.0	-1.6	-3.4	-5.4	-7.6
Shore Property	0.0	+5.6	+10.1	+13.6	+16.1
Total	0.0	+3.3	+5.3	+6.1	+5.6
Geographical Breakdown of Shore Property Benefits					
Superior	0.0	+1.3	+2.2	+2.7	+3.0
Michigan-Huron	0.0	+2.7	+4.9	+6.8	+8.1
Erie	0.0	+0.8	+1.5	+2.0	+2.4
Ontario	0.0	+0.8	+1.5	+2.1	+2.6
Total	0.0	+5.6	+10.1	+13.6	+16.1

B. RAISING THE MEAN LEVELS

	0.00	+0.25	+0.50	+0.75	+1.00 foot
Approximate Annual Benefits					
Power	0.0	+0.6	+1.2	+1.7	+2.2
Navigation	0.0	+1.4	+2.7	+3.9	+5.0
Shore Property	0.0	-7.0	-15.2	-24.8	-35.6
Total	0.0	-5.0	-11.3	-19.2	-28.4
Geographical Breakdown of Shore Property Benefits					
Superior	0.0	-1.8	-4.1	-6.9	-10.3
Michigan-Huron	0.0	-3.2	-6.9	-10.9	-15.4
Erie	0.0	-1.0	-2.2	-3.7	-5.2
Ontario	0.0	-1.0	-2.0	-3.3	-4.7
Total	0.0	-7.0	-15.2	-24.8	-35.6

Note: No costs of providing these benefits are included.

shortening the computer program and thus significantly reducing the output data. Although these generalized loss curves were somewhat crude representations of the detailed functions from which they were derived, investigations showed that they were adequate for optimization procedures, trial plan development and other related preliminary regulation studies. Using these curves, comparisons were made among a variety of plans leading to selection of those which merited closer examination of the effects on the individual interests.

The physical or hydrologic evaluations were made by comparing against predetermined criteria the levels and flows which would result from a plan. Although the existing Orders of Approval did not constitute a constraint on the development of plans, they were used as guidelines for the evaluation of further plans involving Lakes Superior and Ontario. For Lakes Michigan-Huron and Erie, tentative criteria were established to ensure that the frequency of high or low levels would not be substantially increased in any of the plans which were evaluated in detail.

6.4 Trial Plans

A three-stage procedure was employed in the development of trial plans. In the first stage, a mathematical procedure was employed to determine the absolute upper limit of total benefits that would possibly accrue to the three major interest groups under any system of regulation. These figures were then compared with order of magnitude cost estimates to give a preliminary assessment of economic feasibility.

In the second stage, a number of plans covering a broad range of operating objectives were tested. Results from the first stage were used to help identify means of meeting the various objectives. For example, it was apparent from these studies that maximum benefit from Lake Superior regulation (with no control of the outlets of Lakes Michigan-Huron and Erie) could be realized by balancing storage between Lake Superior and Lakes Michigan-Huron for the benefit of the lower lakes. This, accordingly, became the basis of the maximum economic benefit plans for the SO-series*. Using this concept as a base, various outflow constraints and target levels, etc., were applied to provide a wide range of possible objectives. The range of objectives investigated at this stage for each combination of lakes usually included:

(a) Maximum economic benefits for the Great Lakes-St.Lawrence River system;

(b) Maximum economic benefits with approximate satisfaction of existing criteria;

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* Superior and Ontario regulated together

(c) Maximum economic benefits without significantly changing the extremes of levels of any lake or the range of levels of any lake; and

(d) Maximum economic benefits with no significant loss to any major interest on any lake.

In developing the trial plans, using the generalized loss curves, the objectives were considered to be satisfied when stage criteria were met within ± 0.1 foot and monetary targets were achieved within ± $200,000.

The results of plans developed in the second stage, together with their corresponding objectives and criteria were reviewed, and final criteria adopted. The third stage consisted of the development and refinement of a plan to satisfy the adopted criteria. Detailed evaluations, including a subjective appraisal of the plan, were also carried out at this stage. This sometimes required two or more loops from the plan developer, to the evaluator, to the goal setter, and back to the developer, before a satisfactory solution was reached.

Section 7

APPROACH TO EVALUATION OF REGULATION PLANS

7.1 Scope of Evaluation

The 1964 Reference identified the following interests for which improved water level conditions should be investigated: domestic water supply and sanitation, navigation, water for power and industry, flood control, agriculture, fish, wildlife and recreation. In considering the specific interests affected by lake levels, and the evidence submitted at the public hearings in 1965, and in establishing a method to evaluate regulation plans, the Board grouped the interests into four major classifications:

(1) Commercial Navigation.

(2) Power.

(3) Shore Property. This includes the effect of variations in water levels on erosion and inundation of shoreline areas (i.e., covering the subject of "flood control"), the operation of water intakes and sewer outfalls (i.e., "domestic water supply and sanitation" and "water for industry"), and marine structures. "Agriculture" has been found to be affected only by the loss of agricultural land, or its use, through erosion or inundation.

(4) Fish, Wildlife and Recreation.

The Commission had been asked to indicate how the various interests on either side of the boundary would be benefited or adversely affected by any changes in existing works or other measures which are found to be practicable and in the public interest. Furthermore, the Commission was asked to estimate the cost of such changes or other measures and the cost of any necessary remedial works. It was also asked to make an appraisal of the value to the two countries, jointly and separately, of such measures. The design and cost estimates of regulatory works studied are treated in detail in Appendix G.

Each selected regulation plan was evaluated in detail as to its hydrologic, economic and environmental effects. It was found that the economic effects on certain interests, such as fish and wildlife, were not susceptible to meaningful quantification and evaluation in dollar terms. In the case of some other interests, such as water intakes and sewer outfalls, economic assessments produced such small dollar values as to be insignificant.

7.2 Hydrologic Effects

The two primary hydrologic factors are lake levels and outflows. Analysis of these factors includes consideration of maximum, mean and minimum monthly values, range, duration and seasonal distribution. Various criteria expressed in these hydrologic terms have been developed for the purposes of regulation. Evaluation involves the determination of the degree to which any new regulation plan meets such criteria. In certain instances this involves a comparison between regulated and basis-of-comparison data.

7.3 Economic Effects

In an attempt to express regulation effects in terms of dollars for as many interests as possible, methodologies were developed to provide approximate economic evaluations even for those interests which are not easily susceptible to precise quantification. The primary purpose of such methodologies was to assist in the development and selection of regulation plans. The same methodologies were used in preliminary benefit-cost analyses.

It became evident early in the study that methodologies which would express the dollar effects of further regulation could be developed with relative ease for such interests as commercial navigation and power because of their commercial nature and the well-established methods already used by these interests for project evaluation and justification. With regard to regulation effects on other interests, such as erosion and inundation of shoreline properties and recreational beaches, it has not been possible to develop correspondingly precise quantitative methods of evaluation. Indeed, it was recognized that the effects of lake regulation on certain interests in the Great Lakes-St.Lawrence system could not be evaluated in economic terms owing to the intangible nature of the benefits or losses involved.

While acknowledging the great difficulties involved in a precise economic evaluation of regulation effects on the Great Lakes-St.Lawrence system, one is aware that certain changes in the outflow and water level pattern for the system would be beneficial for certain interests. For example, a reduction in the frequency of extreme high levels would be beneficial from the point of view of minimizing erosion and inundation damages. It is possible to make such an appraisal of the effects in these areas by comparing stage-duration and flow-duration curves prepared for the basis-of-comparison with those prepared for the regulation plan. In this report, the effects of regulation plans are thus evaluated with regard to the physical changes produced in the water levels and outflow patterns. Where possible, these effects have been assigned a dollar value derived from the best methodology that could be devised.

In the cost analysis of regulatory works, a project economic life of 50 years was assumed covering the period 1980-2030, which is consistent with common practice in water resources planning. For plans involving re-regulation of Lakes Superior and Ontario which could be accommodated by existing works, the project period was taken as 1972-2022, since a plan could be instituted without delay for major construction.

An interest rate of 7% has been used in determining benefits and costs. For purposes of this study, a common dollar value has been used for Canadian and United States evaluations. Basic price levels used in plan evaluation were those of 1971. Energy and transportation demands are projected to increase with future economic growth. However, the economic unit values associated with navigation and power effects are projected to remain constant. Recreation beach areas are projected by using future population and income increases which change beach usages or require additional beaches. In evaluating effects on water intakes, a uniform increase in water consumption is assumed. Recreational boating facilities are assumed to increase to meet the demands of the growing Great Lakes recreational fleet.

In the case of erosion and inundation, the economic unit values associated with shore property are projected to grow, since the Great Lakes shorelines are quantitatively a fixed resource. With increasing demand from more extensive use, the economic value of each shoreline land unit was assumed to participate fully in the projected economic growth of personal income, population, and productivity in the Great Lakes region's economy. In order to determine equitable future values of shoreline damage, the unit values of these shorelines were projected to reflect changes in land use.

7.3.1 Commercial Navigation

General: The commercial navigation evaluation, carried out for the years 1970, 1995 and 2020, is based on the concept that ships which can take advantage of deeper water will load to the maximum draft available. Since some vessels are designed to take advantage of deeper water than is usually available in dredged channels and harbors, it is in the interest of navigation to maintain lake levels uniformly higher than low water datum during the navigation season. The potential benefit or loss to shipping as a consequence of a change in lake level regulation results primarily from the difference in the payload capacity of ships, computed monthly, with and without the change and the resulting difference in transportation costs. Additional requirements of navigation are that the flows in the connecting channels be maintained as uniform as possible and excessive velocities be avoided.

Assumptions: The assessment of the effect of regulation plans on commercial navigation is based on the following assumptions:

(1) Improvements to channels, locks and harbors would be made during the assumed project life of the regulation plan if and when these are required to accommodate the projected traffic, but such improvements would not include any increase in the present controlling depth of the system (27 feet).

(2) There would be no radical changes in the sources and markets of the principal commodities moving on the Great Lakes, and, therefore, no changes in the present general pattern of traffic.

(3) It is recognized that regulation plans would produce some changes in the percent of time that various depths are available. Such changes would not reduce the present controlling depths in the locks and channels of the Great Lakes system including the Seaway. It was further assumed that if such changes in regulation plans would result in a reduction in the controlling depth of Montreal Harbour and the St. Lawrence Ship Channel, regulatory works would be provided which will ensure the maintenance of the present controlling depth.

(4) By 1995, the approximate midyear of the project period, all harbors shipping or receiving a significant volume of one or more of the four bulk commodities analyzed would be deepened to 27 feet.

(5) By 1995 additional locks (1200 feet long and 110 feet wide) would be provided on the Seaway and Welland Canal.

(6) The St.Lawrence Ship Channel (Montreal to downstream of Quebec, P.Q.) would be a 35-foot waterway generally open to navigation for 12 months of the year.

(7) The navigation season above Montreal extends from 1 April to 30 November (244 days) divided into three shipping seasons: Intermediate (April, October, November), Summer (May, September), and Midsummer (June, July, August).*

(8) A valid assessment of the effect of lake levels on commercial navigation can be obtained by evaluating the effect on the transportation cost of four bulk commodities (iron ore, coal, limestone and grain) which comprise about 80 to 85 percent of the traffic.

(9) There would be no major wars or national economic depressions.

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* This assumption is made for purpose of analysis of historic data and available records. The season has in fact already been extended well into December on the St.Lawrence River and into January on a more or less regular basis on the upper lakes. Furthermore, actual shipping seasons do not begin and end with the months. (See Appendix E, Commercial Navigation, for actual duration of seasons).

Methodology: The commercial traffic in the Great Lakes-St. Lawrence River system has three distinct components: (1) the segment within the upper lakes above the Welland Canal; (2) the segment which uses the Great Lakes and the Seaway; and (3) the segment at and below Montreal. The method of assessment of effects is similar for each of the segments.

The traffic and commodities (iron ore, coal, limestone and grain) considered in this analysis comprise the four major commodity movements on the Great Lakes-St.Lawrence system. This traffic accounts for 80-85% of the total tonnage carried on the waterway. The remaining 15-20% of traffic includes overseas general cargo. Although overseas cargo is of high value, the vessels must transit the 27-foot Seaway. Thus, these vessels cannot take advantage of depths greater than 27 feet available in other harbors and channels when lake levels are above LWD, the datum from which the authorized channel depth of 27 feet is determined. In addition, losses because of lower lake levels occur infrequently because (a) lake levels lower than LWD occur infrequently, and (b) lower lake levels do not necessarily cause losses because vessels have the option to offload or onload on Lake Erie, which rarely is below LWD. In addition, some of these vessels call at several ports and therefore do not often travel fully loaded, and thus cannot normally take full advantage of water depths available. Therefore, overseas general cargo traffic would not be significantly affected by lake regulation.

The 15-20% also includes petroleum products, cement, chemicals, and hundreds of other items. These commodities are either carried by the smaller, lesser draft, vessels which cannot take advantage of lake levels, and/or are not shipped in quantities large enough to warrant analysis in this study.

The methodology employed in evaluating the economic impact of regulation plans is based on the difference in cost of transporting bulk commodities in the United States and Canadian Great Lakes vessel fleets under each regulation plan as compared to the cost under the basis-of-comparison. The difference in cost would be the benefit or loss to commercial navigation.

The methodology takes into account the following general conditions:

(1) Any increase or decrease in lake levels resulting from natural or man-made causes will change the cargo-carrying capacity of the fleet to some degree. For purposes of calculating the extent and effect of these changes, the projected vessel fleet was categorized into the various classes (sizes) of existing and projected vessels.

(2) To the extent that the cargo-carrying capacity of the prospective fleet is increased, by regulatory measures or natural causes, the volume of the commodities available for shipment can be carried in fewer trips; and conversely, to the extent that the fleet capacity is decreased, more trips would be required.

(3) The number of trips required, multiplied by the average length of trip (in hours) for each of the various routes, multiplied by total vessel cost per hour (calculated separately for each size of vessel) was taken as the measure of cost for transportating the selected bulk commodities.

(4) The difference in cost of transporting the various bulk commodities under a new regulation plan as compared to the cost under the basis-of-comparison is taken as the benefit or loss to navigation.

(5) Navigation benefits and losses occur over the 8-month period April through November. The carrying capacities of each vessel are regulated by Federal laws prescribing maximum drafts to which each vessel may be loaded during each of four shipping seasons. These "load-line limits" are so restrictive in the period December through March that lake levels generally do not control the drafts to which ships may be loaded in this period. In the evaluation of benefits and losses for the other three shipping seasons load-line limits were observed in determining the maximum draft to which ships could be loaded at higher lake levels.

A detailed analysis of transportation costs for the four bulk commodities was made for the following three years.

<u>1970</u>: The most recent year for which actual operating data (vessel fleet characteristics and tons carried) were available.

<u>1995</u>: A year representing possible significant physical changes in the system (larger locks on the Seaway and 27-foot depth at all significant harbors).

<u>2020</u>: Representative of conditions 50 years from 1970.

A 27-foot controlling depth was used for 1995 and 2020 evaluation. However, for 1970, benefits were evaluated for both 27-foot depth and less than 27-foot depth harbors (existing conditions).

Vessel fleet characteristics and tonnage carried were determined for each of these three years. A computer program was written to evaluate the transportation cost using these data and water levels obtained under basis-of-comparison conditions and under the regulation plan being evaluated.

The output of this program is the transportation cost to commercial navigation for the years 1970, 1995, and 2020 for each country by commodity, month, traffic route and vessel class. The program also provides the number of vessels in each class required to carry the prospective commerce for each country by commodity under the imposed conditions. The transportation cost for the regulation plan being evaluated is then subtracted from the transportation cost under the basis-of-comparison conditions to obtain the benefits or losses to commercial navigation for the years 1970, 1995 and 2020. The benefits or losses were then plotted for the years 1970, 1995 and 2020. A second computer program interpolates and extrapolates along the straight lines connecting the plotted points and provides the average annual benefits or losses for the appropriate 50-year period (either 1972-2022 or 1980-2030) using a 7% interest rate.

7.3.2 Power

General: The determination of the effects of any plan on hydropower installations is divided generally into two parts; first, the effect on system capacity and energy output; and second, the monetary evaluation of any changes in these two components, as measured by effects on electric system costs.

Hydroelectric installations on the outlet rivers that could be affected by changes in the water level and flow regime of the system are those existing on the St. Marys River, Niagara River, the Welland Canal and St. Lawrence River.

The potential benefits or detriments to the ultimate power user, which might result from additional Great Lakes regulation, can best be understood by seeking to answer the question: "How would the overall cost of producing the power needed to service the loads expected to develop in the various service areas of northern Michigan, New York State, Ontario and Quebec be altered by the flows and levels which would result under the regulation plans being evaluated?"

The capacity and energy available from any of the existing power installations on the connecting channels and the St. Lawrence River, or any modification of such facilities, depend in a relatively straightforward way upon the net head and flows available. For plants with pumped storage reservoirs, the storage reservoir level and units available for pumping and turbining water are also factors.

Assumptions: The assessment of the effect of regulation plans on power is based on the following assumptions:

(1) There will be no change in installed capacity over the evaluation period. The existing hydroelectric installations affected by regulation of any or all of the Great Lakes have a total installed capacity of approximately 7,969,000 kilowatts of which 4,807,000 kilowatts are in Canada.

(2) The analysis is based on anticipated load and power supply conditions estimated to obtain in 1985 because this is about as far ahead as predictions of such conditions in power systems are being made by power utilities. The estimated power supplies required in New York State and the Ontario Hydro system to meet anticipated peak loads plus reserves in 1985 amount to 41,038 megawatts, and 35,726 megawatts, respectively.

(3) The energy and capacity values used in the study for evaluating the effects of regulation on the hydroelectric power generation are shown in Table 9, and reflect 1971 costs. In the light of very large increases in the costs of fuel for thermal power generation during recent years, there is considerable uncertainty associated with the long-term cost of fuel and the value of energy and capacity in the future. Because meaningful projections of these values in the future cannot be made, it was decided that current rather than projected power costs would be used to evaluate the regulation plans.

Methodology - Capacity Benefits: The assessment of any regulation plan as compared to the basis-of-comparison from a peak power standpoint, is determined by comparing the load-meeting capability of the system in each case. If the load-meeting capability of the system under a plan of regulation during the critical load period is greater than for basis-of-comparison, then the installed capacity of the system could be reduced by a like amount and the value of the reduction credited to the regulation plan. The load-meeting capability of the system is defined as the load that can be carried during critical load periods, with a loss of load probability of one day in ten years having regard for the forced outage rates and reserves. The critical load period in the Ontario system is December-January. In the New York State system, the critical load period is in December; however, in the 1985 system some capacity will be required solely to provide for maintenance so the capacity in each month is important rather than simply the capacity in the critical load period. The determination of load-meeting capability is based on a study of duration curves of such capability during the critical periods. The corresponding duration curves during other months of the year are also examined to ensure that, even with reduced loads, a more critical period does not exist because of scheduled maintenance. A computer program has been developed for this study.

It should be emphasized that the determination of relatively small peak differences in very large systems is beyond the accuracy of the study methods and, therefore, the results cannot be precise. However, as the same method is applied to the basis-of-comparison and all regulation methods, the differences thus determined should be reasonably representative of the regulation method in providing system peak capacity.

Ice conditions limit the flow at the time that the Hydro Quebec system experiences peak loads; therefore, no capacity benefits or losses

Table 9

ENERGY AND CAPACITY VALUES USED FOR EVALUATING EFFECTS OF REGULATION ON HYDROELECTRIC POWER GENERATION

System	Energy Values (mills per kwh)			Capacity values* ($ per kw-yr)
	Day	Night	Week-end	
Upper Michigan	8.0	8.0	***	22.70
New York State	8.4	7.1	5.3	18.00
Ontario	4.5	4.4	***	15.00
Quebec	6.0	6.0	***	**

* Values based on 1971 costs.

** Ice conditions limit the flow at the time the system experiences peak loads.

***Week-end rate not applicable.

are expected at Beauharnois for any plan of regulation which does not drastically change the existing flow regime. The output of the plants at Sault St.Marie, Michigan, is normally supplemented by power purchased from the Consumers Power Company (another Michigan system) at fixed capacity rates. Large fluctuations in the power output increase the purchase cost to Edison Sault Electric Company. In the studies of Beauharnois-Cedars (Hydro Quebec) and the Upper Michigan plants (U.S. Government plant and Edison Sault plant), it was considered for purposes of this study that system analysis would not be necessary.

Methodology - Energy Benefits: The value of hydro energy to a power system is dependent upon the cost of obtaining equivalent energy from an alternative source at the time. In a large inter-connected power system with a mix of hydro and thermal generation the cost of energy varies with time. At times of light loading, only the most efficient thermal plants in the system are in use and the incremental cost is small. For large loads, less efficient equipment has to be used so the incremental cost increases. In the New York State and Ontario Hydro systems, the value of energy has been determined by dividing the total load into appropriate subdivisions of time. Typical values of energy have been approximated for the different time categories. For the power plants at Beauharnois, Cedars and Sault Ste. Marie, Michigan, single energy values were assumed because of system characteristics.

By making a computation of the energy available in each of the time categories, for both the basis-of-comparison and a regulation plan, the value of energy attributable to each was computed, and the difference represents the average energy benefits or losses for the regulation plan.

Methodology - Projections: In order to determine the amount of change in capacity associated with any regulation plan, it is necessary to con-sider the number, size and characteristics of each generating unit in the inter-connected power system. The conditions expected in the inter-connected New York State and Ontario Hydro systems in 1985 were used for this analysis. Because of rapid changes in technology and fuel costs, meaningful projection of system conditions beyond about 15 years is not feasible. Capacity benefits may be slightly larger in earlier years and slightly less in later years than computed for 1985, because as the system grows the proportion of capacity supplied by hydroelectric generation tends to decline in relation to the required reserves.

The change in the amount of energy resulting from any regulation plan does not depend upon power system configuration. The energy benefit would be constant throughout the assumed project life except for changes in unit value. The energy benefits have been computed using 1971 unit values. However, the effect of a gradually declining capacity benefit upon the value of an equivalent average annual benefit was computed and it was found that the 1985 benefit would understate the benefit in terms of an equivalent annual series by only 2.5 percent. Therefore, the Board accepted the evaluation of the power benefit for the single year 1985 as representative of the equivalent average annual benefit calculated from yearly benefits projected over a 50-year period.

7.3.3 Shore Property - Erosion and Inundation

General: Shore property damage resulting from fluctuation in water levels may be caused by inundation or direct flooding, wind-generated waves, or a combination of both. The intensity of the shore damage varies with (1) the elevation of the still-water level augmented by (2) the temporary increase in that level at a specific location as a result of wind or barometric pressure gradient, (3) the duration, magnitude and frequency of wind-generated waves, and (4) the extent of wave run-up on shore. The term "ultimate water level" represents the average maximum elevation to which the water level will rise at a reach of the Great Lakes shoreline due to a storm on a lake. The strong winds during a storm cause the water surface of the lake to tilt in the direction of the wind, lowering the water level along the upwind shore and raising the levels along the downwind shore. The maximum elevation of the water surface along the shore due to this tilting of the lake surface is termed the "storm water level." The large waves generated by the winds during the storm break as they arrive at the shore and run up the beach. The maximum vertical distance above the water level to which the breaking wave will rise is called the "wave run-up." Thus the ultimate water level at a reach during a storm is the sum of the storm water level plus the wave run-up. The effects of wind and waves on the lake levels are shown schematically on Figure 12.

A number of other factors contribute to a damaging event such as the nature of shore materials, exposure to on-shore winds, off-shore and on-shore slopes, berms, and back-shore elevations and widths which affect the ability of the shore to absorb the energy which is transferred from the surface of the lake. The effects of these factors are continuous, although specific damaging events are often dramatized while the continuous process is overlooked. Ice on the Great Lakes has damaged the shore line. However, such damage has generally resulted from short-period, local conditions rather than from the overall lake regime. Since such conditions are unpredictable and localized in nature, ice damage has not been included in the evaluation of regulation plans.

The methodologies used to evaluate the effect of various regulation plans on Canadian and United States shorelines are different and are described separately in the following subsections. In both methods, the shoreline on each lake was divided into reaches, depending on the shoreline configuration and profile.

Assumptions and Methodology - United States Unprotected Shoreline: For the United States shoreline, the approach used to evaluate erosion and inundation is based on 1951-52 shore damage data utilizing ultimate water level as an index of damaging capacity. This index was determined by assigning an estimated total damage per month to the highest storm

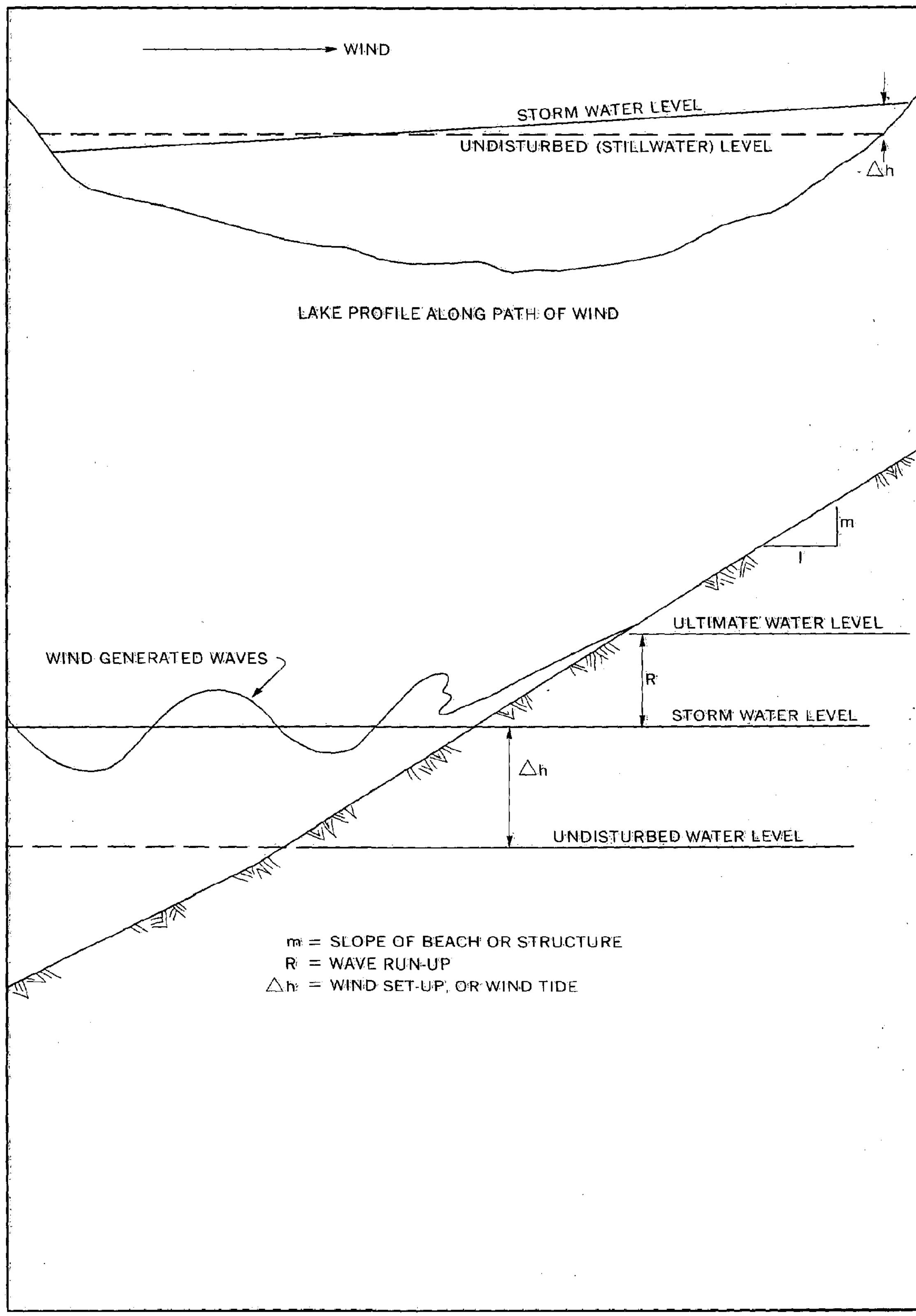

Figure 12
DIAGRAM OF STORM EFFECTS ON WATER LEVELS.

occurrence for that month from damage assessments compiled for the one-year period of May 1951 - April 1952. Development of a relationship between ultimate water levels and damages assumes that the elements of a damaging event, acting either independently or in combination, are capable of damaging shoreline real estate, regardless of the mean lake elevation.

A stage-damage curve for each individual reach was developed, using the 1951-52 damage data or a synthesized estimate thereof. Careful analyses of these data were required in order to exclude then-unprotected properties which sustained damages in 1952, but which are now fully protected and to update the shoreline development from 1952 to 1966 conditions. The profile on Figure 13 is typical of the shore in the study reach Sandusky to Cleveland, Ohio, with shoreline damage related to given elevations.

An ultimate water level damage curve was defined for each reach. A computer program was developed to provide a weighted dollar damage value on the basis of frequency of occurrence of the ultimate water level for each of the 12 months.

A complete survey of the United States shoreline of the Great Lakes and connecting rivers was made during 1966. Since the lake levels were near normal at that time, no significant damage was occurring and therefore no additional data with respect to erosion and inundation were collected.

Assumptions and Methodology - Canadian Unprotected Shoreline: A complete survey of the Canadian shoreline of the Great Lakes and connecting rivers was made during 1966-67. This survey included a detailed inventory of shore characteristics, land use, marine structures, long-term erosion rates and flood levels. Using the information derived from this survey, and making the assumption that erosion and damage are directly proportional to the wave energy reaching a particular shore area, a mathematical model was developed to provide an estimate of damage that would occur for all months, for all reaches, for any water level.

Assumptions and Methodology - Future Damages to Great Lakes Shoreline, Both Countries: The level of future damages to the Great Lakes shoreline is directly related to the economic use to which the shoreline is put. The estimated future utilization of Great Lakes shoreline was projected under the following land use categories: industrial, commercial, utilities, residential, public parks and beaches, fish and wildlife habitat, agricultural, forests and undeveloped.

To determine future erosion and inundation damages, the following procedure was adopted. Future land use was projected from the existing land base as found in the 1966 field surveys. Agricultural, undeveloped, and forestry uses of the shoreline can be expected to yield to urban-oriented residential, recreational and industrial uses, thereby

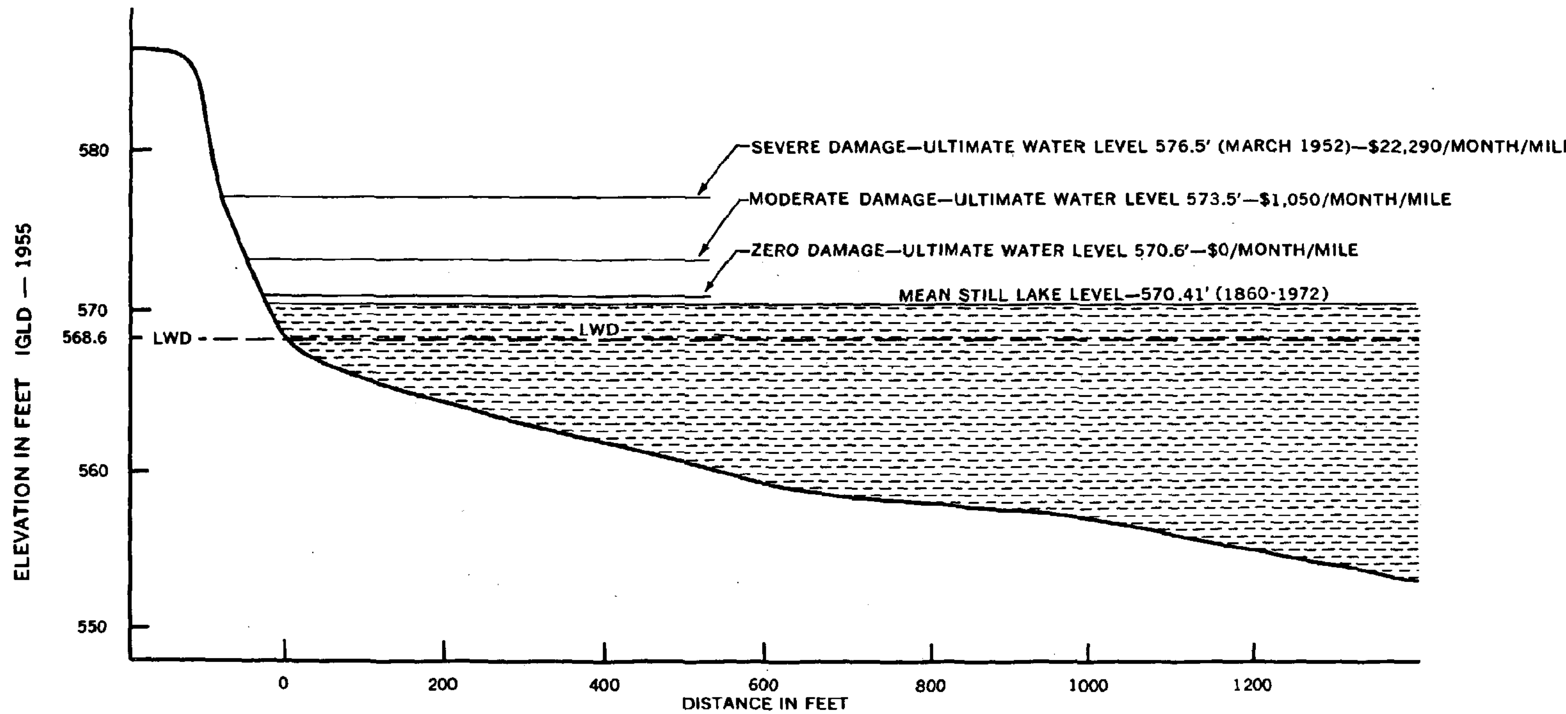

Figure 13
TYPICAL LAKE ERIE SHORELINE PROFILE - SANDUSKY TO CLEVELAND, OHIO

increasing the potential economic damages. A modifying factor is the assumption that as property becomes more valuable, it will be protected by structural measures. It is assumed that when the level of damage equals the cost of protective works, such works will be constructed.

After the future land use was estimated, the shoreline which would be susceptible to damages in each land use category, because of lack of natural or artificial protection, was determined. Each reach of the Great Lakes was analyzed in terms of the economic potential of the area in which it was located. The 1980, 2000 and 2020 total potential damage values were determined on the basis of the projected future land use, protected property and unit value of property. The economic values of shoreland units were projected to grow, participating fully in the economic growth (personal income, population and productivity) of the Great Lakes region. The unit value of property, while increasing in overall value, is represented by constant 1971 dollars.

Any future development on the Great Lakes shorelines should be controlled to some degree by land use planning and zoning. The net effect of zoning would result in the limitation of future damages to existing installations and to loss of land through erosion. It should be noted that land which is changing in use category would be the land base primarily affected by the future zoning restrictions. Residential land is projected to sustain 80 percent of total erosion and inundation damages. While the intensity of use of residential shoreline is expected to increase, it is estimated that only 30 percent more land will be devoted to residential uses by the year 2020. Finally, the dollar damages preventible by effective zoning would be those damages which might otherwise occur near the end of the project life; if the effectiveness of zoning is underestimated such damages are heavily discounted. The damages prevented by zoning are a trade-off to a large extent to protection works placed as property becomes more valuable and fully protected in the future from sustaining damages from erosion and inundation.

The resulting stream of future benefits or losses was discounted to present value at a rate of 7%. The sum of the present value of all the benefits (or losses) during the project life was then multiplied by a partial payment (or amortization) factor. The resulting figure is termed "average annual benefit (or loss)".

7.3.4 Shore Property - Marine Structures

General: The increase in recreational boating in recent years has been accompanied by a general transformation of smaller harbors from commercial to recreational use. Commercial shipping has, to a large extent, become confined to major harbors. Because smaller harbors have turned to the provision of recreational facilities as a means of economic growth, the facilities are rapidly improving and are drawing more people towards activities such as boating and fishing. New resorts are being built all the time and these, too, are drawing people to the recreation areas.

Marine structures are affected differently by high and low water levels. There are two effects of extreme low water:

(1) Increased frequency of exposure of normally submerged untreated timber substructures which accelerates decay and thus reduces the useful life of the structure. An example of this may be found in the piling of the grain elevators at Duluth - Superior Harbor on Lake Superior.

(2) Loss of use of structures due to reduced navigable depth, and hence, restricted access to them.

Extreme high water has the following effects:

(1) Loss of use of some smaller structures, due to inundation of their land approach, or structures unusable, and

(2) Possible physical damage to and even destruction of the structure.

The majority of marine structures are located in or near large urban areas. The major portion of the average annual damage sustained by marine structures is related directly to low water level conditions requiring greater amounts of dredging to be provided to recreational marinas.

While the evaluation of marine structures was intended to include all types of facilities, it was generally found from field surveys that commercial navigation facilities were adequately constructed or that the loss to navigation interests would be evaluated as described in Subsection 7.3.1. The only significant damage identified was related to dredging costs for recreational marina facilities.

Assumptions: The following assumptions were made in the evaluation of marine structures:

(1) Recreational marina facilities generally are designed for an average lake level for the boating season June through September.

(2) Regulation of Great Lakes water levels to raise the long-term mean level for the period June-September would tend to result in savings in the cost of: (a) the initial construction of future marina facilities, and (b) the first occasion for maintenance dredging after implementation of regulation for existing recreational marinas and small-boat harbors.

(3) Maintenance dredging at existing marinas will be carried out or credited at a uniform rate over the initial 10 years of the regulation plan.

Methodology: The evaluation procedure involved determining the difference in dredging costs under the new regulation plan and under the basis-of-comparison. The growth rate of future facilities was estimated based on population projections. A hypothetical standard "average size new marina" was used to estimate dredging costs for new construction. The difference in the first-occasion maintenance dredging costs for existing marinas was determined for the difference in harbor areas and depths due to changes in lake levels.

7.3.5 Shore Property - Water Intakes and Sewer Outfalls

General: The Great Lakes area is characterized by large concentrations of people, industry and fresh water. Many communities and industries near the shoreline have water intakes from and waste outfalls to the lakes or connecting rivers. These water intake and waste facilities were surveyed by U.S. and Canadian agencies to determine the effects on them of extreme variations in lake levels.

Information collected by both the Canadian and U.S. surveys indicates that the average range of fluctuations in the levels of the Great Lakes normally presents no serious problems to intake and outfall facilities, because most were designed for normal fluctuations of levels. However, when extreme levels are reached, such as during the high levels of the early 1950's and the low levels of the middle 1960's, significant problems are encountered by some municipalities and industries. It was found in the surveys that remedial work had been carried out at those facilities which had experienced problems.

The loss of available head due to lower lake levels reduces intake capacities, increases pumping costs and, in the extreme, causes cavitation. Shallow water decreases the quality of the intake water because of increased turbidity as a result of wave action transporting more bottom sediments. Shallow water also increases the risk of frazil ice problems at the water intakes. High lake levels may erode the foundation of a lake-side plant or inundate it. With the exception of increased pumping costs, it was not possible to quantify the effects of regulation on these problems.

Assumptions: The evaluation of the effect of a regulation plan on water intakes is based on the following assumptions:

(1) Future water quality at specific intake locations will be no worse than at present, and extreme low levels will not affect water treatment costs.

(2) Electrical power costs average 5 cents per million gallons per foot pumped and there would be no significant changes in pumping technology over the project life.

(3) Communities and industries will protect pumping and outfall facilities against flooding.

Methodology: The evaluation of water intakes compares pumping costs for the estimated quantity of municipal and industrial water withdrawals for basis-of-comparison and regulated lake level conditions. The total difference in pumping costs between the two conditions represents the benefit or loss attributable to the regulation plan. In the methodology, increase in water use was projected through the project life.

7.3.6 Shore Property - Recreation Beaches

General: The methodology used to evaluate the effects of further regulation of lake levels upon recreation beaches involved a comparison of the seasonal value of beaches under basis-of-comparison conditions and under regulated conditions. The determination of economic benefits and losses was based on an inventory and evaluation of 501 beaches (565 miles) in the United States and 135 beaches (75 miles) in Canada (see Table 10).

The figure of 135 for Canada represents the number of beaches sampled and evaluated. The basis of selection was whether or not use of the beach was affected by fluctuating levels. For example, in the case of beaches on the Canadian shoreline of Lake Superior, intensity of use is very low and fluctuating levels have no effect on their use.

Assumptions: The following assumptions were made in the evaluation of the beaches:

(1) The effects of a regulation plan on recreation beaches may be expressed as computed monetary gains or losses. Such gains or losses are considered to be a function of: (a) an addition or subtraction of total beach area due to regulation, (b) user-day values related to beach and water quality, and (c) intensity of beach use.

(2) The primary seasonal beach use extends from June 1 through September 30 and is distributed as follows: June - 15 percent; July - 40 percent; August - 40 percent; and September - 5 percent.

(3) Beach use on a weekday (workday) would amount to one-third of a beach's daily attendance potential, while beach use on Saturday, Sunday, or holiday (nonwork days) will amount to 100 percent of its daily attendance potential. For the entire recreation season, adverse weather results in a 20 percent reduction in total attendance potential.

(4) Maximum benefits for all beaches on a given lake are assumed to occur at the percent exceedence level at which the value of additional beach area exposed belowthis level is balanced by the drop in value caused by exposure of undesirable beach features.

Table 10

GREAT LAKES AND ST. LAWRENCE RIVER BEACHES EVALUATED

Lake	United States		Canada		Total	
	Number of Beaches Evaluated	Number of Miles	Number of Beaches Evaluated	Number of Miles	Number of Beaches Evaluated	Number of Miles
Superior	43	28.88	None	None	43	28.88
Michigan	223	383.18	None	None	223	383.18
Huron	79	92.55	14	17.56	93	110.11
Erie	138*	52.09*	46	20.61	184	72.70
Ontario	22	9.79	48	25.50	70	35.29
**St. Lawrence River	None	None	27***	11.00***	27	11.00
TOTALS	505	566.49	135	74.67	640	641.16

* Includes Lake St. Clair.
** Cornwall to Trois-Rivières.
*** Inventoried but not evaluated.

Methodology: Based on these assumptions, the evaluation of recreation beaches was computed in the following manner:

(1) (Beach length x beach width) = (beach carrying capacity). (categorized beach density).

(2) [(Beach carrying capacity) x (turnover rate) x (available workdays) x (workday capability utilization)] + [(beach carrying capacity) x (turnover rate) x (available nonwork days) x (nonwork day capability utilization)] = (potential seasonal attendance).

(3) (Potential seasonal attendance) x (average user-day value) x (basis-of-comparison water level duration in percent) = (basis-of-comparison weighted seasonal value) = (economic effects under existing conditions).

(4) (Potential seasonal attendance) x (average user-day value) x (regulated water level duration in percent) = (regulated weighted seasonal value) = (economic effects under regulated conditions).

(5) (Regulated weighted seasonal value) - (basis-of-comparison weighted seasonal value) = (benefit or loss due to regulation expressed in dollars on a weighted average annual basis for the project evaluation period). Values for the last year of the project life are also estimated and an average annual benefit or loss value determined utilizing a 7% discount rate.

7.3.7 Shore Property - Recreational Boating

In view of the large number of recreational boats on the Great Lakes, the Board investigated the extent to which boat usage might be affected by changes in lake regulation. The approach involved efforts to determine the number of days when owners might forego use of their boats because of changes in lake levels. Answers to a pilot questionnaire revealed minimal or no effect from the small changes in lake levels between a new regulation plan and the basis-of-comparison. Because of the very small effect of a new regulation plan on recreational boaters, the final economic evaluation does not include any dollar benefits or losses to recreational boating.

7.3.8 Generalized Loss Relationship

In order to facilitate the development and testing of regulation plans, the needs of the various interests (shore property, navigation and power) were expressed in the form of curves relating dollar loss versus stage or flow for a given month. These relationships, which vary from month to month, express the relative loss for each lake and every interest. They were derived from the detailed evaluation procedures developed for determining the economic effects of a change in water levels on a given interest.

Shore property interests loss relationship is a composite function combining primarily economic assessments of erosion and inundation and recreation beach values. The shore property generalized loss relationships do not include potential benefits from future shoreline developments and uses.

Deep draft navigation loss relationship is dependent upon the controlling depth relative to the various lake combination routes.

Hydroelectric power production is dependent upon outflow and hydraulic head.

The generalized loss relationships, when compared with the detailed evaluation method for shore property, navigation and power for a number of regulation plans examined, adequately reflected the detailed procedures.

7.4 Environmental Effects

The environment can be defined as the sum total of factors affecting the life and growth of an organism. Environment includes both physical and social surroundings. Human environment includes the factors of aesthetics, natural beauty and human sensitivity to quality of life.

Analysis of environmental effects of a considered action was accomplished in two basic steps. The first step was to identify the probable changes that would be induced by the considered action. The second step was to evaluate changes in terms of their beneficial or adverse effects. Due to the magnitude of the proposal, these evaluations have been of a preliminary nature only.

Putting into operation a new or changed plan of regulation will involve changes in the level and flow regime and may involve changes in existing regulatory works or possibly new works. Such changes have definitive effects on the environment which can be evaluated in four categories: ecological effects, hygienic effects, aesthetic effects and social well-being.

7.4.1 Ecological Effects

Ecology pertains to the relationship of one organism to another and to its environment, i.e., the basic structure of ecosystems. An attempt has been made to identify any change in the ecosystem structure and function that affects ecosystem integrity. Ecological changes are related to: hydrologic cycle, biogeochemical cycle, organic production, and organism diversity-stability relationships. Indicators used to measure change include: physical modification of land forms, physical modification of water courses or flow conditions, toxicants, pathogens, heat, surface materials, bio-stimulants, dissolved solids, suspended matter, and radio-active wastes. Parameters which relate to organisms themselves are also important. These include: growth rate, reproductive capability, and species composition. All these factors are important but the present study has been able to deal with them only on a superficial basis.

The Great Lakes comprise an extensive ecosystem with the following basic components: inorganic substances, organic compounds, climate regime, producer organisms, consumer organisms, and decomposer organisms. This ecosystem supports a great variety of fish and wildlife populations important to the human population of the region. An effort was made to quantify in monetary terms the effect of changing the level and flow regime. No reasonable basis was found for such an evaluation to the extent possible for other interests considered in the study. This is understandable because quantification of ecological effects resulting from man-made changes in the environment is still a developing science. Attaching a dollar value to the quantified results presents yet another problem, a problem which is very difficult, if not impossible, to solve for certain environmental values.

Consider, for example, the task of putting a dollar value on a pleasant view of an uninterrupted flowing river, on Niagara Falls or on a beautiful sunset. The methodology presented below does, however, provide for a measured analysis of the major effects of lake regulation, utilizing physical terms of comparison, and, for one regulation plan, an estimate of the effects, utilizing monetary terms to provide an example of the type of costs which can be expected when the environment is exploited. A continuing effort is being made to quantify the environmental effects for certain sensitive areas where information is available to define the cost of regulation plans. This is particularly true where fish and wildlife resources are involved and hunting and fishing are affected.

Fishery: To evaluate the effects of water level fluctuations on fish, the study was divided into three sections: the effects of varying lake levels on the sport fishery from shore structures and on the use of docks and wharves for commercial fishing operations; the effects of lake level regulation on the fish stocks; and the effects of regulation on the water levels in the connecting channels. Although this approach was chosen, it is now recognized as being inadequate. The analysis should have considered greater numbers of the physical, chemical, and biological changes that might be expected to occur with lake regulation, including the effects on the structure of aquatic communities, the effects on recreational resources in areas where fish and wildlife populations are affected, and the effects of present regulation which may be producing adverse effects that could be mitigated.

The amounts and dates of damages to commercial fishing from shore structures under basis-of-comparison conditions were obtained from field interviews, letters of inquiry, shoreline data sheets and the U.S. Army Corps of Engineers December 1965 Report, "Water Levels of the Great Lakes."

During the period of record, there have been continuing changes in the environment and in the fish populations in the Great Lakes. Many factors such as pollution and the introduction of different species of fish and the sea lamprey have caused catastrophic changes in the fish species complex. In evaluating the effects of lake level regulation on the fish stocks, two techniques were used. First, in an attempt to see if any correlation existed between lake levels and commercial fish production, irrespective of other factors, the water levels of the main basins were plotted against the recorded commercial catch of fish. This was done for each of the five lakes using both individual species and the combined total of all the species. These graphs were then used to compare water level to production. Secondly, the expertise of fishery biologists and administrators was polled by means of a letter of inquiry. This letter was an attempt to pull together all the existing information with regard to lake levels and fish stocks. A follow-up request was then sent to the academic community involved in Great Lakes fisheries research. The responses to these letters were then used to evaluate the potential effects on the fish stocks. Cause-effect ideas advanced in the letters were examined for their favorable, unfavorable, and neutral effects attributable to level fluctuations. In retrospect, it is apparent that other parameters besides levels should have been dealt with, including flow, velocity, current patterns, temperatures, and numerous other expected changes in the physical, chemical, and biological components of the system, particularly in the connecting channel areas.

In order to fully involve the management agencies responsible for fisheries in the Great Lakes, the five Lake Committees formed by the Great Lakes Fisheries Commission were requested to consider the impact of regulation of lake levels on the fishery. The Great Lakes Fishery Commission is an international body that coordinates the activities of fisheries expertise on the Great Lakes and their Lake Committees are composed of representatives from federal, state and provincial fishery management agencies. Input from the Lake Committees was used in the analysis.

An experiment performed in the St.Marys River Rapids in late July and early August 1971, provided on-site information as to the effects of the existing regulatory works at the outlet of Lake Superior on the aquatic environment of that area. To obtain adequate information as to the effects of various gate settings on the conditions of the upper St.Marys River, data on the following factors were collected at various gate settings: water quality; benthic organisms important to the local aquatic food chain; exposure of shoal areas; and the rate of flow through the structure. In addition, staff gages were set at various downstream locations to record changes in water levels.

A continuing effort is being made by the responsible federal, state and provincial agencies to assess the impacts on fisheries of all the regulation plans studied. Experiments carried out in the St.Marys River in July and August 1971 indicated that the aquatic environment may be improved by providing increased minimum flows. Special consideration is being given to evaluating the effects on fish populations due to the loss of marshland (which is expected for all the plans), the effects on outdoor recreation caused by damage to sport fisheries and wildlife habitat, and the effects of present regulation rules.

Wildlife: All of the shoreline and the abutting shoal waters of the Great Lakes provide an ecosystem supporting a wide variety of plant and animal organisms important to mankind's recreation, health and aesthetic well-being. Throughout this extensive fresh water shoreline are scattered pockets of extremely important habitat - the marshes, wetlands, swamps, and shallow bays and ponds often cut off from the main lakes by a bar or ridge. Aside from the aquatic habitat, there are innumerable and diverse types of terrestrial habitat, but these would not be directly affected by lake regulation.

There are three zones of aquatic habitat of value to wildlife - waters greater than 20 feet deep, shoal waters less than 20 feet, and the marshes and wetlands to the high-water mark of record. The latter two zones encompass the most valuable wildlife habitat on the Great Lakes and also will be most affected by any adopted regulation plan. It is considered that these types of habitat are best suited to measure the impact of lake regulation on wildlife. The study, therefore, was concerned primarily with determining the effect of altered lake levels on the shoal waters and shoreline marshes. It should be noted, however, that the whole lake plus its tributaries are essential to the maintenance of a complex and diverse aquatic ecosystem and that direct changes to the system caused by regulation plans may have effects on the whole system and not just in shoal waters or shoreline marshes.

The Great Lakes shoreline totals 11,240 miles of which 4,110 miles are offshore islands and 1,200 miles are connecting shoreline (Table 11). Of this total shoreline, 644 miles in the United States and 419 miles in Canada are considered extremely valuable for fish and aquatic-oriented wildlife. There is an equal amount of shoreline classified as undeveloped and recreational, supporting a wildlife environment of lesser value. The total acreage of marshland wildlife habitat considered in this study is given in Table 12.

There are five points to be considered in evaluating the effects of a regulation plan on the ecosystem:

1. Rapid short-term fluctuations of water levels in connecting channels should be minimal due to the adverse drying effect on wetlands and spawning areas caused by such fluctuations.

Table 11

MILES OF GREAT LAKES SHORELINE

Shoreline	In United States		In Canada	
	Mainland	Islands	Mainland	Islands
Lake Superior	863	382	866	615
St. Marys River	29	89	66	63
Lake Michigan	1,400	238	0	0
Lake Huron	580	257	1,270	1,720
St. Clair River	28	0	30	5
Lake St. Clair	59	84	71	43
Detroit River	30	39	30	33
Lake Erie	431	43	368	29
Niagara River	36	34	33	3
Lake Ontario	300	28	334	50
St. Lawrence River*	151	164	150	188
Totals (rounded)	3,910	1,360	3,220	2,750

*Above Moses-Saunders Powerhouses

Table 12

ACREAGE OF GREAT LAKES MARSHLAND WILDLIFE HABITAT

	Maximum Elevation Evaluated	Total Acreage at Maximum Elevation Evaluated		Acreage Inundated per Foot Lake Level	
	(feet IGLD)	U. S.	Canada	U. S.	Canada
Superior	603	20,400	Nil	4,080	Nil
Michigan	582	32,600	-	4,660	-
Huron	582	49,400	68,600	7,060	9,800
Erie	574	34,700	55,700	5,000	7,960
Ontario	248	18,400	8,400	2,630	1,200
TOTAL		155,500	132,700		

2. Avoidance within any given year of providing water levels less than the mean basis-of-comparison levels during the spawning months of April through June and August through October.

3. Adequate flows through the St.Marys River should be maintained at the control structure in order to provide sufficient water in the rapids, marshes, and shallow water zones so as to inundate them properly at each location.

4. Seasonally fluctuating water levels comparable to those of the historic record, should be maintained for the benefit of aquatic wildlife.

5. The extreme high stages should be lowered and extreme low stages raised for Lakes Ontario, Erie and St. Clair, the amounts should approximate one foot in each case. For Lakes Huron, Michigan and Superior, lesser amounts would be acceptable.

The methodology considers two known factors: (1) maximum acreage of wildlife lands in each lake and connecting channels affected by this study; and (2) the percent of time these lands are inundated over the study period 1900-1967 at each level of operating range.

The potential marshland acreage affected under basis-of-comparison conditions and any regulation plan is computed as follows:

$$T_1 = A\ E$$

where:

A = acreage inundated per foot of lake level
E = percent of exceedence of the given lake level
T_1 = acreage attributable to a plan at a given elevation

For example, on Lake Superior, A is taken to be 4,080 and E is 0.023 at elevation 602 so that the affected acreage at that elevation is 4,080 x 0.023 = 93.8. By considering all incremental elevations, an overall acreage affected, T_x is obtained.

$$T_x = T_1 + T_2 + \dots\dots\dots$$

Comparison of the two marshland acreages available is then a measure of the benefit or loss attributable to any plan.

7.4.2 Hygienic Effects

Hygienic effects pertain to toxic, infectious, irritating agents or other agents of disease which may have an impact upon the public health and welfare. Hygienic effects may be a direct result of the alteration of physical or biochemical factors, such as direct toxicity of certain chemicals, or the indirect result of ecological impacts, such as the uptake and biomagnification of these elements in the food chain. In this study, especially critical are hygienic effects or those related to the utility of the water resource of the Great Lakes for municipal, domestic and recreational purposes. Both direct and indirect effects upon the health of man are considered. Direct effects to be considered were those in which the public might ingest or otherwise come in contact with water-borne toxic, irritating or other disease agents. Indirect effects to be considered were the impact of changing water levels on existing water intake and sewage treatment structures. Indicators for measuring change were to include: (1) pathogens, (2) toxicants, (3) disease vectors, and (4) radioactive substances. Only the impact of changing water levels on existing water intakes and sewer outfall structures was fully addressed in the study. Other hygienic considerations were considered in lesser detail.

7.4.3 Aesthetic Effects

Aesthetic effects are defined in terms of man's sensory perception of the environment to include visual, olfactory, auditory, taste and preferential considerations. Assessment of aesthetic values and effects require planners' judgments to a large degree. Such judgments are inherently destined for some disagreement. Consequently, assessment of aesthetic effects in this study was to concentrate on those changes that are clearly study-related and would predictably produce a reaction from a significant portion of the populace. Indicators for measuring changing in aesthetic conditions included: (1) appearance of the aquatic environment, such as color, clarity and movement of water, as well as its surface characteristics (i.e., is the surface clean or is there debris, scum, foam or froth); (2) appearance of the terrestrial environment and associated vegetation characteristics, and the topography; (3) perceptible changes in noxious substances, such as hydrogen sulfide, methane, or changes due to organic decay induced by pollutant alterations; (4) presence of nuisance organisms, such as algae, uprooted aquatic plants, insects, rodents, and rough fish; (5) taste in water or in organisms or commercial fish and wildlife; (6) consonance of any proposed structural works with the existing environment; and (7) bottom characteristics such as clean sand, shiny or attractive stones. In general, aesthetic effects resulting from lake regulation are measured by probable perceptible changes in any environmental feature to which society has attached some intrinsic, and often tangible value. Only preliminary assessments have been made of the aesthetic impacts of the regulation plans. Assessments for specific sensitive areas have not been made.

7.4.4 Social Well-Being

Social well-being is defined in terms of the general well-being of individuals and the viability of communities in which they reside. The assessment and evaluation of impacts on social well-being are hindered by the inability to quantitatively assess the values of many, if not most, human experiences and needs. Physical changes such as displacement of individuals or groups of individuals, are obvious. But many of the emotional, intangible impacts that result from change, are not so obvious. A prime sociological concern is to preserve existing intra and inter-community relationships that are essential to community viability and integrity. Indicators used to measure change in social well-being are: (1) the conveniences to communities and individuals, such as recreational and employment opportunities, (2) disruption of life styles, such as relocation of individuals, land use changes, and nuisance effects, and (3) general security of life and health. Assessment of effects on social well-being required full use of information generated in the assessment of ecological, hygienic, aesthetic, and economic effects. Economic effects are related to social well-being in many areas including the loss of desirable fish and wildlife communities which are important to recreational resources and have economic value.

7.5 Effects of Alternative Bases-of-Comparison

As mentioned in Subsection 5.5, the bases-of-comparison adopted for evaluating plans for all lake combinations except Superior-Ontario and Superior-Erie-Ontario included the 1933 outlet conditions for Lake Huron. For SO and SEO plans (except for SEO-33), the 1962 outlet conditions for Lake Huron were applied.

This raised the question of the economic difference between these alternative bases-of-comparison. Hydrologically, 1962 conditions result in Lakes Michigan-Huron levels 0.59 foot lower than those produced by the 1933 conditions. All hydrographs and stage duration curves for Lakes Michigan-Huron are lowered by this amount. No effect is registered on the other lakes. Economically the effects are also confined to Lakes Michigan-Huron representing an average annual value of $10.7 million, as shown on Table 13. This table also shows that the major monetary effect is in respect of shore property interests. This is a reflection of the fact that, during the 4-decade period following 1933, shoreline developments have gradually adjusted themselves downward to the lower regime of water levels. Any restoration of the 1933 Lake Huron outlet conditions, by compensatory works such as underwater sills or a structure in the St. Clair-Detroit Rivers, would thus raise the levels regime back by about 7 inches and encroach upon these riparian developments. This example also provides a good illustration of the merits of the need for strict land use zoning and structural setback requirements. If shoreline development on any lake continues to be allowed to freely follow changing water level regimes, such as improved stages produced by a new regulation plan, the benefits to shore property interests will be dissipated and their problems of today will simply continue at the new lower

Table 13

AVERAGE ANNUAL ECONOMIC EFFECTS OF CHANGED LAKE HURON OUTLET CONDITIONS FROM 1933 TO 1962

($1,000)

	U.S.	Canada	Total
Erosion & Inundation	6,379	209	6,588
Marine Structures	- 68	- 2	- 70
Recreation Beaches	4,980	632	5,612
Water Intakes	- 121	- 2	- 123
Total Shore Property	11,170	837	12,007
Navigation	- 1,102	- 238	- 1,340
Power	0	0	0
TOTALS	10,068	599	10,667

elevations. So far as navigation is concerned, the effect of the difference between the two bases-of-comparison is minor in relation to the shore property effect. This is because, even with Michigan-Huron levels lowered 0.59 foot the percentage of time when channel and harbor depths on this lake and its connecting rivers control through-navigation is not significantly greater than under 1933 conditions. There is no effect on power evaluations since flows are unchanged. Environmentally, the effect of the 0.59 foot on fishery and wildlife was transitory; their habitat adjusted to the changed regime during the period 1930's to the 1960's.

Section 8

DEVELOPMENT AND EVALUATION OF LAKES SUPERIOR-ONTARIO PLANS

8.1 General

In the development and evaluation of improved plans for the regulation of Lakes Superior and Ontario, the Board first addressed non-structural plans based upon manipulation of outflows to balance the levels of Lakes Superior and Michigan-Huron, using the best available statistical procedures. This would be done without any major construction to change the regulatory works at the outlets of Lakes Superior and Ontario. The Board also addressed structural plans for further regulation of these two lakes. Such plans were based upon such concepts as increasing the storage and discharge capacities of Lakes Superior and Ontario. Subsections 8.2 through 8.5 cover the non-structural plans, while Subsection 8.6 addresses structural plans.

In accordance with the Commission's Orders of Approval of May 26 and 27, 1914, the present regulation plan for Lake Superior is designed for the benefit of the power, navigation and shore property interests on Lake Superior and its outlet river. The investigation of the further regulation of Lake Superior in the overall public interest led directly to consideration of a basic policy change under which Lake Superior would be regulated for the benefit of interests not only on Lake Superior but also on the lower lakes. This section describes the process of development and evaluation of a new plan for Lake Superior reflecting such a policy change. The plan is based upon the operating principle of balancing the amount of water stored on Lake Superior and Lakes Michigan-Huron.

The original intent was to design a plan involving improved regulation of Lakes Superior and Ontario. It was found, however, that the present regulation plan 1958-D was the most effective Lake Ontario element in such a coordinated two-lake plan. Thus the new plan, although designated SO, is essentially only a new Lake Superior plan. The selected plan, SO-901, was presented in an interim report to the International Joint Commission as referenced in Section 1.6 and as further detailed in this section.

Since the new plan was developed, there has been a period of extremely high supplies to Lake Ontario, in excess of those recorded during 1960-1967, the period used in the study. Accordingly, the International St.Lawrence River Board of Control has subsequently initiated a review of Plan 1958-D to determine whether modifications to improve its effectiveness are feasible and desirable.

8.2 Trial Plans

As noted previously, the Board sought a plan which would distribute long-term benefits within the system to the overall advantage of the Great Lakes region without incurring detrimental effects to any individual lake or major interest. To implement this approach and to assist in the selection of objectives for a coordinated regulation plan, various physical and economic constraints were considered and combined into sets of objectives, for which plans were developed, as follows:*

(a) Maximum economic benefits for the system - Plan SO-702;

(b) Maximum economic benefits for the system with approximate satisfaction of all existing Lake Superior and Lake Ontario criteria - Plan SO-703;

(c) Maximum economic benefits for the system with satisfaction of the present Lake Superior and Lake Ontario stage criteria - Plan SO-602;

(d) No economic loss to any major interest in the system, (navigation, shore property, power) - Plan SO-704;

**(e) No economic loss to shore property interests on any lake; approximate satisfaction of existing Lake Superior and Lake Ontario criteria; power losses within the system held to a minimum; winter maximum Lake Superior outflow 85,000 cfs (December - April); and no winter gate movements - Plan SO-801;

**(f) No economic loss to shore property interests on any lake; approximate satisfaction of existing Lakes Superior and Ontario criteria; power losses within the system held to a minimum; winter maximum Lake Superior outflow 85,000 cfs, with winter gate movements permitted - Plan SO-802; and

**(g) No economic loss to shore property interests on any lake; approximate satisfaction of existing Lakes Superior and Ontario criteria; power losses within the system held to a minimum; winter maximum Lake Superior outflow 95,000 cfs, with winter gate movements permitted - Plan SO-803.

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* The numerical designations given to regulation plans developed in this study were purely for technical identification purposes and have no quantitative or other significance.

** These plans employ Plan 1958-D for the regulation of Lake Ontario.

Table 14 shows the range of stage and economic benefits and losses resulting from the evaluation of these trial plans over the study period. The values from Table 14 were used only to provide a means of comparing the effects of trial plans developed for the various objectives. Shown also in this table are the basis-of-comparison data for each lake.

The Board, after reviewing the results shown on Table 14 noted that plan SO-802, on the basis of the historic sequence of supplies, would give the maximum overall relative benefit without appreciable net loss to any major interest or to any of the lakes. After a detailed review of this plan, the Board concluded that a coordinated regulation plan for Lakes Superior and Ontario could be developed to satisfy the existing International Joint Commission criteria for these lakes and to provide small benefits to the users of the system without resulting in any appreciable loss to any major interest on any lake or on the St.Lawrence River. The Board further concluded that this could be accomplished without requiring major capital expenditure on regulatory works or channel improvements in either the St.Marys or St.Lawrence Rivers.

The Board recommended and the Commission concurred that coordinated regulation of Lakes Superior and Ontario should meet the following objectives with respect to the 50-year project life:

(1) No economic loss to any major interest (shore property, navigation, power) on any lake or its outflow river;

(2) Satisfaction of existing Lake Superior and Lake Ontario regulation criteria.

The Commission discussed the preliminary results with the Board, accepted the objectives on March 12, 1971, and asked the Board to develop an operational regulation plan which would meet them. The Commission further stated that the plan developed should minimize losses, whenever possible, within any major area of interest.

Accordingly, a new regulation plan for Lake Superior, SO-901, has been developed, in combination with Plan 1958-D to meet the foregoing objectives. This plan, a refined and improved operational version of trial plan SO-802, provides slightly increased benefits while decreasing the minor losses provided by SO-802. In the course of its development, a number of modifications to Lake Ontario regulation were investigated, but it was found that Plan 1958-D, without modification, best met the objectives in combination with SO-901. A description of Plan 1958-D is given in Annex D. The description and basic rule curves for the new Lake Superior part of Plan SO-901 are given in Annex E.

Table 14

REGULATION OF LAKES SUPERIOR AND ONTARIO
SUMMARY OF RANGES OF STAGE AND ECONOMIC EVALUATIONS OF TRIAL PLANS

Lake Levels (feet)

	Basis-of-Comparison	a SO-702	b SO-703	c SO-602	d SO-704	e SO-801	f SO-802	g SO-803
Lake Superior								
Mean	600.38	600.69	600.58	600.40	600.69	600.33	600.38	600.38
Max.	601.91	602.73	602.28	602.04	602.73	602.06	601.99	602.06
Min.	598.36	598.71	598.67	598.22	598.71	598.60	598.58	598.57
Range	3.55	4.02	3.61	3.82	4.02	3.46	3.41	3.49
Lakes Michigan-Huron*								
Mean	577.95	577.95	577.95	577.96	577.95	577.95	577.94	577.94
Max.	580.91	580.48	580.55	580.64	580.48	580.78	580.79	580.81
Min.	575.15	575.36	575.31	575.29	575.36	575.30	575.36	575.36
Range	5.76	5.12	5.24	5.35	5.12	5.48	5.43	5.45
Lake Erie								
Mean	570.60	570.60	570.60	570.61	570.60	570.60	570.60	570.60
Max.	573.01	572.90	572.94	572.92	572.90	573.06	573.00	573.01
Min.	567.95	568.16	568.13	568.15	568.16	568.09	568.06	568.05
Range	5.06	4.74	4.81	4.77	4.74	4.97	4.94	4.96
Lake Ontario								
Mean	244.53	243.76	243.77	243.72	244.33	244.56	244.57	244.55
Max.	246.95	246.99	247.01	246.64	247.38	246.91	246.90	246.90
Min.	241.31	241.27	241.27	241.51	242.14	241.30	241.48	241.49
Range	5.64	5.72	5.74	5.13	5.24	5.61	5.42	5.41

Approximate Annual Benefits ($ Millions)

	Basis-of-Comparison	a SO-702	b SO-703	c SO-602	d SO-704	e SO-801	f SO-802	g SO-803
Power	0.0	-0.5	-0.6	-1.2	0.0	0.0	0.0	0.0
Navigation	0.0	+1.7	+1.2	+0.5	+1.8	+0.2	+0.6	+0.5
Shore Property	0.0	+2.6	+2.9	+2.9	+0.7	+0.6	+0.7	+0.7
Total	0.0	+3.8	+3.5	+2.2	+2.5	+0.8	+1.3	+1.2

Geographical Breakdown of Shore Property Benefits ($ Millions)

	Basis-of-Comparison	a SO-702	b SO-703	c SO-602	d SO-704	e SO-801	f SO-802	g SO-803
Superior	0.0	-2.2	-1.4	-1.4	-2.2	-0.2	-0.2	-0.2
Michigan-Huron	0.0	+2.0	+1.5	+1.2	+2.0	+0.8	+0.9	+0.9
Erie	0.0	+0.2	+0.2	+0.2	+0.2	+0.1	+0.1	+0.1
Ontario	0.0	+2.6	+2.6	+2.9	+0.7	-0.1	-0.1	-0.1
Total	0.0	+2.6	+2.9	+2.9	+0.7	+0.6	+0.7	+0.7

* 1962 outlet conditions

8.3 Selected Plan

The current Lake Superior regulation plan provides for setting the gates of the control works based upon Lake Superior's mean water level during the previous month. The fundamental principle of Plan SO-901 is to manipulate the St.Marys River flows in such a way as to keep the levels of Lakes Superior and Michigan-Huron at relatively the same position with respect to their mean levels (i.e., the same number of standard deviations from their respective means). This would tend to reduce extreme levels on both lakes because the lake which would be in a less extreme situation would be used to relieve conditions on the other. Under this principle nearly half of the net total supply to Lakes Michigan-Huron would be regulated on the basis of the levels of these lakes and Lake Superior.

Plan SO-901 maintains the same minimum outflow as the present Lake Superior regulation plan, the 1955 Modified Rule of 1949, in the winter months. In the summer months, Plan SO-901 maintains a slightly lower minimum outflow than the present regulation plan. Under both SO-901 and the 1955 Modified Rule of 1949 approximately 3,000 cfs are discharged over the St.Marys Rapids, when the total Lake Superior discharge is less than 65,000 cfs. After satisfying water requirements for the navigation locks, the remaining flow is divided between the power interests.

The hydrologic, economic and environmental effects of Plan SO-901 were analyzed in detail. The results are shown in the following subsections. The effects on navigation, power and shore property, the latter consisting of erosion and inundation, marine structures, water intakes and sewer outfalls, recreational boating and recreation beaches, were evaluated in terms of both hydrologic changes and dollar benefits or losses. The fish and wildlife interests were evaluated primarily in qualitative terms.

8.3.1 Hydrologic Effects

This subsection discusses the hydrologic evaluation of Plan SO-901 with respect to the major interests and the criteria and objectives for regulation. Tables and figures showing the water levels and outflows which result from the application of the Plan to the 1900-67 study period, and upon which these discussions are based, are given in Appendix B. Table 15 gives a summary of ranges of stage and flow on each of the lakes.

Major Interests: Plan SO-901 raises the water levels on Lake Superior; because these levels frequently control ship drafts in inter-lake movement, a benefit to navigation could be expected.

Table 15

REGULATION OF LAKES SUPERIOR AND ONTARIO
SUMMARY OF RANGES OF STAGE IN FEET
AND OUTFLOW IN THOUSANDS OF CUBIC FEET PER SECOND

	Basis-of-Comparison		SO-901	
	Stage	Outflow	Stage	Outflow
Lake Superior				
Mean	600.38	77	600.41	77
Maximum	601.91	123	602.00	123
Minimum	598.36	55	598.81	55
Range	3.55	68	3.19	68
Lakes Michigan-Huron*				
Mean	577.95	183	577.96	183
Maximum	580.91	233	580.64	227
Minimum	575.15	107	575.46	113
Range	5.76	126	5.18	114
Lake St. Clair				
Mean	573.33	187	573.35	187
Maximum	575.91	240	575.85	235
Minimum	570.45	114	570.48	119
Range	5.46	126	5.37	116
Lake Erie				
Mean	570.60	204	570.61	204
Maximum	573.01	258	573.04	259
Minimum	567.95	149	568.14	152
Range	5.06	109	4.90	107
Lake Ontario				
Mean	244.53	238	244.55	238
Maximum	246.95	310	246.92	310
Minimum	241.31	176	241.53	188
Range	5.64	134	5.39	122

* 1962 outlet conditions

The slight raising of the mean level of all lakes and improvement of winter outflows can also be expected to provide an overall benefit to the power interest.

A regulation plan will show a benefit for erosion and inundation if the plan reduces the frequency of high levels during the spring and fall months, when major damaging storms normally occur. The frequency of very high mean monthly elevations on Lake Superior in these months is reduced under Plan SO-901, but the frequency of above-the-mean levels is increased. On Lakes Michigan-Huron and Erie, regulated conditions result in a much lower frequency of occurrence of high levels. On Lake Ontario the frequency of levels above the mean is changed very little. These results would lead one to expect a loss from erosion and inundation on Lake Superior due to Plan SO-901 and benefits on Lakes Michigan-Huron and Erie with little difference on Lake Ontario. With respect to recreation beaches, the plan reduces the frequency of higher levels during the summer months on all lakes except Lake Superior. By thus exposing greater areas of beach, a benefit can be expected on these lakes.

Hydrologic Criteria: The existing IJC Orders of Approval for Lake Ontario contain a set of criteria to be met by regulation. To facilitate the hydrologic evaluation of the effects of Lake Superior regulation on the upper lakes, the Board prepared a similar set of criteria reflecting the requirements of the existing IJC Orders of Approval for Lake Superior and the objective adopted in this study. In the following presentation of the hydrologic evaluation of effects on the upper lakes, criteria (a) and (b) express the requirements of the Lake Superior Orders of Approval and the other criteria relate to the objectives adopted by the Board. In the hydrologic evaluation of effects on Lake Ontario all criteria are from the IJC Orders of Approval.

Lake Superior: Plan SO-901 has been designed to satisfy the general requirements contained in the IJC Orders of Approval of May 26 and 27, 1914, without incurring a net detrimental effect to any major interest on any lake. The following paragraphs evaluate the degree to which the plan meets these requirements and criteria on Lake Superior. All elevations in the Orders of Approval have been converted to IGLD (1955).

Criterion (a). The Commission's Orders require that the control works shall be so operated as to maintain the level of Lake Superior as nearly as may be between levels 600.5 and 602.0 feet, and in such manner as not to interfere with navigation.

The maximum monthly mean level of Lake Superior under Plan SO-901 is 602.0 feet, as against 601.9 feet under the basis-of-comparison, thus satisfying the criterion. It is also important to note that Plan SO-901 only slightly increases the frequency of occurrence of levels above 601.5 feet.

The minimum monthly mean level of Lake Superior, under Plan SO-901, is 598.81 feet as against 598.36 feet under the basis-of-comparison. During the navigation season, comparable levels are 598.82 feet and 598.36 feet. Neither Plan SO-901 nor the current operating plan satisfies the minimum level portion of this criterion. However, it should be noted that Plan SO-901 raises the minimum level by approximately 0.4 foot and reduces the frequency of occurrence of low levels.

Criterion (b). The Commission's Orders specify that, to guard against unduly high stages of water in the lower St.Marys River, the excess discharge at any time over and above that which would have occurred at a like stage of Lake Superior prior to 1887, shall be restricted so that the elevation of the water surface immediately below the locks shall not be greater than 582.9 feet.

In the test of SO-901, the maximum stage at the U.S. Slip gage, located below the locks, was at elevation 582.1 feet. The criterion is therefore satisfied.

Criterion (c). The maximum May through November outflow from Lake Superior shall not exceed 65,000 cfs, plus the flow through 16 gates of the Compensating Works.

The plan employs this outflow limitation and therefore this criterion is satisfied.

Criterion (d). The maximum winter outflow (December through April) from Lake Superior shall not be greater than 85,000 cfs.

Plan SO-901 exceeded the criterion on only one occasion, reaching a winter maximum outflow of 86,000 cfs. It is considered that the criterion has been satisfied. Under the basis-of-comparison, the maximum outflow was 83,000 cfs.

Criterion (e). The minimum outflow from Lake Superior shall not be less than 55,000 cfs.

The minimum outflow under Plan SO-901 was limited to the rate specified and thus the criterion is satisfied. Under the basis-of-comparison the minimum outflow during the months May through November was limited to 58,000 cfs while during the period December through April it was 55,000 cfs. It should be noted also that the frequency of occurrence of flows less than 65,000 cfs would be increased by Plan SO-901 from 186 occurrences for the basis-of-comparison to 259 occurrences.

One of the provisions of the 1914 Orders of Approval is that:

> "At all times said Board shall determine the amount of water available for power purposes. Said Board will cause the amount of water so used to be reduced whenever in its opinion such reductions are necessary in order to prevent unduly low stages of water in Lake Superior, and will fix the amounts of such reductions; provided, that whenever the monthly mean level of the lake is less than 600.5 feet above said mean tide, the total discharge permitted shall be no greater than that which it would have been at the prevailing stage and under the discharge condition which obtained prior to 1887; provided further, before any flow of primary water on either side of the river is reduced, the use of all secondary water shall be discontinued."

This provision could not be evaluated because it depends upon discretionary action that might be taken by the International Lake Superior Board of Control. To the extent that the provision dictates action based solely on the level of Lake Superior, it will have to be amended if the decision is made to base the outflow of Lake Superior on the levels of both Lake Superior and Lakes Michigan-Huron.

Lakes Michigan-Huron: The following paragraphs give the evaluation of the effects of Plan SO-901 on Lakes Michigan-Huron.

Criterion (f). Consistent with other requirements, reduce the frequency of occurrence of high Lakes Michigan-Huron levels.

Plan SO-901 reduces the frequency of occurrence of high levels above elevation 579.0 feet from 160 to 140 occurrences, as well as reducing the maximum level to 580.6 feet from 580.9 feet under the basis-of-comparison, thus satisfying the criterion.

Criterion (g). Consistent with other requirements, reduce the frequency of occurrence of low Lakes Michigan-Huron levels, especially during the navigation season (April-November).

Plan SO-901 reduces the frequency of occurrence of levels below low water datum (576.8 feet) from 131 to 108, as well as increasing the minimum levels by about 0.3 foot. The frequency of occurrence of low levels during the navigation season has been reduced from 75 to 55 occurrences and the minimum level has been raised by 0.3 foot. Thus the criterion would be satisfied.

Lake Erie: The following paragraphs give the evaluation of effects of Plan SO-901 on Lake Erie.

Criterion (h). Consistent with other requirements, reduce the frequency of occurrence of high Lake Erie levels.

Plan SO-901 reduces the frequency of occurrence of levels above elevation 572.0 feet from 60 to 52 occurrences. The maximum level of 573.0 feet would be unchanged from that which would occur under the basis-of-comparison. This criterion is satisfied.

Criterion (i). Consistent with other requirements, reduce the frequency of occurrence of low Lake Erie levels, especially during the navigation season, from 4 to 2 occurrences.

Plan SO-901 reduces the frequency of occurrence of levels below low water datum (568.6 feet), as well as raising the minimum levels by about 0.2 foot, thus satisfying the criterion.

Lake Ontario: The criteria and supplementary requirements stated hereunder have been taken from the 1963 Report entitled, "Regulation of Lake Ontario Plan 1958-D" by the International St. Lawrence River Board of Control to the International Joint Commission. These criteria, and the tests of regulation plans by that Board, relate to the period 1860-1954. For evaluation purposes in this study, as noted in Subsections 5.2 and 5.5, the study period is 1900-1967 and the basis-of-comparison includes the current operating plan (1958-D), as designed for the period 1900-1960 and as operated thereafter. In the following paragraphs, each criterion and supplementary requirement of regulation is stated, together with a discussion showing the degree to which Plan SO-901 fulfills these requirements with respect to the basis-of-comparison. Plan 1958-D would have fulfilled the requirements to an acceptable degree over its 1860-1954 test period and in actual operation through 1967. Therefore, comparison with this plan over the shorter period will provide a measure of the expected performance of Plan SO-901 over the longer period.

Criterion (a). The regulated outflow from Lake Ontario from April 1 to December 15 shall be such as not to reduce the minimum level of Montreal Harbour below that which would have occurred in the past with the supplies to Lake Ontario since 1860* adjusted to a condition assuming a continuous diversion** out of the Great Lakes basin of 3,100 cfs at Chicago and a continuous diversion into the Great Lakes basin of 5,000 cfs from the Albany River basin (hereinafter called the "supplies of the past as adjusted").

The minimum Lake St.Louis outflow under Plan SO-901 is 211,000 cfs as compared to 208,000 cfs under basis-of-comparison. The Montreal Harbour minimum level criterion would be satisfied. Further the frequency of low outflows from Lake St.Louis under Plan SO-901 would be reduced, which means that the frequency of low levels in Montreal Harbour would also be reduced.

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* As stated in the IJC Orders of Approval. The period used in this study begins January 1900.

** See Subsection 5.5 for assumed conditions adopted for this study.

Criterion (b). The regulated winter outflows from Lake Ontario from December 15 to March 31 shall be as large as feasible and shall be maintained so that the difficulties of winter operation are minimized.

Plan SO-901 and the basis-of-comparison have approximately the same average winter outflows from Lake Ontario. However, Plan SO-901 provides increased minimum outflows in each of the winter months, thus satisfying the criterion to a greater extent than Plan 1958-D

Criterion (c). The regulated outflow from Lake Ontario during the annual spring break-up in Montreal Harbour and in the river downstream shall not be greater than would have occurred assuming supplies of the past as adjusted.

The maximum basis-of-comparison Lake Ontario outflow for March of 280,000 cfs has been reduced by 1,000 cfs by Plan SO-901. Also, in the first half of April, the maximum outflow of 295,000 cfs would be reduced by 4,000 cfs, thus satisfying the criterion.

Criterion (d). The regulated outflow from Lake Ontario during the annual flood discharge from the Ottawa River shall not be greater than would have occurred assuming supplies of the past as adjusted.

Lake St.Louis levels and outflows are dependent on the combined effects of the St.Lawrence and Ottawa Rivers and are thus an indicator of the flood potential in the Canadian reach of the St. Lawrence. There is very little difference between Lake St. Louis levels and flows under the basis-of-comparison and under Plan SO-901 during the annual flood discharge from the Ottawa River. Thus, the criterion would be satisfied.

Criterion (e). Consistent with other requirements, the minimum regulated outflows from Lake Ontario shall be such as to secure the maximum dependable flow for power.

Under Plan SO-901, the absolute minimum monthly mean outflow would be increased to 188,000 cfs from 176,000 cfs under the basis-of-comparison; the average of the minimums for all months of the year would be increased by 12,000 cfs; and the average of the minimums for the months October through March would be increased about 16,000 cfs. Criterion (e) would be satisfied.

Criterion (f). Consistent with other requirements, the maximum regulated outflow from Lake Ontario shall be maintained as low as possible to reduce channel excavation to a minimum.

Comparison of the envelopes of levels and flows for Plan SO-901 and Plan 12-A-9, the latter being the regulation plan specified in the Supplementary Order of Approval, dated 2 July, 1956, shows that this criterion would be met.

Criterion (g). Consistent with other requirements, the levels of Lake Ontario shall be regulated for the benefit of property owners on the shores of Lake Ontario in the United States and Canada so as to reduce the extremes of stage which have been experienced.

Plan SO-901 lowers the maximum level by 0.03 foot, raises the minimum level by 0.22 foot, and reduces the range of stage from 5.64 feet to 5.39 feet, thus satisfying the criterion.

Criterion (h). The regulated monthly mean level of Lake Ontario shall not exceed elevation 246.77 with the supplies of the past as adjusted.

Neither the basis-of-comparison nor Plan SO-901 meets this criterion. The maximum regulated monthly mean level of Lake Ontario under Plan SO-901 is 246.92; under the basis-of-comparison it is 246.95. Elevation 246.77 was exceeded 3 times during the study period under Plan SO-901, the same exceedence frequency as the basis-of-comparison.

Criterion (i). Under regulation, the frequency of occurrences of monthly mean elevations of approximately 245.77 and higher on Lake Ontario shall be less than would have occurred in the past with the supplies of the past as adjusted and with present channel conditions in the Galop Rapids Section of the St. Lawrence.

Under Plan SO-901, a monthly mean elevation of 245.77 was exceeded 79 times or about 10 percent of the time as compared to 80 times under the basis-of-comparison. Thus the criterion would be satisfied.

Criterion (j). The regulated level of Lake Ontario on April 1 shall not be lower than elevation 242.77. The regulated mean level of the lake from April 1 to November 30 shall be maintained at or above elevation 242.77.

The minimum April 1 level, 241.84, under the Plan SO-901 occurred in 1965. The comparable value under the basis-of-comparison would be 242.08 on April 1, 1965. The criterion is thus not satisfied. As noted previously, the levels for Lake Ontario under the basis-of-comparison were obtained by operation of Plan 1958-D as designed through 1960, and as operated thereafter. During the drought of the mid-sixties, Criterion (k) was employed and deviations from the plan occurred. These deviations were not employed in computing the levels under Plan SO-901. Application of Criterion (k) to Plan SO-901 would result in satisfaction of Criterion (j) to at least the same degree as resulted under the basis-of-comparison.

The minimum monthly mean level from April through November for Plan SO-901 would be 242.77, occurring in April 1965, as compared to the basis-of-comparison minimum level of 241.85 for November 1964. Plan SO-901 does not satisfy the criterion; however, it does improve upon the basis-of-comparison level. As in the case of the minimum April 1 level, further improvement upon the minimum monthly level would be expected if discretionary authority was applied.

Criterion (k). In the event of supplies in excess of the supplies of the past as adjusted, the works in the International Rapids Section shall be operated to provide all possible relief to the riparian owners upstream and downstream. In the event of supplies less than the supplies of the past as adjusted, the works in the International Rapids Section shall be operated to provide all possible relief to navigation and power interests.

This is an operational criterion and cannot be used in evaluating a proposed plan.

Lake St.Louis: One requirement of regulation specified in the Supplementary Order of Approval dated July 2, 1956, states, "The project works shall be operated in such a manner as to provide no less protection for navigation and riparian interests downstream than would have occurred under preproject conditions with the supplies of the past as adjusted, as defined in criterion (a) herein." Riparian interests on Lake St. Louis and downstream are interested in the frequency of low levels, particularly during the summer months, June through September.

The minimum Lake St. Louis water level is about 0.37 foot higher under Plan SO-901 than under the basis-of-comparison, and the frequency of occurrence of levels below elevation 65.5 feet would be reduced from 3 to 0 occurrences. By raising the minimum monthly mean level and reducing the frequency of occurrence of low levels, conditions under Plan SO-901 improve upon the basis-of-comparison.

8.3.2 Economic Effects

A summary of average annual economic benefits or losses for Plan SO-901 is given in Table 24. It is important to note that the dollar values given in the tables are those directly resulting from application of previously described methodologies; consequently they posses accuracies and are subject to uncertainties of different orders of magnitude and, therefore, the figures have varying degrees of significance. They are presented in this manner in order to illustrate fully and clearly the evaluation process. If these computed dollar values were "rounded off," on a common basis, to figures that would be significant in light of the uncertainties inherent in methodologies or of the magnitude of base economic values, many arrays of zeros would appear in the tables.

In all tables of quantitative economic evaluation, positive figures indicate benefits attributable to Plan SO-901, and negative figures indicate losses, both relative to the basis-of-comparison.

Commercial Navigation: Detailed analysis of transportation costs were made as described in Subsection 7.3.1. The annual benefits to commercial navigation resulting from operation of Plan SO-901 are plotted on Figure 14.

Plan SO-901 would produce an average annual benefit of $927,000 to commercial navigation. It was found that some 50 percent of the total average annual benefit would be provided to the traffic route using Lakes Superior, Michigan-Huron, and Erie. An additional 26 percent would accrue to the traffic traversing Lakes Superior and Michigan-Huron. This reflects a better balance of Lake Superior levels relative to those of the lower lakes and a greater volume of traffic over these routes, as compared to other traffic routes. Since the level of Lake Superior frequently controls the draft to which ships using the lakes can load, an upward relative adjustment in its levels, as under Plan SO-901, would provide direct benefits to the traffic involved. Table 16 shows the net difference in the cost of transportation by traffic routes. The cost of moving the projected commerce, over any of the ten routes, was found to be less in all instances under Plan SO-901 than under the basis-of-comparison. It is worth noting that, on the average, each navigation month shows a net improvement.

Table 16 also presents the net difference in the cost of transportation broken down for the various commodity trades of Canada and the United States. Under Plan SO-901 some 76 percent or $708,000 of the total average annual benefit is to U.S. Commerce, of which $610,000 would accrue to the U.S. iron ore traffic. The remaining 24 percent, amounting to $219,000 would accrue to Canadian commerce.

A detailed evaluation of navigation in the Canadian reach of the St. Lawrence River was not made as examination of Lake St. Louis outflows under Plan SO-901 indicated no adverse effects on the level of Montreal Harbour with respect to the basis-of-comparison.

Power: The following paragraphs present a summary of the detailed economic evaluation of Plan SO-901 as compared to the basis-of-comparison for the power interest.

As shown in Table 17, the overall annual net benefit to power generation due to Plan SO-901 is $640,000. This effect varies between power systems. There would be an annual loss of $160,000 to the Upper Michigan system, which would be significant in relation to the relatively small local power system involved. On the other hand, the total annual benefits of $460,000, $260,000 and $80,000 for the New York State, Ontario, and Quebec systems, respectively, are small in relation to the size of the systems.

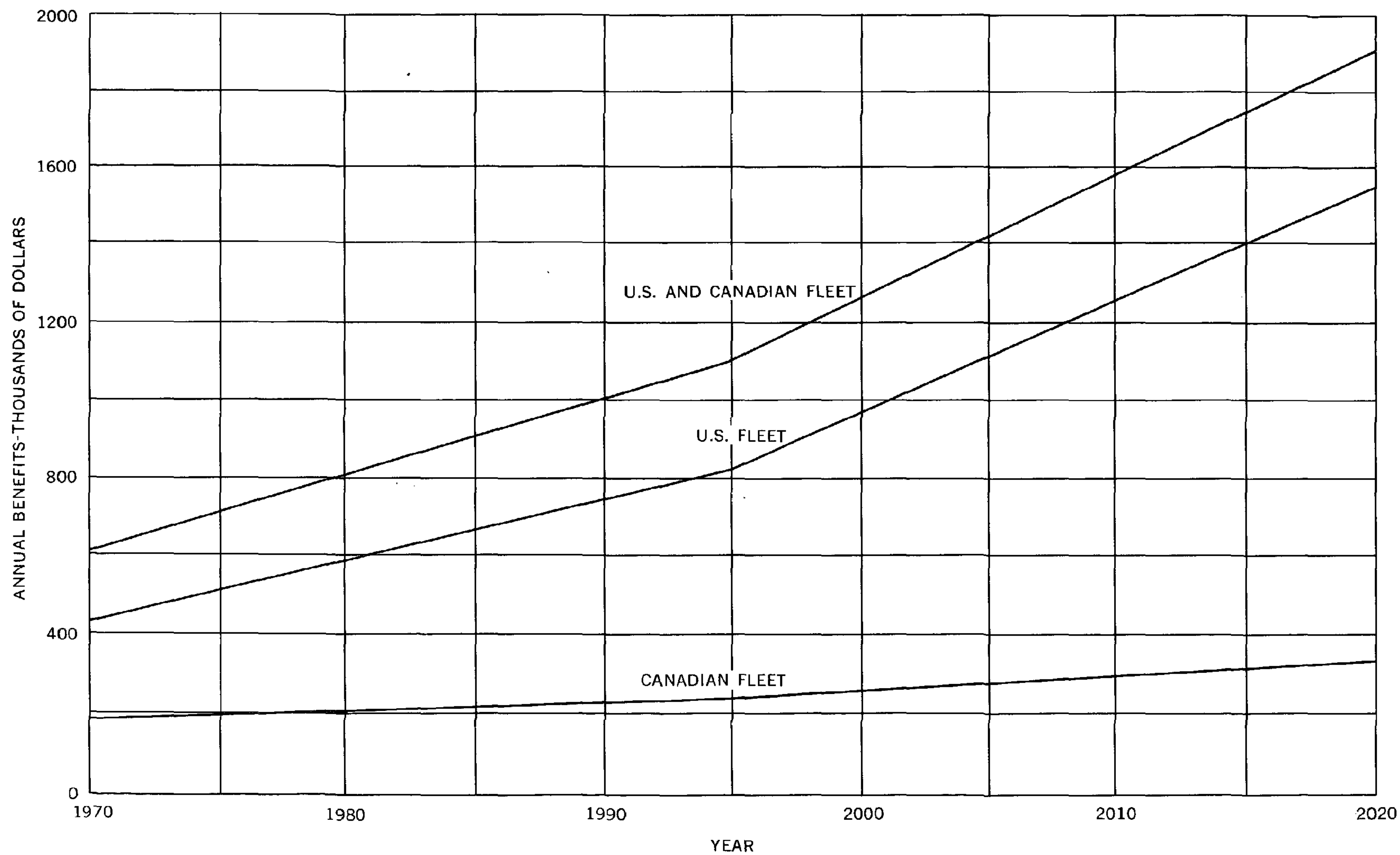


Figure 14
COMMERCIAL NAVIGATION BENEFIT CURVES FOR PLAN SO-901

Table 16

EFFECTS OF PLAN SO-901 ON COMMERCIAL NAVIGATION FOR PROJECTED PERIOD
LISTED BY COMMODITY AND COUNTRY, AND BY TRAFFIC ROUTES
($1,000)

	Transportation Cost Difference (Benefit) Between Plan SO-901 and Basis-of-Comparison			
	(1970)	(1995)	(2020)	Equivalent Annual Benefit for 1972-2022 @ 7% Interest
BY COMMODITY AND COUNTRY				
U.S.A. Fleet				
Iron Ore	313	777	1,361	610
Coal	39	0	26	19
Limestone	36	52	118	50
Grain	45	12	38	29
Total	433	841	1,543	708
Canadian Fleet				
Iron Ore	44	85	111	69
Coal	28	16	18	22
Limestone	3	6	9	4
Grain	108	130	187	124
Total	183	237	325	219
Combined U.S.A. and Canadian Fleet				
Iron Ore	357	862	1,472	679
Coal	67	16	44	41
Limestone	39	58	127	54
Grain	153	142	225	153
Total	616	1,078	1,868	927
BY TRAFFIC ROUTES				
S	0	1	1	1
MH	30	25	49	29
E	3	2	3	2
O	0	1	1	1
S-MH	103	330	577	245
S-MH-E	326	525	957	467
S-MH-E-O	91	132	177	117
MH-E	41	29	59	36
MH-E-O	19	29	39	25
E-O	3	4	5	4
Total	616	1,078	1,868	927

Note: See discussion of significance of figures in introduction to Subsection 8.3.2.

Table 17

EFFECTS OF PLAN SO-901 ON POWER

System	Nameplate Capacity (kw)	Annual Energy Value ($1,000) Basis-of-Comparison	Annual Energy Value ($1,000) Plan SO-901	Annual Energy Value ($1,000) Difference Between Plan SO-901 and Basis-of-Comparison	Annual Capacity Benefit ($1,000)	Annual Total Net Benefit ($1,000)
Ontario						
St. Lawrence	912,000	+ 28,360	+ 28,380	+ 20		
Niagara	2,116,800	+ 57,040	+ 57,160	+ 120		
St. Marys	31,000	+ 1,050	+ 1,050	0		
Total	3,059,800	+ 86,450	+ 86,590	+ 140	+ 120	+ 260
Quebec						
Beauharnois	1,585,780	+ 71,060	+ 71,140	+ 80	0	+ 80
Cedars	162,000					
Total	1,747,780	+ 71,060	+ 71,140	+ 80	0	+ 80
New York State						
St. Lawrence	912,000	+ 45,300	+ 45,350	+ 50		
Niagara	2,190,000	+ 99,860	+ 100,030	+ 170		
Total	3,102,000	+ 145,160	+ 145,380	+ 220	+ 240	+ 460
Upper Michigan	59,600	+ 3,280	+ 3,150	- 130	- 30	- 160
TOTAL	7,969,180	+ 305,950	+ 306,260	+ 310	+ 330	+ 640

Note: See discussion of significance of figures in introduction to Subsection 8.3.2

Determination of energy output from Ontario Hydro plants was made for each month of the study period for both the basis-of-comparison and Plan SO-901. The average daytime and nighttime monthly energy outputs over the study period were computed for the Robert H. Saunders plant on the St.Lawrence River, for the Niagara area plants and for the Edison Sault Electric Company plant on the St.Marys River. The average annual energy production from the three groups of plants for both the basis-of-comparison and Plan SO-901 and their differences were computed in terms of megawatt hours and equivalent dollar value. The total average annual energy benefit to the Ontario Hydro plants from Plan SO-901 would be $140,000 with no effect on the Great Lakes Power Corporation plant at Sault Ste.Marie, Ontario.

The period 1926 to 1964 was chosen for peak capacity determination as this is the longest period for which coordinated daily flows are available at Niagara and these were necessary to determine daily peak outputs. Duration curves of daily peak for each calendar month were derived for Niagara, St.Lawrence and St.Marys generation. For the purposes of this study, a correspondence in time between these sources was assumed.

From the analysis of loss of load probability, it was determined that the month of January was the most critical from the standpoint of load-meeting capability and that maintenance requirements did not govern. The results indicate that Plan SO-901 would produce a gain in peak capacity on the Ontario system of 8 Mw, which has an equivalent annual value of $120,000.

It should be emphasized that the detection of a gain of this magnitude in a 1985 system totalling over 30,000 Mw installed capacity is beyond the accuracy of study methods and, therefore, the gain is in reality negligible. However, as the same method is applied to both the basis-of-comparison and Plan SO-901, the difference thus determined is considered to be reasonably representative of the ability of the regulation method in providing peak capacity.

The configuration of the New York State system affects the evaluation of energy benefits somewhat since the hydroelectric energy must be dispatched into a load duration pattern for the entire system in order to determine its most economic use. As in the case of capacity, the same system model for energy determination is used for both basis-of-comparison and Plan SO-901 so that changes in the overall power system have little effect on the difference in energy production attributable to differences in regime of levels and flows. The total average annual benefit of Plan SO-901 to the New York State system would be about $460,000.

Energy outputs from existing major hydro installations in New York State were determined for the sequence of levels and flows which occurred on Lakes Erie and Ontario from 1900 through 1967, for both basis-of-comparison and Plan SO-901.

Unit energy values for 1971, in dollars per Mwh, were applied to the appropriate incremental differences in energy output between Plan SO-901 and the basis-of-comparison, for three distinct periods of time: week-day daytime, week-day nighttime and week-ends. The total average annual benefit of Plan SO-901 to energy production for New York State plants is $220,000.

Capacity-duration tables were developed for major hydro plants in New York State reflecting the flow conditions under basis-of-comparison and Plan SO-901. Other considerations which went into the determination of these tables were the reservoir levels available at the Lewiston pumped storage plant, unit forced outage rates, unit maintenance schedules and seasonal effects of aquatic growth on Niagara River flows.

The resulting tables indicate the frequency for which a given capacity can be expected to be equalled or exceeded. These tables were then combined with capacity-duration tables based on the forced outage rates of the remainder of the New York State inventory and were compared with the expected load requirements using the loss of load probability method.

It was found that for 1985 New York State loads, the variation in load from month to month will not provide enough time to do all necessary maintenance in low load months, as is the present case. In 1985, therefore, some capacity will be required solely to provide for maintenance, and the capacity in each month will become important, rather than simply the capacity in the peak load month.

Under Plan SO-901, the overall State of New York State system would be required to install 13 Mw less additional capacity than it would if the basis-of-comparison conditions continued. At the rates currently available for Power Authority financing, the indicated savings would be $240,000 per year. It must be emphasized that in an expected system totalling over 40,000 Mw, gains of the magnitude indicated are virtually negligible.

An increase in the frequency of the St.Marys River flow equal to or less than 70,000 cfs under Plan SO-901 produces an average annual energy loss in the Upper Michigan system of $130,000 and a small capacity loss of $30,000. The resultant total loss of $160,000 represents about a five percent loss to the Upper Michigan system.

Shore Property - Erosion and Inundation: The evaluation of effects of regulation on unprotected shore property is based on damage to structures, loss of land through erosion, and damage due to inundation. Where protective structures are expected to be built, evaluation of benefits is based on the reduced structure crest elevation required.

Minor changes in lake levels provided by any regulation plan would have little effect on erosion rates for the Canadian shoreline of Lake

Superior because of its generally high, rocky nature. However, this is not true for the United States shores of this lake where Plan SO-901 provides an average annual loss of $109,000 (See Table 18). In order to verify this loss, a detailed analysis was made on Reach 9004, which accounts for 50 percent of the total annual loss on the U. S. shoreline of Lake Superior. Reach 9004 extends from the Wisconsin-Michigan state line, to the northern tip of Keweenaw Peninsula. The analysis showed that, in those months which have severe storm activity, Plan SO-901 increased levels more times than it lowered them. Therefore, the conclusion is that because of the wave climate for this reach, based on historic records, Plan SO-901 would increase the occasions for erosion and inundation damages over that of the basis-of-comparison. This occurs not only in Reach 9004, but also to lesser degrees in the adjacent southerly shoreline reaches starting on the west in the vicinity of Bayfield, Wisconsin, and extending on the east to Whitefish Bay, Michigan. Because of a different wave climate, the reach from Two Harbors, Minnesota, to Superior, Wisconsin, essentially has no increased damages from Plan SO-901.

Plan SO-901 provides moderately improved level conditions and, therefore, average annual benefits of $156,000 on Lake Michigan and $101,000 on Lake Huron. It was found that the Plan SO-901 generally lowers the levels in those months when storm activities are normally most severe.

On Lake St.Clair, Plan SO-901 provides an annual benefit of $73,000.

On Lake Erie, Plan SO-901 provides a situation where, on the southern shoreline reaches in United States, primarily between Sandusky, Ohio, and Erie, Pennsylvania, there is a benefit of about $348,000. Plan SO-901 provides a benefit of $38,000 to Canadian reaches on Lake Erie.

On Lake Ontario, Plan SO-901 would result in a very slight increase in ultimate water level which would produce an estimated loss from erosion and inundation of about $43,000 to the southerly U.S. shoreline and a $5,000 benefit to the Canadian shoreline. Erosion and inundation losses are not specific to any local area but are generally distributed uniformly in the identified reaches of shoreline.

Shore Property - Marine Structures: From the standpoint of marine structures a regulation plan will show a benefit if the plan reduces the frequency of water levels outside the range from low water datum to plus two feet. While Plan SO-901 does reduce these extreme value frequencies, the benefit to marine structures would not be expected to be large. The results of the economic evaluation show, in fact, that Plan SO-901 will provide a relatively small net average annual benefit in the order of $10,000.

Shore Property - Water Intakes and Sewer Outfalls: Based on the available data and methodology, it is concluded that for all the lakes there are no significant benefits or losses to intakes and sewer

Table 18

EFFECTS OF PLAN SO-901 ON EROSION AND INUNDATION
($1,000)

	Basis-of-Comparison	SO-901	Difference Between SO-901 and Basis-of-Comparison	Average Annual Benefit or loss
			United States	
Lake Superior	3,721	3,789	- 68	- 109
Lake Michigan*	7,210	7,092	+ 118	+ 156
Lake Huron*	649	616	+ 33	+ 89
Lake St. Clair*	1,260	1,253	+ 7	+ 10
Lake Erie	4,255	4,074	+ 181	+ 348
Lake Ontario	1,158	1,173	- 15	- 43
Sub-Total	18,253	17,997	+ 256	+ 451
		Canada		
Lake Superior	20	23	- 3	- 6
Lake Huron*	67	61	+ 6	+ 12
Lake St. Clair*	465	421	+ 44	+ 63
Lake Erie	965	944	+ 21	+ 38
Lake Ontario	1,082	1,079	+ 3	+ 5
Sub-Total	2,599	2,528	+ 71	+ 112
TOTAL	20,852	20,525	+ 327	+ 563

* 1962 outlet conditions

outfalls resulting from Plan SO-901. In the past, extreme high or low water levels required construction of protective works and remedial measures to existing intake and outfall facilities. Since Plan SO-901 will reduce the extremes of both high and low levels, it is anticipated that these works if properly maintained will provide adequate protection.

Shore Property - Recreation Beaches: Subtracting the Plan SO-901 weighted seasonal value from the basis-of-comparison weighted seasonal value, Plan SO-901 would result in 1971 value gains of $86,000 for United States beaches and $60,000 for Canadian beaches (Table 19). Annual benefits would be evident on all lakes, except Lake Superior, which would experience a loss of $5,000, and the St.Lawrence River which would experience no change.

For projections to the year 2022, it was assumed that the use of low and moderate intensity use beaches will increase; that the beaches presently closed due to pollution will be reopened due to improved water quality; that the 1971 beach acreage for the United States portions will be increased by 50 percent along Lake Superior, by 70 percent along Lake Michigan, by 90 percent along Lake Huron, by 20 percent along Lake Erie, and by 70 percent along Lake Ontario. For Canada, it is estimated that the present day beach value will increase by a factor of 3.14 by 2022. Thus, in 2022, SO-901 is projected to result in value gains over the basis-of-comparison of $270,000 for United States beaches and $188,000 for Canadian beaches. Again, only Lake Superior would be expected to experience a loss.

The total average annual benefit would amount to $116,000 for the United States portions and $112,000 for the Canadian portions.

Shore Property - Recreational Boating: Plan SO-901 is found to have very little effect on recreational boating. A comparison of the stage-duration curves for the basis-of-comparison and Plan SO-901 as they apply to the four primary boating months, June through September, shows the curves to be almost coincident. The plan is favorable to recreational boating in that lower levels are raised, providing a more suitable situation for boating.

8.3.3 Environmental Effects

Fishery: In regulating the Great Lakes under Plan SO-901, there would be only minor construction changes in the Sault Ste.Marie control structure to provide for winter operations. The incremental changes in levels and flows during any year should have very little effect on the majority of fishery resources in the main basins of the Great Lakes. The connecting waters and littoral zones are the areas most affected by Plan SO-901.

The sequence, timing, volume and duration of flows through the connecting channels are most important to the fishery resource. Because all regulation is accomplished through variation in flow, the problems

Table 19

EFFECTS OF PLAN SO-901 ON RECREATION BEACHES
($1,000)

	Basis-of-Comparison	SO-901	Difference Between SO-901 and Basis-of-Comparison	Average Annual Benefit or loss
			United States	
	(1)	(1)		
Lake Superior	51	55	- 4	- 5
Lake Michigan *	7,301	7,239	+ 62	+ 82
Lake Huron *	866	856	+ 10	+ 17
Lake St. Clair *	15	15	0	0
Lake Erie	894	879	+ 15	+ 18
Lake Ontario	284	281	+ 3	+ 4
Sub-Total	9,411	9,325	+ 86	+ 116
			Canada	
	(2)	(2)		
Lake Superior	0	0	0	0
Lake Huron *	9,108	9,138	+ 30	+ 56
Lake St. Clair *			- negligible effect -	
Lake Erie	7,806	7,836	+ 30	+ 56
Lake Ontario	5,637	5,637	0	0
St. Lawrence River (Cornwall to Trois-Rivières			- negligible effect -	
Sub-Total	22,551	22,611	+ 60	+ 112
TOTAL				+ 228

(1) Average damage.
(2) Average value.
NOTE: See discussion of significance of figures in introduction to Subsection 8.3.2.
* 1962 outlet conditions

encountered in all regulation plans, regardless of complexity, are similar, although not of the same magnitude. Since there is no significant construction involved in the implementation of Plan SO-901, there should be none of the dredging and silting problems associated with this activity.

Preliminary regulation plans were found to have negligible effects on sport fishing from shore structures and on the use of docks and wharves for commercial fishing operations. Therefore, no economic evaluation of Plan SO-901 was made for these interests.

The complexities of the interacting population dynamics of the fish stocks, plus the influence of many other environmental variables, tend to mask any effects that could be attributed to incremental changes of water levels (either natural or controlled). The amount of refinement of data necessary to isolate and quantify the effect of this single variable, particularly in economic terms, is simply not available. This fact, coupled with the small differences between Plan SO-901 and the basis-of-comparison, would indicate that very little change in "stocks" would take place, particularly in the main lake basins, as a result of changes in water level fluctuations. If any effects are to be found, they will most likely occur in the littoral zone and connecting channels.

The probable effects of regulation on the connecting waters are numerous, but in many cases cannot be defined, making it a difficult task to come to grips with the central problems. However, it is in these areas that the operational effects of the regulatory structures will have their greatest impact on the fishery interests.

The St.Marys Rapids and River have been identified as sensitive areas where impacts of change in regulation plans would be of significance with respect to the local sport fishery. The current operating procedure for the present plan (1955 Modified Rule of 1949) calls for a minimum outflow from Lake Superior of 58,000 cfs in the summer and 55,000 cfs in the winter. The operating procedure during periods of low flow provides for a minimum of one-half gate (about 3,000 cfs) open in the control works at the head of the St.Marys Rapids. An experiment carried out in the St.Marys River in August 1971 provided information on the effects on the aquatic environment of various low flow gate settings. Based upon these studies and observations, fishery experts have stated that flows less than 26,000 cfs in the rapids can cause a spatial shift in the littoral zone of the lower river and a reduced fish population in and around the rapids.

With Plan SO-901, the minimum Lake Superior outflow, when required, would be 55,000 cfs year around. Plan SO-901, when compared with the basis-of-comparison, would increase the frequency of occurrence of low flows (55,000 cfs) from 29 times to 117 times. Such increase in the frequency of low flows would cause an adverse impact on the fish habitat greater than that which now occurs, unless remedial measures were provided or the operating procedure changed to provide a greater share of the flow to the rapids. The economic evaluation of Plan SO-901 is based on the current practice of a minimum setting of one-half gate open. Any increase of the flow in the rapids over the present minimum would increase the economic losses to the St. Marys River power interest.

In July 1973, the International Joint Commission requested that a study be initiated by the International Lake Superior Board of Control in cooperation with representatives of appropriate federal, provincial and state agencies to consider the feasibility of remedial works to ensure that the crucial areas of the St.Marys River Rapids are not dried up under low flow conditions. These studies include consideration of training dikes to distribute the same minimum flow more uniformly over the rapids.

The daily and seasonal extreme fluctuations in the levels of Lake St.Lawrence, as a result of the St.Lawrence River discharges to regulate the levels of Lake Ontario, have adversely affected the sport fishery. Remedial measures may be possible to obviate such conditions. Plan SO-901 does not aggravate the conditions obtained under the basis-of-comparison.

Wildlife: Plan SO-901 is moderately beneficial to water-oriented wildlife and animal organisms. This plan will maintain water over the marshlands in the upper two feet of the vertical operating range for a longer period of time than would have occurred under the basis-of-comparison. The plan would provide for longer periods of inundated wildlife lands during periods of levels below low water datum. However, in the water level range of plus three feet above LWD (for Lake Superior, plus 2 feet), wildlife would not benefit from the plan. Comparison of stage duration analyses prepared for this regulation plan indicates that in all lakes, except Superior, there would be less aquatic wildlife acreage under water within the LWD plus 3 feet range than prevailed throughout the period of record. The extent of marsh acreage loss would be greatest on Lake Huron with progressively smaller losses on Lakes Erie and Michigan, with an overall gain on Lake Ontario. These reductions in acreage would have an adverse influence on the wildlife resources found in the Great Lakes ecosystems from year to year during the most critical spring and fall months.

A summary of the marshland acreage available under both basis-of-comparison and Plan SO-901 is given in Table 20. Due to different methodologies, basis-of-comparison and plan figures represent "acreages adversely affected" for the U. S. and "acreages available" for Canada.

Hygienic Effects: There would be no hygienic effects on water intakes and waste treatment facilities from Plan SO-901. Plan SO-901 is not likely to produce measurable overall changes in water quality in the lakes and

Table 20

EFFECTS OF PLAN SO-901 ON WILDLIFE HABITAT
(Acreage)

	Basis-of-Comparison	Plan SO-901	Difference in Acreage (3)
		United States	
	(1)	(1)	
Lake Superior	10,490	9,860	+ 630
Lake Michigan*	16,201	16,453	- 252
Lake Huron*	24,546	24,926	- 380
Lake Erie	15,325	15,558	- 233
Lake Ontario	8,879	8,883	- 4
Sub-Total	75,441	75,680	- 239
		Canada	
	(2)	(2)	
Lake Superior	0	0	0
Lake Huron*	27,350	27,375	+ 25
Lake Erie	18,150	18,186	+ 36
Lake Ontario	7,884	8,002	+ 118
Sub-Total	53,384	53,563	+ 179
TOTAL			- 60

(1) Acreage lost from maximum elevation evaluated (Table 12).
(2) Acreage available.
(3) + indicates a benefit and - indicates a detriment.
* 1962 outlet conditions

connecting channels. Some minor local effects on water quality may be found in the St.Marys River because of the small increase in the frequency of occurrence of low flows. The beneficial and adverse effects attributable to these flow changes may well be compensating. Since there is no major construction involved, there would be none of the basic problems normally associated with construction, such as siltation, turbidity and other physical disturbances.

Aesthetic Effects: Water quality implications of Plan SO-901 are of concern for some erodible shores of Lake Superior; in particular, of some areas in Wisconsin and Minnesota. These shores are composed of erodible red clay, loam and silt. Several federal, state and local agencies are involved in studies to reduce the erosion of interior areas, and to a limited extent, the Lake Superior shore lands.

At this time, data from these studies do not identify the relative magnitude of impacts on Lake Superior water quality by eroded materials from interior drainage as compared to materials contributed by shoreline erosion.

Because the process of erosion is accelerated during periods of high lake levels, especially when such levels are coupled with storm activities, Plan SO-901 may increase erosion of red clay shore areas. Historical data necessary to relate erosion and lake stage are very limited. Estimates show that the average annual erosion damages attributable to Plan SO-901, for the 110 miles of erodible Wisconsin shoreline (out of approximately 156 miles of shoreline), would be in the range of $22,000 to $33,000. It is expected that the change in erosion rates attributable to Plan SO-901 would be difficult to identify.

The Minnesota shore of Lake Superior has substantially less erodible material (about 30 miles out of approximately 206 miles of shoreline) than the Wisconsin shore. Because of the prevailing wave and climate conditions, Plan SO-901 essentially produces no change in the average erosion damages for the Minnesota portion of the Lake Superior shore when compared to the basis-of-comparison.

A major benefit of Plan SO-901 to most areas of Lakes Michigan, Huron, St. Clair and Erie would be the reduction in erosion and inundation damages to the shoreline areas.

Generally speaking, any local ecological changes in both the aquatic and shoreline ecosystems, attributable to regulation of lake levels, would be subtle. In the case of Plan SO-901, no visual, olfactory or auditory pollution is expected. Surface characteristics of water, such as debris, oil, algae or dead fish, would not be aggravated and man's sensitivity to the aesthetic aspects of any changes would be low.

Social Well-being: In the area of human betterment, the impact of Plan SO-901 on each individual would be small. However, the plan contributes to the broad concept of better resource management, better economic opportunities, enhancement of recreational opportunities and the overall betterment of the aesthetic aspects of the shores of the Great Lakes.

Plan SO-901 would not require any changes in "life styles" such as forced relocation of individuals, changes in land use by man, or any nuisance effects to man.

8.4 Regulatory Works

The Board's March 15, 1973 interim report is confined to the further regulation of Lake Superior and Lake Ontario without major construction. The Board has assessed potential maintenance requirements and investigated minor modifications to the existing Lake Superior regulatory works to permit greater flexibility of operations.

Part of the combined outflow capacity of all the works in the St. Marys River, is the capability to divert up to 7,000 cfs through the Abitibi pulp and paper plant. During these studies, the Board has assumed the continued use of this diversion. However, in recent years it has become apparent that the physical condition of the hydraulic equipment in the plant is deteriorating to the point where it may no longer be possible to guarantee the availability of the outflow capacity. In this event, alternative capacity would be required. One method of achieving this outflow capacity might be the construction of an additional gate at the control structure.

A physical appraisal of the existing Lake Superior control structure indicated that, with appropriate maintenance procedures and repair work, it is basically adequate for use during the 50-year project life adopted in this study. However, early in these investigations, it became evident that it might be possible to realize economic benefits if greater flexibility could be achieved in the regulation of Lake Superior by changing the operation of the existing control facilities. Currently, this inflexibility occurs during the five winter months when the outflow remains fixed except for rare instances when a change in gate setting is required to or from maximum or minimum outflow. The present maximum winter outflow permitted is a discharge of 85,000 cfs in the St.Marys River. The existing policy for winter setting of the gates is due to the difficulties of moving them when they are frozen in ice; the flow limitation was arbitrarily set at what was considered to be a "safe" maximum as a result of past experience with ice jams at higher flows. The questions posed, therefore were:

(1) Is this "safe" maximum too conservative? Can it be increased?

(2) Can the St.Marys River carry a higher flow during winter (or during part of it)? If so, when, and to what limit?

(3) Is it practicable to change the gate settings and vary the flow as a normal procedure during winter? If so, by what means and how much would it cost?

To answer these questions, a program of field tests was conducted during the winters of 1968-69, 1969-70, 1970-71 and 1971-72. These experiments, employing temporary steam-heating facilities, provided not only much valuable operating experience, but also realistic indications of the cost of de-icing and moving the gates and of monitoring the resulting hydraulic and ice effects in the river. Subsequent studies included an appraisal of the effectiveness and costs of alternative methods of de-icing the gates.

Four winter seasons of field tests were found to be insufficient to provide conclusive answers to the above questions. It would require many seasons, under a wide variety of hydrologic and meteorologic conditions, to adequately investigate the capability of the river to safely handle a range of higher flows, at different lake stages, under various ice conditions, throughout or during specific periods of winter; there are too many combinations of these parameters which would have to be tested. Furthermore, current efforts to lengthen the navigation season are an additional complicating factor, since this involves ice breaking activity and thus disturbance of the natural ice cover in the river.

Nevertheless, some tentative answers have been reached, even though they must be considered valid only in the context of the conditions which prevailed in these four particular years. It was found that it is definitely possible to change gate settings during the winter, even under quite severe conditions, and that the costs of such operations are reasonable. De-icing and closing gates is easier and quicker than de-icing and opening them. Flows of 95,000 cfs may be feasible, although it appears desirable not to exceed 85,000 cfs until after stable ice cover conditions have been established. This latter provision may well be the key to the problem and if so, then even higher flows may be possible on this basis. Even if higher flows did produce ice-jamming, the dangers of resulting flooding could be quickly averted by the now proven ability to promptly close gates and reduce the flow. This calls for continuous monitoring of ice conditions and water levels in the river, particularly in certain critical reaches, to enable immediate identification of any developing ice jam and prompt action at the control structure. The test program demonstrated the practicability of the monitoring procedures used and their ability to give adequate lead-time for responsive action in any emergency. Surveillance of the river included ground observations, aerial reconnaissance and photography, and the installation and operation of strategically located water level gages capable of detecting water profile changes that could signify the onset of ice jamming conditions. Coupled with this was an emergency warning and a communications system, and at certain critical periods, personnel standby arrangements, so that immediate gate closing action could be taken to alleviate the effects of any incipient ice jam. These hydraulic monitoring and emergency standby procedures are a significant element in the cost of winter operations.

Although steam was chosen as the most expedient method of heating the gates for the purposes of the test program, it is only one of a number of alternative methods. These include electrical, air bubbler, radiant and hot air systems. The feasibility and costs of alternative methods were investigated. The recommended method is to provide electrical tubular heaters for heating 6 gates and 8 pairs of gains, motorized drives for all 16 gates, and a number of other improvements, including a metal-clad protective enclosure over 10 of the gates. Apart from increased operational efficiency, these modifications will provide for modern standards of personnel safety. As shown on Table 21 the estimated capital and annual costs of winter operation based on this method are about $574,000 and $70,000, respectively.

8.5 Evaluation Against Simulated Future Water Supplies

The foregoing evaluation of Plan SO-901 is based on the water supplies experienced during the study period 1900-1967. Future water supplies are unknown. Any plan can be expected to have different results under different sequences and magnitudes of supplies. To obtain some indication of the range of possible results, Plan SO-901 was accordingly tested against 10 simulated supply sequences, mentioned previously in Subsection 5.4.2. Table 22 summarizes the results of these tests, which were carried out using the generalized loss curves. It shows that, in all tests against simulated supply sequences, overall benefits accrue to the Great Lakes system.

Changes in the level of Lakes Michigan-Huron result in changed outflows to the lower lakes. Because of the time lag such changed flows may moderate or accentuate level fluctuations on the lower lakes. Examination of the effects occurring with the historic and simulated water supply sequences suggests that the net effect on Lake Erie would be beneficial. The data indicate that effects on Lake Ontario would be small, but do not permit determination of whether they would be beneficial or adverse.

8.6 Alternatives Requiring Major Construction

The four basic structural alternatives for improving the regulation of the Great Lakes through changes in the regulation of Lake Superior and Lake Ontario are:

(a) increasing the discharge capacity of Lake Superior;
(b) increasing the storage capacity of Lake Superior;
(c) increasing the discharge capacity of Lake Ontario; and
(d) increasing the storage capacity of Lake Ontario.

When the Board addressed these alternatives based upon the supplies received over the study period 1900-1967, it found that Plan 1958-D for regulating Lake Ontario within existing discharge and storage constraints satisfies the criteria and other requirements of the IJC Orders of Approval with only a few exceptions. These

Table 21

AVERAGE ANNUAL COSTS OF WINTER OPERATION
OF THE CONTROL STRUCTURE AT SAULT STE. MARIE
FOR PLAN SO-901

(Recommended Method, Using Electrical Equipment)

	Initial Capital Costs		Annual* Costs
1. Capital Expenditure			
(a) Tubular heaters for 6 gates and 8 pairs of gains	$ 208,000		$ 15,600
(b) Structural modifications for 6 gates	54,000		4,050
(c) Electrical power line through Great Lakes Power Company to the north end of the structure	80,000		6,000
(d) Telephone line to north end of structure	10,000		750
(e) Modifications to provide motorized drive for all 16 sets of gate hoist machinery	102,000		7,650
(f) Metal clad enclosures over 10 gates including convenient lighting	115,000		8,625
(g) Hinged sheet steel covers over open gears of 16 sets of hoist machinery	5,000		375
Total Capital Cost	$ 574,000	Sub-Total	$ 43,050
2. Annual Maintenance			
(a) Maintenance of heating equipment			$ 300
(b) Maintenance of motorized drives			200
(c) Maintenance of power line, sub-station and telephone line			600
(d) Maintenance of metal housing and lighting equipment			450
(e) Snow removal and site access			300
		Sub-Total	$ 1,850
3. Annual Operations			
(a) Annual cost of gate heating operations			$ 8,100
(b) Annual cost of gate moving operations			250
(c) Annual cost of operation of lighting equipment and telephone			200
(d) Annual cost of hydraulic monitoring of the river and emergency stand-by procedures			16,000
		Sub-Total	$24,550
Total Annual Cost			$69,450

*Based on a useful life of 40 years for capital expenditures at an interest rate of 7%

Table 22

TESTS OF PLAN OF SO-901 ON TEN SIMULATED DATA SEQUENCES
SUMMARY OF RANGES OF STAGE (FEET) AND APPROXIMATE ECONOMIC EVALUATIONS ($ Millions)

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Superior Max. Base Case	601.72	601.63	601.47	601.50	601.65	602.18	601.95	601.65	601.93	601.56
Superior Max. SO-901	602.00	601.87	601.90	601.79	601.60	602.19	601.99	601.78	602.23	601.86
Superior Min. Base Case	599.36	599.31	598.72	599.11	599.04	599.11	599.22	599.29	599.34	599.36
Superior Min. SO-901	599.09	599.05	598.54	599.12	599.03	598.90	599.04	599.17	599.28	599.14
Superior Mean Base Case	600.50	600.43	600.37	600.43	600.41	600.44	600.46	600.44	600.49	600.45
Superior Mean SO-901	600.77	600.45	600.36	600.55	600.42	600.50	600.44	600.53	600.54	600.44
Mich/Hur Max. Base Case	580.80	580.51	580.61	580.35	580.29	580.68	580.78	580.17	580.74	580.32
Mich/Hur Max. SO-901	580.69	580.37	580.38	580.17	580.13	580.42	580.59	580.04	580.54	580.13
Mich/Hur Min. Base Case	575.51	575.77	574.82	576.22	575.53	575.59	575.39	576.34	576.32	575.89
Mich/Hur Min. SO-901	575.74	575.89	574.83	576.28	575.72	575.69	575.56	576.62	576.44	575.96
Mich/Hur Mean Base Case	578.74	578.06	577.88	578.30	578.03	578.15	577.99	578.23	578.17	578.03
Mich/Hur Mean SO-901	578.73	578.05	577.88	578.29	578.02	578.13	577.97	578.22	578.16	578.01
Erie Max. Base Case	573.37	573.16	573.52	573.24	573.45	572.78	572.84	573.01	572.94	573.17
Erie Max. SO-901	573.32	573.12	573.42	573.17	573.42	572.63	572.81	572.99	572.86	573.13
Erie Min. Base Case	566.97	568.52	568.04	568.79	568.35	568.19	567.89	568.51	568.90	568.26
Erie Min. SO-901	567.12	568.67	568.07	568.83	568.48	568.25	568.06	568.69	568.94	568.36
Erie Mean Base Case	571.25	570.79	570.58	570.95	570.71	570.62	570.52	570.72	570.67	570.56
Erie Mean SO-901	571.26	570.79	570.59	570.95	570.71	570.62	570.53	570.72	570.67	570.56
Ontario Max. Base Case	247.73	247.19	247.46	246.92	247.50	246.66	247.05	247.78	246.91	248.08
Ontario Max. SO-901	247.50	247.01	246.75	247.21	246.73	247.45	246.69	247.49	247.12	247.93
Ontario Min. Base Case	240.69	241.78	240.94	242.38	242.17	242.06	239.47	240.55	242.76	241.89
Ontario Min. SO-901	241.60	242.64	241.91	242.85	242.03	242.22	241.94	242.59	242.35	242.06
Ontario Mean Base Case	244.63	244.53	244.38	244.59	244.56	244.55	244.22	244.54	244.59	244.48
Ontario Mean SO-901	244.63	244.58	244.53	244.59	244.54	244.58	244.54	244.53	244.55	244.63
Power Benefit	+ 0.3	+ 0.2	+ 0.6	- 0.3	- 0.1	+ 0.2	+ 1.1	+ 0.4	+ 0.5	+ 0.7
Navigation Benefit	+ 1.3	+ 0.2	+ 0.3	+ 0.7	+ 0.2	+ 0.4	+ 1.1	+ 0.7	+ 0.3	+ 0.1
Superior Shore Benefit	- 2.3	- 0.3	- 0.4	- 0.1	- 0.2	- 0.8	- 0.2	- 0.7	- 0.4	- 0.2
Mich/Hur Shore Benefit	+ 0.7	+ 0.3	+ 0.4	+ 0.5	+ 0.4	+ 1.0	+ 0.6	+ 0.6	+ 0.5	+ 0.6
Erie Shore Benefit	+ 0.1	+ 0.1	+ 0.1	+ 0.1	+ 0.1	+ 0.2	+ 0.1	+ 0.1	+ 0.1	+ 0.1
Ontario Shore Benefit	+ 0.3	+ 0.1	- 0.3	+ 0.2	+ 0.1	- 0.2	0.0	+ 0.6	+ 0.4	- 0.6
Total	+ 0.4	+ 0.6	+ 0.7	+ 1.1	+ 0.5	+ 0.8	+ 2.7	+ 1.7	+ 1.4	+ 0.7

are discussed in Subsection 8.3.1 on hydrologic effects. A study of potential benefits of further regulation based upon the 1900-1967 period did not indicate benefits commensurate with anticipated costs. Thus, the Board was prepared to conclude that the structural alternatives for Lake Ontario did not merit further consideration. However, the record supplies of 1972 and 73 changed the picture substantially. Time has not permitted a full reexamination based upon these recent supplies. Section 13 explains more fully the need for further studies.

The following subsections summarize the investigation of structural alternatives for Lake Superior.

8.6.1 Increasing the Discharge Capacity of Lake Superior

The effect of increasing the maximum outflows from Lake Superior in Plan SO-901 was investigated in detail. The first alternative considered was adding more capacity to the control works and dredging in the St. Marys River to increase its maximum discharge capacity. The second alternative was to increase the winter maximum discharge capacity by utilizing ice control structures or devices to allow for higher discharges without causing ice jams. The various increments and combination of increases provided up to 20,000 cfs greater discharge than the present maximum outflow of 123,000 cfs and up to 20,000 cfs greater discharge than the present winter outflow of 85,000 cfs. The results demonstrated that increasing the St. Marys River discharge capacity would not significantly improve the benefits to the Great Lakes system under the objectives utilized in developing Plan SO-901. Such would also be the case with any other operating policy as well since, historically, high levels generally occur at the same time on all the lakes. Any attempt to increase Lake Superior maximum flows during periods of high water supplies would cause greater damage to the lower lakes. The approximate cost to increase the St. Marys River discharge would be about $3.0 million for each 5,000 cfs increment of discharge. Since little improvement over Plan SO-901 would be achieved by channel capacity improvements, no further efforts were made to develop a plan for Lake Superior which requires increased capacity of the St. Marys River.

8.6.2 Increasing the Storage Capacity of Lake Superior

Alternative SO regulation plans were developed using an expanded range of stage on Lake Superior to increase its storage capacity. The minimum level for Lake Superior could be lowered from 598.8 feet to 597.8 feet without adverse effect on navigation if all channels and harbors on Lake Superior and the upper St. Marys River were dredged one foot deeper. Plan SO-901 was modified to use Lake Superior's natural range plus a one-foot lowering of the minimum stage. This increased the variance about the mean level and lowered the mean level of Lake Superior while reducing the variance about the mean level of Lakes Michigan-Huron. Various combinations of variance and mean level were tested over the 1900-1967 study period. All other restrictions employed in Plan SO-901 remain unchanged.

Table 23 compares representative results from the tests with the basis-of-comparison and Plan SO-901. The comparison shows that SO-Mod Plans would provide benefits throughout the system. The maximum levels on all lakes, except on Lake Superior under Mod 7, would be reduced. The minimum stages would be raised, except on Lake Superior. The range of stage on Lake Superior would become larger, and the ranges of stage on the downstream lakes would be further reduced.

Based upon the concept of deepening all harbors and channels in Lake Superior to eliminate losses to navigation on that lake, dollar benefits to the system were computed using the generalized loss functions. The results are presented in Table 23. The modifications to Plan SO-901 increase benefits up to $4.1 million. The greatest increase compared to Plan SO-901 is in benefits to Lake Superior shore property interests.

The estimated cost of dredging all harbors and channels in Lake Superior one foot deeper is:

	Capital Cost	Annual Cost
United States	$ 31,500,000	$ 2,500,000
Canada	$ 17,000,000	$ 1,300,000
TOTAL	$ 48,500,000	$ 3,800,000

Therefore, Plan SO-901 Mod 7 would have an incremental benefit-cost ratio over Plan SO-901 of 1.1. In view of the very large quantity of dredging required, detailed analysis of benefits, costs and environmental effects would be necessary to determine the feasibility and desirability of this plan.

8.7 Summary

Lakes Superior and Ontario are currently regulated by the International Lake Superior Board of Control and the International St.Lawrence River Board of Control using regulation plans known as the September 1955 Modified Rule of 1949 and Plan 1958-D, respectively. These regulation plans were developed on the basis of criteria specified by the International Joint Commission in relation to specific problems associated with each lake and its outlet river. In the development of Plan SO-901, based on 1900-1967 supplies, it was found unnecessary to make any changes to the existing Plan 1958-D. Under Plan SO-901, the regulated outflows of Lake Superior would be dependent upon the levels of Lakes Michigan-Huron, as well as Lake Superior.

Table 23

REGULATION OF LAKES SUPERIOR AND ONTARIO
MODIFICATIONS OF PLAN SO-901
SUMMARY OF RANGES OF STAGE AND ECONOMIC EVALUATIONS

Lake Levels (feet)

	Basis-of-Comparison	SO-901	SO-901 Mod 7	SO-901 Mod 8
Lake Superior				
Mean	600.38	600.41	599.94	599.71
Max	601.91	602.00	602.00	601.97
Min	598.36	598.81	597.89	597.42
Range	3.55	3.19	4.11	4.55
Lakes Michigan-Huron*				
Mean	577.95	577.96	577.98	577.99
Max	580.91	580.64	580.41	580.27
Min	575.15	575.46	575.67	575.71
Range	5.76	5.18	4.74	4.56
Lake Erie				
Mean	570.60	570.61	570.62	570.63
Max	573.01	573.04	572.90	572.82
Min	567.95	568.14	568.21	568.25
Range	5.06	4.90	4.69	4.57
Lake Ontario				
Mean	244.53	244.55	244.56	244.56
Max	246.95	246.92	246.89	246.89
Min	241.31	241.53	241.92	242.13
Range	5.64	5.39	4.97	4.76
Approximate Annual Benefits ($ Millions)				
Power	0.0	+0.4	+0.6	+0.9
Navigation	0.0	+0.8	+2.9	+2.0
Shore Property	0.0	+0.9	+2.7	+3.1
Total	0.0	+2.1	+6.2	+6.0
Geographical Breakdown of Shore Property Benefits ($ Millions)				
Superior	0.0	-0.1	+1.2	+1.5
Michigan-Huron	0.0	+0.9	+1.2	+1.3
Erie	0.0	+0.1	+0.2	+0.2
Ontario	0.0	+0.0	+0.1	+0.1
Total	0.0	+0.9	+2.7	+3.1

* 1962 outlet conditions

Table 15 summarizes the effects of Plan SO-901 on the levels and outflows of the Great Lakes. It demonstrates that it reduces the range of stage on all the lakes, raises all minimum levels, and lowers the maximum level of Lakes Michigan-Huron while not significantly changing the maximum levels of the other lakes. It shows that the range of outflows of Lake Superior is unchanged while for all other lakes the range of flows has been stabilized by raising the minimums and reducing the maximums. This new regime of levels and flows essentially satisfies all criteria adopted for this study, including those given in existing IJC Orders of Approval. It is also favorable to the needs of the major Great Lakes interests.

The economic evaluation of Plan SO-901 is summarized by country, lake and interest in Table 24. It indicates that the plan is beneficial to navigation interests in both countries. With the exception of a small loss to U.S. plants at Sault Ste. Marie, Michigan, power benefits would similarly accrue to both countries from operation of the plan. The shore property evaluation indicates that three-quarters of the benefits accrue from reduction of erosion and inundation damages; nearly all the remainder are the result of an increase in the availability of recreation beaches. The shore property benefits to the U.S. shoreline are about three times the Canadian benefits. The overall economic benefits of Plan SO-901 are calculated to be $2.37 million annually, of which 64% would accrue to United States interests. This economic evaluation is consistent with the hydrologic analysis of the effects of the new levels and flows regime under the plan.

The average annual costs of Plan SO-901 have been estimated to be $70,000, this being to provide the capability of safely operating the Lake Superior control structure during winter. This figure includes the annual cost of the capital expenditure of $574,000.

The relatively small variations between Plan SO-901 and the basis-of-comparison are not expected to produce any measurable change in either the present or long-term productivity of the aquatic community, or in fishery stocks, in the main basins of the Great Lakes. If any adverse effects on fishery stocks are to be found, they will likely occur in the littoral zones and connecting channels. Low flows in the St. Marys Rapids and River have been identified as having an adverse impact on the local sport fishery. However, the adverse effects of such low flows can be largely eliminated by remedial structures and changes in operational procedures. Therefore, the increase in frequency of low flows from Lake Superior under Plan SO-901 on aquatic wildlife, i.e., marsh animals and waterfowl, would be minor. From the points of view of hygienic and aesthetic effects and social well-being, evaluation of the plan disclosed no significant changes from existing conditions and is therefore considered satisfactory.

Table 24

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.

Section 9

DEVELOPMENT AND EVALUATION OF LAKES SUPERIOR-MICHIGAN-HURON-ONTARIO PLANS

9.1 General

This section considers plans for the coordinated regulation of the four lakes, Superior, Michigan, Huron and Ontario. Plan development was based upon use of the existing regulatory works for Lake Superior and Lake Ontario and regulation of Lakes Michigan-Huron by control works to be constructed in the St. Clair and Detroit Rivers. The economic feasibility of Superior-Michigan-Huron-Ontario (SMHO) plans is determined by a comparison of the net benefits of further regulation of the Lakes with the cost of the St. Clair and Detroit River regulatory works. Preliminary estimates indicated that this benefit-cost ratio was much less than unity. Therefore, the study was pursued only in enough detail to substantiate this preliminary conclusion. This involved a detailed evaluation of one of the plans to verify the magnitude of the benefits and determine the distribution of effects among the interests and lakes and between the two countries. Since the plan was economically infeasible, detailed environmental impact studies were not undertaken.

9.2 Trial Plans

Trial SMHO regulation plans were developed for the following objectives:

(a) Maximum economic benefits for the system - SMHO-8;

(b) No economic loss to any major interest - SMHO-6;

(c) No change in mean lake levels - SMHO-11;

(d) Maximum economic benefits to the system with satisfaction of the present Lakes Superior and Ontario criteria - SMHO-3; and

(e) Reduction in range of stage on all lakes - SMHO-5.

Table 25 shows the ranges of stage and approximate economic benefits and losses of these trial regulation plans over the study period relative to the basis-of-comparison.

A review of all the SMHO plans developed indicates that plans which provided benefits greater than obtained under the SO lake combination lower the mean levels of the lakes, thereby resulting in losses to both navigation and power interests. Hence, it was concluded that, if Lake Erie is to remain unregulated and losses to any interest are to be avoided, natural regulation of the outflow from Lakes Michigan-Huron provides the most benefits.

Table 25

REGULATION OF LAKES SUPERIOR, MICHIGAN-HURON AND ONTARIO
SUMMARY OF RANGES OF STAGE AND ECONOMIC EVALUATIONS OF TRIAL PLANS

	Basis-of-Comparison	a SMHO-8	b SMHO-6	c SMHO-11	d SMHO-3	e SMHO-5
Lake Levels (Feet)						
Lake Superior						
Mean	600.38	600.46	600.37	600.38	600.35	600.35
Max.	601.91	602.10	602.09	602.09	601.96	601.96
Min.	598.36	598.82	598.73	598.73	598.72	598.72
Range	3.55	3.28	3.36	3.36	3.24	3.24
Lakes Michigan-Huron*						
Mean	578.54	577.69	578.48	578.48	578.35	578.35
Max.	581.50	580.33	581.20	581.20	581.02	581.02
Min.	575.74	575.20	576.03	576.03	575.89	575.89
Range	5.76	5.13	5.17	5.17	5.13	5.13
Lake Erie						
Mean	570.60	570.64	570.63	570.63	570.62	570.62
Max.	573.01	573.12	573.00	572.99	573.12	573.12
Min.	567.95	568.01	568.37	568.36	567.98	567.98
Range	5.06	5.11	4.63	4.63	5.14	5.14
Lake Ontario						
Mean	244.53	244.32	244.72	244.56	244.23	244.42
Max.	246.95	246.89	247.15	246.96	246.77	246.85
Min.	241.31	240.97	242.58	241.86	241.96	242.21
Range	5.64	5.92	4.57	5.10	4.81	4.64
Approximate Annual Benefits ($ Millions)						
Power	0.0	- 0.4	- 0.2	- 0.4	- 1.6	- 1.2
Navigation	0.0	- 1.5	+ 0.6	+ 0.6	+ 0.3	+ 0.3
Shore Property	0.0	+ 8.2	+ 0.8	+ 1.5	+ 3.9	+ 3.3
Total	0.0	+ 6.3	+ 1.2	+ 1.7	+ 2.6	+ 2.4
Geographical Breakdown of Shore Property Benefits ($ Millions)						
Superior	0.0	- 0.2	- 0.1	- 0.1	- 0.1	- 0.1
Michigan-Huron	0.0	+ 8.1	+ 1.5	+ 1.6	+ 3.3	+ 3.3
Erie	0.0	- 0.2	+ 0.2	+ o.2	- 0.1	- 0.1
Ontario	0.0	+ 0.5	- 0.8	- 0.2	+ 0.8	+ 0.2
Total	0.0	+ 8.2	+ 0.8	+ 1.5	+ 3.9	+ 3.3

* 1933 outlet conditions

All the plans are beneficial to shore property interests and detrimental to power interests. Except for Plan SMHO-8, all the plans present a benefit to navigation interests.

The Board compared the benefits listed in Table 25 with preliminary cost estimates for the regulatory works described hereafter in Subsection 9.4. Average annual costs were found to be in the order of $18 million compared to average annual benefits of $2 million. Furthermore, construction and the changed regime in the St. Clair and Detroit Rivers would likely have significant environmental impacts. For these reasons extensive studies were not pursued.

9.3 Selected Plan

Notwithstanding the lack of economic feasibility of SMHO plans, one plan was selected for detailed evaluation to verify the magnitude of benefits and demonstrate their distribution among the interests and lakes and between the two countries. The plan selected was SMHO-11. It was formulated on the principle of balancing storage among the upper four lakes in such a way as to maintain their existing mean lake levels. The following paragraphs summarize the data from the detailed evaluations reported in Appendices C, D, E, and F.

Plan SMHO-11, along with the other selected plans, was subjected to detailed shore property, navigation and power evaluations principally to illustrate the distribution of benefits among the lakes and between countries from regulation of Lakes Michigan-Huron in addition to Lakes Superior and Ontario. However, as already indicated, the order of magnitude of its benefits is small in relation to the costs of the required works at the outlet of Lake Huron. Only a summary of the detailed evaluations is presented in this section to illustrate the magnitude and distribution of the benefits. The detailed evaluation for each interest is presented in the appropriate appendix.

9.3.1 Hydrologic Effects

Since Plan SMHO-11 raises the water levels on Lake Superior and because these levels frequently control ship drafts in interlake movements, a benefit to navigation would be expected. On the other hand, higher levels increase erosion and inundation damages. Reduction in high levels on Lakes Michigan-Huron and Erie can be expected to decrease erosion and inundation damages. Increased minimum outflows from Lakes Erie and Ontario may benefit power if they are received at favorable times.

The results of Plan SMHO-11, except in one instance, would equal or meet to a better degree than the basis-of-comparison the water level and flow criteria used in this study for evaluating all selected plans. The exception is that the maximum level of Lake Superior under Plan SMHO-11 would exceed 602.00 feet on one occasion by 0.09 foot. The criterion is not rigid in this regard, since the range of levels is modified by the phrase "as nearly as may be." For the reasons explained previously, SMHO-11 was not refined. Such refinement, if subsequently justified, could remove this one-time violation of the criterion.

The detailed evaluation of this plan against the various hydrologic criteria and requirements is given in Appendix B - Lake Regulation. These criteria are also presented in Section 8 with reference to the detailed evaluation of SO-901. Table 26 gives a summary of ranges of stage and outflow for SMHO-11 and the basis-of-comparison.

9.3.2 Economic Effects

The results of the detailed economic evaluation are presented in Table 27. It will be noted that the four items making up the bulk of the effects are commercial navigation, power, erosion and inundation and recreation beaches.

Commercial Navigation: Plan SMHO-11 produces an average annual benefit of $295,000 to commercial navigation. Some $207,000 or 70% of benefits would accrue to U. S. commerce. The remaining $88,000 or 30% would accrue to the Canadian fleet. Nearly all ($187,000) of the benefits to the U. S. fleet accrue to U. S. iron ore traffic. Most of the Canadian benefits accrue to Canadian grain traffic ($51,000) and iron ore traffic ($27,000). Table 28 summarizes the effects of Plan SMHO-11 on commercial navigation.

Power: Table 26 shows that, except for Lake Superior, the minimum outflows would be raised appreciably and the range of outflows reduced. This is beneficial to the Niagara River power plants. However, on the St. Lawrence River, winter ice cover reduces the head available at the Moses-Saunders Powerhouses for a given flow and limits the maximum flow in the canal leading to the Beauharnois Powerhouse. These effects limit the additional power which can be generated in the winter even though flows are raised. Since additional flows in winter are not used as efficiently for power generation as they would be in other seasons, the redistribution of flow from other seasons to the winter results in a net loss to St. Lawrence River power generation.

Table 26

REGULATION OF LAKES SUPERIOR, MICHIGAN-HURON AND ONTARIO
SUMMARY OF RANGES OF STAGE IN FEET
AND OUTFLOW IN THOUSANDS OF CUBIC FEET PER SECOND

	Basis-of-Comparison		SMHO-11	
	Stage	Outflow	Stage	Outflow
Lake Superior				
Mean	600.38	77	600.38	77
Maximum	601.91	123	602.09	123
Minimum	598.36	55	598.73	55
Range	3.55	68	3.36	68
Lakes Michigan-Huron*				
Mean	578.54	183	578.48	183
Maximum	581.50	233	581.20	236
Minimum	575.74	107	576.03	132
Range	5.76	126	5.17	104
Lake Erie				
Mean	570.60	204	570.63	204
Maximum	573.01	258	572.99	257
Minimum	567.95	149	568.36	160
Range	5.06	109	4.63	97
Lake Ontario				
Mean	244.53	238	244.56	238
Maximum	246.95	310	246.96	305
Minimum	241.31	176	241.86	200
Range	5.64	134	5.10	105

* 1933 outlet conditions

Table 27

SUMMARY OF AVERAGE ANNUAL ECONOMIC BENEFITS OF PLAN SMHO-11
($1,000)

LAKE	COUNTRY	NAVIGATION*	POWER: Energy	POWER: Capacity**	SHORE PROPERTY: Erosion and Inundation	SHORE PROPERTY: Marine Structures	SHORE PROPERTY: Water Intakes and Sewer Outfalls	SHORE PROPERTY: Recreation Beaches	SHORE PROPERTY: Sub-total	TOTAL
Superior	U.S.		- 130		- 176	- 2	0	0	- 178	
	Canada		0		- 9	- 2	0	0	- 11	
Michigan	U.S.		-		+ 145	+ 5	- 15	+ 347	+ 482	
Huron	U.S.		-		+ 41	+ 3	0	+ 86	+ 130	
	Canada		-		+ 34	0	0	+ 92	+ 126	
St.Clair	U.S.		-		- 2			+ 5	+ 3	
	Canada		-		+ 159			0	+ 159	
Erie	U.S.		+ 500		+ 240	+ 3	+ 2	+ 86	+ 331	
	Canada		+ 100		+ 91	- 8	0	+ 88	+ 171	
Ontario	U.S.		- 210		- 118	+ 2	0	+ 13	- 103	
	Canada		- 750***		+ 21	+ 5	+ 6	+ 405	+ 437	
Great Lakes	U.S.	+ 207	+ 160	+ 280	+ 130	+ 11	- 13	+ 537	+ 665	+ 1,312
	Canada	+ 88	- 650	+ 200	+ 296	- 5	+ 6	+ 585	+ 882	+ 520
	TOTAL	+ 295	- 10		+ 426	+ 6	- 7	+ 1,122	+1,547	+ 1,832

* Navigation benefits are computed for traffic routes, not for individual lakes.
** Capacity benefits are computed for power systems, not for individual lakes.
*** Including downstream plants in Quebec.

Table 28

EFFECTS OF PLAN SMHO-11 ON COMMERCIAL NAVIGATION FOR PROJECTED PERIOD
LISTED BY COMMODITY AND COUNTRY, AND BY TRAFFIC ROUTES
($1,000)

	Transportation Cost Difference (Benefit) Between Plan SMHO-11 and Basis-of-Comparison (1970)	(1995)	(2020)	Equivalent Annual Benefit for 1980-2030 @ 7% Interest
BY COMMODITY AND COUNTRY				
U.S.A. Fleet				
Iron Ore	74	190	333	187
Coal	17	0	8	5
Limestone	10	9	1	8
Grain	11	4	10	7
Total	112	203	352	207
Canadian Fleet				
Iron Ore	14	29	37	27
Coal	11	7	7	8
Limestone	1	3	4	2
Grain	40	49	72	51
Total	66	88	120	88
Combined U.S.A. and Canadian Fleet				
Iron Ore	88	119	370	214
Coal	28	7	15	13
Limestone	11	12	5	10
Grain	51	53	82	58
Total	178	291	472	295
BY TRAFFIC ROUTES				
S	0	- 1	- 1	- 1
MH	7	- 1	- 23	- 3
E	4	3	4	3
O	0	1	2	1
S-MH	23	78	140	76
S-MH-E	75	127	235	133
S-MH-E-O	39	56	75	55
MH-E	20	12	20	15
MH-E-O	6	10	13	10
E-O	4	6	7	6
Total	178	291	472	295

Table 29

EFFECTS OF PLAN SMHO-11 ON POWER
($1,000)

System	Annual Energy Benefit	Annual Capacity Benefit	Annual Total Net Benefit
Ontario			
St. Lawrence	- 150		
Niagara	+ 100		
St. Marys	0		
Total	- 50	+ 200	+ 150
Quebec			
Beauharnois	- 600		
Cedars			
Total	- 600	0	- 600
New York State			
St. Lawrence	- 210		
Niagara	+ 500		
Total	+ 290	+ 310	+ 600
Upper Michigan	- 130	- 30	- 160
TOTAL	- 490	+ 480	- 10

There is an overall computed annual net loss to power generation due to Plan SMHO-11 of $10,000; however, not all of the power systems involved realize losses. There would be an annual loss of $160,000 to the Upper Michigan system which would be significant in relation to the relatively small local power system involved, and an annual loss of $600,000 to Beauharnois and Cedars plants of the Quebec system. There would be total annual benefits of $600,000 and $150,000 for the New York State system and the Ontario system respectively. These benefits are small in relation to the size of the systems. A summary of the effects of Plan SMHO-11 on power is provided in Table 29.

Shore Property - Erosion and Inundation: Table 30 provides a detailed evaluation of Plan SMHO-11. Under this plan the Lake Superior long-term mean level would be essentially unchanged; however, the range of levels in certain months would be increased. Therefore, the plan would produce annual losses of $176,000 to erosion and inundation on the U. S. shores of Lake Superior and $9,000 to Canadian shores. However, the plan produces an overall erosion and inundation benefit of $130,000 to U. S. shores and $296,000 to Canadian shores for a total of $426,000.

Shore Property - Recreation Beaches: Table 31 shows that Plan SMHO-11 produces substantial benefits to recreation beaches since the lower regime of lake levels exposes greater areas of beach. The majority of these benefits accrue to Lakes Michigan-Huron and Ontario. The plan produces an overall benefit of $537,000 to U. S. shores and $585,000 to Canadian shores for a total benefit of $1,122,000.

9.3.3 Environmental Effects

Fishery: In regulating the Great Lakes under Plan SMHO-11 there would be little known effect on the fisheries in the main basins of the lakes. However, an adverse effect would occur in the connecting channels, particularly the St. Clair-Detroit River system, because this plan would entail significant construction in these rivers. No quantification of these effects is possible with presently available data. During the estimated six years of construction, there would be adverse effects on aquatic organisms as a result of dredging and building in the rivers. This would cause a stirring of bottom materials and sedimentation downstream covering spawning areas and vegetation in the area influenced by the construction program. In the case of fish and invertebrates inhabiting the areas affected, such conditions could clog up their breathing apparatus. Compounding the sedimentation problem is the fact that the sediment in both rivers contains mercury contaminants. Information is not now available on the potential effects dredging and the moving of contaminated sediments have on mercury transport. Special disposal techniques would be required for any dredged sediments that contain excessive mercury pollutants.

Table 30

EFFECTS OF PLAN SMHO-11 ON EROSION AND INUNDATION
($1,000)

	Basis-of-Comparison	SMHO-11	Difference Between SMHO-11 and Basis-of-Comparison	Average Annual Benefit or Loss
		United States		
Lake Superior	3,721	3,810	- 89	-176
Lake Michigan*	10,100	10,011	+ 89	+145
Lake Huron*	961	949	+ 12	+ 41
Lake St. Clair*	1,355	1,357	- 2	- 2
Lake Erie	4,255	4,154	+101	+240
Lake Ontario	1,158	1,190	- 32	-118
Sub-Total	21,550	21,471	+ 79	+130
		Canada		
Lake Superior	21	26	- 5	- 9
Lake Huron*	118	98	+ 20	+ 34
Lake St. Clair*	545	434	+111	+159
Lake Erie	965	915	+ 50	+ 91
Lake Ontario	1,082	1,071	+ 11	+ 21
St. Lawrence River (Cornwall to Trois-Rivières)	- - - - - -	Negligible effect	- - - - - -	
Sub-Total	2,731	2,544	+187	+296
TOTAL	24,281	24,015	+266	+426

* 1933 outlet conditions

Table 31

EFFECTS OF PLAN SMHO-11 ON RECREATION BEACHES
($1,000)

	Basis-of-Comparison	SMHO-11	Difference Between SMHO-11 and Basis-of-Comparison	Average Annual Benefit or Loss
		United States		
	(1)	(1)		
Lake Superior	51	51	0	0
Lake Michigan *	9,830	9,613	+217	+347
Lake Huron *	1,175	1,145	+ 30	+ 86
Lake St. Clair *	17	15	+ 2	+ 5
Lake Erie	894	831	+ 63	+ 86
Lake Ontario	284	275	+ 9	+ 13
Sub-Total	12,251	11,930	+321	+537
		Canada		
	(2)	(2)		
Lake Superior	0	0	0	0
Lake Huron *	8,771	8,820	+ 49	+ 92
Lake St. Clair *	- - - - - -	Negligible effect	- - - - - -	
Lake Erie	7,806	7,853	+ 47	+ 88
Lake Ontario	5,637	5,853	+216	+405
St. Lawrence River (Cornwall to Trois-Rivières)	- - - - - -	Negligible effect	- - - - - -	
Sub-Total	22,214	22,526	+312	+585
TOTAL				+1,122

(1) Average Damage
(2) Average Value
* 1933 outlet conditions

Changes in flow patterns in the St. Clair River and the dispersal of pollutants could create conditions which would interfere with migrations of pickerel and walleye between Lake St. Clair and Lake Huron. Flow and current changes in the Anchor Bay and St. Clair Flats areas could adversely affect fisheries in these regions. Anchor Bay, in particular, is sensitive to environmental changes because of its shallow water. Severe winter kills occur occasionally in these areas now and decreases in oxygen-carrying flow in the winter could cause fish kills and destruction of other aquatic organisms.

The physical placement of structures would have a direct effect on spawning grounds and present productive areas. For example, sturgeon, a species rapidly decreasing in abundance in the Great Lakes, are known to spawn in the area. Massive physical changes and construction in the area would be detrimental to this species.

Since Plan SMHO-11 incorporates the same concept of operation of the Lake Superior control works as provided by Plan SO-901, the same types of ecological effects can be expected to occur in the St. Marys River Rapids. As explained in Subsection 8.3.3, unless mitigating measures can be taken, there would be adverse effects in the St. Marys River Rapids from this plan.

Wildlife: The water level regime of Plan SMHO-11 will adversely affect the lake margin wetland habitat and the associated wildlife resources (See Table 32). Considering the full range of fluctuation, for all the lakes, Plan SMHO-11 would result in a considerable loss of acres and values of wetland habitat in both the United States and Canada. The extent of marsh acreage loss would be greatest on Lakes Huron and Michigan with much smaller losses on Lakes Ontario and Erie in that order. Only Lake Superior shows a benefit for the wetland habitat. These acreage depletions would have an adverse influence on the wildlife resources found in the Great Lakes ecosystems from one year to the next, especially during the most critical periods of spring and fall months, when the greatest number of wildlife, primarily the migratory birds, are using the shoreline wetlands. Of all the selected plans evaluated, SMHO-11 produces the least acceptable regime of levels on Lakes Michigan-Huron for wildlife. The St. Clair and Detroit Rivers are located in two major flyways for migratory waterfowl and are important nesting areas. Therefore, increased use of the area for construction of regulatory structures, with accompanying environmental effects, could be a threat to wildlife and recreational values of the area.

Table 32

EFFECTS OF PLAN SMHO-11 ON WILDLIFE HABITAT
(Acreage)

	Basis-of-Comparison	Plan SMHO-11	Difference in Acreage (3)
		United States	
	(1)	(1)	
Lake Superior	10,490	10,265	+ 225
Lake Michigan*	13,626	14,597	- 971
Lake Huron*	20,644	22,114	-1,471
Lake Erie	15,325	15,374	- 49
Lake Ontario	8,879	9,544	- 664
Sub-Total	68,964	71,894	-2,930
		Canada	
	(2)	(2)	
Lake Superior	0	0	0
Lake Huron*	42,018	40,959	-1,059
Lake Erie	18,150	18,070	- 80
Lake Ontario	7,884	8,120	+ 236
Sub-Total	68,052	67,149	- 903
TOTAL			- 3,833

(1) Acreage lost from maximum elevation evaluated (Table 12).
(2) Acreage available.
(3) + indicates a benefit and - indicates a detriment.
* 1933 outlet conditions

Hygienic Effects: The St. Clair and Detroit Rivers contain toxic substances from industrial discharges and municipal sewage. Although the number of combined sewer outfalls in the Detroit area has been reduced, they still exist and storm sewers alone contribute greatly to decreased water quality. The St. Clair River receives untreated wastes from some small communities. Structures in either river might divert pollutants to areas now receiving relatively clean flows. Structures in both rivers would serve to pool up water and promote increases in fecal coliforms. During the construction period there would be an increase in turbidity of the water and any polluted sediments present would be redistributed. During this period water quality would be degraded with an increased hazard to human health. One of the most serious pollutants in the bottom sediments of the area is mercury. Special disposal techniques would be necessary to dredge any sediment that contains excessive mercury pollutants.

Aesthetic Effects: The St. Clair River area is bounded by small communities and in the delta area by vast open space. The Blue-Water area near Port Huron and Sarnia is a popular tourist area, widely used for boating. The entire area is of very high quality for outdoor recreation.

Nine structures provided by this plan would be located in the St. Clair and Detroit Rivers, which now are free-flowing rivers unobstructed by major structures. Aesthetic impact was given strong consideration in the selection of the type of control structure. A singular feature of the sites is the low hydraulic head across the structures and full advantage is taken of this with the proposed use of submersible gates. The ancillary works at each site have been designed to best suit the setting at each site. The training walls at each site would be about six feet above the water surface and would restrict the view of the river to small boaters in the immediate vicinity.

Social Well-Being: Since present recreation values in the connecting channel area affected by this plan are such an important resource, the effect on social well-being provided by this plan are of importance.

A navigation passage for small boats would be provided through each structure in each channel. Due to the small head differentials, gates are not required in these passages and the velocity will be restricted. Some of these structures lend themselves to development of recreation areas in their lee; and consequently, adjacent marinas are anticipated and provided for in the cost estimates. It would be expected that recreation values would be gained from these structures.

In the St. Clair River area the small communities have close ties to the river in its present condition, relying on it for water, income, recreation, and community identity. The regulatory works have been designed so as to preserve and enhance these ties.

9.4 Regulatory Works

Plan SMHO-11 would require additional regulatory works in the St. Clair and Detroit Rivers. Those presently in the St. Marys and St. Lawrence Rivers are adequate for this regulation plan, provided that modifications are made to the Lake Superior control works to insure reliable winter operation. The design and costs of these modifications, described in Section 8, apply to SMHO-11.

Plan SMHO-11 would require a channel capacity increase of 11,000 cfs in the St. Clair and Detroit Rivers from 1933 channel conditions. Because of dredging since 1933, the existing St. Clair River channel is adequate to accommodate this flow increase. However, the existing Detroit River channel capacity must be increased by 5,000 cfs at a total capital cost of $55.7 million.

SMHO-11 requires a capability to retard flow by 29,000 cfs in the St. Clair and Detroit Rivers relative to 1933 conditions. Cost curves were developed for regulatory works in the St. Clair and Detroit Rivers that would raise the river profiles and reduce flows by various amounts. The St. Clair River cost curve indicates that four structures with a total capital cost of $84 million are required to restore the 1933 profile and reduce flows in that river by 29,000 cfs. The proposed St. Clair River control structures are located as follows:

(a) Port Huron
(b) Stag Island
(c) St. Clair
(d) North and Middle Channels

The Detroit River cost curve shows that five structures with a total capital cost of $100 million are required to restore the 1933 profile and reduce flows in that river by 29,000 cfs. These structures are located in the following areas of the Detroit River:

(a) Head of Detroit River, north and south of Peach Island
(b) Belle Isle
(c) Zug Island
(d) East Fighting Island (Grassy Island)
(e) Trenton Channel

The location of each of these structures is shown on Figure 15. A conceptual sketch of a structure is shown on Figure 16.

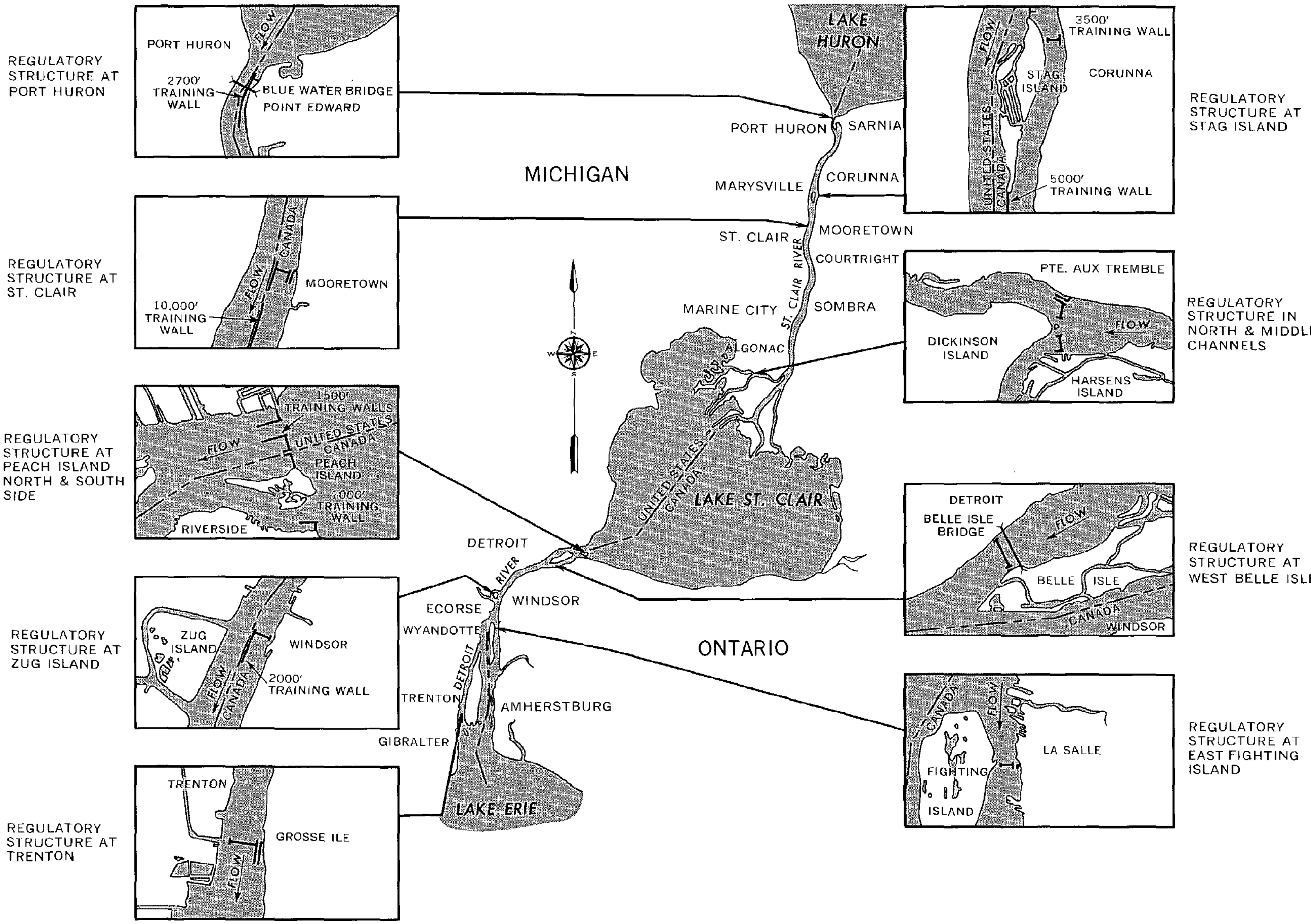
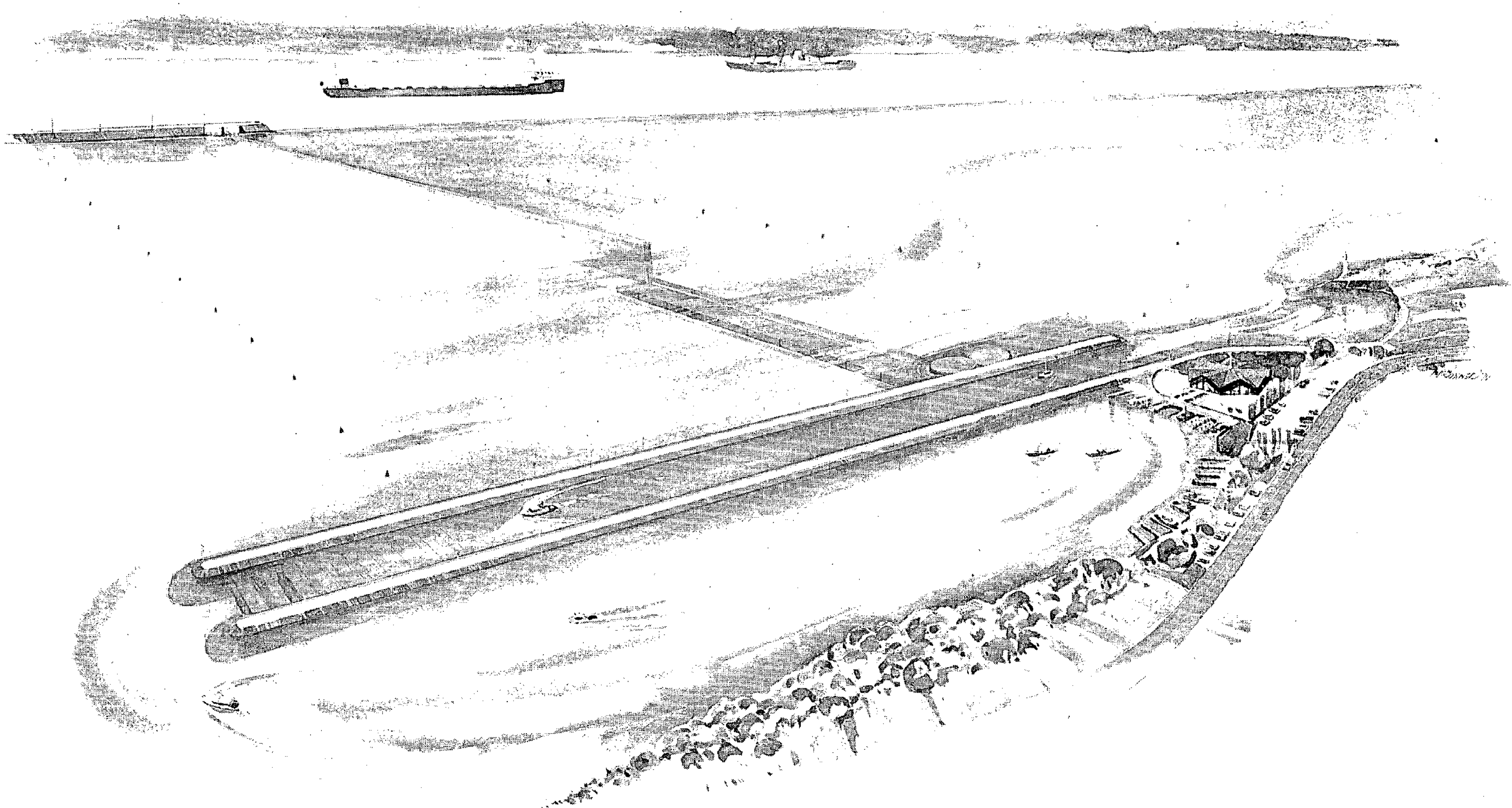


Figure 15
LOCATION OF PROPOSED ST. CLAIR-DETROIT RIVERS STRUCTURES



SOURCE: H.G. ACRES, ST. CLAIR DETROIT RIVERS CONCEPT OF REGULATORY STRUCTURES VOL. I CONCEPTUAL DESIGN AND ESTIMATES, APRIL 1972.

Figure 16

CONCEPTUAL SKETCH OF REGULATORY STRUCTURE

The total capital cost for Lakes Michigan-Huron regulatory works for regulation Plan SMHO-11 would be $239.7 million including dredging costing $55.7 million. It is estimated that construction of the St. Clair and Detroit Rivers regulatory control structures would require 6 years to complete. Table 33 gives details of the cost estimates of the regulatory works.

These cost estimates are based on conceptual designs which meet the distinctive requirements involved in control of the St. Clair and Detroit Rivers. The three main requirements are: (a) to permit commercial navigation through the main shipping channel without hindrance of a lockage system; (b) to maintain the river profile within the limits imposed by shoreline developments; and, (c) to provide adequate depths for navigation in the channels. The first of these needs is met by locating the structures only across secondary channels so as to leave the main shipping channel unblocked. The second and third needs result in a series of low-head structures, i.e., having a water level differential in the order of one foot and, in many cases, much less. It is not possible to fully control the outlet of Lake Huron by means of a single structure and at the same time meet these three requirements.

The conceptual designs which evolved embody the following principal features of interest (See Figure 17):

(a) Floating flap gates, double-hinged at their lower extremity, mounted on a concrete boxed shell on gravel bed foundations. The gates would be raised by pumping air into them and lowered by flooding them. The double-hinging is a device to accommodate critical loadings from potential seismic forces. The gates are designed to allow river ice to pass over them instead of being impounded and exerting heavy pressures on the gates and supporting structure. This concept eliminates the need for gate moving machinery, expensive piling, and massive unsightly piers and superstructure.

(b) Facilities to permit the safe passage of recreational boating in the secondary channels without introducing gated locks. The proposed design involves parallel rockfill embankments creating a passage in which water velocities would be held back to tolerable limits by means of bottom-roughening sills.

(c) Although a novel floating diaphragm type of training wall was conceived, and is considered to be a more economical solution, the cost estimates for training walls and dykes are based on conventional rockfill construction and are therefore conservative.

(d) The use of a modular concept permits design and construction standardization for all the structures and hence cost economies.

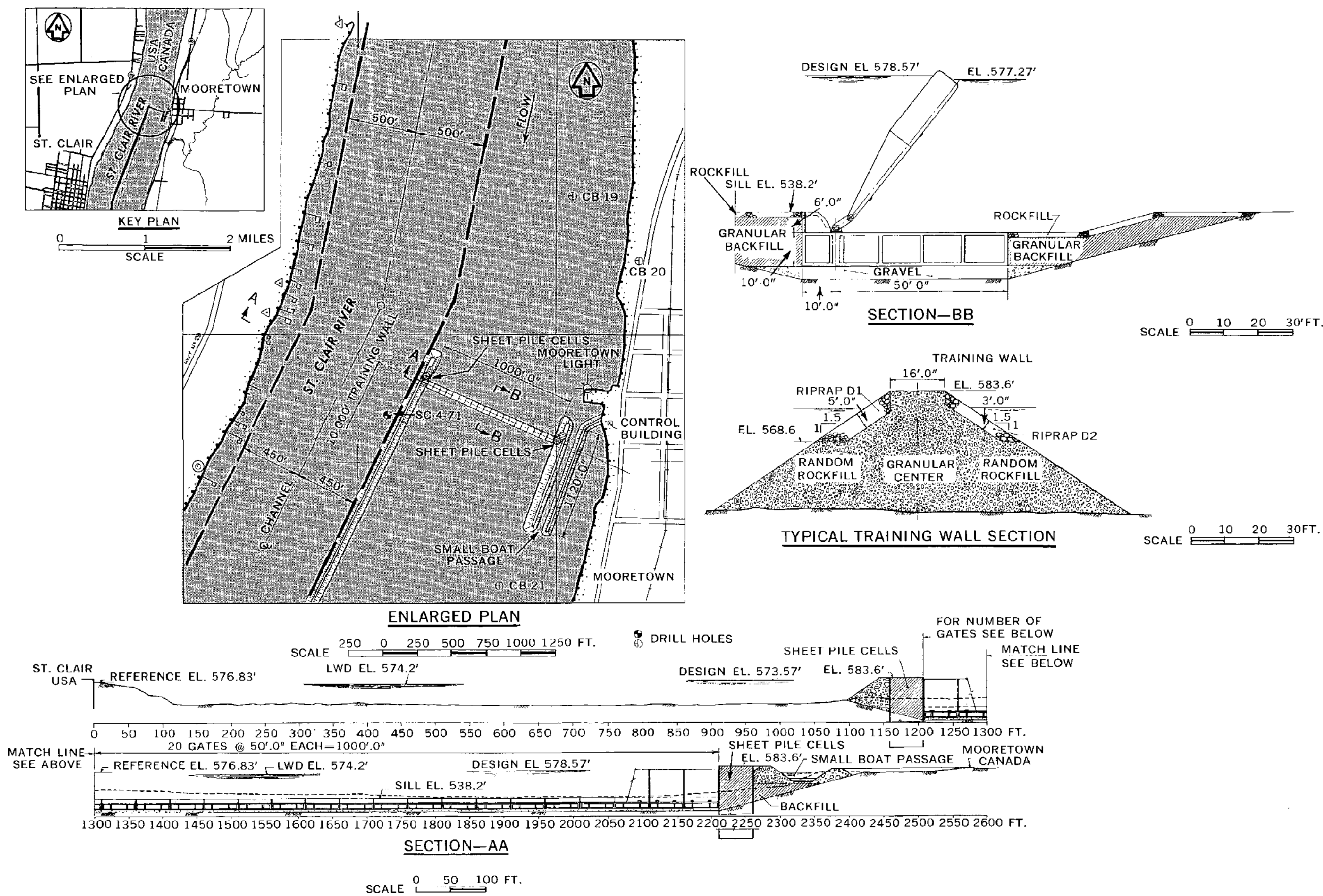


Figure 17

REGULATORY STRUCTURE AT ST. CLAIR, MICHIGAN

Table 33

SUMMARY OF ESTIMATED COSTS OF
REGULATORY WORKS REQUIRED
FOR
PLAN SMHO-11
($1,000)

	Lake Outlet			
	Superior	Michigan-Huron	Ontario	Total
Total First Costs	574	198,100	0	198,674
Total Capital Costs at End of Construction Period	574	239,700	0	240,274
Annual Interest and Amortization	43	17,369	0	17,412
Annual Operation and Maintenance	27	564	0	591
Total Annual Costs	70	17,933	0	18,003

(e) An overall design which serves to alleviate some of the significant problems usually associated with locks and dams during both construction and operation. More details on the designs envisioned are given in Appendix G - Regulatory Works.

9.5 Potential Benefit from SMHO Plan

SMHO-11 is a trial plan, not a refined plan. Because its cost would be so much greater than its benefits, no attempt was made to refine it and optimize benefits. However, the following comparison of SMHO-11 with trial and refined SO plans suggests the upper limit of benefits obtainable with a plan satisfying SMHO-11 objectives.

($ 1,000)

	Trial Plan SO-802	Refined Plan SO-901		Trial Plan SMHO-11	
	(Prelim. eval. Table 14)	(Prelim. eval. Table 23)	(Detail. eval. Table 24)	(Prelim. eval. Table 25)	(Detail. eval. Table 27)
Navigation	$ +600	$ +800	$ +927	$ +600	$ +295
Power	0	+400	+640	-400	- 10
Shore Property	+700	+900	+803	+1,500	+1,547
Totals	$+1,300	$+2,100	$+2,370	$+1,700	$+1,832

The table shows that there is about a 10% increase in benefits from the preliminary evaluation to the detailed evaluation for Plan SO-901 and Plan SMHO-11. There is also about a 60% improvement in benefits from the trial SO plan to the refined SO plan based upon the preliminary evaluations. Assuming a similar potential for refining and improving the benefits from a SMHO plan, the Board estimates the upper limit of benefits to be about $3 million.

The comparison raises the question of why a refined SMHO plan, with an average annual cost of $18 million, would produce only $0.5 million more in benefits than Plan SO-901, with an average annual cost of only $70,000. There are two main reasons. First, the benefits of both plans are derived mainly from reducing the range of stage on Lakes Michigan-Huron and Lake Erie. Most of this reduction is achieved with Plan SO-901 and only a small additional amount can be obtained by regulating the outflow of Lake Huron. Second, the reduction in the range of stage is achieved by balancing the storage on the lakes. The amount of balancing that can be done is severely limited as long as Lake Erie is not regulated and its outflow is determined by the natural stage-discharge relationships of the Niagara River. The large difference in cost is due to the fact that SO-901 employs existing regulatory works, whereas a SMHO plan would require major new construction.

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 over Plan SO-901 of 0.03.

9.6 Summary

The Board has developed and evaluated a plan, SMHO-11, formulated on the principle of balancing storage among the upper four lakes in such a way as to maintain their mean lake levels. This analysis has demonstrated that the benefits of such a four-lake plan are completely outweighed by the cost of the necessary regulatory works.

SECTION 10

DEVELOPMENT AND EVALUATION OF LAKES SUPERIOR-ERIE-ONTARIO PLANS

10.1 General

This section considers plans for the coordinated regulation of the three lakes, Superior, Erie and Ontario. Three approaches were investigated, all using the existing regulatory works for Lake Superior and Lake Ontario and preserving the existing criteria and other requirements of the IJC Orders of Approval governing the regulation of Lake Ontario. Initial studies concerned regulation of Lake Erie with channel enlargement and a control structure in the upper Niagara River. These studies revealed that the benefits of such regulation were derived more from lowering the mean level of Lake Erie than from any reduction in the range of stage. Therefore, a second approach studied was channel enlargement only in the upper Niagara River with regulation of Lakes Superior and Ontario in accordance with Plan SO-901. It should be noted that in this approach only Lakes Superior and Ontario would continue to be directly controlled; Lake Erie levels would fluctuate naturally in a lower range. Finally, studies were made of 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. In this third approach, termed "partial regulation," the rule curves for Lake Ontario Regulation Plan 1958-D were modified to avoid detriments to Lake Ontario and downstream interests which otherwise would have resulted from the increased discharges from Lake Erie.

10.2 Trial Plans

The objectives for the initial trial plans were:

(a) Maximum economic benefits for the system - SEO-16;

(b) No loss to any major interest - SEO-13;

(c) No loss to any major interest on any lake - SEO-12;

(d) No change in the mean lake levels and a reduction in range of stage - SEO-6; and

(e) Satisfaction of the present Lakes Superior and Ontario criteria - SEO-17.

Trial regulation plans, with the designated nomenclature noted above, were developed for the purpose of satisfying the stated objectives, employing the techniques previously described. Table 34 shows the range of stage and the approximate economic benefits and losses obtained from the generalized loss curves for these trial regulation plans over the study period. Shown also on this table are the basis-of-comparison data for each lake.

The Board, after reviewing the results shown on Table 34 sought an improved plan for the coordinated regulation of Lakes Superior, Erie and Ontario providing significant benefits to the users of the system without resulting in any appreciable loss to any major interest on any lake or on the St. Lawrence River.

10.3 Selected Plans

Plans were developed and evaluated for the three alternative approaches to SEO regulation as follows:

(a) Channel enlargement and control works in the upper Niagara River - SEO-33;

(b) Channel enlargement only in the upper Niagara River - SEO-901; and

(c) Black Rock Canal diversion up to 8,000 cfs during periods of above average supply - SEO-42P.

10.3.1 Hydrologic Effects

Table 35 presents a summary of the levels and flows for the three selected plans and the basis-of-comparison.

Plan SEO-33 would raise the maximum and minimum monthly levels on Lake Superior with little change in the mean level of that lake. The range of mean monthly outflows would remain unchanged, but there would be an increase in the frequency of low flows. This plan would lower the maximum and mean monthly levels of Lakes Michigan-Huron while the minimum level on that lake would be raised. Plan SEO-33 would lower the maximum and mean monthly levels of Lake Erie while raising the minimum level. This plan would raise the maximum and minimum monthly levels on Lake Ontario while lowering the mean level. Plan SEO-33 does not satisfy a number of the criteria of Lake Ontario regulation.

Table 34

REGULATION OF LAKES SUPERIOR, ERIE AND ONTARIO
SUMMARY OF RANGES OF STAGE AND ECONOMIC **EVALUATIONS OF** TRIAL PLANS

Lake Levels (feet)

	Basis-of-Comparison	a SEO-16	b SEO-13	c SEO-12	d SEO-6	e SEO-17
Lake Superior						
Mean	600.38	600.48	600.49	600.50	600.39	600.41
Max.	601.91	602.11	602.13	602.15	602.00	602.05
Min.	598.36	598.85	598.86	598.88	598.78	598.79
Range	3.55	3.26	3.27	3.27	3.22	3.26
Lakes Michigan-Huron*						
Mean	578.54	578.12	578.43	578.46	578.49	578.54
Max.	581.50	580.84	581.14	581.20	581.22	581.26
Min.	575.74	575.65	575.96	575.98	576.04	576.06
Range	5.76	5.19	5.18	5.22	5.18	5.20
Lake Erie						
Mean	570.60	569.48	570.30	570.39	570.47	570.59
Max.	573.01	572.06	572.85	573.02	572.85	573.06
Min.	567.95	566.85	567.74	567.78	567.96	568.04
Range	5.06	5.21	5.11	5.24	4.89	5.02
Lake Ontario						
Mean	244.53	244.39	244.54	244.50	244.57	244.69
Max.	246.95	247.08	247.42	247.10	247.25	247.24
Min.	241.31	241.92	241.95	241.96	241.83	241.78
Range	5.64	5.16	5.47	5.14	5.42	5.46

Approximate Annual Benefits ($ Millions)

	Basis-of-Comparison	a SEO-16	b SEO-13	c SEO-12	d SEO-6	e SEO-17
Power	0.0	-0.5	0.0	0.0	-0.5	+0.2
Navigation	0.0	-0.1	+0.9	+1.1	+0.7	+0.8
Shore Property	0.0	+8.7	+3.5	+3.1	+2.7	+0.9
Total	0.0	+8.1	+4.4	+4.2	+2.9	+1.9

Geographical Breakdown of Shore Property Benefits ($ Millions)

	Basis-of-Comparison	a SEO-16	b SEO-13	c SEO-12	d SEO-6	e SEO-17
Superior	0.0	-0.2	-0.2	-0.2	-0.1	-0.2
Michigan-Huron	0.0	+5.2	+2.3	+1.9	+1.6	+1.0
Erie	0.0	+2.6	+1.1	+0.8	+0.7	+0.1
Ontario	0.0	+1.1	+0.3	+0.6	+0.5	0.0
Total	0.0	+8.7	+3.5	+3.1	+2.7	+0.9

* 1933 outlet conditions

Table 35

REGULATION OF LAKES SUPERIOR, ERIE AND ONTARIO
SUMMARY OF RANGES OF STAGE IN FEET
AND OUTFLOW IN THOUSANDS OF CUBIC FEET PER SECOND

	Basis-of-Comparison		SEO-901		SEO-42P		Basis-of-Comparison		SEO-33	
	Stage	Outflow	Stage	Outflow	Stage	Outflow	Stage	Outflow	Stage	Outflow
Lake Superior										
Mean	600.38	77	600.41	77	600.37	77	600.38	77	600.39	77
Maximum	601.91	123	602.00	123	601.95	123	601.91	123	602.01	123
Minimum	598.36	55	598.81	55	598.76	55	598.36	55	598.79	55
Range	3.55	68	3.19	68	3.19	68	3.55	68	3.22	68
Lakes Michigan-Huron	(1962 outlet conditions)						(1933 outlet conditions)			
Mean	577.95	183	577.89	183	577.86	183	578.54	183	578.48	183
Maximum	580.91	233	580.57	227	580.52	227	581.50	233	581.20	227
Minimum	575.15	107	575.39	113	575.39	113	575.74	107	576.02	111
Range	5.76	126	5.18	114	5.13	114	5.76	126	5.18	116
Lake Erie										
Mean	570.60	204	570.42	204	570.36	204	570.60	204	570.45	204
Maximum	573.01	258	572.85	259	572.69	259	573.01	258	572.90	266
Minimum	567.95	149	567.95	152	567.97	149	567.95	149	568.02	154
Range	5.06	109	4.90	107	4.72	110	5.06	109	4.88	112
Lake Ontario										
Mean	244.53	238	244.55	238	244.48	238	244.53	238	244.41	238
Maximum	246.95	310	246.92	310	246.89	310	246.95	310	247.05	310
Minimum	241.31	176	241.53	188	241.29	188	241.31	176	241.75	179
Range	5.64	134	5.39	122	5.60	122	5.64	134	5.30	131

Plan SEO-901 would raise the mean monthly levels of Lake Superior. The range of mean monthly outflows would remain unchanged, but there would be an increase in the frequency of low flows. This plan would lower the maximum and mean monthly levels of Lakes Michigan-Huron while the minimum level on that lake would be raised. Plan SEO-901 would lower the maximum and mean monthly levels of Lake Erie while maintaining the same minimum level. This plan would produce little change in the maximum and mean monthly levels of Lake Ontario, while moderately raising its minimum level.

Plan SEO-42P lowers the mean levels of all lakes. Similar to SEO-33, the range of monthly mean outflows on Lake Superior would remain unchanged, but there would be an increase in the frequency of low flows. The maximum levels would be lowered on Lakes Michigan-Huron and Erie. A minor lowering of maximum level occurs on Lake Ontario with the maximum level raised slightly on Lake Superior. The minimum levels are raised on Lakes Superior and Michigan-Huron with Lakes Erie and Ontario remaining about the same. The range of stage is decreased on all lakes. The reduction in range of stage on Lake Erie is the same for Plans SEO-33 and SEO-901 where Lakes Michigan-Huron are not regulated. However, the reduction in range of monthly mean level on Lake Erie under Plan SEO-42P is greater because the rule curve for Plan 1958-D was adjusted to allow greater discharges out of Lake Ontario while still adhering to the maximum flow limitation of 310,000 cfs.

10.3.2 Economic Effects

Tables 36-38 summarize the results of the detailed economic evaluations of Plans SEO-33, SEO-901 and SEO-42P.

Commercial Navigation: As shown in Table 39, Plan SEO-33 would provide navigation benefits totalling $324,000 of which $236,000, or 73%, would accrue to the United States fleet, derived primarily from benefits to the iron ore traffic ($235,000). The remaining 27%, or $88,000, would accrue to the Canadian fleet with most of the benefits deriving from the grain traffic ($54,000) and iron ore traffic ($28,000).

As summarized in Table 40, Plan SEO-901 would provide $950,000 benefits, of which $745,000, or 78%, would accrue to the United States fleet deriving primarily from iron ore traffic. The remaining benefits of $205,000, or 22% of the total, would accrue to the Canadian fleet primarily as a result of the benefits to the grain ($121,000) and iron ore ($69,000) traffic.

Table 41 summarizes the effects of Plan SEO-42P on commercial navigation. Plan SEO-42P would provide average annual benefits of $630,000. This is 34% lower than the benefits provided by Plan SEO-901. Virtually all of the gain is to iron ore and grain traffic. The loss to U. S. limestone traffic is slightly greater for SEO-42P ($26,000) than for SEO-33 ($10,000). Distribution of benefits to the two nations, and to the fleets, is nearly identical for all three SEO plans.

Table 36

SUMMARY OF AVERAGE ANNUAL ECONOMIC BENEFITS OF PLAN SEO-33
($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		+ 4	- 2	0	- 3	- 1	
	Canada		0		- 3	- 2	0	0	- 5	
Michigan	U.S.				+ 863	+ 3	- 12	+ 305	+ 1,159	
Huron	U.S.				+ 316	+ 2		+ 65	+ 383	
	Canada				+ 26	- 1	0	+ 116	+ 141	
St.Clair	U.S.				+ 133			+ 5	+ 138	
	Canada				+ 216			0	+ 216	
Erie	U.S.		- 130		+ 2,645	- 5	- 13	+ 220	+ 2,847	
	Canada		+ 100		+ 332	+ 1	0	+ 198	+ 531	
Ontario	U.S.		- 140		+ 749	- 5	- 2	+ 127	+ 869	
	Canada		- 80		+ 256	+ 2	- 2	+ 384	+ 640	
Great Lakes	U.S.	+ 236	- 400	+ 480	+ 4,710	- 7	- 27	+ 719	+ 5,395	+ 5,711
	Canada	+ 88	+ 20	+ 210	+ 827	0	- 2	+ 698	+ 1,523	+ 1,841
	TOTAL	+ 324	+ 310		+ 5,537	- 7	- 29	+ 1,417	+ 6,918	+ 7,552

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

Table 37

SUMMARY OF AVERAGE ANNUAL ECONOMIC BENEFITS OF PLAN SEO-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		- 150	- 2	0	- 4	- 156	
	Canada		0		- 17	- 6	0	0	- 23	
Michigan	U.S.				+ 634	- 3	- 15	+ 653	+ 1,269	
Huron	U.S.				+ 234	- 1	0	+ 130	+ 363	
	Canada				+ 16	0	0	+ 261	+ 277	
St.Clair	U.S.				+ 124			+ 5	+ 129	
	Canada				+ 117			0	+ 117	
Erie	U.S.		+ 170		+ 2,268	- 14	- 19	+ 238	+ 2,473	
	Canada		+ 120		+ 245	- 7	- 1	+ 153	+ 390	
Ontario	U.S.		+ 50		- 86	+ 1	0	+ 12	- 73	
	Canada		+ 100		+ 4	+ 1	0	+ 0	+ 5	
Great Lakes	U.S.	+ 745	+ 90	+ 210	+ 3,024	- 19	- 34	+ 1,034	+ 4,005	+ 5,050
	Canada	+ 205	+ 220	+ 120	+ 365	- 12	- 1	+ 414	+ 766	+ 1,311
	TOTAL	+ 950	+ 640		+ 3,389	- 31	- 35	+ 1,448	+ 4,771	+ 6,361

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

Table 38

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.

Table 39

EFFECTS OF PLAN SEO-33 ON COMMERCIAL NAVIGATION FOR PROJECTED PERIOD LISTED BY COMMODITY AND COUNTRY, AND BY TRAFFIC ROUTES ($1,000)

	Transportation Cost Difference (Benefit) Between Plan SEO-33 and Basis-of-Comparison			
	(1970)	(1995)	(2020)	Equivalent Annual Benefit for 1980-2030 @ 7% Interest
		BY COMMODITY AND COUNTRY		
		U.S.A. Fleet		
Iron Ore	96	237	418	235
Coal	8	0	11	4
Limestone	4	- 4	- 49	- 10
Grain	13	4	10	7
Total	121	237	390	236
		Canadian Fleet		
Iron Ore	12	31	38	28
Coal	6	6	7	6
Limestone	0	2	- 3	0
Grain	42	52	75	54
Total	60	91	117	88
		Combined U.S.A. and Canadian Fleet		
Iron Ore	108	268	456	263
Coal	14	6	18	10
Limestone	4	- 2	- 52	- 10
Grain	55	56	85	61
Total	181	328	507	324
		BY TRAFFIC ROUTES		
S	0	0	0	0
MH	7	- 2	- 24	- 4
E	- 5	- 2	- 13	- 5
O	0	0	1	1
S-MH	31	103	185	101
S-MH-E	99	167	308	174
S-MH-E-O	40	59	78	58
MH-E	1	- 9	- 43	- 12
MH-E-O	5	8	10	7
E-O	3	4	5	4
Total	181	328	507	324

Table 40

EFFECTS OF PLAN SEO-901 ON COMMERCIAL NAVIGATION FOR PROJECTED PERIOD
LISTED BY COMMODITY AND COUNTRY, AND BY TRAFFIC ROUTES
($1,000)

	Transportation Cost Difference (Benefit) Between Plan SEO-901 and Basis-of-Comparison			
	(1970)	(1995)	(2020)	Equivalent Annual Benefit for 1980-2030 @ 7% Interest
		BY COMMODITY AND COUNTRY		
		U.S.A. Fleet		
Iron Ore	291	724	1,264	716
Coal	12	0	22	6
Limestone	9	8	- 25	3
Grain	41	9	33	20
Total	353	741	1,294	745
		Canadian Fleet		
Iron Ore	35	75	96	69
Coal	17	12	12	13
Limestone	0	3	- 3	2
Grain	97	118	170	121
Total	149	208	275	205
		Combined U.S.A. and Canadian Fleet		
Iron Ore	326	799	1,360	785
Coal	29	12	34	19
Limestone	9	11	- 28	5
Grain	138	127	203	141
Total	502	949	1,569	950
		BY TRAFFIC ROUTES		
S	1	1	1	1
MH	3	- 6	- 41	- 10
E	- 12	- 6	- 24	- 10
O	0	1	1	1
S-MH	98	315	552	306
S-MH-E	311	502	913	526
S-MH-E-O	84	122	164	120
MH-E	2	- 3	- 27	- 6
MH-E-O	13	20	27	19
E-O	2	3	3	3
Total	502	949	1,569	950

Table 41

EFFECTS OF PLAN SEO-42P ON COMMERCIAL NAVIGATION FOR PROJECTED PERIOD LISTED BY COMMODITY AND COUNTRY, AND BY TRAFFIC ROUTES
($1,000)

	Transportation Cost Difference (Benefit) Between Plan SEO-42P and Basis-of-Comparison			
	(1970)	(1995)	(2020)	Equivalent Annual Benefit for 1980-2030 @ 7% Interest
BY COMMODITY AND COUNTRY				
U.S.A. Fleet				
Iron Ore	200	496	853	488
Coal	- 1	0	18	3
Limestone	- 3	- 15	- 98	- 26
Grain	27	7	23	14
Total	223	488	796	479
Canadian Fleet				
Iron Ore	21	53	66	48
Coal	7	8	8	8
Limestone	- 1	2	- 8	0
Grain	76	92	132	95
Total	103	155	198	151
Combined U.S.A. and Canadian Fleet				
Iron Ore	221	549	919	536
Coal	6	8	26	11
Limestone	- 4	- 13	-106	- 26
Grain	103	99	155	109
Total	326	643	994	630
BY TRAFFIC ROUTES				
S	- 1	- 1	- 1	- 1
MH	- 7	- 18	- 77	- 25
E	- 15	- 6	- 29	- 12
O	0	0	0	0
S-MH	68	220	382	213
S-MH-E	215	349	630	365
S-MH-E-O	67	97	130	96
MH-E	- 14	- 17	- 64	- 24
MH-E-O	12	18	23	17
E-O	1	1	2	1
Total	326	643	994	630

All three plans would benefit navigation in every month. About 49 percent of the average annual benefits derived from either plan would occur in the summer season (June, July, August), the busiest portion of the navigation season.

Power: Table 42 summarizes the effects of Plan SEO-33 on power. The overall annual net benefit to power generation due to Plan SEO-33 is computed to be $310,000; however, not all of the power systems involved realize benefits. There would be an annual loss of $160,000 to the Upper Michigan system which would be significant in relation to the relatively small local power system involved. The annual effect on the Beauharnois and Cedars plants of the Quebec system would be a benefit of $10,000. There would be total annual benefits of $240,000 and $220,000 for the New York State system and the Ontario system, respectively. These are small in relation to the size of the systems.

Since Plan SEO-901 is a combination of Plan SO-901 with an increased, but uncontrolled, outlet capacity from Lake Erie, the effect of the resulting lower regime on Lake Erie is to lower very slightly the level of Lakes Michigan-Huron. This would tend to increase the heads at the power plants at Sault Ste. Marie. For the purpose of this study the effects of SEO-901 on these plants has been assumed to be the same as those evaluated for Plan SO-901. Plan SEO-901 would have no effect on power developments in the Niagara region or along the St. Lawrence River.

Table 43 summarizes the effects of Plan SEO-42P on power. For this plan there would be an annual loss of $160,000 to the Upper Michigan system which would be significant in relation to the relatively small local power system involved. The annual effect on the Beauharnois and Cedars plants of the Quebec system would be a loss of $10,000. There would be total annual benefits of $120,000 and $60,000 for the New York State system and the Ontario system, respectively. These are small in relation to the size of the systems.

Shore Property - Erosion and Inundation: Tables 44 and 45 summarize the effects of the three selected plans on erosion and inundation.

Plan SEO-33 would lower the high levels and raise the low levels on Lakes Michigan-Huron. Hence, it would provide a benefit of $863,000 for Lake Michigan and $342,000 for Lake Huron ($316,000 on U. S. shores and $26,000 on Canadian shores).

About 40% of benefits would be concentrated in the southern portion of Lake Michigan, with all other reaches being benefited. Similarly, all reaches on the shores of Lake Huron would be benefited. On U. S. shores, about one-half of the total benefit would accrue to the reach extending from East Tawas, Michigan, to Bay City, Michigan.

Table 42

EFFECTS OF PLAN SEO-33 ON POWER
($1,000)

System	Annual Energy Benefit	Annual Capacity Benefit	Annual Total Net Benefit
Ontario			
St. Lawrence	- 90		
Niagara	+ 100		
St. Marys	0		
Total	+ 10	+ 210	+ 220
Quebec			
Beauharnois	+ 10		
Cedars			
Total	+ 10	0	+ 10
New York State			
St. Lawrence	- 140		
Niagara	- 130		
Total	- 270	+ 510	+ 240
Upper Michigan	- 130	- 30	- 160
TOTAL	- 380	+ 690	+ 310

Table 43

EFFECTS OF PLAN SEO-42P ON POWER
($1,000)

System	Annual Energy Benefit	Annual Capacity Benefit	Annual Total Net Benefit
Ontario			
St. Lawrence	- 30		
Niagara	+ 70		
St. Marys	0		
Total	+ 40	+ 20	+ 60
Quebec			
Beauharnois	- 10		
Cedars			
Total	- 10	0	- 10
New York State			
St. Lawrence	- 50		
Niagara	+ 60		
Total	+ 10	+ 110	+ 120
Upper Michigan	- 130	- 30	- 160
TOTAL	- 90	+ 100	+ 10

Table 44

EFFECTS OF PLAN SEO-33 ON EROSION AND INUNDATION
($1,000)

	Basis-of-Comparison	SEO-33	Difference Between SEO-33 and Basis-of-Comparison	Average Annual Benefit or Loss
		United States		
Lake Superior	3,721	3,719	+ 2	+ 4
Lake Michigan*	10,100	9,571	+ 529	+ 863
Lake Huron*	961	878	+ 83	+ 316
Lake St. Clair*	1,355	1,242	+ 113	+ 133
Lake Erie	4,255	3,145	+ 1,110	+ 2,645
Lake Ontario	1,158	956	+ 202	+ 749
Sub-total	21,550	19,511	+ 2,039	+ 4,710
		Canada		
Lake Superior	21	22	- 1	- 3
Lake Huron*	118	104	+ 14	+ 26
Lake St. Clair*	545	394	+ 151	+ 216
Lake Erie	965	787	+ 178	+ 332
Lake Ontario	1,082	945	+ 137	+ 256
Sub-total	2,731	2,252	+ 479	+ 827
TOTAL	24,281	21,763	+ 2,518	+ 5,537

* 1933 outlet conditions

Table 45

EFFECTS OF PLANS SEO-42P AND SEO-901 ON EROSION AND INUNDATION
($1,000)

	Basis-of-Comparison	SEO-42P	Difference Between Plan SEO-42P and Basis-of-Comparison	Average Annual Benefit or Loss	SEO-901	Difference Between Plan SEO-901 and Basis-of-Comparison	Average Annual Benefit or Loss
United States							
Lake Superior	3,721	3,645	+ 76	+ 150	3,796	- 75	- 150
Lake Michigan*	7,210	6,642	+ 568	+ 926	6,821	+ 389	+ 634
Lake Huron*	649	568	+ 81	+ 300	586	+ 63	+ 234
Lake St. Clair*	1,260	1,127	+ 133	+ 157	1,155	+ 105	+ 124
Lake Erie	4,255	2,925	+ 1,330	+ 3,165	3,302	+ 953	+ 2,268
Lake Ontario	1,158	984	+ 174	+ 644	1,181	- 23	- 85
Sub-Total	18,253	15,891	+ 2,362	+ 5,342	16,841	+ 1,412	+ 3,025
Canada							
Lake Superior	20	18	+ 2	+ 3	30	- 10	- 17
Lake Huron*	67	56	+ 11	+ 16	57	+ 10	+ 16
Lake St. Clair*	465	288	+ 177	+ 248	382	+ 83	+ 117
Lake Erie	965	746	+ 219	+ 344	809	+ 156	+ 244
Lake Ontario	1,082	1,015	+ 67	+ 105	1,080	+ 2	+ 4
St. Lawrence River (Cornwall to Trois-Rivières)	- - - - - - Negligible Effect - - - - - -				- - - - Negligible Effect - - - -		
Sub-Total	2,599	2,123	+ 476	+ 716	2,358	+ 241	+ 364
TOTAL	20,852	18,014	+ 2,838	+ 6,058	19,199	+ 1,653	+ 3,389

* 1962 outlet conditions

The largest part of the erosion and inundation benefits of Plan SEO-33 is provided to Lake Erie, as a result of lowering the maximum and minimum levels of that lake. A total of $2,645,000 would accrue to the U. S. shores and $332,000 to the Canadian shores. A further benefit of about $1,005,000 will accrue to Lake Ontario, about 75% of which will be on the U. S. shore.

Plan SEO-901 would provide an average annual benefit on Lake Michigan of $634,000; while on Lake Huron it would provide benefits of of $234,000 on U. S. and $16,000 on Canadian shores.

On Lake Erie, Plan SEO-901 would lower the long-term monthly mean levels about 0.2 foot, a major benefit for erosion and inundation to the entire shoreline. There would be a large decrease in shoreline damages due to such changes. The annual benefit provided would be $2,268,000 to United States shores and $244,000 to Canadian shores.

On Lake Ontario, Plan SEO-901 would result in very slight increases in some monthly levels during periods of increased storm activity producing a loss on United States shores of $85,000, but a relatively small benefit of $4,000 on the Canadian shoreline.

Plan SEO-42P in general would lower the mean level of all lakes and hence provide benefits to all lakes in both United States and Canada. U. S. shores of Lake Erie experience a large benefit of $3,165,000 and Canadian shores experience a benefit of $344,000. Also, Lake Michigan gets a benefit of $926,000. The plan produces an overall erosion and inundation benefit of $5,342,000 to U. S. shores and $716,000 to Canadian shores for a total benefit of $6,058,000.

Shore Property - Recreation Beaches: Table 46 shows that Plan SEO-33 is beneficial to recreation beaches since the lower regime of lake levels provides greater areas of beach during the period June through September. Plan SEO-33 would provide a benefit to U. S. beach areas of $719,000 and to Canadian beach areas of $698,000 for a total benefit of $1,417,000.

Table 47 shows that Plans SEO-42P and SEO-901 produce benefits to recreation beaches since these plans would lower the lake levels in general and hence greater areas of beaches would become exposed. The majority of the benefits accrue to Lakes Michigan-Huron, Erie and Ontario. Plan SEO-901 would provide benefits of $1,034,000 to U. S. beach areas and $414,000 to Canadian beach areas, for a total benefit of $1,448,000. Plan SEO-42P produces an overall benefit of $1,409,000 to U. S. beaches and $767,000 to Canadian beaches, for a total benefit of $2,176,000.

Table 46

EFFECTS OF PLAN SEO-33 ON RECREATION BEACHES
($1,000)

	Basis-of-Comparison	SEO-33	Difference Between SEO-33 and Basis-of-Comparison	Average Annual Benefit or Loss
		United States		
	(1)	(1)		
Lake Superior	51	53	- 2	- 3
Lake Michigan *	9,830	9,625	+ 205	+ 305
Lake Huron *	1,175	1,145	+ 30	+ 65
Lake St. Clair *	17	15	+ 2	+ 5
Lake Erie	894	766	+ 128	+ 220
Lake Ontario	284	196	+ 88	+ 127
Sub-Total	12,251	11,800	+ 451	+ 719
		Canada		
	(2)	(2)		
Lake Superior	0	0	0	0
Lake Huron *	8,771	8,832	+ 61	+ 116
Lake St. Clair *	- - - - - - - - -	Negligible effect	- - - - - - - - -	
Lake Erie	7,806	7,910	+ 104	+ 198
Lake Ontario	5,637	5,839	+ 202	+ 384
St. Lawrence River (Cornwall to Trois-Rivières)	- - - - - -	No change due to regulation	- - - - -	
Sub-Total	22,214	22,581	+ 367	+ 698
TOTAL				+ 1,417

(1) Average Damage
(2) Average Value
* 1933 outlet conditions

Table 47

EFFECTS OF PLANS SEO-42P AND SEO-901 ON RECREATION BEACHES
($1,000)

	Basis-of-Comparison	SEO-42P	Difference Between SEO-42P and Basis-of-Comparison	Average Annual Benefit or Loss	SEO-901	Difference Between SEO-901 and Basis-of-Comparison	Average Annual Benefit or Loss
United States							
	(1)	(1)			(1)		
Lake Superior	51	50	+ 1	+ 1	54	- 3	- 4
Lake Michigan *	7,301	6,763	+ 538	+ 850	6,888	+ 413	+ 653
Lake Huron *	866	800	+ 66	+ 168	815	+ 51	+ 130
Lake St. Clair *	15	12	+ 3	+ 8	13	+ 2	+ 5
Lake Erie	894	661	+ 233	+ 319	720	+ 174	+ 238
Lake Ontario	284	242	+ 42	+ 63	276	+ 8	+ 12
Sub-Total	9,411	8,528	+ 883	+ 1,409	8,766	+ 645	+ 1,034
Canada							
	(2)	(2)			(2)		
Lake Superior	0	0	0	0	0	0	0
Lake Huron *	9,108	9,190	+ 82	+ 156	9,245	+ 137	+ 261
Lake St. Clair *	- - - - - -	Negligible effect	- - - - - -	- - - - - -	- - -	Negligible effect	- - - -
Lake Erie	7,806	7,945	+ 139	+ 222	7,888	+ 82	+ 153
Lake Ontario	5,637	5,880	+ 243	+ 389	5,637	+ 0	+ 0
St. Lawrence River (Cornwall to Trois-Rivières)	- - - - - -	Negligible effect	- - - - - -	- - - - - -	- - -	Negligible effect	- - - -
Sub-Total	22,551	23,015	+ 464	+ 767	22,770	+ 219	+ 414
TOTALS				+ 2,176			+ 1,448

(1) Average Damage
(2) Average Value
* 1962 outlet conditions

10.3.3 Environmental Effects

Plans SEO-33, SEO-901 and SEO-42P require regulatory works to be constructed in the Niagara River in addition to the modifications to the Lake Superior Control Structure in the St. Marys River. A description of the necessary regulatory works for each plan is provided in Subsection 10.4. Since all of these plans incorporate the same concept of operation of the Lake Superior control works as provided for by Plan SO-901, the same types of ecological effects can be expected to occur in the St. Marys River Rapids. As explained in Subsection 8.3.3, unless mitigation measures can be taken, there would be adverse effects in the St. Marys River Rapids from these plans.

Other possible environmental impacts occurring on the Great Lakes, and particularly in the Niagara River, due to these plans are described below.

Fishery: Sport fisheries in the upper Niagara River are very productive and provide muskellunge, rainbow trout and smallmouth bass. The dredging and blasting operations required by Plans SEO-901 and SEO-33 could cause effects which would be detrimental to the fisheries resources.

In the channel area, dredging operations would disturb the bottom and destroy living organisms in the immediate area. However, the disruption in the productivity of the dredged area would be only temporary. Plan SEO-33 requires dredging of 0.4 square mile of river bottom which is less than 1% of the Niagara River area upstream of Niagara Falls. Plan SEO-901 requires dredging of only 0.05 square mile of river. During construction, water quality would be impaired by stirring of bottom materials and by sedimentation. Disruption of flow patterns may result from the Plan SEO-33 control structure. Sedimentation and changes in water quality and flow patterns are of concern as to the effect on the species composition of the aquatic community. Sedimentation may have adverse effects on fish spawning areas. Changes in flow patterns could affect the distribution of pollutants and the dissolved oxygen content of the river waters to an extent great enough to alter the species composition in the aquatic community. A potential detrimental effect in the Niagara River area might be disruption of the caddis fly populations, which provide a food base for sport fish populations.

Effects on the river ecosystem, caused by physical changes in the water flows and levels, are the most difficult to identify. Among the most serious impacts is the change in flow patterns or current velocities which may affect the movement of fish populations to and from Lake Erie and the river area. Data on these aspects are limited and detailed studies are needed.

Under natural conditions which presently exist, wind and barometric pressure affect the flow in the Niagara River and hence the water surface profile. Regulation would produce no worse conditions; in fact, the control structure would be used to modify such extreme flows.

Wildlife: Dredging operations at the mouth of the Niagara River will have temporary adverse effects on the wildlife of the upper Niagara River area which provides high quality waterfowl habitat close to a large metropolitan area. The area experiences large waterfowl concentrations during seasonal migrations, when used for staging areas and stopover points. A million or more waterfowl come to the area annually. Included in the waterfowl species that use the area are whistling swans and canvasback and redhead ducks, which are protected species.

Details of the habitat acreages affected by the Plans SEO-33, SEO-901 and SEO-42P are given in Tables 48 and 49. Considering the full range of fluctuations for all the lakes, Plan SEO-33 would result in a loss of acres and values of wetland habitat in both the United States and Canada. The extent of marsh acreage loss would be greatest on Lake Erie (2,775 acres), with progressively smaller losses on Lakes Huron (1,860 acres), Ontario (1,083 acres), and Michigan (451 acres). Only Lake Superior shows a slight benefit for the wetland habitat. These acreage depletions would have an adverse influence on the wildlife resources found in the Great Lakes ecosystems from one year to the next, especially during the most critical periods of spring and fall months when the greatest number of wildlife, primarily the migratory birds, are using the shoreline wetlands.

Plan SEO-901 would lower Lake Erie by 0.18 foot. The level of Lakes Michigan-Huron would be lowered by 0.06 foot. Reduction in wetlands would be the greatest on Lake Huron (4,905 acres), with progressively smaller losses on Lakes Erie (2,466 acres), Michigan (531 acres) and Ontario (296 acres). However, the plan would provide for longer periods of inundated wildlife lands during periods of extreme low lake levels (below the low water datum). Also, there would be a slight gain in wildlife wetlands on Lake Superior (615 acres).

Hygienic Effects: Effects related to public health aspects of the aquatic environment are mostly concerned with the level of fecal coliform bacteria present in the water and, in general, the water quality of any given body of water. Only Plan SEO-33 requires a regulatory structure to retard Lake Erie outflows from time to time. Gates of the structure could be designed to provide continuous flushing to prevent any unacceptable build-up of bacteria level or adverse impacts on the quality of the waters adjacent to the structure. The municipal water intakes for the cities of Buffalo, New York and Fort Erie, Ontario are located in Lake Erie, a considerable distance upstream of the control structure and would not be affected by Plan SEO-33.

Table 48

EFFECTS OF PLAN SEO-33 ON WILDLIFE HABITAT
(Acreage)

	Basis-of-Comparison	Plan SEO-33	Difference in Acreage (3)
	United States		
	(1)	(1)	
Lake Superior	10,490	9,945	+ 545
Lake Michigan*	13,626	14,077	- 451
Lake Huron*	20,644	21,327	- 683
Lake Erie	15,325	16,612	- 1,287
Lake Ontario	8,879	9,218	- 339
Sub-total	68,964	71,179	- 2,215
	Canada		
	(2)	(2)	
Lake Superior	0	0	0
Lake Huron*	42,018	40,841	- 1,177
Lake Erie	18,150	16,662	- 1,488
Lake Ontario	7,884	7,140	- 744
Sub-total	68,052	64,643	- 3,409
TOTAL			- 5,624

(1) Acreage lost from maximum elevation evaluated (Table 12)
(2) Acreage available
(3) + indicates a benefit and - indicates a detriment.
* 1933 outlet conditions

Table 49

EFFECTS OF PLANS SEO-42P AND SEO-901 ON WILDLIFE HABITAT
(Acreage)

	Basis-of-Comparison	SEO-42P	Difference in Acreage	SEO 901	Difference in Acreage (3)
		United States			
Lake Superior	(1) 10,490	(1) 10,085	+ 405	(1) 9,875	+ 615
Lake Michigan*	16,201	16,830	- 628	16,733	- 531
Lake Huron*	24,546	25,497	- 952	25,350	- 805
Lake Erie	15,325	16,544	- 1,219	16,238	- 913
Lake Ontario	8,879	9,021	- 142	8,921	- 42
Sub-total	75,441	77,977	- 2,536	77,117	- 1,676
		Canada			
Lake Superior	(2) 0	(2) 0	0	(2) 0	0
Lake Huron*	27,350	26,160	- 1,190	23,250	- 4,100
Lake Erie	18,150	15,682	- 2,468	16,597	-1,553
Lake Ontario	7,884	7,592	- 292	7,630	- 254
Sub-total	53,384	49,434	- 3,950	47,477	- 5,907
TOTAL			- 6,486		- 7,583

(1) Acreage lost from maximum elevation evaluated (Table 12)
(2) Acreage available
(3) + indicates a benefit and - indicates a detriment
* 1962 outlet conditions

Water quality concerns include the presence and distribution of toxic substances, pesticides, disease transmittal, and any other substances in the water which would create environmental conditions that could be injurious to human health. Plan SEO-42P requires a diversion canal excavated on Squaw Island across the City of Buffalo's sanitary land fill. Special handling of excavated material during construction would be essential in order to prevent any spoils from entering the river.

Dredging required by Plans SEO-33 and SEO-901 could cause changes in flow pattern and alter the distribution of pollutants.

Aesthetic Effects: Plan SEO-901 does not require the erection of regulatory structures which might impact upon the visual aesthetics of the lakes and connecting rivers and channels. The plan does require dredging in the upper Niagara River. During the dredging operations there would be increased noise levels from the operation of dredging equipment and increased turbidity in the waters of the Niagara River. Aside from these temporary and localized impacts, implementation of Plan SEO-901 should not cause any other visual, olfactory or auditory pollution. The two-inch lowering of the mean level of Lake Erie would result in a subtle spatial shift in ecological communities. Man's sensitivity to the long range aesthetic aspects of such changes would be low.

Plan SEO-33 requires the erection of regulatory structures in the Niagara River. During construction, there would be temporary localized impacts of increased noise levels and increased turbidity of the waters of the Niagara River. Probably the most significant long range aesthetic impacts of Plan SEO-33 would be the effect of the regulatory structure upon the visual aesthetics of the Niagara River. The aesthetic impact of such a structure is a relative thing and depends primarily upon the compatibility of the structure with the setting. Since the shores of the Niagara River in the vicinity are highly developed, the aesthetic impact of the regulatory structure should be relatively minor.

Plan SEO-42P involves a scheme for diversion of water from Lake Erie via the Black Rock Canal and a proposed diversion channel bisecting Squaw Island between the International Railroad Bridge and the Black Rock Lock. Construction of the 1200-foot long diversion channel and related control works would cause temporary increases in in noise level and turbidity in the Niagara River. However, construction of the channel would not require the loss of any unique wildlife habitat or scenic landscapes. Aside from the impacts of construction, there would not likely be any discernible aesthetic impacts from Plan SEO-42P. Comparatively speaking, there is a positive aesthetic value of Plan SEO-42P in that no visual obstructions would be required in the Niagara River.

Social Well-Being: Plans SEO-33, SEO-901, and SEO-42P are all oriented toward the broad concept of better resource management, better economic opportunities, enhancement of recreation opportunities and overall betterment of the aesthetic aspects of life on the shores of the Great Lakes. None of these plans would require forced relocation of individuals, nor cause major changes in land use or any lasting nuisance effects to man.

Specific effects of each SEO plan on the social well-being are reflected primarily through the hygienic, ecological and aesthetic effects discussed elsewhere in this subsection.

Benefits common to all of the three plans are the economic advantages effected by reduction in shore damage on Lakes Erie, St. Clair and Michigan-Huron. Also, from all three plans would come substantial recreation benefits from exposure of greater areas of beaches during the period June to September.

A potential adverse impact to Plan SEO-33 is the change in flow patterns which could alter the distribution of pollutants and contaminants. Detailed investigations of the design and of the operating characteristics of the structure would be required to minimize such potential impacts.

The benefits and costs, both economic and environmental, of alternative plans must be considered in the evaluation of relative impacts on social well-being. It has been determined that Plan SEO-33 is not economically feasible; Plans SEO-901 and SEO-42P provide essentially the same economic benefits. However, of these two plans, SEO-42P can produce such benefits with less aesthetic impact on the Niagara River and with less overall environmental detriment than Plan SEO-901. Of the three SEO plans discussed here, Plan SEO-42P appears to be the most practical and efficient means for achieving the desired water level controls and thereby contributing to social well-being of the residents of the Great Lakes area.

10.4 Regulatory Works

The plans that have been studied would utilize the existing regulatory works in the St. Marys and St. Lawrence Rivers. However, modification would be required to the Lake Superior control works to ensure safe winter gate operation. The design and costs of these modifications, described in Subsection 8.3, will apply to Plans SEO-33, SEO-901 and SEO-42P. No works are proposed in the St. Clair-Detroit River system under these schemes. The summaries of costs for regulatory works for SEO Plans are shown in Tables 50, 51 and 52.

Table 50

SUMMARY OF ESTIMATED COSTS OF REGULATORY WORKS REQUIRED
FOR PLAN SEO-33
($1,000)

	Lake Outlet			
	Superior	Erie	Ontario	Total
Total First Costs	574	88,986	0	89,560
Total Capital Costs at End of Construction Period	574	107,673	0	108,247
Annual Interest and Amortization	43	7,802	0	7,845
Annual Operation and Maintenance	27	287	0	314
Total Annual Costs	70	8,089	0	8,159

Table 51

SUMMARY OF ESTIMATED COSTS OF REGULATORY WORKS REQUIRED
FOR PLAN SEO-901
($1,000)

	Lake Outlet			
	Superior	Erie	Ontario	Total
Total First Costs	574	1,270	0	1,844
Total Capital Costs at End of Construction Period	574	1,360	0	1,934
Annual Interest and Amortization	43	99	0	142
Annual Operation and Maintenance	27	0	0	27
Total Annual Costs	70	99	0	169

Table 52

SUMMARY OF ESTIMATED COSTS OF REGULATORY WORKS REQUIRED
FOR PLAN SEO-42P
($1,000)

	Lake Outlet			
	Superior	Erie	Ontario	Total
Total First Costs	574	4,900	0	5,474
Total Capital Costs at End of Construction Period	574	4,900	0	5,474
Annual Interest and Amortization	43	355	0	398
Annual Operation and Maintenance	27	25	0	52
Total Annual Costs	70	380	0	450

10.4.1 Plan SEO-33

Plan SEO-33 requires a channel capacity increase of 27,000 cfs and a channel capacity decrease of 40,000 cfs from existing conditions in the Niagara River. The former involves channel dredging in the upper part of the river at the outlet of Lake Erie; the latter requires provision of a gated control structure at the head of the river, together with ancillary dikes immediately above it. Plan SEO-33 requires a control structure consisting of an open section of river 255 feet wide, an 8-gate structure 735 feet in length, with a rock dike over the remaining 925-foot river span. Channel enlargement requires the dredging of 2.57 million cubic yards of rock material in the central 800-foot portion of the river starting from about 600 feet downstream of the structure to 10,000 feet above the structure. The channel excavation covers 0.4 square mile of river bottom.

Figure 18 shows the locations of two alternate sites at the head of the Niagara River for the purpose of regulating the levels of Lake Erie. Figure 19 is a map of the lower site structure which was selected as the most favorable location for a control structure required by Plan SEO-33. The total capital cost of Lake Erie regulatory works for SEO-33, based on 1971 price levels, is $107.7 million, comprising excavation $49.6 million, structure $52 million and shore protection works $6 million. The annual cost would be $8.1 million.

These designs do not provide for within-the-day flow variations for power, since power evaluations have indicated that the costs, about double those for the basic plan, would not be balanced by corresponding benefits.

10.4.2 Plan SEO-901

Plan SEO-901 involves dredging of the Niagara River to provide a channel capacity increase of 4,000 cfs at a capital cost of $1.36 million, and an annual cost of $99,000. No structure is required. Such a plan would require channel excavation of approximately 49,000 cubic yards of rock material in the river just below the Peace Bridge, covering a river bottom area of 27 acres or 0.05 square mile. This channel enlargement would result in a permanent general lowering of 0.18 foot on Lake Erie and 0.06 foot on Lakes Michigan-Huron.

10.4.3 Plan SEO-42P

Plan SEO-42P involves a scheme for the diversion of water from Lake Erie via the Black Rock Canal. The scheme calls for diverting 8,000 cfs through the Black Rock Canal and thence through a proposed diversion channel and control structure bisecting Squaw Island between the International Railroad Bridge and the Black Rock Lock. A diversion channel required to pass 8,000 cfs would be 35 feet wide, approximately 1,500 feet long, and would require a control structure with a 35-foot wide submersible tainter gate. The diversion channel and tainter gate were designed to pass 8,000 cfs under a design total Niagara River flow of 208,000 cfs. Maximum velocities in the canal for a discharge of 8,000 cfs are estimated to be approximately 1.5 feet per second, which is considered safe for shipping. The total capital cost of Lake Erie regulatory works for Plan SEO-42P is $4.9 million with a total annual cost of $380,000 including amortization at an interest rate of 7%. Figure 20 shows the plan and cross-sectional views of the diversion canal.

Studies were also made of diversion channels of 15,000 and 20,000 cfs capacity and their respective costs were estimated to be $6.4 million and $8.1 million. The maximum velocity in the canal would be approximately 3.7 feet per second for a design discharge of 20,000 cfs.

10.5 Summary

The Board has developed and evaluated plans for the coordinated regulation of the three lakes, Superior, Erie and Ontario, under three alternative approaches. All would employ the existing regulatory works for Lake Superior and Lake Ontario and preserving the existing criteria and other requirements of the IJC Orders of Approval governing the regulation of Lake Ontario.

- Plan SEO-33 would regulate Lake Erie with channel enlargement and control works in the upper Niagara River, based upon the principle of balancing storage in all the lakes.

- Plan SEO-901 would permanently lower the mean level of Lake Erie by channel enlargement in the upper Niagara River and employ Plan SO-901 for the regulation of Lakes Superior and Ontario.

- Plan SEO-42P would employ the Black Rock Canal to increase Lake Erie outflows during periods of above average supply, regulate Lake Superior in accordance with Plan SO-901, and use a modified Plan 1958-D rule curve for the regulation of Lake Ontario.

SEO-33 and SEO-42P are trial plans, not refined plans. SEO-901 is essentially a refined plan in that one can estimate with some precision the effects of lowering the mean level of Lake Erie by a certain amount, and the amount of lowering was determined so that the minimum level of the lake would not be changed from natural conditions. Notwithstanding the differences between trial and refined plans, the following comparison of SO-901, SEO-33, SEO-901, and SEO-42P suggests the relative merits of the three different approaches to Lake Erie regulation.

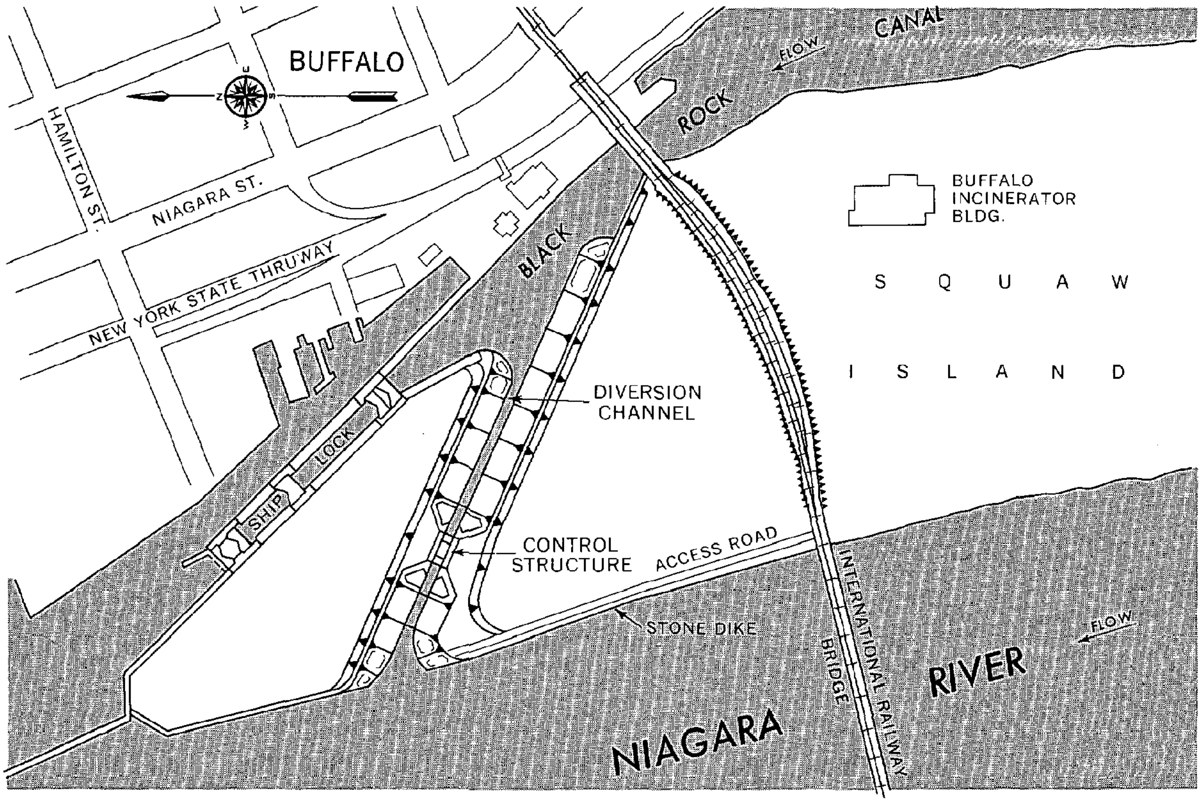
($1,000)

	Refined Plan SO-901 (Table 24)	Trial Plan SEO-33 (Table 36)	Refined Plan SEO-901 (Table 37)	Trial Plan SEO-42P (Table 38)
Annual Benefits				
Navigation	$ 927	$ 324	$ 950	$ 630
Power	640	310	640	10
Shore Property	803	6,918	4,771	8,156
Total Benefits	$2,370	$7,552	6,361	$8,796
	(Table 21)	(Table 50)	(Table 51)	(Table 52)
Annual Costs	$ 70	$8,159	$ 169	$ 450
Benefit-Cost Ratio				
Total Benefits & Costs	33.9	0.93	37.6	19.5
Incremental Benefits & Costs Over SO-901	-	0.64	40.3	16.9

Although SEO-33 provides slightly more than $7.5 million in annual benefits, the large cost of construction results in a benefit-cost ratio of 0.9. The incremental benefit-cost ratio with respect to Plan SO-901 is only 0.6.

SEO-901 provides annual benefits of almost $6.4 million at an annual cost of $169,000, giving a benefit-cost ratio of 37.6. The incremental benefit-cost ratio with respect to Plan SO-901 is 40.3. However, the concept of enduring shore property benefits from permanently lowering the lake levels is highly suspect. Such benefits could be assured only by strict controls on shoreland development which absolutely precluded encroachment as the lake receded. Furthermore, permanently lowering the lake would adversely affect the environment by reducing wetlands by 7,583 acres, predominantly on Lake Erie, but also on Lakes Michigan, Huron, and Ontario. Such lowering would be an irreversible commitment to reduce the average volume of Lake Erie by 372 billion gallons, a trend which seems fundamentally inconsistent with preservation of a great natural resource endangered with eutrophication. Finally, the enlarged channel of the Niagara River would discharge greater flows in periods of low supply, as well as in periods of high supply, risking more extreme lows than have been experienced heretofore.

SEO-42P provides annual benefits of $8.8 million at an annual cost of $450,000, giving a benefit-cost ratio of 19.5. Its incremental benefit-cost ratio with respect to Plan SO-901 is 16.9. SEO-42P achieves benefits similar to SEO-901 without making an irreversible commitment to lower permanently the average level of Lake Erie. It would maintain natural conditions during periods of low supply when the concern is to keep lake levels above minimums.



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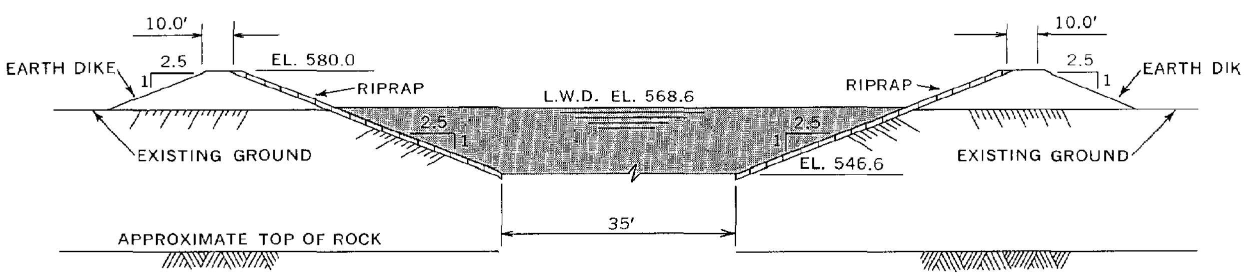


TYPICAL SECTION OF DIVERSION CHANNEL
UPSTREAM OF CONTROL STRUCTURE

Figure 20
LAKE ERIE DIVERSION VIA BLACK ROCK NAVIGATION CANAL, PLAN SEO-42P

SEO-42P is a trial plan representative of a concept, not a refined plan. SEO-42P is based on a maximum diversion through the Black Rock Canal of 8,000 cfs. A diversion as high as 30,000 cfs is possible, and much larger benefits to Lake Erie could be achieved thereby. However, the effects of increased outflows on the Niagara River hydroelectric power projects and riparian interests and on the regulation of Lake Ontario have not been adequately investigated. Therefore, SEO-42P must be viewed as a promising plan requiring further study to confirm its feasibility and optimize its design.

Section 11

DEVELOPMENT AND EVALUATION OF LAKES SUPERIOR-MICHIGAN-HURON-ERIE-ONTARIO PLANS

11.1 General

To insure a comprehensive consideration of all combinations of lakes under regulation, a study was made of plans for the regulation of all five lakes. These would require new regulation works in the St. Clair, Detroit and Niagara Rivers. However, as with the four-lake SMHO combination, preliminary estimates indicated that capital costs far outweighed the benefits. Accordingly, only one typical plan was evaluated to confirm the magnitude and distribution of benefits. No attempt was made to develop a refined operational five-lake plan. For the same reason, detailed environmental impact studies were not undertaken.

11.2 Trial Plans

The objectives for the initial trial plans were:

(a) Maximum economic benefits - SMHEO-25;

(b) No economic loss to any major interest on any lake - SMHEO-21;

(c) No change in mean lake levels - SMHEO-3;

(d) Maximum economic benefit to the system with satisfaction of the present Lakes Superior and Ontario criteria - SMHEO-26; and

(e) Reduction in range of stage on all lakes - SMHEO-7.

Trial regulation plans, with the designated nomenclatures noted above, were developed for the purpose of satisfying the stated objectives. Table 53 shows the ranges of stage and the approximate economic benefits and losses resulting from the evaluation of these trial regulation plans over the study period. Shown also in this table are the basis-of-comparison data for each lake. All the plans are beneficial to shore property interests and detrimental to power interests; while some of the plans show net benefits to navigation, others show net losses to navigation.

Table 53

REGULATION OF LAKES SUPERIOR, MICHIGAN-HURON, ERIE AND ONTARIO
SUMMARY OF RANGES OF STAGE AND ECONOMIC EVALUATIONS OF TRIAL PLANS

	Basis-of-Comparison	a SMHEO-25	b SMHEO-21	c SMHEO-3	d SMHEO-26	e SMHEO-7
Lake Levels (feet)						
Lake Superior						
Mean	600.38	600.31	600.33	600.36	600.32	600.49
Max.	601.91	602.10	602.13	602.09	602.09	602.22
Min.	598.36	598.63	598.65	598.73	598.64	598.86
Range	3.55	3.47	3.48	3.36	3.45	3.36
Lakes Michigan-Huron*						
Mean	578.54	578.06	578.12	578.46	578.18	578.48
Max.	581.50	581.02	581.01	581.24	581.11	581.31
Min.	575.74	575.38	575.49	576.02	575.55	576.17
Range	5.76	5.64	5.52	5.22	5.56	5.14
Lake Erie						
Mean	570.60	569.61	569.59	570.45	569.60	569.87
Max.	573.01	572.06	572.04	573.33	572.08	572.35
Min.	567.95	567.36	567.15	567.17	567.15	568.11
Range	5.06	4.70	4.89	6.16	4.93	4.24
Lake Ontario						
Mean	244.53	244.53	244.50	244.35	244.51	244.43
Max.	246.95	246.81	246.79	247.01	246.83	246.86
Min.	241.31	242.49	242.33	240.70	242.33	242.45
Range	5.64	4.32	4.46	6.31	4.50	4.41
Approximate Annual Benefits ($ Millions)						
Power	0.0	-0.8	-0.7	-0.2	-0.9	-1.8
Navigation	0.0	-0.5	-0.3	+0.4	-0.2	+1.2
Shore Property	0.0	+8.4	+7.9	+2.8	+7.5	+4.9
Total	0.0	+7.1	+6.9	+3.0	+6.4	+4.3
Geographical Breakdown on Shore Property Benefits ($ Millions)						
Superior	0.0	-0.2	-0.2	-0.1	-0.2	0.0
Michigan-Huron	0.0	+5.9	+5.4	+1.9	+5.0	+2.3
Erie	0.0	+2.7	+2.7	+0.6	+2.7	+2.4
Ontario	0.0	0.0	0.0	+0.4	0.0	+0.3
Total	0.0	+8.4	+7.9	+2.8	+7.5	+4.9

* 1933 outlet conditions

The trial plans indicate net benefits in excess of those obtainable from Plan SO-901. However, although substantially improving shore property benefits, they require heavy expenditure of funds for regulatory works in the St. Clair and Detroit Rivers. These costs completely outweigh the benefits and thus render SMHEO plans economically infeasible. Furthermore, construction and the changed regime in the St. Clair and Detroit Rivers would likely produce significant environmental impacts. For these reasons, extensive studies were not pursued.

11.3 Selected Plan

One typical plan was developed to provide:

(1) Minimal loss to any interest; and
(2) More beneficial range of stage.

This plan was designated SMHEO-38 and formulated on the principle of balancing storage among all the lakes.

Plan SMHEO-38 has been subjected to a detailed evaluation principally to illustrate the distribution of benefits among the lakes and between countries from regulation of Lakes Michigan-Huron and Erie, in addition to Lakes Superior and Ontario. However, as already indicated, the order of magnitude of its benefits is small in relation to the costs of the required additional works at the outlets of Lakes Huron and Erie. Only a summary of the detailed evaluation is presented in this section to illustrate the magnitude and distribution of the benefits. The detailed evaluations for each interest are presented in the appropriate appendix.

11.3.1 Hydrologic Effects

Table 54 gives a summary of ranges of stage and outflows for Plan SMHEO-38 and the basis-of-comparison. Plan SMHEO-38 raises the water levels of Lake Superior. Because these levels frequently control ship drafts in interlake movements, a benefit to navigation could be expected. On the other hand, higher levels increase erosion and inundation damages. Reduction in high levels on Lakes Michigan-Huron and Erie can be expected to decrease erosion and inundation damages. Increased minimum outflows for Lakes Erie and Ontario would provide benefits to power.

The results of Plan SMHEO-38, except in one instance, equal or meet to a better degree than the basis-of-comparison the water level and flow criteria used by the Board in evaluating all selected plans. One exception is that the maximum level of Lake Superior under Plan SMHEO-38 would exceed 602.00 feet on some occasions with the greatest difference being 0.19 foot. This criterion is not rigid in this regard since the range of levels is modified by the expression "as nearly as may be." However, for the reasons explained previously, SMHEO-38 was not refined. If refinements were justified, it is possible that these violations of the criteria could be minimized at a sacrifice in benefits.

Table 54

REGULATION OF LAKES SUPERIOR, MICHIGAN-HURON, ERIE AND ONTARIO
SUMMARY OF RANGES OF STAGE IN FEET
AND OUTFLOW IN THOUSANDS OF CUBIC FEET PER SECOND

	Basis-of-Comparison		SMHEO-38	
	Stage	Outflow	Stage	Outflow
Lake Superior				
Mean	600.38	77	600.41	77
Maximum	601.91	123	602.19	124
Minimum	598.36	55	598.74	55
Range	3.55	68	3.45	69
Lakes Michigan-Huron*				
Mean	578.54	183	578.38	183
Maximum	581.50	233	581.26	220
Minimum	575.74	107	575.90	130
Range	5.76	126	5.36	90
Lake Erie				
Mean	570.60	204	570.17	204
Maximum	573.01	258	572.89	259
Minimum	567.95	149	567.39	165
Range	5.06	109	5.50	94
Lake Ontario				
Mean	244.53	238	244.51	238
Maximum	246.95	310	247.02	308
Minimum	241.31	176	241.35	210
Range	5.64	134	5.67	98

* 1933 outlet conditions

The detailed discussions as to how well these plans meet various criteria and other hydrologic constraints are given in Appendix B - Lake Regulation. These criteria are also presented in Section 8 with reference to the detailed evaluation of Plan SO-901.

11.3.2 Economic Effects

Table 55 present the results of the detailed economic evaluations.

Commercial Navigation: Regulation Plan SMHEO-38 would produce an annual benefit of $273,000 to commercial navigation. It was found that $224,000 of the benefits would be provided to the traffic route using Lakes Superior, Michigan-Huron, and Erie (S-MH-E). An additional $137,000 would accrue to the traffic traversing Lakes Superior and Michigan-Huron (S-MH) and $56,000 to the Lakes Superior, Michigan-Huron, Erie and Ontario (S-MH-E-O) route. Losses in the order of $48,000 would accrue to the Michigan-Huron (MH) route, $25,000 to the Erie (E) route, $71,000 to the Michigan-Huron-Erie (MHE) route and $4,000 to the Erie-Ontario (EO) route. Although these losses total $148,000, the benefits of $421,000 accruing to the seven other traffic routes produce the net benefit of $273,000. This is the result of generally higher levels on Lakes Superior and Ontario and generally lower levels on Lakes Michigan-Huron and Erie. Table 56 summarizes the effects of Plan SMHEO-38 on Commercial Navigation.

Power: The overall annual net benefit to power generation due to Plan SMHEO-38 is computed to be $90,000 however, not all of the power systems involved would realize benefits. There would be an annual loss of $140,000 to the Upper Michigan system which would be significant in relation to the relatively small local power system involved. The annual effect on the Beauharnois and Cedars plants of the Quebec system would be a loss of $80,000. There would be total annual benefits of $110,000 and $200,000 for the New York State system and the Ontario system, respectively. These are small in relation to the size of the systems. A summary of the effects of Plan SMHEO-38 on power is provided in Table 57.

Shore Property - Erosion and Inundation: Table 58 provides the results of the detailed evaluation of Plan SMHEO-38. Under this plan, on Lake Superior, the annual long-term mean would be essentially unchanged; however, the range of levels in certain months would be increased. Therefore, the plan would produce annual losses to erosion and inundation of $499,000 to U. S. shores and $27,000 to Canadian shores.

Table 55

SUMMARY OF AVERAGE ANNUAL ECONOMIC BENEFITS OF PLAN SMHEO-38
($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.		- 120		- 499	- 1	0	- 4	- 504	
	Canada		0		- 27	- 1	0	0	- 28	
Michigan	U.S.				+ 970	0	0	+ 1,019	+ 1,989	
Huron	U.S.				+ 178	0	- 32	+ 259	+ 405	
	Canada				+ 61	0	0	+ 196	+ 257	
St.Clair	U.S.				+ 234			+ 14	+ 248	
	Canada				+ 428			0	+ 428	
Erie	U.S.		- 200		+ 4,637	- 39	- 37	+ 580	+ 5,141	
	Canada		0		+ 682	+ 4	- 1	+ 482	+ 1,167	
Ontario	U.S.		+ 20		- 137	0	0	+ 62	- 75	
	Canada		- 90		+ 48	+ 3	0	+ 586	+ 637	
Great Lakes	U.S.	+ 204	- 300	+270	+ 5,383	- 40	- 69	+ 1,930	+ 7,204	+ 7,378
	Canada	+ 69	- 90	+210	+ 1,192	+ 6	- 1	+ 1,264	+ 2,461	+ 2,650
	TOTAL	+ 273	- 90		+ 6,575	- 34	- 70	+ 3,194	+ 9,665	+10,028

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

Table 56

EFFECTS OF PLAN SMHEO-38 ON COMMERCIAL NAVIGATION FOR PROJECTED PERIOD
LISTED BY COMMODITY AND COUNTRY, AND BY TRAFFIC ROUTES
($1,000)

Transportation Cost Difference (Benefit) Between Plan SMHEO-38 and Basis-of-Comparison

	(1970)	(1995)	(2020)	Equivalent Annual Benefit for 1980-2030 @ 7% Interest
BY COMMODITY AND COUNTRY				
U.S.A. Fleet				
Iron Ore	117	284	504	283
Coal	- 18	0	20	- 1
Limestone	- 25	- 61	-254	- 84
Grain	13	3	9	6
Total	87	226	279	204
Canadian Fleet				
Iron Ore	3	27	31	22
Coal	- 9	2	2	0
Limestone	- 4	0	- 22	- 4
Grain	40	50	72	51
Total	30	79	83	69
Combined U.S.A. and Canadian Fleet				
Iron Ore	120	311	535	305
Coal	- 27	2	22	- 1
Limestone	- 29	- 61	-276	- 88
Grain	53	53	81	57
Total	117	305	362	273
BY TRAFFIC ROUTES				
S	1	1	1	1
MH	- 16	- 37	-137	- 48
E	- 31	- 14	- 59	- 25
O	0	0	0	0
S-MH	42	140	256	137
S-MH-E	127	214	400	224
S-MH-E-O	38	56	75	56
MH-E	- 43	- 54	-173	- 71
MH-E-O	2	3	4	3
E-O	- 3	- 4	- 5	- 4
Total	117	305	362	273

Table 57

EFFECTS OF PLAN SMHEO-38 ON POWER
($1,000)

System	Annual Energy Benefit	Annual Capacity Benefit	Annual Total Net Benefit
Ontario			
St. Lawrence	- 10		
Niagara	0		
St. Marys	0		
Total	- 10	+ 210	+ 200
Quebec			
Beauharnois	- 80		
Cedars			
Total	- 80	0	- 80
New York State			
St. Lawrence	+ 20		
Niagara	- 200		
Total	- 180	+ 290	+ 110
Upper Michigan	- 120	- 20	- 140
TOTAL	- 390	+ 480	+ 90

Table 58

EFFECTS OF PLAN SMHEO-38 ON EROSION AND INUNDATION
($1,000)

	Basis-of-Comparison	SMHEO-38	Difference Between SMHEO-38 and Basis-of-Comparison	Average Annual Benefit or Loss
		United States		
Lake Superior	3,721	3,973	- 252	- 499
Lake Michigan*	10,100	9,505	+ 595	+ 970
Lake Huron*	961	913	+ 48	+ 178
Lake St. Clair*	1,355	1,156	+ 199	+ 234
Lake Erie	4,255	2,310	+ 1,945	+ 4,637
Lake Ontario	1,158	1,195	- 37	- 137
Sub-total	21,550	19,052	+ 2,498	+ 5,383
		Canada		
Lake Superior	21	36	- 15	- 27
Lake Huron*	118	84	+ 34	+ 61
Lake St. Clair*	545	246	+ 299	+ 428
Lake Erie	965	586	+ 379	+ 682
Lake Ontario	1,082	1,015	+ 67	+ 121
St. Lawrence River (Cornwall to Trois-Rivières)	23	63	- 40	- 73
Sub-total	2,754	2,030	+ 724	+ 1,192
TOTAL	24,304	21,082	+ 3,222	+ 6,575

* 1933 outlet conditions

The plan would reduce the Lakes Michigan-Huron long-term mean by 0.16 foot. It would provide annual benefits to Lake Michigan shores of $970,000 and to Lake Huron shores of $178,000 in the United States and $61,000 in Canada. Greater portions of the benefits would be obtained in those reaches which contain more highly developed shoreline. Such areas include Green Bay and the southern portion of Lake Michigan and Saginaw Bay on Lake Huron.

On Lake Erie, by lowering the mean level, the plan would provide substantial benefits to U. S. shores of $4,637,000 and $682,000 to Canadian shores.

On Lake Ontario, Plan SMHEO-38 would result in losses of $137,000 to U. S. shores because of very slight increases in some monthly levels during periods of increased storm activity; however, due to the prevailing wave climate, a moderate benefit of $121,000 would occur on the Canadian shores.

Plan SMHEO-38 would provide a combined overall annual benefit to United States shores of $5,383,000, and $1,192,000 to Canadian shores, for a total of $6,575,000.

Shore Property - Recreation Beaches: Table 59 shows that the plan would produce substantial benefits on all the lakes, except Lake Superior, since the lower regime of lake levels would expose greater areas of beaches. The plan would provide benefits to Lake Michigan amounting to $1,019,000. On Lake Huron, the plan would provide benefits of $259,000 to U. S. beaches and $196,000 to Canadian beaches. The plan would provide benefits to beaches on Lake Erie amounting to $580,000 in the U. S. and $482,000 in Canada. Benefits would accrue to beaches on Lake Ontario in the amounts of $62,000 in the U. S. and $586,000 in Canada.

11.3.3 Environmental Effects

Since this plan contains the same regulatory works as those provided by Plans SEO-33 and SMHO-11, and the same concept of operation as provided for by Plan SO-901, the same types of ecological effects can be expected to occur with Plan SMHEO-38 as in all the others combined. As previously mentioned in Subsection 8.3.3, unless mitigating measures can be taken, there would be adverse effects in the St. Marys River Rapids from this Plan.

Fishery: Proposed regulatory structures in the St. Clair and Detroit Rivers could interfere with the migration of walleye and smallmouth bass, which move through the area to both Lake Huron and Lake Erie. Such migrations could be affected by these structural barriers, increased current velocities, and bubbler systems or other ice-preventive measures associated with the regulatory works.

Table 59

EFFECTS OF PLAN SMHEO-38 ON RECREATION BEACHES
($1,000)

	Basis-of-Comparison	SMHEO-38	Difference Between SMHEO-38 and Basis-of-Comparison	Average Annual Benefit or Loss
			United States	
	(1)	(1)		
Lake Superior	51	54	- 3	- 4
Lake Michigan *	9,830	9,187	+ 643	+1,019
Lake Huron *	1,175	1,093	+ 82	+ 259
Lake St. Clair *	17	12	+ 5	+ 14
Lake Erie	894	475	+ 419	+ 580
Lake Ontario	284	243	+ 41	+ 62
Sub-Total	12,251	11,064	+1,187	+1,930
			Canada	
	(2)	(2)		
Lake Superior	0	0	0	0
Lake Huron *	8,771	8,880	+ 109	+ 196
Lakes St. Clair *	- - - - - - - -Negligible effect - - - - - - - - - -			
Lake Erie	7,806	8,074	+ 268	+ 482
Lake Ontario	5,637	5,963	+ 326	+ 586
St. Lawrence River (Cornwall to Trois-Rivières)	- - - - - -Negligible effect - - - - - - - - - - -			
Sub-Total	22,214	22,917	+ 703	+1,264
TOTAL				+3,194

(1) Average damage
(2) Average value
* 1933 outlet conditions

Dredging for construction of the St. Clair and Detroit Rivers structures would be of particular concern because mercury-polluted sediments are present in the area. In the Detroit River, the increased channel capacity and operation of the structures could cause current pattern changes in the western basin of Lake Erie. Some adverse effects from dredging can be expected as described in Subsection 9.3.3.

The upper Niagara River, which would be the site for a structure and dredging, is now an excellent sport fishery near a metropolitan area. Regulatory works in the reach would degrade the sport fishery and tend to isolate it, restricting fish movement in and out of Lake Erie.

The St. Lawrence River - Lake St. Lawrence reach is a region which provides a variety of recreational activities. However, the potential for sport fishing is not fully realized, mainly because of poor fish production due primarily to the fluctuation of water levels as described in Subsection 8.3.3.

Wildlife: In the St. Clair River, Lake St. Clair, lower Detroit River and western Lake Erie areas, there are excellent sport fishing and waterfowl habitat and staging areas. The entire connecting channels area is in two major flyways for migratory waterfowl and, like the Niagara River, is an important nesting area. Increased use of the area for construction of regulatory structures with accompanying environmental effects could be a threat to the wildlife and recreation values of the area.

Wildlife habitat losses would be significant for this plan as shown in Table 60.

Hygienic Effects: Since this plan includes provisions of Plans SEO-33, SMHO-11, and SO-901, any impacts previously described for these plans can be expected here. No adverse hygienic effects have been identified for Plan SO-901.

Aesthetic Effects: Aesthetic impact was given strong consideration in selection of the type of control structures. Any aesthetic effects of placement of regulatory works and their operations in the St. Clair, Detroit and Niagara Rivers would be the same as described in Subsections 9.3.3 and 10.3.3.

Social Well-Being: Impact on social well-being of this plan includes the social effects of Plans SEO-33, SMHO-11, and SO-901. The effects on social well-being, if any, from Plan SMHEO-38 would be the same as described in Subsections 9.3.3 and 10.3.3.

Table 60

EFFECTS OF PLAN SMHEO-38 ON WILDLIFE HABITAT
(Acreage)

	Basis-of-Comparison	Plan SMHEO-38	Difference in Acreage (3)
		United States	
	(1)	(1)	
Lake Superior	10,490	10,280	+ 210
Lake Michigan*	13,626	15,756	- 2,130
Lake Huron*	20,644	23,871	- 3,227
Lake Erie	15,325	18,278	- 2,953
Lake Ontario	8,879	8,850	+ 29
Sub-total	68,964	77,035	- 8,071
		Canada	
	(2)	(2)	
Lake Superior	0	0	0
Lake Huron*	42,018	38,954	- 3,064
Lake Erie	18,150	13,866	- 4,284
Lake Ontario	7,884	7,379	- 505
Sub-total	68,052	60,199	- 7,853
TOTAL			-15,924

(1) Acreage lost from maximum elevation evaluated (Table 12).
(2) Acreage available.
(3) + indicates a benefit and - indicates a detriment.
* 1962 outlet conditions.

11.4 Regulatory Works

The plans that have been studied would utilize the existing regulatory works in the St. Marys and St. Lawrence Rivers. However, modification to the Lake Superior control works would be required to ensure safe winter gate operation. The design and costs of these modifications, described in Subsection 8.4, will apply to Plan SMHEO-38.

In the St. Clair and Detroit Rivers, structures would be required to provide control of Lakes Michigan-Huron. The locations and type of structures would be the same as described in Subsection 9.4 for Plan SMHO-11. An additional structure in the St. Clair River at Fawn Island would be required in order to maintain the water surface profiles for a channel capacity decrease of 37,000 cfs from 1933 outlet conditions. The estimated capital cost of this structure would be $38 million. No dredging is necessary in the St. Clair River because the required channel capacity increase of 11,000 cfs, based on 1933 outlet conditions, is available in the existing channels. The Detroit River requires dredging in the Trenton Channel to provide for an additional 5,000 cfs discharge capacity at a capital cost of $55 million. The total capital cost of regulatory works for Plan SMHEO-38, including dredging and structures, is $277 million based on 1971 price levels, or $20.8 million annually (over 50 years). The estimated construction period is 6 years.

In the Niagara River, dredging to provide a channel capacity increase of 24,000 cfs, and a structure to provide a capacity decrease of 33,000 cfs, would be required. These works will be similar to those described in Subsection 10.3 for Plan SEO-33. The total capital cost is $93 million based on 1971 price levels, comprising dredging $37.9 million, structures $49.4 million, and shore protection works $5.7 million. The estimated construction period is 4 years.

Table 61 summarizes the cost estimates for Plan SMHEO-38.

11.5 Potential Benefit from SMHEO Plan

SMHEO-38, like the SMHO and SEO plans previously analyzed, is a trial plan, not a refined plan. The annual cost of providing regulatory works in the St. Clair and Detroit Rivers for SMHEO-38 would amount to $28 million. Because such cost would be so much greater than the ensuing benefits, no attempt was made to refine the plan and optimize its benefits. However, the following comparison of SMHEO-38 with trial and refined SO plans suggests the upper limit of benefits obtainable with a plan satisfying SMHEO-38 objectives.

Table 61

SUMMARY OF ESTIMATED COSTS OF
REGULATORY WORKS REQUIRED
FOR
PLAN SMHEO-38
($1,000)

	Lake Outlet				
	Superior	Michigan-Huron	Erie	Ontario	Total
Total First Costs	574	229,100	81,384	0	311,058
Total Capital Costs at End of Construction Period	574	277,211	92,778	0	370,563
Annual Interest and Amortization	43	20,087	6,723	0	26,853
Annual Operation and Maintenance	27	687	287	0	1,001
Total Annual Costs	70	20,774	7,010	0	27,854

($1,000)

	Trial Plan SO-802	Refined Plan SO-901		Trial Plan SMHEO-38	
	(Prelim. eval. Table 14)	(Prelim. eval. Table 23)	(Detail. eval. Table 24)	(Prelim. eval.	(Detail. eval. Table 55)
Navigation	$ +600	$ +800	$ +927	$ +200	$ +273
Power	0	+400	+640	+100	+ 90
Shore Property	+700	+900	+803	+5,300	+9,665
Totals	$+1,300	$+2,100	$+2,370	$+5,600	$+10,028

The table shows that there is about a 10% increase in benefits from the preliminary evaluation to the detailed evaluation of Plan SO-901 and about an 80% increase in benefits from the preliminary to the detailed evaluation of Plan SMHEO-38. There is about a 60% improvement in benefits from the trial SO plan to the refined SO plan based upon the preliminary evaluations. Assuming a similar potential for refining and improving the benefits from a SMHEO plan, the Board estimates the upper limit of benefits to be about $15 million.

With annual benefits of $10 million and an average annual cost of $28 million, SMHEO-38 would have a benefit-cost ratio of 0.36. Plan SMHEO-38 has an incremental benefit-cost ratio of 0.28 over Plan SO-901.

11.6 Summary

The Board has developed and evaluated a plan, SMHEO-38, formulated on the principle of balancing storage among all five lakes in such a way as to maintain the mean lake levels. This analysis has demonstrated that the benefits of such a five-lake plan are completely outweighed by the costs of the necessary regulatory works.

Section 12

COMPARISON AND DISCUSSION OF REGULATION PLANS

12.1 General

The study began with a broad examination of theoretical possibilities for further regulation of the Great Lakes. As a more thorough understanding of the hydrologic-economic mechanisms of the system developed, the scope of the study was progressively narrowed by introducing various constraints and by concentrating on those regulation principles which showed the greatest potential for overall improvement. One such constraint was the adopted objective of providing benefits only where they could be achieved without significant loss to any interest on any lake or its outlet river. The Board found that this objective could be satisfied best by plans based upon the operating principle of maintaining the lakes at the same relative position with respect to their mean levels.

Preliminary and trial plans were formulated, in most cases using this principle. The most promising plans for each combination of lakes (SO, SMHO, SEO and SMHEO) were evaluated in more detail. Because the preliminary evaluation of SO and SEO plans yielded more promising benefit-cost ratios, the Board concentrated greater effort on further study of these lake combinations.

This section compares and discusses the selected plans for the four lake combinations, by lake and by country, and reviews certain factors which would affect estimated benefits from regulation.

The study of the Lakes Superior-Ontario (SO) combination indicated that benefits to the system could be obtained by changing the current operating policy for Lake Superior. The change would require the regulation of the outflow to keep the levels of Lake Superior and Lakes Michigan-Huron at the same relative position with respect to their mean levels. The resulting benefits would derive mainly from a reduced range of stage on Lakes Michigan-Huron.

The study of the Lakes Superior-Michigan-Huron-Ontario (SMHO) combination did not reveal a plan which would provide total benefits greater than any obtained under the SO combination, except those plans which would lower the mean levels of Lakes Michigan-Huron and Ontario. Such lowering, although providing substantial benefits to shore property, would result in significant losses to navigation and power. Because of the large cost of regulatory works in the St. Clair and Detroit Rivers, the annual costs of SMHO plans would greatly exceed the benefits.

The study of the Lakes Superior-Erie-Ontario (SEO) combination yielded plans providing greater total benefits than the SO combination. The benefits of all three selected SEO plans derive mainly from a general lowering of Lake Erie and Lakes Michigan-Huron. Such lowering would not cause losses to navigation because Lake Erie depths are generally not controlling and the associated lowering on Lakes Michigan-Huron is not enough to affect the controlling depths on these lakes.

The study of the Lakes Superior-Michigan-Huron-Erie-Ontario (SMHEO) combination produced a plan with total benefits greater than any under SO and SEO regulation. The additional benefits derived more from a general lowering of lake levels than from reducing the extremes of stage. The SMHEO lake combination would require costly regulatory structures with annual costs much greater than annual benefits obtained.

12.2 Hydrologic Comparison by Lake (Including Its Outlet River)

Table 62 summarizes the effects of the six selected plans described in Sections 8 through 11 on the levels and outflows of the Great Lakes. The table also includes data for the two bases-of-comparison used in the evaluation of the Lakes Michigan-Huron effects.

12.2.1 Lake Superior

The SO and SEO plans would achieve the same reduction in range of stage on Lake Superior by application of a common regulation method and similar minimum outflow constraints. For SMHO and SMHEO regulation plans, where the outlet of Lakes Michigan-Huron would be controlled, the reduction in range of stage for Lake Superior would be smaller because of interactions with downstream constraints.

All the plans would generally satisfy the Lake Superior criteria given in Section 8. Under the plans presented, Criterion (a), which specifies that the level be maintained as nearly as may be between 600.5 feet and 602.0 feet, would be satisfied to essentially the same degree as the basis-of-comparison. For all the plans and the basis-of-comparison, the average level is below 600.5 feet. The frequency of occurrence of levels above 601.5 feet in general has been reduced by all plans, except SMHEO-38.

The selected plans would reduce the frequency of occurrence of low levels not only during the navigation season, but also for all months of the year. All plans would raise the minimum level of the lake by approximately one-half foot.

Criterion (b) restricts the excess discharge at any time over and above that which would have occurred at a like stage of Lake Superior prior to 1887 so that the elevation of the water surface immediately below the locks shall not be greater than 582.9 feet. All plans would satisfy this criterion.

Table 62

HYDROLOGIC EVALUATION

SUMMARY OF RANGES OF STAGE 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

12.2.2 Lakes Michigan-Huron

Under the Exchange of Notes between the two countries concerning the navigation improvements completed in 1962, Canada has given approval in principle to the request of the United States to construct sills to compensate for any lowering of the levels of Lakes Michigan-Huron, subject to agreement on the amount of hydraulic compensation required. Recognizing the possibility that plans requiring minimal construction might be implemented before final resolution of the issue of compensation, the Board used the 1962 outlet conditions of Lakes Michigan-Huron as the basis for evaluating Plans SO-901, SEO-901 and SEO-42P. On the other hand, plans requiring extensive construction were evaluated against the 1933 outlet conditions.

The reduction in range of mean monthly levels of Lakes Michigan-Huron would be similar for all plans, except SMHEO-38. The improvement on Lakes Michigan-Huron obtainable from SMHEO plans is limited by permissible maximum and minimum outflows from Lake Ontario.

12.2.3 Lake Erie

With Lakes Michigan-Huron unregulated, the reduction in range of stage on Lake Erie is similar for all plans, except SEO-42P. This plan, which would produce a greater reduction in the range of stage, is a special case in that it is essentially Plan SO-901 with modified operation on Lakes Erie and Ontario. This modification consists of releasing additional water from Lake Erie during periods of greater than normal supplies and revising Plan 1958-D to accommodate this increased supply from Lake Erie, while meeting the established criteria and other requirements for Lake Ontario and the St. Lawrence River. Under SMHO-11, the reduction in the range of monthly mean stage results from the ability to store or release water from Lakes Michigan-Huron during periods of greater or less than normal supply to Lake Erie. Under SMHEO-38, the present Lake Ontario regulation was also changed by allowing increased minimum releases from those specified under Plan 1958-D. However, in order to maintain the stipulated minimum stage on Lake Ontario, it was necessary to use additional storage on Lake Erie, thus increasing its range of stage.

12.2.4 Lake Ontario

The range of monthly mean stages of Lake Ontario would be reduced for all plans except SMHEO-38. The improved range would result from an increased minimum stage with essentially the same maximum stage and the same minimum flows specified by Plan 1958-D. This was accomplished through better utilization of the storage and releases from Lake Erie. Plans SEO-42P and SMHEO-38 would maintain essentially the same range of monthly mean stages and maximum and minimum stages as the basis-of-comparison.

The adoption of the objective of achieving benefits without significant loss to any interest on any lake or the St. Lawrence River necessitated retention of the criteria and other requirements of the IJC Orders of Approval for the regulation of Lake Ontario. These in turn became a major constraint in the development of all regulation plans. In general, Plans SEO-33, SMHO-11 and SMHEO-38 satisfy these criteria. The following paragraphs review the degree to which Plans SO-901, SEO-901 and SEO-42P, which have the most promising benefit-cost ratios, have satisfied these important criteria.

Criterion (a) states that the regulated outflow from Lake Ontario from April 1 to December 15 shall be such as not to reduce the minimum level of Montreal Harbour below that which would have occurred in the past with the supplies to Lake Ontario since 1860 adjusted to a condition assuming a continuous diversion out of the Great Lakes basin of 3,100 cfs at Chicago and a continuous diversion into the Great Lakes basin of 5,000 cfs from the Albany River basin.

The frequency of low outflows from Lake St. Louis under regulation Plans SO-901, SEO-901, and SEO-42P is less, and the magnitude of the minimum flow is greater than the basis-of-comparison outflows. This would result in a higher minimum level in Montreal Harbour, and a reduced frequency of low levels, than under the basis-of-comparison, thereby satisfying Criterion (a).

Criterion (b) states that the regulated winter outflows from Lake Ontario from December 15 to March 31 shall be as large as feasible and shall be maintained so that the difficulties of winter operation are minimized.

The minimum outflow under Plans SO-901, SEO-901 and SEO-42P would be raised in all winter months above the basis-of-comparison and thus the criterion would be satisfied.

Criterion (c) states that the regulated outflow from Lake Ontario during the annual spring break-up in Montreal Harbour and in the river downstream shall not be greater than would have occurred assuming supplies of the past as adjusted.

Plans SO-901, SEO-901 and SEO-42P satisfy the criterion by reducing the maximum flow by up to 5,000 cfs from the basis-of-comparison during March and the first half of April.

Criterion (d) states that the regulated outflow from Lake Ontario during the annual flood discharge from the Ottawa River shall not be greater than the discharge that would have occurred assuming supplies of the past as adjusted.

There is very little difference in discharge between the basis-of-comparison and Plans SO-901 and SEO-901. However, improvement under this criterion would be provided under Plan SEO-42P compared with the basis-of-comparison. All three plans satisfy the criterion.

Criterion (e) states that, consistent with other requirements, the minimum regulated outflows from Lake Ontario shall be such as to secure the maximum dependable flow for power.

The absolute minimum monthly mean outflow would be raised for Plans SO-901, SEO-901 and SEO-42P; therefore, Criterion (e) would be satisfied.

Criterion (f) states that, consistent with other requirements, the maximum regulated outflow from Lake Ontario shall be maintained as low as possible to reduce channel excavation to a minimum.

The plans presented herein have been designed so that channel enlargement would not be necessary. The most important consideration in connection with Criterion (f) is that the plans should not produce more critical conditions than those of the current operating plan (1958-D). Plans SO-901, SEO-901 and SEO-42P would not violate the minimum river profile.

Criterion (g) states that consistent with other requirements, the levels of Lake Ontario shall be regulated for the benefit of property owners on the shores of Lake Ontario in the United States and Canada so as to reduce the extremes of stage which have been experienced.

The maximum stage for Plans SO-901, SEO-901 and SEO-42P would be essentially the same, while the minimum stage would be raised. Relative to the basis-of-comparison (1958-D), these plans show a decrease in frequency of high levels above 246.0 feet.

Criterion (h) states that the regulated monthly mean level of Lake Ontario shall not exceed elevation 246.77 with the supplies of the past as adjusted.

Elevation 246.77 was exceeded 3 times during the period of record not only under the basis-of-comparison (1958-D) but also under Plans SO-901, SEO-901 and SEO-42P.

Criterion (i) states that under regulation, the frequency of occurrence of monthly mean elevations of approximately 245.77 and higher on Lake Ontario shall be less than would have occurred in the past with the supplies of the past as adjusted and with present channel conditions in Galop Rapids of the International Rapids Section of the St. Lawrence River.

Plans SO-901, SEO-901 and SEO-42P reduce the number of occurrences of levels above 245.77 relative to the basis-of-comparison (1958-D). Thus, the criterion would be satisfied.

Criterion (j) states that the regulated level of Lake Ontario on April 1 shall not be lower than elevation 242.77. The regulated mean level of the lake from April 1 to November 30 shall be maintained at or above elevation 242.77.

The Lake Ontario level requirement would not be satisfied on April 1 nor during April through November. If discretionary deviations could have been made under these plans, the April 1 level could have been satisfied at least to the same degree as under the basis-of-comparison. However, these plans would improve upon the basis-of-comparison level from April through November and would reduce the frequency of occurrence of low levels.

One supplementary requirement of regulation relates to Lake St. Louis low water levels and is covered by the Supplementary Order of Approval dated July 2, 1956, which states, "The project works shall be operated in such a manner as to provide no less protection for navigation and riparian interest downstream than would have occurred under preproject conditions with the supplies of the past as adjusted, as defined in Criterion (a) herein." Riparian interests on Lake St. Louis and downstream are interested also in the frequency of low levels.

These plans would increase the minimum level of Lake St. Louis in the order of 0.4 foot; however, there would be an increase in the frequency of low levels.

Criterion (k) states that in the event that future supplies occur in excess of the supplies of the past as adjusted, the works in the International Rapids Section shall be operated to provide all possible relief to the riparian owners upstream and downstream. In the event of future supplies less than the supplies of the past as adjusted, the works in the International Rapids Section shall be operated to provide all possible relief to navigation and power interests. This is an operational criterion and could not be reflected in the computations of the effects of selected plans.

12.3 Summary of Regulatory Works and Costs

A summary of regulatory works costs is given in Table 63. A discussion of these costs and other aspects of the requirement for regulatory works is given below.

12.3.1 Lake Superior

All plans require routine changes in the setting of the gates in the St. Marys regulatory works throughout the year. Field tests carried out during the study have shown frequent operation during the winter season to be feasible. The annual cost of $70,000 for the implementation of any of these plans includes charges for modifications to the existing Lake Superior control structure to insure safe winter operation. No other modifications or changes to the existing regulatory works in the St. Marys River would be required for any of the plans.

Table 63

ESTIMATED COSTS OF REGULATORY WORKS
(Based on 1971 Price Levels and Annual Interest Charges of 7%)
($1,000)

REGULATION PLAN	LAKE OUTLET	CAPITAL COSTS	ANNUAL COSTS		
		Capital Costs to End of Construction	Interest and Amortization	Operation and Maintenance	Total
SO-901	Superior	574	43	27	70
	Ontario	-	-	-	-
	Total	574	43	27	70
SMHO-11	Superior	574	43	27	70
	Michigan-Huron	239,700	17,369	564	17,933
	Ontario	-	-	-	-
	Total	240,274	17,412	591	18,003
SEO-33	Superior	574	43	27	70
	Erie	107,673	7,802	287	8,089
	Ontario	-	-	-	-
	Total	108,247	7,845	314	8,159
SEO-901	Superior	574	43	27	70
	Erie	1,360	99	-	99
	Ontario	-	-	-	-
	Total	1,934	142	27	169
SEO-42P	Superior	574	43	27	70
	Erie	4,900	355	25	380
	Ontario	-	-	-	-
	Total	5,474	398	52	450
SMHEO-38	Superior	574	43	27	70
	Michigan-Huron	277,211	20,087	687	20,774
	Erie	92,778	6,723	287	7,010
	Ontario	-	-	-	-
	Total	370,563	26,853	1,001	27,854

12.3.2 Lakes Michigan-Huron

Plan SMHO-11 requires additional works totaling nine structures in the St. Clair and Detroit Rivers and a channel capacity increase of 11,000 cfs over 1933 channel conditions. Because of deepening between 1933 and 1962, the existing channels in the St. Clair River are adequate to accommodate this flow increase. However, the Trenton Channel of the Detroit River would still require a capacity increase of 5,000 cfs over 1962 conditions at an estimated total cost of $46 million. The channel capacity decrease for the St. Clair and Detroit Rivers required under Plan SMHO-11 is 29,000 cfs based on 1933 conditions. Five regulatory structures are required in the Detroit River and four structures are required in the St. Clair River to meet the flow decrease requirements and to maintain the river profile. The estimated total capital cost at the end of construction is $240 million and the annual cost is $18 million.

For Plan SMHEO-38, the works required in the St. Clair-Detroit River system consist of 10 control structures and channel excavation in the Trenton Channel of the Detroit River. Five structures are required in both the St. Clair and Detroit Rivers in order to provide control of Lakes Michigan-Huron levels and to maintain the river profile. The locations and types of structures will be the same as described in Subsection 9.3 for Plan SMHO-11 except for an additional structure in the St. Clair River at Fawn Island. The existing channels (1962 conditions) in the St. Clair River are adequate to accommodate the channel capacity increase requirement of 11,000 cfs based on the 1933 channel conditions. In the Detroit River a channel capacity increase of 5,000 cfs is required. Based on the requirement of decreasing the channel capacity by 37,000 cfs from the 1933 channel condition profile for the critical regulated design condition, the total decrease, taking into account the channel capacity increase, was determined to be 48,000 cfs and 43,000 cfs for the St. Clair and Detroit Rivers, respectively. The estimated total capital cost at the end of construction is $277 million and the annual cost is $21 million.

12.3.3 Lake Erie

Plan SMHEO-38 requires work in the Niagara River consisting of a control structure, shore protection works on both sides of the river and channel excavation. Dredging in the Niagara River is required to provide a channel capacity increase of 22,000 cfs. A structure to provide a capacity decrease of 25,000 cfs is required. These works would be similar to those described in Subsection 10.3 for Plan SEO-33. The estimated total capital cost is $93 million based on 1971 price levels, comprising dredging ($38 million), structures ($49 million), and shore protection works ($6 million). Total annual cost for Lake Erie amounts to $7 million. The total annual cost for Plan SMHEO-38 is $28 million.

Plan SEO-33 requires a channel capacity increase of 27,000 cfs and a channel capacity decrease of 40,000 cfs from existing conditions in the Niagara River. The former involves channel dredging in the upper part of the river at the outlet of Lake Erie; the latter requires a gated control structure at the head of the river, together with ancillary shore protection works immediately above it. The estimated total capital cost at the end of construction is $108 million, comprising excavation ($53 million), structure ($49 million) and shore protection works ($6 million). The total annual cost to control Lake Erie outflow under this plan would be $8.1 million.

Plan SEO-901 involves dredging to provide a Niagara River channel capacity increase of 4,000 cfs at a total capital cost of $1.4 million. The total annual cost would be $99,000. Dredging would amount to approximately 50,000 cubic yards of material with a maximum of 4-foot depth over 1,500-foot length of river bottom at the head of the Niagara River. No structure would be required. The total annual cost under this plan would be $169,000.

Plan SEO-42P requires construction of a gated diversion canal across Squaw Island at the head of the Niagara River to discharge 8,000 cfs from the Black Rock Canal at an estimated total capital cost at the end of construction of $4.9 million which is equivalent to an annual cost of $380,000. The total annual cost under this plan would be $450,000.

12.3.4 Lake Ontario

All plans would use the existing works at the outlet of Lake Ontario, and no new construction would be required.

12.4 Comparison of Benefits (by Interest and Country) and Costs

A summary of benefits, by interest and country, and costs for each plan is given in Table 64.

Plans SO-901, SEO-901 and SEO-42P provide net annual benefits in the order of two to four times greater in the United States than in Canada. The net navigation benefit for the United States' fleet is about three times that of the Canadian fleet for these plans. Plans SO-901 and SEO-901 provide equal power benefits to each country. However, Plan SEO-42P would produce a small loss to U. S. power interests and a small benefit to Canadian power interests. Overall, Plans SO-901, SEO-901 and SEO-42P produce higher net benefits to shore property interests in the United States than in Canada, the total U. S. benefits being 2-1/2 times greater for SO-901, over 3 times greater for SEO-901 and 4-1/2 times greater for SEO-42P. The shore property benefits would be greater in the United States than in Canada primarily because of the greater reduction in erosion and inundation damages along the highly developed U. S. shorelines of Lakes Michigan, Huron and Erie than along the less developed Canadian shorelines of Lakes Huron and Erie.

Table 64

SUMMARY OF AVERAGE ANNUAL BENEFITS AND COSTS*
($1,000)

	SO-901	SEO-901	SEO-42P	SEO-33	SMHEO-38	SMHO-11
		Annual Benefits				
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	4,005	6,676	5,395	7,204	665
Canada	224	766	1,480	1,523	2,461	882
	803	4,771	8,156	6,918	9,665	1,547
Total Benefits						
U.S.	1,587	5,050	7,115	5,711	7,378	1,312
Canada	783	1,311	1,681	1,841	2,650	520
	2,370	6,361	8,796	7,552	10,028	1,832
Incremental Benefits Over SO-901						
U.S.		3,463	5,528	4,124	5,791	- 275
Canada		528	898	1,058	1,867	- 263
		3,991	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	37.6	19.5	0.93	0.36	**
Incremental Benefits and Costs Over SO-901		40.3	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.

** As discussed in Subsection 9.5, 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.

The costs exceed benefits for Plans SMHO-11, SEO-33 and SMHEO-38. The benefit-cost ratios for Plans SO-901 and SEO-901 are large, being 33.9 and 37.6, respectively. With respect to SO-901, the incremental benefit-cost ratio for SEO-901 is 40.3. However, as discussed in Subsection 10.5, SEO-901 would permanently lower the level of Lake Erie and result in irreversible harm to the environment. Plan SEO-42P would provide a lower benefit-cost ratio than Plans SO-901 and SEO-901; however, with respect to SO-901, it provides a favorable incremental benefit-cost ratio of 16.9.

The distribution of net benefits among shore property, power and navigation interests varies among Plans SO-901, SEO-901 and SEO-42P. Essentially, the interests share equally the net benefits provided by SO-901. Both Plans SEO-901 and SEO-42P would provide large benefits to shore property interests. They would lower the levels of Lakes Erie and Michigan-Huron, significantly reducing erosion and inundation damages and providing greater recreation beach areas. Plan SEO-901 provides power with the same benefit as Plan SO-901, while there is little effect on power from Plan SEO-42P. Plan SEO-42P would produce less benefits to navigation than Plan SO-901. When comparing Plan SEO-42P to Plan SO-901 as the base condition, the net effect would be losses to power of $630,000 annually and to navigation of $297,000 annually.

12.5 Factors Affecting Ultimate Benefits from Regulation

Three factors, in particular, may change the ultimate benefits for the various regulation plans from the estimates in this report. These are: departures from supply sequences used in the evaluation; growth in the consumptive use of water from the Great Lakes; and, changes in rates and patterns of shoreline development. Crustal movement, while it would affect the system, would not impact on the estimated benefits because it would affect the basis-of-comparison and any plan in a similar manner.

12.5.1 Departure from Historical Supply

The sensitivity of the economics to the sequence variability of the recorded water supplies was tested with ten 68-year sequences of net basin supply in order to obtain some indication of the range of possible results. These simulated sequences were developed by a stochastic approach and included associated winter flow values for the connecting channels. These simulated water supplies were employed in evaluation of the benefits obtained under the SO, SEO and SMHEO lake combinations. These lake combinations were selected since increased economic benefits were obtained by regulation of an additional lake. This was not true of the SMHO lake combination. Using the simulated water supplies, the regulation plans were tested using the decision model for each lake combination. In the model where regulation is imposed on a connecting channel, it was assumed that the regulatory works would have the capability to pass the designed flow under the most severe winter conditions. The levels and outflows to be used as the basis-of-comparison were obtained by routing the simulated water supplies through the system employing the model. Table 22 indicates the results of testing Plan SO-901 with the simulated data. Benefits would be obtained in all ten sequences, ranging from $0.4 to $2.7 million, with all but one of the sequences giving less benefits than those computed with the study period sequence. Similar results were obtained for SEO-33 and SMHEO-38.

12.5.2 Consumptive Use

As discussed in Subsection 3.3.3, the term "consumptive use" refers to that portion of the water withdrawn or withheld from the Great Lakes and not returned. Estimates indicate that the total basin consumptive use of 2,300 cfs in 1965 would grow to 4,000 cfs by 1985, 6,000 cfs by the year 2000, and 13,000 cfs by the year 2030.

The approach taken in the assessment of the effect of consumptive use on future benefits from regulation is that the supply to the lakes would be reduced by these amounts. For computation purposes, it was assumed that the percentage of the total system consumptive use occurring in each individual lake basin would remain constant throughout the 1966-2030 test period and that the consumptive use rate would increase linearly between the base and projection years.

The consumptive use breakdown among the lakes and the percentage of the total are as follows:

Lake	1965 Consumptive Use (CFS)	Percentage of Total Use
Lake Superior	40	2%
Lakes Michigan-Huron	1250	55%
Lake Erie	680	30%
Lake Ontario	300	13%

Table 65 compares the levels and flows of the basis-of-comparison and Plan SO-901 without and with projected consumptive use. The data without projected consumptive use are the same as presented in Table 15. The results with projected consumptive use were obtained by routing through the lake system the 1900-1967 water supplies reduced by the 1968-2035 projected consumptive use.

To facilitate the calculations, it was assumed that outflows would be maintained even if this required decreasing lake levels and changes in the physical dimensions of the outflow channels. However, this is only one alternative for adjusting regulation as supplies decrease. In the case of an unregulated lake, a decrease in water supply will lower

Table 65

HYDROLOGIC EVALUATION OF CONSUMPTIVE USE
SUMMARY OF RANGES OF STAGE IN FEET AND OUTFLOW IN THOUSANDS OF CUBIC FEET PER SECOND

	Without Projected Consumptive Use				With Projected Consumptive Use			
	Basis-of-Comparison (1900-1967)		Plan SO-901 (1900-1967)		Basis-of-Comparison		Plan SO-901	
	Stage	Outflow	Stage	Outflow	Stage	Outflow	Stage	Outflow
Lake Superior								
Mean	600.38	77	600.41	77	600.38	77	600.33	77
Maximum	601.91	123	602.00	123	601.91	123	601.92	123
Minimum	598.36	55	598.81	55	598.36	55	598.69	55
Range	3.55	68	3.19	68	3.55	68	3.23	68
Lakes Michigan-Huron								
Mean	577.95	183	577.96	183	577.74	181	577.75	181
Maximum	580.91	233	580.64	227	580.77	231	580.52	225
Minimum	575.15	107	575.46	113	574.61	103	575.00	108
Range	5.76	126	5.18	114	6.16	128	5.52	117
Lake Erie								
Mean	570.60	204	570.61	204	570.41	200	570.43	200
Maximum	573.01	258	573.04	259	572.88	256	572.92	256
Minimum	567.95	149	568.14	152	567.59	145	567.86	148
Range	5.06	109	4.90	107	5.29	111	5.06	108
Lake Ontario								
Mean	244.53	238	244.55	238	244.20 (1)	234	244.30	234
Maximum	246.95	310	246.92	310	246.99 (1)	310	246.93	310
Minimum	241.31	176	241.53	188	237.67 (1)	188	238.49	188
Range	5.64	134	5.39	122	9.32 (1)	122	8.44	122

ECONOMIC EVALUATION OF CONSUMPTIVE USE

Approximate Annual Benefits ($ Millions)

	Without Projected Consumptive Use	With Projected Consumptive Use	
	Plan SO-901 (2)	Basis-of-Comparison (4)	Plan SO-901 (3)
Power	+ 0.4	(-7.0)	+ 0.7
Navigation	+ 0.8	(-1.8)	+ 1.2
Shore Property	+ 0.9	(+2.1)	+ 1.0
Total	+ 2.1	(-6.7)	+ 2.9

(1) Without discretionary deviations.
(2) Benefits and losses relative to the basis-of-comparison without projected consumptive use.
(3) Benefits and losses relative to the basis-of-comparison with projected consumptive use.
(4) The annual effects shown in parentheses under basis-of-comparison with projected consumptive use are in relation to the basis-of-comparison without projected consumptive use.

the mean level and the outflow. In the case of a regulated lake, the mean level could be maintained even with a reduced supply by changing the regulation rules. The effect of this action would be transmitted downstream in the form of reduced outflows. Thus, for the lake system as a whole, reduced supplies will lead to reduced levels or reduced flows or a combination depending upon the way in which regulation is modified progressively to compensate for decreasing supplies. The results in Table 65 show the extreme effect on levels if outflows were maintained and levels were allowed to decline.

The benefits and losses displayed in Table 65 suggest the economic consequences of consumptive use. They do not reflect the costs to change channel capacities and control works to satisfy hydraulic requirements. The economic data in Table 65 are based on the generalized loss curves described in Subsection 6.3, without adjustment for anomalous results at the extremes of stage experienced with consumptive use. Under the basis-of-comparison with projected consumptive use are shown the benefits and losses of current regulation plans relative to the performance of these plans without projected consumptive use (1900-1967 basis-of-comparison). The very high loss to power is due to loss of head at very low stage and is only an order-of-magnitude approximation.

If the present growth trend in consumptive use continues, the problem will require careful and serious study, and it will be necessary ultimately to revise the regulation of the lakes.

12.5.3 Changes in Shoreline Development

Without question, the benefits to shore property interests are subject to great change if the development of the shoreline becomes more intense. In fact, all the benefits attributable to shoreline property could diminish if proper land use practices are not followed.

The demand for waterfront property has resulted in development of low-lying shorelines during the record low water levels of the 1960's even though such areas were flooded by high water in 1951-52. Some beach and bluff areas which were relatively stable during the low water period have also been developed even though they were subjected to erosion in 1951-52. All these areas are again experiencing damage from high water levels. A prime example is a 350-home residential development on a low-lying area which has been built since the low level period of 1964. The 1972-73 high lake levels produced considerable flood and wave impact damage to this development. Other vulnerable shoreline areas in the Great Lakes have been unwisely developed in recent years. Continuation of such practice will increase future losses despite improved lake regulation.

Section 13

AREAS REQUIRING FURTHER STUDY

13.1 General

In the foregoing sections the Board has reported on its investigation of further regulation of various combinations of the Great Lakes. These studies were planned and conducted with the intent of investigating all possibilities within the provisions of the Reference from Governments for reducing the extremes of stage and for bringing about a more beneficial range of stage on the several lakes. The studies proceeded using available hydrologic data from the study period 1900-1967 in the development and evaluation of possible new regulation plans. As the studies progressed, the Board, in consultation with the Commission, narrowed its investigation to those avenues which appeared most fruitful based upon its adopted evaluation methodology.

However, near the scheduled end of the Board's studies the lower Great Lakes experienced a sequence of record high supplies, exceeding any for the study period 1900-1967 and, in fact, any during the entire period of record. In light of these recent high supplies, the Board reviewed the scope of the studies and concluded that there was a potential for improvement in some areas which had not been pursued exhaustively. Specifically, there is a need to investigate further regulation of the lakes based upon the full period 1900-1973 so as to determine the feasibility and desirability of plans that would better accommodate future supplies of the magnitude recently experienced. There is also a need to study further means of meeting or modifying existing constraints on regulation so as to reduce damages to both upstream and downstream riparian interests during periods of extreme supplies. Improvement in regulation from better and faster determination of the hydrologic response of the basins is another area requiring further study.

This section presents background information and the Board's rationale for suggesting further study in the foregoing areas. Since the conditions which gave rise to the need for further study came about quite recently and in fact are still continuing, the Board has not been able to make a comprehensive study of these aspects and to include definitive findings and conclusions thereon in this report.

13.2 Effects of Recent High Supplies

Since 1967 the precipitation on the Great Lakes basin has averaged 8% more than the 31.4 inches per year averaged over the study period 1900-1967. As a result of this persistent above normal precipitation and the resulting high basin supplies, all the lakes rose above normal levels. In 1973 Lakes Michigan and Huron reached their highest levels since 1886, and Lakes St. Clair and Erie exceeded any previously recorded levels. The following subsections analyze the nature of the recent high supplies, the performance of current regulation plans in this period, and the performance of two selected regulation plans assuming they had been in effect since 1968.

13.2.1 Nature of the Supplies

The following table shows the abnormality of the recent period of high supplies to the Great Lakes. It compares the average monthly net basin and net total supplies received during the period July 1972-June 1973 with those of the study period 1900-1967. The recent net basin supplies to the various lakes were from 27% to 119% above the 68-year period averages; the net total supplies were from 25% to 47% greater. The table also shows that the recent supplies were greater than those of the corresponding period July 1951-June 1952, which was the last occasion of extreme high lake levels.

AVERAGE MONTHLY SUPPLIES
(Thousands of Cfs-Months)

	Net Basin Supplies			Net Total Supplies		
Lake	Jan. 1900 thru Dec. 1967	July 1951 thru June 1952	July 1972 thru June 1973	Jan. 1900 thru Dec. 1967	July 1951 thru June 1952	July 1972 thru June 1973
Superior	71	88	90	76	93	95
Michigan-Huron	110	162	180	187	266	275
Erie	21	29	46	205	238	260
Ontario	34	43	59	238	275	308

Inclusion of the greater than normal water supplies of the last five years is needed to make the study period more representative of the supplies to be expected in the future.

13.2.2 Performance of Current Regulation Plans

Table 66 compares hydrologic data and economic benefits for current and two selected plans for three different periods: the basic study period 1900-1967, an extended study period 1900-1973 and the recent period 1968-1973. The starting water levels for the period January 1, 1968, through June 30, 1973, are the recorded January 1, 1968, Great Lakes levels.

The basis-of-comparison data for 1900-1967, 1900-1973 and 1968-1973 indicate the relative performance of the current regulation plans over these three periods. In order to give a more valid comparison, the

Table 66

HYDROLOGIC EVALUATION OF CURRENT AND SELECTED PLANS
OVER DIFFERENT PERIODS OF RECORD
SUMMARY OF RANGES OF STAGE IN FEET

	1900 - 1967			1900 - 1973 (June)**			1968 - 1973 (June)**		
	Basis-* of-Comparison	Plan SO-901	Plan SEO-42P	Basis-* of-Comparison	Plan SO-901	Plan SEO-42P	Basis-* of-Comparison	Plan SO-901	Plan SEO-42P
Lake Superior									
Mean	600.38	600.41	600.37	600.41	600.45	600.40	600.73	600.97	600.95
Max.	601.91	602.00	601.95	601.91	602.00	601.95	601.72	601.71	601.67
Min.	598.36	598.81	598.76	598.36	598.81	598.76	599.72	599.84	599.84
Range	3.55	3.19	3.19	3.55	3.19	3.19	2.00	1.87	1.83
Lakes Michigan-Huron									
Mean	577.95	577.96	577.86	578.04	578.02	577.92	579.03	578.93	578.86
Max.	580.91	580.64	580.52	581.10	580.74	580.59	581.08	580.75	580.65
Min.	575.15	575.46	575.39	575.15	575.46	575.39	577.53	577.47	577.47
Range	5.76	5.18	5.13	5.95	5.28	5.20	3.55	3.28	3.18
Lake Erie									
Mean	570.60	570.61	570.36	570.69	570.67	570.42	571.61	571.60	571.28
Max.	573.01	573.04	572.69	573.75	573.55	573.19	573.74	573.55	573.23
Min.	567.95	568.14	567.97	567.95	568.14	567.97	570.42	570.44	570.19
Range	5.06	4.90	4.72	5.80	5.41	5.22	3.32	3.11	3.04
Lake Ontario									
Mean	244.53	244.55	244.48	244.53	244.56	244.51	245.12	244.86	244.93
Max.	246.95	246.92	246.89	249.26	248.91	248.81	249.21	248.51	248.50
Min.	241.31	241.53	241.29	241.31	241.53	241.29	243.71	243.63	243.62
Range	5.64	5.39	5.60	7.95	7.38	7.52	5.50	4.88	4.88

ECONOMIC EVALUATION
Approximate Annual Benefits ($ Millions)

	Plan SO-901	Plan SEO-42P	Plan SO-901	Plan SEO-42P	Plan SO-901	Plan SEO-42P
Superior Shores	- 0.1	0.0	- 0.2	- 0.1	- 1.9	- 1.7
Michigan-Huron Shores	+ 0.9	+ 1.9	+ 1.0	+ 2.0	+ 1.6	+ 2.8
Erie Shores	+ 0.1	+ 1.0	+ 0.1	+ 1.1	+ 0.4	+ 2.0
Ontario Shores	0.0	+ 0.1	0.0	+ 0.1	+ 0.7	+ 0.7
Total	+ 0.9	+ 3.0	+ 0.9	+ 3.1	+ 0.8	+ 3.8
Navigation	+ 0.8	+ 0.6	+ 0.8	+ 0.6	+ 0.7	+ 0.6

* Current regulation plans for Lakes Superior and Ontario under conditions described in Section 5.
** Without discretionary deviations of 1973 described in Subsection 13.2.2.

basis-of-comparison for both 1900-1973 and 1968-1973 adheres to plan flows for the first six months of 1973, rather than incorporating the extraordinary deviations which were taken and are described below.

With less extreme supplies than the lower lakes, Lake Superior experienced a maximum level for 1968-1973 about 0.2 foot lower than the maximum for 1900-1967. All the other lakes exceeded the 1900-1967 maximums during the recent period.

The International Joint Commission and its boards of control took extraordinary action in 1973 to alleviate conditions on the lower lakes. On January 26 the United States Government applied to the Commission to reduce the outflow of Lake Superior to provide relief from critical high water levels on the lower lakes. In response to this request and expressions of concern from the Government of Canada, the Commission directed the International Lake Superior Board of Control to deviate from the existing Lake Superior regulation plan (the 1955 Modified Rule of 1949), reducing the discharge effective February 1. This emergency action continued through 1973 under instructions from the Commission to regulate Lake Superior using Plan SO-901 as a guide. In mid-August Lake Superior was 8 inches higher, at 601.6 feet, and Lakes Michigan-Huron 5 inches lower, at 581.0 feet, than they would have been if Lake Superior outflows had been in strict accord with the 1955 Modified Rule of 1949. During the first week of September Lake Superior reached a peak level of 601.9 feet, 0.1 foot below the prescribed upper limit of regulation. The mid-August peak of Lakes Michigan-Huron was the highest level since 1886.

Lake Ontario received record high supplies during 1972 and 1973. In consultation with the Commission, the International St. Lawrence River Board of Control began deviating from Plan 1958-D in mid-December 1972 in an effort to satisfy the regulation criteria. Even with continued deviation throughout the early months of 1973, it was not possible to avoid exceeding the upper limit of 246.77 feet IGLD specified under Criterion (h) of the IJC Orders of Approval for the regulation of Lake Ontario. This situation persisted from March through July 1973. On a daily basis, the elevation of 246.77 feet was first exceeded on March 18, 1973, and the lake did not return to elevation 246.77 until August 4, having peaked at 247.99 on May 28 through June 1. The maximum monthly mean was 247.94 feet in May. In order to reduce the level of Lake Ontario as rapidly as possible, the St. Lawrence Board continued to use its discretionary powers to authorize releases higher than Plan 1958-D and in excess of pre-project flow for 12 weeks. For all of June and July 1973, the outflow was 350,000 cfs. This exceeded by 32,000 cfs the maximum flow ever recorded before the St. Lawrence Seaway and Power Project was built and by 13,000 cfs the peak flow that would have occurred this summer without the Project. The outflows under the discretionary authority of Criterion (k) kept Lake Ontario at least one foot lower at all times than it would have been if the Project had never been built.

13.2.3 Performance of Two Selected Regulation Plans

The following paragraphs summarize the performance of Plans SO-901 and SEO-42P as reflected in Table 66.

Plan SO-901: In the 1968-1973 period Plan SO-901 would have lowered the 1973 maximum levels of all the lakes except Lake Superior. Like the extraordinary action described above, Plan SO-901 would have raised the level of Lake Superior in June 1973 about 0.7 foot above the basis-of-comparison without deviation in 1973. The maximum level for Lakes Michigan-Huron would be lowered by 0.3 foot, while the Lake Erie maximum level would be lowered by 0.2 foot and the Lake Ontario maximum level would be lowered by 0.7 foot. The mean level of all the lakes, except Lake Superior, would be lowered slightly. Therefore, the performance of Plan SO-901 over the period 1968-1973 would provide benefits to Lakes Michigan-Huron, Erie and Ontario.

The test of Plan SO-901 over the extended period of 1900-1973, provided similar results, whereby the maximum levels of all the lakes except Lake Superior would have been lowered.

Plan SEO-42P: In the 1968-1973 period Plan SEO-42P would have lowered the 1973 maximum levels of all the lakes except Lake Superior, where the effect would have been similar to Plan SO-901. The maximum level of Lakes Michigan-Huron would be 0.4 foot lower, the Lake Erie maximum level would be 0.5 foot lower, and the Lake Ontario maximum level would be 0.7 foot lower. Except for Lake Superior, the mean level of all the Lakes would have been lowered slightly. Therefore, the performance of Plan SEO-42P like that of Plan SO-901 over the period 1968-1973 would be beneficial to the lower lakes.

Over the extended period of 1900-1973, the test of Plan SEO-42P provided similar results. The plan would lower the maximum levels of Lakes Michigan-Huron by 0.5 foot and Lake Erie by 0.6 foot. Lake Ontario maximum level would be lowered by about 0.4 foot.

The data in Table 66 and the foregoing discussion exclude the effects of any extraordinary deviation from Plan 1958-D, such as described in the last paragraph of Subsection 13.2.2. If the same degree of discretionary deviation were applied under Plan SO-901 or Plan SEO-42P as occurred in the actual operation of Plan 1958-D in 1973, the maximum level of Lake Ontario in the 1968-1973 period would be approximately 247.3 feet, 0.6 foot below that actually experienced.

13.3 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 so as to permit reducing the range of stage on Lake Ontario and improving the distribution of outflows, without changing the regime to the detriment of downstream interests. Supplies of the period 1860-1954 were used in extensive studies to arrive at an economical design which would serve the interests of navigation, power and shore property on the lake and along the river to tidewater at Trois-Rivières below Montreal. After extensive public hearings the design was recommended by the International Joint Commission and approved by the Governments of Canada and the United States.

To the extent that the regulation criteria and facilities were designed to satisfy certain requirements of navigation, power and shore property under certain assumed supply conditions, as specified in the IJC's Orders of Approval, the system lacks the flexibility to accommodate more extreme supplies without adverse effects on the interests. Physical constraints downstream were a major factor in the inability to meet all the criteria and other requirements of the IJC's Orders during the recent high supplies. The following summary of these constraints will give some appreciation for the areas requiring consideration in any further study of Lake Ontario regulation.

To meet the needs of navigation on Lake Ontario, the St. Lawrence Seaway and the St. Lawrence Ship Channel, the project design and the regulation plan provide for certain navigable depths and limiting current velocities and cross currents. Important power developments on the St. Lawrence River at Moses-Saunders and Beauharnois-Cedars require certain flows and water levels for best power production. Also certain limiting velocities during winter are necessary to allow the formation and preservation of a stable ice cover which will avoid disruptive ice jams. Such jams can interfere with maintaining adequate flows for lake regulation, as well as interrupt power generation. The IJC's Orders of Approval contain criteria and guidelines aimed at maintaining water levels within ranges which will avoid damage to shore property interests not only on Lake Ontario, but all along the St. Lawrence River system, including Lake St. Francis, Lake St. Louis and the river at and downstream of Montreal.

All along the river the physical dimensions of critical reaches determine the relation between water levels and flows. Hence these dimensions become the governing factor determining the capability of the system to regulate levels and flows within acceptable limits. If the system is to handle more extreme supplies and still provide the same degree of protection and accommodation for the interests, the governing physical dimensions will have to be revised. The logical approach to this problem is to determine the changes in the system dimensions and the regulation plan needed to handle more extreme supplies, then analyze the benefits and costs of effecting such changes.

13.4 Need for Further Regulation Studies

The need for further regulation studies stems from the conditions described in Subsection 13.2 regarding recent high supplies and Subsection 13.3 regarding downstream physical constraints and the preliminary nature of the SEO plans discussed in Section 10.

As reported in Subsection 13.2.2 on the performance of current regulation plans, the practical experience of the last two years has demonstrated the limited capability of the present system to accommodate record supplies without major damage.

From the examination of the performance of two selected regulation plans in Subsection 13.2.3, it is evident that these plans would have improved conditions if they had been in effect throughout the recent period. However, the lower four lakes would still have experienced record or near-record levels.

After consultation with the Levels Board and as part of its continuing duties assigned by the IJC, the International St. Lawrence River Board of Control has undertaken studies of recent operating experience with a view toward developing improved regulation procedures. The St. Lawrence Board is concentrating its studies on means of better satisfying the criteria and other requirements of the existing IJC Orders of Approval for the regulation of Lake Ontario within the existing physical constraints described in Subsection 13.3.

The St. Lawrence Board studies have already confirmed that it is not practicable within the existing physical constraints to design a plan which will meet all the criteria and other requirements of the IJC Orders of Approval governing the regulation of Lake Ontario. As explained in Subsection 13.3, this situation results from the fact that the physical dimensions of the present project were not designed to accommodate supplies as high as those recently experienced. In its Order of July 2, 1956, the Commission anticipated the possibility that supplies might exceed those used in design and provided discretionary authority in Criterion (k). It is now clear that only if changes were made in the physical configuration of the project, or the criteria, or both, would it be practicable to design a plan which would meet all applicable criteria under the full range of supplies experienced to date.

Beneficial changes in the configuration of the St. Lawrence River would be costly. Analysis based upon the study period 1900-1967 did not reveal potential benefits commensurate with potential costs. However, considering the extent of damage to riparian interests both upstream and downstream during recent high supplies, the Levels Board would expect significantly greater benefits from an analysis based upon an extended study period of 1900-1973. Therefore, the Board considers that further study is warranted on the regulation of Lake Ontario, addressing the feasibility and desirability of changes in the physical configuration of the St. Lawrence River, or the regulation criteria, or both, and taking into account the full range of supplies received to date.

As reported in Section 10, the Board has developed and evaluated trial plans for the combined regulation of Lakes Superior, Erie and Ontario which have favorable benefit-cost ratios. However, these plans need refinement and further examination of their effects on Niagara River hydroelectric power and riparian interests before a final judgement can be made as to feasibility and desirability.

In the development of these Lake Erie plans, benefits tended to be limited by the amount of water which could be discharged into Lake Ontario and down the St. Lawrence River within present constraints. Thus, the ultimate refinement of any SEO plans depends on the results of further studies of the regulation of Lake Ontario. Such studies should consider all the benefits on all the lakes which could be obtained through regulation of Lake Erie and changes in the regulation of Lake Ontario. The benefit-cost ratio for any Niagara River control works and changes in the configuration of the St. Lawrence River would reflect total system benefits. The Board believes that such further studies of the combined regulation of Lakes Superior, Erie and Ontario are warranted.

Regulation of Lakes Michigan-Huron by construction of control works in the St. Clair and Detroit Rivers is so costly that there is no point to considering it in any further studies.

13.5 Improvement in Regulation from Better Hydrologic Forecasting

The essence of regulation is the storage or release of supplies received in order to achieve more beneficial levels and flows. If we knew in advance the supplies to be received, we could anticipate their effects and make better regulation decisions. In order to determine how much benefit could be obtained from such advance knowledge, the Board analyzed the improvement in regulation under a plan similar to SO-901 assuming perfect foreknowledge of water supplies ranging from one to 12 months. For example, under the 7-month forecasting situation, Lake Superior was regulated so as to balance the forecasted storage on Lakes Superior and Michigan-Huron over the 7-month period. The results for different periods are not strictly comparable because the rate at which the balancing is achieved is related to the length of the forecast period. However, the technique does provide approximate estimates of the benefits from supply forecasting.

Table 67 compares the benefits of Plan SO-901 with the benefits obtainable with perfect supply forecasts of from one to 12 months. The results indicate that significant additional benefits would be obtainable only with forecasts of at least 4 months. Such a capability would increase the benefits about one-third. The same level of benefits results from a forecast capability of from 4 to 12 months.

Although long-range weather forecasting has received increasing attention, the consensus of the leading meteorologists is that even with perfect knowledge of weather conditions statistical variation precludes accurate weather forecasts of more than a few weeks. Thus, there is very little promise for forecasting precipitation over the 4-month period required to improve regulation significantly.

Table 67

HYDROLOGIC EVALUATION OF PLAN SO-901 WITH FOREKNOWLEDGE OF SUPPLIES
SUMMARY OF RANGES OF STAGE IN FEET

	Basis-of-Comparison	SO-901	1 Mo.	2 Mo.	3 Mo.	4 Mo.	5 Mo.	6 Mo.	9 Mo.	12 Mo.
Lake Superior										
Mean	600.38	600.41	600.41	600.44	600.40	600.46	600.47	600.46	600.45	600.47
Maximum	601.91	602.00	601.89	601.89	601.89	601.90	601.97	601.98	602.02	601.98
Minimum	598.36	598.81	598.84	598.88	598.65	598.89	598.84	598.77	598.68	598.68
Range	3.55	3.19	3.05	3.01	3.24	3.01	3.13	3.21	3.35	3.30
Lakes Michigan-Huron*										
Mean	577.95	577.96	577.95	577.95	577.95	577.95	577.95	577.96	577.96	577.96
Maximum	580.91	580.64	580.62	580.60	580.53	580.62	580.60	580.60	580.54	580.54
Minimum	575.15	575.46	575.39	575.43	575.46	575.51	575.53	575.53	575.56	575.55
Range	5.76	5.18	5.23	5.17	5.07	5.11	5.07	5.07	4.98	4.99
Lake Erie										
Mean	570.60	570.61	570.61	570.61	570.61	570.61	570.61	570.61	570.61	570.61
Maximum	573.01	573.04	573.04	573.03	572.98	573.01	573.00	572.98	572.93	572.89
Minimum	567.95	568.14	568.14	568.14	568.15	568.16	568.17	568.18	568.18	568.16
Range	5.06	4.90	4.90	4.89	4.83	4.85	4.83	4.80	4.75	4.73

ECONOMIC EVALUATION
Approximate Annual Benefits ($ Millions)

	Basis-of-Comparison	SO-901	1 Mo.	2 Mo.	3 Mo.	4 Mo.	5 Mo.	6 Mo.	9 Mo.	12 Mo.
Superior Power	0.0	-0.2	-0.3	-0.2	-0.1	0.0	0.0	0.0	0.0	0.0
Erie Power	0.0	+0.4	+0.3	+0.3	+0.3	+0.3	+0.3	+0.3	+0.3	+0.3
Superior Shore	0.0	-0.1	+0.3	+0.2	-0.1	-0.1	0.0	-0.2	-0.4	-0.4
Michigan-Huron Shore	0.0	+0.9	+0.4	+0.5	+0.7	+0.9	+0.7	+1.0	+1.2	+1.1
Erie Shore	0.0	+0.1	+0.1	+0.1	+0.1	+0.1	+0.1	+0.2	+0.2	+0.2
Navigation	0.0	+0.8	+0.7	+0.9	+0.7	+1.1	+1.0	+1.1	+1.1	+1.2
Total (excluding Lake Ontario)	0.0	+1.9	+1.5	+1.8	+1.6	+2.3	+2.1	+2.4	+2.4	+2.4

* 1962 outlet conditions

While future precipitation cannot be known, there is potential for improving our knowledge of future runoff to the lakes of precipitation which has already fallen on the tributary land areas. Hydrologic lag--the time between actual precipitation and the arrival of the supplies in the lakes--is a significant factor in the seasonal fluctuation of the lakes.

Present regulation decisions are based upon actual lake levels, without analytical use of such factors as recent precipitation, tributary stream flow, soil moisture content, and air and water temperatures. The instrumentation and communications presently installed do not provide sufficient area coverage or timely information to permit an analytical approach. Expansion of the meteorological and hydrologic networks and provision of adequate communications would be costly. Such an investment would be justified only if benefits are commensurate with costs.

On the basis of its preliminary examination the Board believes that the potential benefits will justify expansion and provision of more timely information from the basin's meteorological and hydrologic networks. The responsible national agencies of Canada and the United States should cooperate 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.

Section 14

FINDINGS AND CONCLUSIONS

14.1 General

This section summarizes the findings and conclusions reached by the International Great Lakes Levels Board within the scope of its study as defined by the Reference. The study deals only with the further regulation of the Great Lakes based on the available supplies of water within the basin as modified by current diversions. The Board and its supporting Working Committee and Subcommittees devoted themselves to understanding the complex hydrology and hydraulics of the Great Lakes system as well as to analyzing the economic and environmental impact of fluctuation in the lake levels and outflows. Engineering and scientific experts in the fields of hydraulics, hydrology, economics, structural design, biology, mathematics and related disciplines have participated and assisted the Board in carrying out its study. The Board has reached the findings and conclusions presented in the following paragraphs.

14.2 Findings

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. Wind and differences in barometric pressure over the surface of a lake create temporary imbalances in the water levels at various locations in the lake. Although the level of a lake at a particular location may change as much as 8 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. This cycle is characterized by higher supplies during the spring and early summer and 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. Lake Ontario has the largest average seasonal fluctuations because it is the lowest and smallest in the chain of lakes. 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 in the Great Lakes basin indicates that there are no regular, predictable cycles such as one might expect. The intervals between periods of high and low levels and the length of such periods vary widely and erratically over a number of years. Maximum recorded ranges of levels, from extreme high to extreme low, vary from 3.8 feet on Lake Superior to 6.6 feet on Lakes Michigan-Huron and Ontario.

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

Scientists have been giving increasing attention to climatic change, which would influence both the amounts of precipitation received by the lakes and their basins and the amounts lost by evaporation. Although there have been fluctuations in climate, the data have not permitted the identification of any current long-term climatic trend in the Great Lakes region.

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 runoff to them, constitute a unique feature of this waterway. Small differences in lake level, therefore, represent enormous quantities of water. Both seasonal and long-term fluctuations in the lake levels are the result of changes in lake volume.

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 to the next lake in the chain or, in the case of Lake Ontario, through the St.Lawrence River to the ocean. 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 to the lake. 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. The magnitude of the lake level and outflow fluctuations which will occur in the system depends upon the magnitude of water supply change and the timing of the passage of water supply through the Great Lakes system. The variation in the supply, which is primarily the difference between precipitation on the Great Lakes and their basins and evaporation from them, is the primary cause of seasonal and long-term fluctuations. Net monthly water supplies to Lakes Michigan-Huron, for example, range from a maximum of 594,000 cfs-months to a minimum of -86,000 cfs-months, the negative value indicating that losses from evaporation and outflow exceed the supply from precipitation and inflow. However, large variations in supplies to the lakes are absorbed and modulated to such an extent that their outflows are remarkably steady in comparison with the variations in flows exhibited by large rivers elsewhere.

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 Lake Superior to be realized in the outflow from Lake Erie. Therefore, the result of a change in supply to 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 to Lake Superior 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.

(1) The increasing consumptive use of water will gradually decrease the net supply to the lakes. Based on projected land uses, industry and power growths and population increases, the rates of consumptive use could increase from a basin total of 2,300 cfs in 1965, to 6,000 cfs in 2000 and to 13,000 cfs by 2030. The effect of this will be to decrease the mean water elevation of an unregulated lake and its outflow. In the case of a regulated lake, the mean level could be maintained even with the reduced supply by

changing the regulation rules, but the effect of this action would be transmitted downstream in the form of reduced outflows. Alternatively, an attempt could be made to maintain outflows by lowering levels. If the present growth trend in consumptive use continues, this problem will require careful and serious study.

(2) 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 apparent on individual lakes; for example, on Lakes Michigan-Huron land at 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. This relative movement is probably the rebounding of the earth's crust from the weight of ice-age glaciers. 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. Ultimately the limiting factor of such compensating adjustment is the regulation capability, including the capacity of the outflow works and channels. 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.

The objective of the Reference was to determine whether measures would be practicable to further regulate the Great Lakes in order to reduce the extremes of stage and to indicate how the various interests would be affected thereby. 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 stage 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 stage 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 relative to the quantities of water received and stored means 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. This means that the lake in the more favorable condition with regard to supplies and water levels is used when possible to modify less favorable conditions in the other lake.

The operational rules for Plan SO-901 are based upon the levels of both Lake Superior and Lakes Michigan-Huron and involve routine changes in the setting of the gates in the regulatory works during the winter period as well as during the open-water season. Field tests carried out during the study have shown year-round operation to be feasible. The annual cost would be $70,000, including amortization charges and surveillance of river ice conditions. Computations have shown that no benefits would accrue for a winter flow greater than the present maximum of 85,000 cfs.

The changes in flow regime of the St. Marys River resulting from Plan SO-901 would be modified by the natural regulative characteristics of Lakes Michigan-Huron and Lake Erie with the result that the modified supplies to Lake Ontario could be accommodated by the current operating plan for Lake Ontario, Plan 1958-D. However, Criteria (h) and (j) for the regulation of this lake specified by the Orders of October 29, 1952, and July 2, 1956, would not be met, any more than they are met by the existing plan.

If Plan SO-901 had been in operation over the period 1900-1967, it would have decreased the range of stage on Lake Superior from 3.55 to 3.19 feet, although there would have been a slight increase in the maximum level of record from 601.91 to 602.00. The plan would have reduced the extremes of stage on Lakes Michigan-Huron and thus their range of stage by 0.58 foot. The maximum levels recorded in the study period on Lakes Erie and Ontario would have been essentially unchanged by the plan although the minimum levels of record on both lakes would have been increased, resulting in a reduction in the range of stage on Lake Erie by 0.16 foot and on Lake Ontario by 0.25 foot.

While uncertainties exist in the evaluation of the economic effects on the interests, particularly shore property and recreation, it supports the hydrologic assessment. 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. The distribution of the computed average annual benefits among the interests and between Canada and the United States is summarized in the following tabulation:

	United States $	Canada $	Total $
Shore property	579,000	224,000	803,000
Navigation	708,000	219,000	927,000
Power	300,000	340,000	640,000
Total	1,587,000	783,000	2,370,000

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 FAVORABLE BENEFIT-COST RATIOS.

Three approaches were investigated for the coordinated regulation of the three lakes, Superior, Erie and Ontario, of which two exhibited favorable benefit-cost ratios:

(a) Regulation of Lake Erie with channel enlargement and a control structure in the upper Niagara River, based upon the principle of balancing storage in all the lakes (Plan SEO-33): Annual benefits in the order of $7.6 million could be obtained from the plan at an estimated annual cost of $8.2 million. The incremental benefit-cost ratio with respect to Plan SO-901 would be 0.64.

(b) 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 6.4 million would be obtained from such a plan at an estimated annual cost of $169,000. The incremental benefit-cost ratio with respect to Plan SO-901 would be 40.3. The permanent lowering of Lake Erie under this plan would result in irreversible harm to the environment.

(c) Increasing the outflow of Lake Erie during periods of above-average supply by controlled diversions 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. The incremental benefit-cost ratio with respect to Plan SO-901 would be 16.9.

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.

Several alternative plans were developed, and a trial plan was evaluated in detail. This representative 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 annual costs, including additional costs for Lake Superior, would be $18 million. The estimated upper limit of 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.

Several alternative plans were developed and a trial plan was evaluated in detail. This representative 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 annual costs, including additional costs for Lake Superior, would be $28 million. The estimated upper limit of 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 $12.0 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, based upon data from a remote-access, hydrometeorological network, 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. Conversely, if such measures are not taken, future development will continue to follow the general lake levels and total shoreline damage will continue to increase.

14.3 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, particularly the shore property interests. Shore property, navigation and power interests would share 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 this many works 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 cooperate 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.

ANNEX A

INTERNATIONAL JOINT COMMISSION

DIRECTIVE TO THE INTERNATIONAL GREAT LAKES LEVELS BOARD
(Dated: December 2, 1964)

1. The Governments of Canada and the United States have forwarded the attached Reference, dated October 7, 1964, to the Commission for examination and report pursuant to Article IX of the Boundary Waters Treaty.

2. The Commission established the International Great Lakes Levels Board on December 2, 1964, to undertake, through appropriate agencies in Canada and the United States, the necessary investigations and studies and to advise the Commission on all matters which it must consider in making a report or reports under the said Reference.

3. The Board is requested to review and, so far as possible, make use of relevant information and technical data which have been or may be acquired by the agencies of Canada and the United States.

4. The Board shall advise the Commission as to the feasibility of regulating water levels in the Great Lakes and connecting channels so as to bring about a more beneficial range of stage and other improvements for the purposes enumerated in the attached Reference; the changes in existing works or other measures within the Basin needed to accomplish such regulation; the costs of such measures; and the probable effects, beneficial or adverse, in each country of any regulation and measures proposed.

5. The Board is requested to prepare and submit for Commission approval, as soon as practicable, a preliminary outline of the program of investigations, surveys and studies that it proposes to undertake, and a schedule of the estimated time and costs involved in the completion of each of the several phases and submission of a final report to the Commission.

6. The Board shall carry out the program in accordance with the outline approved by the Commission, except to the extent that it is subsequently modified with the Commission's approval. If it appears to the Board at any time in the course of its investigation that the program should be expanded, reduced or otherwise modified, it shall so advise the Commission and request instructions.

7. The Commission may amend existing instructions or issue new instructions to the Board at any time.

8. The Board shall establish and maintain liaison with the International Great Lakes Pollution Board to the end that each Board shall be informed of any activities of the other which may be useful to it or may have a bearing on the conduct of the investigation for which it is responsible.

9. The Board shall consist of a United States Section and a Canadian Section, each having three members. The Commission shall appoint one member of each Section to be Chairman of that Section, and may similarly appoint a Vice-Chairman of each Section.

10. At the request of any member, the Commission may appoint an alternate member to act in the place and stead of such member whenever the said member, for any reason, is not available to act as a member of the Board. Unless otherwise provided for by the Commission, an alternate member may act as Chairman of a Section with the unanimous consent of the Board.

11. The Chairmen of the two Sections shall be joint Chairmen of the Board and shall be responsible for maintaining proper liaison between the Board and the Commission and between their respective Sections of the Board and the corresponding Sections of the Commission.

12. Each Chairman shall ensure that the members of his Section of the Board are informed of all instructions, inquiries and authorizations received from the Commission; also of activities undertaken by or on behalf of the Board, progress made and any developments affecting such progress.

13. A Chairman, after consulting the members of his Section of the Board, may appoint a Secretary of that Section. Under the general supervision of the Chairman, the Secretary shall carry out such duties as are assigned to him by the Section.

14. The Board may establish such committees and working groups as may be required to discharge its responsibilities effectively and may enlist the cooperation of other Federal, Provincial or State Departments or agencies in the United States and Canada. The Commission shall be kept informed of the duties and composition of any such committee. Unless other arrangements are made, members will make their own arrangements for reimbursement of necessary expenditures for travel.

15. The Board shall submit written reports to the Commission semi-annually two weeks in advance of the April and October meetings and at such other times as the Commission may request or the Board may desire. Such reports shall normally be available only to the Commission, members of the Board and its committees, and Government officials concerned.

16. In addition, the Chairmen shall keep the Commission currently informed of the Board's plans and progress and of any developments actual or anticipated, which are likely to impede, delay or otherwise affect the carrying out of the Board's responsibilities. This will enable the Commission to take such action as may be appropriate to the circumstances without the delay that otherwise would occur while the members familiarized themselves with the background of the problem.

17. If, in the opinion of the Board or of any member, there is a lack of clarity or precision in any instruction, directive or authorization received from the Commission which needs to be removed, the matter shall be referred promptly to the Commission for appropriate action.

18. The Board shall not conduct public hearings but will be provided with copies of the record of any hearing conducted by the Commission which relates to matters within the Board's terms of reference.

19. Except with the prior approval of the Commission, the Board shall not make public any of its proceedings nor undertake to publicise the Board's undertakings. This is not intended to prevent explanation of activities upon inquiry. Reports to the Commission shall remain a matter between the Board and Commission unless and until released by the Commission.

ANNEX B

PARTICIPANTS IN THE INTERNATIONAL GREAT LAKES LEVELS STUDY 1964-1973

Note: The names of present Board and Working Committee Members and Secretaries are underlined below.

NAME	AGENCY	PARTICIPATION	PERIOD
Aase, J. H.	BOM, DOI	Member, Reports Subcommittee	3/68-3/70
		Member, Navigation Subcommittee	1/71-6/73
ABELSON, M.	DOI	Alternate member, IGLLB	12/64-9/67
		Alternate member, Working Committee	4/65-3/67
		Member, Working Committee	3/67- *
		Member, Power Subcommittee	9/68- *
		Member, IGLLB	9/69- *
		Member, Ad Hoc Economics Group	6/70-8/70
Alexeichenko, N.	DPW	Member, AHG Evaluation Shore Property Results	6/71-12/72
Anderson, H.	BSFW, DOI	Member, AHG Wildlife	7/72-12/72
		Member, AHG Evaluation Shore Property Results	6/71-12/72
		Member, Shore Property Subcommittee	6/72- *
Argiroff, C.	COE	Coordinator, Shore Property Subcommittee	3/66-12/67
Armstrong, G. C.	OMNR	Associate, Shore Property Subcommittee	1/68- *
Aune, C. A.	COE	Member, AHG Terms of Reference Heating Study Lake Superior Regulatory Works	12/70-5/71
		Associate, Regulatory Works Subcommittee	1/69- *
Baker, F.	BOR	Associate, Shore Property Subcommittee	12/71-12/72
Ballard, J. C.	DOC	Member, Regulation Subcommittee	7/65-9/65
BATHURST, J.	DOE	Member, Working Committee	4/65-3/70
		Member, Regulatory Works Subcommittee	6/68- *
		Chairman, Reports Subcommittee	3/68- *
		Member, AHG St. Marys Winter Gate Tests Program	7/68-12/72
		Member, Shore Property Subcommittee	4/69-3/70
		Secretary, Working Committee	3/70- *
		Member, AHG Terms of Reference Detroit-St. Clair Regulatory Works	10/71-12/72
		Chairman, Regulatory Works Subcommittee	7/72- *

* present

NAME	AGENCY	PARTICIPATION	PERIOD
Berry, G.	PASNY	Member, Power Subcommittee	7/65-12/72
Bhamidipaty, DR. S.	COE	Alternate Chairman, Shore Property Subcommittee	4/72-11/73
Bishop, O. M.	BOM, DOI	Member, Navigation Subcommittee	7/65-3/68
Black, H.	MOT	Member, Recreational Boating AHG	1/69-12/69
BLAKEY, DR. L. H.	COE	Chairman, Working Committee	7/72- *
BLUST, F. A.	NOAA, LSC	Member, Working Committee	1/72- *
Bouchard, J.	SLSA, MOT	Member, AHG St. Marys Winter Gate Tests Program	7/68-12/72
		Member, AHG Terms of Reference Heating Study Lake Superior Regulatory Works	12/70-5/71
		Member, AHG Low Flow	11/71-12/72
Brown, D.	DOE	Member, Shore Property Subcommittee	5/72- *
Bryant, J. B.	DOE	Member, AHG Wildlife	7/68-6/69
Bryce, J. B.	HEPCO	Member, Power Subcommittee	8/65- *
Buchar, A. J.	DOC	Member, Working Committee	4/65-4/70
Bunch, COL J. E.	COE	Chairman, Regulation Subcommittee	5/67-3/70
		Member, Reports Subcommittee	3/68-3/70
Carlson, R. E.	COE	Coordinator, Shore Property Subcommittee	1/67- *
		Member, Recreational Boating AHG	1/69-12/69
Caulfield, H.P., Jr.	DOI	Member, IGLLB	12/64-12/65
Christopher, E.	NMFS, NOAA	Associate, Shore Property Subcommittee	7/71- *
CLARK, R. H.	DOE	Chairman, Working Committee	1/65- *
		Member, AHG Economics	6/70-8/70
Code, R. G.	ODLF	Member, Shore Property Subcommittee	8/65-3/67
Collins, J. M.	DOE	Member, AHG Wildlife	4/71-12/72
Coniglio, A.	PASNY	Member, Power Subcommittee	1/73- *

* present

NAME	AGENCY	PARTICIPATION	PERIOD
Daly, C. J.	MOT	Member, Navigation Subcommittee	9/68-9/69
DeCooke, B. G.	COE	Associate, Regulation Subcommittee	1/66-10/70
		Chairman, Regulation Subcommittee	10-70- *
		Member, Reports Subcommittee	10/70- *
		Member, AHG Low Flow	11/71-12/72
		Member, Power Subcommittee	3/73- *
de Fayer, T. L.	DOE	Co-chairman, AHG Economics	6/70-8/70
Deslauriers, C. E.	QDNR	Member, Shore Property Subcommittee	1/66- *
Dodge, BG R. T.	COE	Chairman, Working Committee	1/65-10/67
Ervin, L.	DOC	Member, Navigation Subcommittee	1/71- *
Feil, L. G.	COE	Chairman, IGLLB	9/68-7/72
Fonda, S. H., Jr.	COE	Alternate Chairman, Shore Property Subcommittee	3/67-12/68
		Member, Regulatory Works Subcommittee	7/68-4/73
		Acting Secretary, Working Committee	1/68-3/69
		Member, AHG St. Marys Winter Gate Tests Program	8/69-12/72
		Chairman, Shore Property Subcommittee	12/68-3/72
		Acting Secretary, IGLLB	2/69-4/69
		Secretary, Working Committee	3/69-4/73
		Acting Chairman, Regulatory Works Subcommittee	7/70-6/71
		Member, AHG Low Flow	11/71-12/72
Gallagher, R.	BOR	Associate, Shore Property Subcommittee	1/68-12/70
Gallinger, R. H.	COE	Chairman, Regulatory Works Subcommittee	7/68-12/70
Gehring, N.	COE	Member, AHG Dredge Disposal	12/71-12/72
Giles, J. W.	OMNR	Member, Shore Property Subcommittee	3/67- *
Goelzer, V. G.	COE	Alternate Chairman, Regulatory Works Subcommittee	7/68-7/70
Goodno, R. S.	COE	Member, Recreational Boating AHG	1/69-12/69

* present

NAME	AGENCY	PARTICIPATION	PERIOD
Gossom, R. C.	DOC	Member, Navigation Subcommittee	3/68-12/70
GRAVES, MG E.	COE	Chairman, Working Committee Chairman, IGLLB	12/70-7/72 7/72- *
Gregory, R. L.	COE	Coordinator, Shore Property Subcommittee	10/68-1/71
Griffith, G. B.	COE	Secretary, IGLLB	1/65-3/66
Grosh, W.	BOM	Member, Navigation Subcommittee	3/68-12/70
Hall, LTC J. B.	COE	Chairman, Regulation Subcommittee Member, Reports Subcommittee	3/70-7/70 3/70-7/70
Hallock, K.	COE	Member, Regulatory Works Subcommittee Member, AHG Terms of Reference Detroit-St. Clair Regulatory Works Member, AHG Dredge Disposal	7/71- * 10/71-12/72 12/71-12/72
Harris, D. L.	DOC	Member, Regulation Subcommittee	3/66-3/68
Henry, F. J.	COE	Member, AHG Erosion and Inundation Member, AHG Evaluation Shore Property Results Coordinator, Shore Property Subcommittee	11/70-12/72 6/71-12/72 3/73- *
Helmer, F. L.	COE	Member, Recreational Boating AHG	1/69-12/69
Hebson, J.	FPC	Alternate Chairman, Power Subcommittee	1/72- *
HURST, C. K.	DPW	Member, IGLLB Chairman, IGLLB	12/64-12/71 1/72- *
JAMES, N. H.	DOE	Member, Regulatory Works Subcommittee Member, Reports Subcommittee Member, IGLLB	7/68-1/72 3/68-3/70 1/72- *
Johnson, D. P.	MOT	Chairman, Navigation Subcommittee Member, AHG Economics	9/69-12/70 6/70-8/70
Jordahl, H. C., Jr.	DOI	Member, Working Committee Member, IGLLB	4/65-3/67 1/67-9/67

* present

NAME	AGENCY	PARTICIPATION	PERIOD
JOSE, B. T.	SLSDC	Member, IGLLB	4/66- *
Keefe, J. D. A.	DOE	Member, AHG Terms of Reference Detroit-St. Clair Regulatory Works	10/71-12/72
		Member, AHG Dredge Disposal	12/71-12/72
		Member, Regulatory Works Subcommittee	1/72- *
Kandl, G. P.	COE	Member, AHG Evaluation Shore Property Results	6/71-12/72
King, J. M.	DOE	Member, AHG Terms of Reference Heating Study Lake Superior, R.W	12/70-5/71
King, J. S.	COE	Chairman, Shore Property Subcommittee	7/65-11/68
		Member, AHG Economics Criteria	3/66-3/67
Kite, G.	DOE	Member, Shore Property Subcommittee	3/70-5/72
		Chairman, AHG Evaluation Shore Property Results	6/71-5/72
Kleveno, C.	EPA	Member, Shore Property Subcommittee	8/71- *
Klyce, D.	BOM, DOI	Member, AHG Economics	6/70-8/70
Klopchic, P.	ODTI	Member, Navigation Subcommittee	8/66-*
		Member, Recreational Boating AHG	1/69-12/69
Kolberg, T.	DPW	Member, AHG Erosion and Inundation	11/70-12/72
		Member, AHG Evaluation Shore Property Results	6/71-12/72
Korkigian, I. M.	COE	Member, Regulatory Works Subcommittee	7/68- *
		Member, AHG St. Marys Winter Gate Test Programs	7/68-12/72
		Member, Reports Subcommittee	3/70- *
		Member, AHG Terms of Reference Detroit-St. Clair Regulatory Works	10/71-12/72
Larsen, C. W.	COE	Member, Reports Subcommittee	1/71- *
		Member, Recreational Boating AHG	1/69-12/69
Larsen, G.	COE	Associate, Regulation Subcommittee	1/69- *
		Associate, Regulatory Works Subcommittee	1/69- *

* present

NAME	AGENCY	PARTICIPATION	PERIOD
Lawhead, H. F.	COE	Secretary, Working Committee	9/65-12/67
LAWRIE, C. J. R.	MOT	Member, Regulatory Works Subcommittee	2/70- *
		Member, Working Committee	3/70- *
Leavens, D. C.	DOC	Member, IGLLB	2/64-9/65
LEONARD, D. J.	COE	Member, Reports Subcommittee	3/68-10/70
		Alternate Chairman, Shore Property Subcommittee	9/70-3/72
		Vice-Chairman, Reports Subcommittee	10/70- *
		Member, AHG Erosion and Inundation	11/70-12/72
		Chairman, Shore Property Subcommittee	3/72- *
		Secretary, Working Committee	4/73- *
Lykowski, G. S.	COE	Chairman, Recreational Boating AHG	1/69-12/69
		Chairman, Navigation Subcommittee	1/66- *
Lynde, G.	COE	Coordinator, Shore Property Subcommittee	3/66-3/73
Malamud, B.	COE	Member, AHG Terms of Reference Detroit-St. Clair Regulatory Works	10/71-12/72
		Member, AHG Dredge Disposal	12/71-12/72
		Chairman, Regulatory Works Subcommittee	2/72- *
Manzardo, A. H.	EPA	Member, Shore Property Subcommittee	1/69-8/71
		Member, AHG Evaluation Shore Property Results	6/71-10/71
Marion, J. P.	Hydro Quebec	Member, Power Subcommittee	8/65-3/70
McIntyre, R. M.	COE	Alternate Member, AHG Economics	6/70-8/70
		Economic Associate, Working Committee	9/70- *
McKee, R. B.	COE	Acting Member, Regulatory Works Subcommittee	8/70-6/71
McLeod, G. G.	MOT	Chairman, Navigation Subcommittee	8/65-10/67
Megerian, E.	COE	Associate, Regulation Subcommittee	1/66-12/71

* present

NAME	AGENCY	PARTICIPATION	PERIOD
Millar, G.	DPW	Chairman, Regulatory Works Subcommittee	6/68-6/72
Miller, J. F.	NWS, NOAA	Member, Regulation Subcommittee	3/70- *
Miller, LTC J. M.	COE	Chairman, Regulation Subcommittee	7/70-10/70
		Member, Reports Subcommittee	7/70-10/70
Morgan, J. M.	DOT	Member, Power Subcommittee	7/65-9/68
Munro, W. T.	DOE	Member, AHG Wildlife	6/69-4/71
Nelson, E. W.	COE	Chairman, Navigation Subcommittee	7/65-12/65
Nichols, LTC W. S.	COE	Chairman, Regulation Subcommittee	7/65-9/66
Nord, W. H.	BSFW, DOI	Member, Shore Property Subcommittee	7/65-6/72
		Chairman, AHG Wildlife	6/69-6/72
		Member, AHG St. Marys Rapids	6/71-10/71
		Member, AHG Dredge Disposal	12/71-6/72
Officer, J. D.	SLSDC	Alternate Member, IGLLB	9/67-6/73
		Member, Navigation Subcommittee	1/71-6/73
		Member, Working Committee	1/72-6/73
Olson, H. E.	COE	Co-chairman, AHG Economics	6/70-8/70
Otto, W. C.	COE	Member, AHG Terms of Reference Heating Study Lake Superior, R.W.	12/70-5/71
PAQUETTE, C. H.	COE	Secretary, IGLLB	4/69- *
Patterson, T. M.	DOE	Chairman, IGLLB	12/64-12/71
Paulhus, J. L. H.	DOC	Member, Regulation Subcommittee	3/68-3/70
Pemberton, C., Jr.	DOI	Member, Shore Property Subcommittee	7/65-12/68
Pentland, R.	DOE	Associate, Regulation Subcommittee	1/67-2/73
PERSOAGE, N. P.	DOE	Secretary, Working Committee	5/65-2/70
		Member, Shore Property Subcommittee	8/65-3/70
		Chairman, Power Subcommittee	3/68-1/71
		Member, Reports Subcommittee	3/68-1/71
		Acting Secretary, IGLLB	9/69-3/70
		Secretary, IGLLB	3/70- *

* present

NAME	AGENCY	PARTICIPATION	PERIOD
Peterson, V.	COE	Coordinator, Shore Property Subcommittee	6/66-6/68
Pritchard, DR. A.L.	DOE	Member, Shore Property Subcommittee	2/66-4/69
QUINLAN, D. W.	DPW	Member, Working Committee	4/65- *
		Chairman, Shore Property Subcommittee	7/65- *
		Member, Navigation Subcommittee	8/65- *
		Member, AHG Economic Criteria	3/66-3/67
		Member, Reports Subcommittee	3/70- *
		Member, Recreational Boating AHG	1/69-12/69
Quinn, F.	COE	Associate, Regulatory Works Subcommittee	1/66-10/70
Raoul, J.	COE	Member, AHG Evaluation Shore Property Results	6/71-12/72
		Member, Regulatory Works Subcommittee	4/73- *
Revtyak, CPT C. G.	DOC	Member, Navigation Subcommittee	8/66-3/68
		Member, Navigation Subcommittee	12/70-1/71
Richards, T. L.	DOE	Member, Regulation Subcommittee	7/65- *
Roberts, R. H.	MOT	Chairman, Navigation Subcommittee	10/67-9/68
Robinson, J.	DOE	Associate, Regulation Subcommittee	1/69- *
ROBB, D. N. C.	SLSDC	Member, Working Committee	7/73- *
		Member, Navigation Subcommittee	7/73- *
Roberts, R. H.	MOT	Chairman, Navigation Subcommittee	10/67-9/68
Robinson, J.	DOE	Associate, Regulation Subcommittee	1/69- *
Roche, J. W.	COE	Secretary, IGLLB	3/66-2/69
Roellig, D. A.	COE	Coordinator, Shore Property Subcommittee	1/71- *
Sainsbury, G. V.	SLSA, MOT	Chairman, Navigation Subcommittee	12/70- *
Santerre, F.	Hydro Quebec	Member, Power Subcommittee	3/70- *
Schuder, LTC W.J.	COE	Chairman, Regulation Subcommittee	9/66-5/67

* present

NAME	AGENCY	PARTICIPATION	PERIOD
Schueler, R. L.	NMFS, NOAA	Associate, Shore Property Subcommittee	6/66-7/71
Shonk, D.	BOR	Associate, Shore Property Subcommittee	6/66-12/67
Simkin, D.	OMNR	Member, AHG Wildlife	6/69- *
Simon, M. V.	DOC	Member, Working Committee	4/70-1/72
Skene, G.	COE	Coordinator, Shore Property Subcommittee	7/68- *
Smith, J.	COE	Associate, Regulatory Works Subcommittee	11/70-5/73
SMITH, R. H.	MOT	Member, IGLLB	12/64- *
SPELLMAN, J. H.	FPC	Member, Working Committee	4/65- *
		Chairman, Power Subcommittee	7/65- *
Stenson, J.	BOR	Member, AHG Evaluation Shore Property Results	6/71-11/71
		Associate, Shore Property Subcommittee	1/71-11/71
Stewart, COL W.G.,Jr.	COE	Chairman, Working Committee	9/70-12/70
Stoddard, C. H.	DOI	Member, IGLLB	4/66-1/67
		Member, IGLLB	12/67-9/69
Sylvester, J.	MOT	Member, Shore Property Subcommittee	8/65-4/69
Tarbox, BG R. M.	COE	Chairman, Working Committee	10/67-3/69
Taylor, R.	BOR	Associate, Shore Property Subcommittee	1/72- *
Tibbles, DR. J. J.	DOE	Member, Shore Property Subcommittee	5/69- *
		Member, AHG Evaluation Shore Property Results	6/71-12/72
		Member, AHG St. Marys Rapids	6/71-10/71
		Member, AHG Low Flow	11/71-12/72
		Member, AHG Dredge Disposal	12/71-12/72
Ujjainwalla, S. H.	DOE	Member, AHG Terms of Reference Detroit-St. Clair R. W.	10/71-12/72

* present

NAME	AGENCY	PARTICIPATION	PERIOD
Wanket, A. E.	COE	Alternate Chairman, Regulatory Works Subcommittee	7/70-6/71
		Chairman, Regulatory Works Subcommittee	6/71-1/72
		Member, AHG Terms of Reference Detroit-St. Clair R. W.	10/71-1/72
Watkin, BG W.W.,Jr.	COE	Chairman, Working Committee	7/69-9/70
Watt, D.	MOT	Member, Shore Property Subcommittee	3/70- *
Weinkauff, H. C. C.	COE	Chairman, IGLLB	12/64-9/68
Wilshaw, R. C.	COE	Associate, Regulation Subcommittee	1/72- *
Weinrub, J.	COE	Member, Power Subcommittee	7/65-3/73
Witherspoon, D. F.	DOE	Chairman, Regulation Subcommittee	4/68- *
		Chairman, Power Subcommittee	1/71- *
		Member, Reports Subcommittee	1/71- *
Woll, L. B.	COE	Member, AHG Economics Criteria	3/66-3/67
Wong, P.	COE	Coordinator, Shore Property Subcommittee	1/68-10/68
Yee, P. P.	DOE	Member, AHG Dredge Disposal	2/72-12/72

* present

LIST OF ABBREVIATIONS AND AGENCY INDEX

AGENCIES

U. S. Department of the Interior, Bureau of Mines	BOM
U. S. Department of the Interior, Bureau of Outdoor Recreation	BOR
U. S. Department of the Interior, Bureau of Sport Fisheries and Wildlife	BSFW
U. S. Army Corps of Engineers	COE
U. S. Department of Commerce	DOC
Department of the Environment, Canada	DOE
U. S. Department of the Interior	DOI
Department of Public Works, Canada	DPW
U. S. Environmental Protection Agency	EPA
U. S. Federal Power Commission	FPC
Hydro Electric Power Commission of Ontario	HEPCO
Quebec Hydro Electric Power Commission	Hydro Quebec
Ministry of Transport, Canada	MOT (formerly the Dept. of Transport)
Lake Survey Center, National Oceanic and Atmospheric Administration	NOAA
National Marine Fishery Service, National Oceanic and Atmospheric Administration	NMFS
National Weather Service, National Oceanic and Atmospheric Administration	NWS,NOAA
Ontario Department of Tourism and Information	ODTI
Ontario Ministry of Natural Resources	OMNR
Power Authority of the State of New York	PASNY
Quebec Department of Natural Resources	QDNR
St. Lawrence Seaway Authority, Ministry of Transport	SLSA,MOT
U. S. Department of Transportation, St. Lawrence Seaway Development Corporation	SLSDC

LIST OF AD HOC GROUPS (AHG)

1. Dredge Disposal
2. Economic Criteria
3. Economics
4. Effects of Minimum Gate Openings on Water Quality in the St. Marys River Rapids
5. Erosion and Inundation
6. Evaluation Shore Property Results
7. Low Flow
8. Recreational Boating
9. St. Marys Winter Gate Tests Programs
10. Terms of Reference for Heating Study - Lake Superior Regulatory Works
11. Terms of Reference St. Clair-Detroit Regulatory Works
12. Wildlife

ANNEX C

LAKE SUPERIOR REGULATION PLAN "SEPTEMBER 1955 MODIFIED RULE OF 1949"

Lake Superior has been regulated since 1921. The current operating plan, the Rule of 1949, has been in use since 1951 and was modified in 1955. The rule is based on a specified release of water depending on the level of Lake Superior as shown on Figure C1. Based on the monthly mean level of the previous month, the plan discharge is chosen from Figure C1 for the following month on the first of each month from 1 May to 1 December. Alterations to planned discharge are made between 1 December and 30 April only when successive monthly mean stages of the lake move from the intermediate range to the maximum or minimum stage range or when successive monthly mean stages move from the maximum or minimum to the intermediate stage range. Gate adjustments are specified from Figure C2. The limitations of flow are shown on Figure C1. This plan was designed to satisfy the requirements of the Orders of Approval of the International Joint Commission.

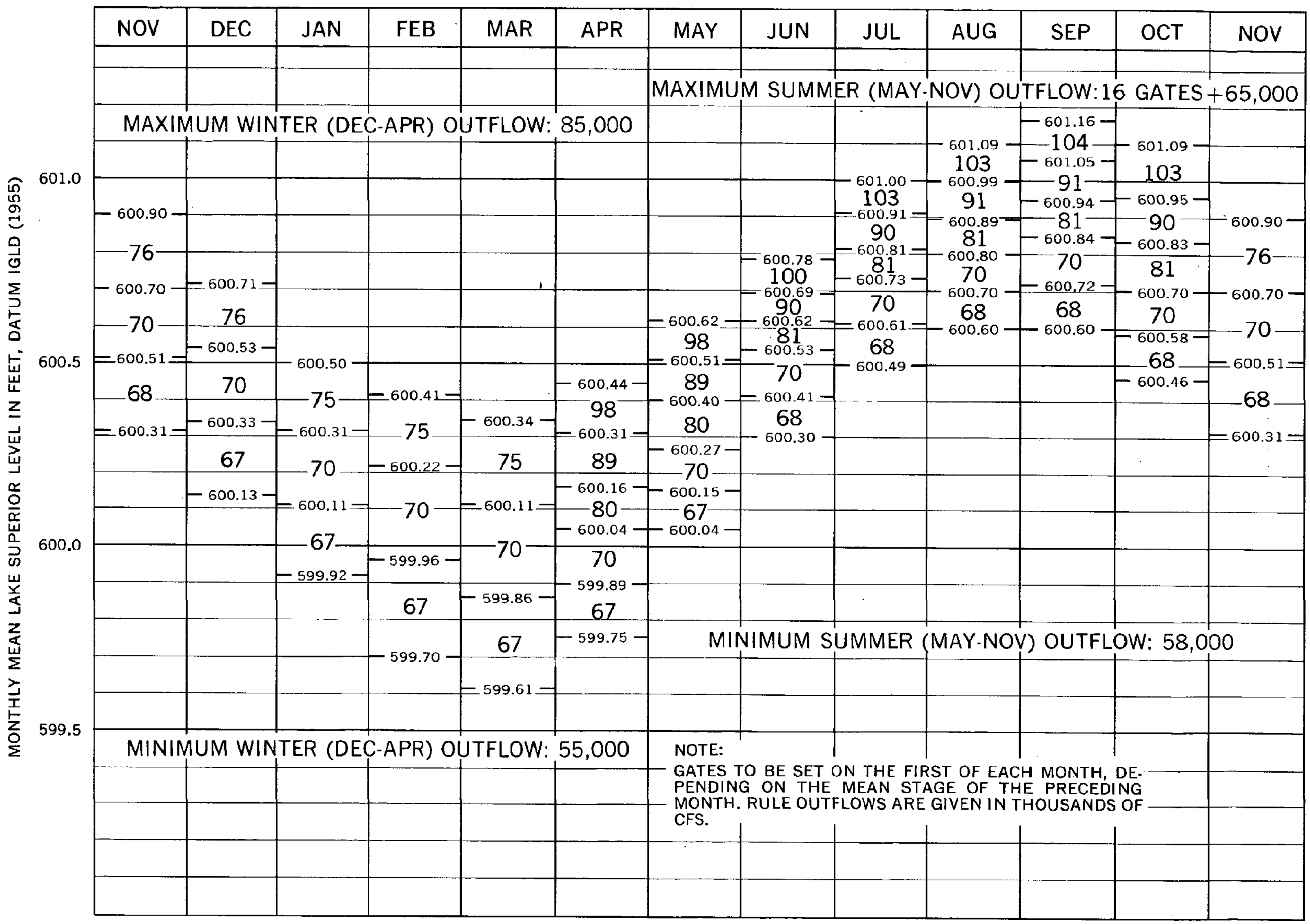


Figure C-1
REGULATION OF LAKE SUPERIOR MODIFIED RULE OF 1949

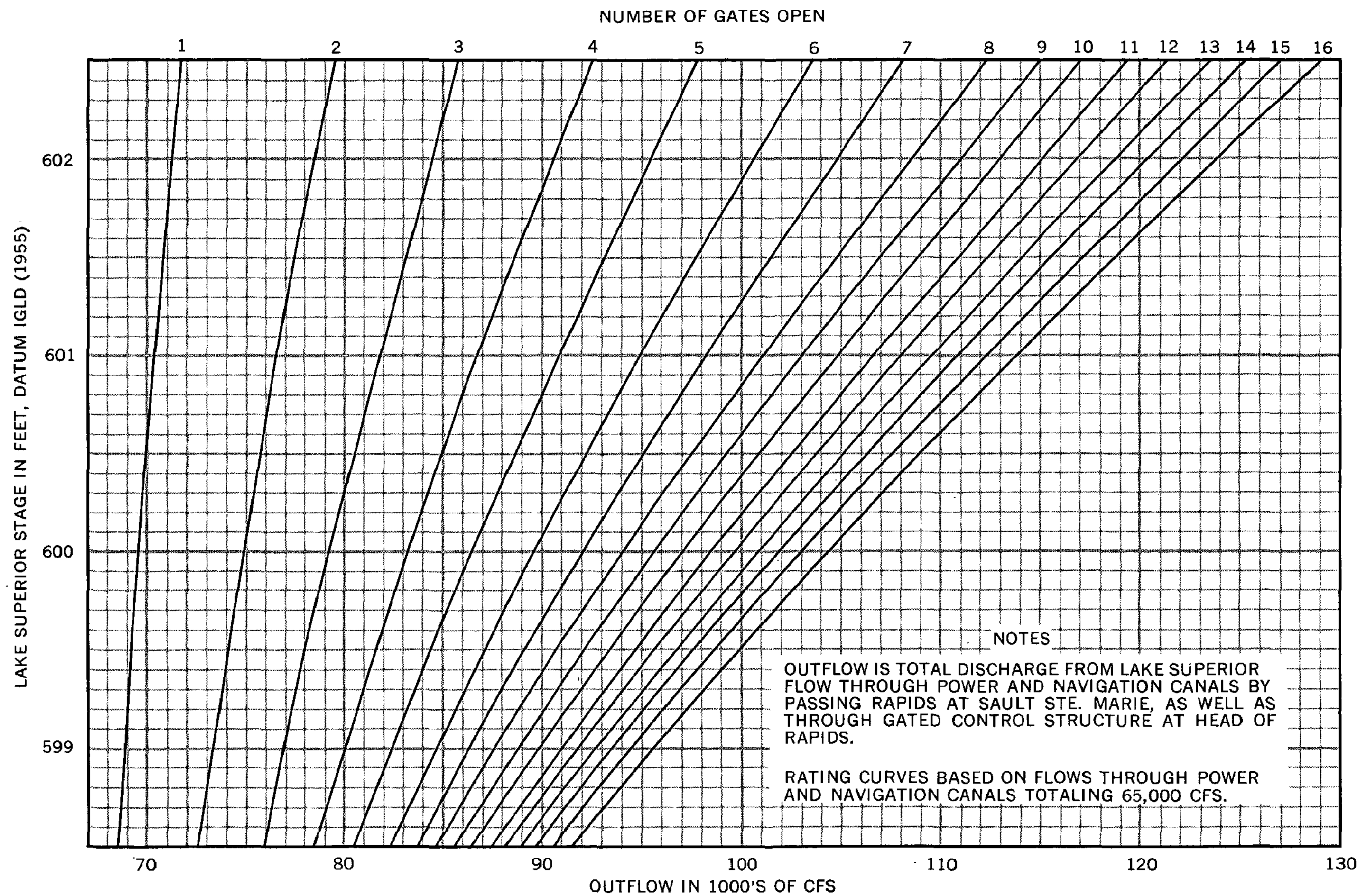


Figure C-2

LAKE SUPERIOR RATING CURVES FOR VARIOUS GATE OPENINGS

ANNEX D

LAKE ONTARIO REGULATION PLAN "1958-D"

Artificial control of the outflows and levels of Lake Ontario follow a plan that is designed to satisfy the criteria and other requirements that have been established to protect or to provide beneficial effects to the various interests concerned. By testing this plan over the period of record employing the supplies derived for the basis-of-comparison, assessment was made of the degree to which the plan satisfied the criteria and other requirements of the Orders of Approval. The results obtained with this plan were then used as a basis of comparison for future regulation studies.

Plan 1958-D consists of a supply indicator, two basic rule curves as shown on Figures D1 and D2, the seasonal adjustments listed in Table E1 and a number of maximum outflow limitations as shown on Figure D3 and maximum and minimum outflow limitations in Table D1. In the application of Plan 1958-D, the regulated Lake Ontario outflow is obtained in three steps. In the first step, the basic regulated outflow is derived from a family of curves (Figure D1 or D2) which show the basic regulated outflow as a function of the end-of-period Lake Ontario level and the "adjusted supply indicator." In the second step, the basic regulated outflow is adjusted by applying the seasonal adjustment tabulated in Table D1. In the third step, the resultant seasonal adjusted outflow is compared with the maximum and minimum outflow limitations (shown on Figure D3 and Table D1) which have been chosen to meet various requirements of regulation. These outflow limitations vary throughout the year. If the seasonal adjusted outflow is between the maximum and minimum limitations for the period, it is adopted as the regulated outflow. If it is higher than the maximum limitation or lower than the minimum limitation, the applicable outflow limitation is adopted as the regulated outflow. A sample computation sheet and explanation is presented on Tables D2 and D3.

TABLE D-1

REGULATION OF LAKE ONTARIO PLAN 1958-D

TABLE OF NORMAL SUPPLY INDICES AND FLOW LIMITATIONS

IN THOUSANDS OF CUBIC FEET PER SECOND

MONTH	QUARTER	WEIGHTED NORMAL SUPPLY	SEASONAL ADJUSTMENT TO BASIC RULE OUTFLOW	MINIMUM FLOW LIMITATIONS: Add to Supply Indicator at End of Preceding Period (P)*	MINIMUM FLOW LIMITATIONS: Minimum (M)	MAXIMUM FLOW LIMITATIONS: For Channel Design (L)	MAXIMUM FLOW LIMITATIONS: For Ice Formation Lachine (I)	MAXIMUM FLOW LIMITATIONS: Add to Supply Indicator at End of Preceding Period (P)
1	2	3	4	5	6	7	8	9
JANUARY	1	234	0	-	210		-	-
	2	234	- 6	-	210		-	-
	3	233	- 6	-	210		-	-
	4	233	- 6	-	210		-	-
FEBRUARY	1	233	- 6	-	207	PLATE 2	-	248
	2	233	- 6	-	207		-	248
	3	233	- 6	-	207		-	248
	4	233	- 6	-	207		-	248
MARCH	1	233	- 6	-	204		-	248
	2	235	- 6	-	204		-	248
	3	237	- 6	-	204		-	248
	4	242	- 6	-	204		-	248
APRIL	1	246	- 8	-	188		-	248
	2	249	- 10	-	188		-	253
	3	252	- 12	-	188		-	257 (When outflow from Lake St. Louis for previous quarter exceeds 345,000 cfs.)
	4	254	- 14	-	188		-	259
MAY	1	257	- 16	-	188		-	261
	2	258	- 18	-	188		-	263
	3	260	- 20	227*	188		-	265
	4	261	- 20	232*	188		-	266
JUNE	1	262	- 20	237*	190		-	267
	2	262	- 20	242*	190		-	267
	3	263	- 20	245*	190		-	268
	4	263	- 20	247*	190		-	268
JULY	1	262	- 18	249*	193		-	268
	2	262	- 16	251*	193		-	267
	3	261	- 14	252*	193		-	266
	4	259	- 12	253*	193		-	265
AUGUST	1	258	- 10	254*	193		-	-
	2	256	- 8	255*	193		-	-
	3	254	- 6	256*	193		-	-
	4	252	- 4	256*	193		-	-
SEPTEMBER	1	250	- 2	256*	193		-	-
	2	248	0	256*	193		-	-
	3	246	+ 2	255*	193		-	-
	4	244	+ 2	252*	193		-	-
OCTOBER	1	243	+ 2	249*	193		-	-
	2	241	+ 2	247*	193		-	-
	3	239	+ 2	245*	193		-	-
	4	238	+ 4	243*	193		-	-
NOVEMBER	1	237	+ 4	241*	198		-	-
	2	236	+ 6	240*	198		-	-
	3	235	+ 6	239*	198		-	-
	4	235	+ 8	238*	198		-	-
DECEMBER	1	235	+ 8	238*	210		-	-
	2	235	+ 8	238*	210		-	-
	3	234	+ 6	-	210		280 from Lake St. Louis	-
	4	234	+ 6	-	210			-

*If sum exceeds (225 - 1/6 I) where I is the difference between the outflows of Lake St. Louis and Lake Ontario for preceding quarter, use (225 - 1/6 I) (P).

TABLE D-2

EXPLANATION OF SAMPLE COMPUTATION SHEET

COLUMN NUMBER	PROCEDURE	Example for 1 April 1937
1.	The regulation periods are quarter month periods as defined in paragraph 13.	
2.	Supply to Lake Ontario = $\bar{I}$ = Outflow plus change in storage when lake level rises during period and minus change in storage when lake level falls. These supplies were determined as described in paragraphs 28 and 29 and are tabulated in Table 8 Volumn 2 of the report on Regulation Plan 1958-A.	
3.	16.5 x Weighted Supply = "KO" forms part of the routing procedure described in paragraphs 36 to 38. To compute KO, subtract the value of O (Column 4) for previous period from the value of KO for previous period and add the value of $\bar{I}$ (Column 2) for current period.	3636 - 220 + 273 = 3688
4.	Weighted Supply = "O" also forms part of the routing procedure and is derived by dividing value in Column 3 by 16.5.	$\frac{3688}{16.5} = 223$
5.	Weighted Normal Supply = These data are tabulated on Plate 3 for each regulation period.	
6.	Supply Indicator. Subtract value in Column 5 from that in Column 4.	223 - 246 = - 22
7.	Change in Supply Indicator in Three Months.	- 22 - (- 34) = + 12
8.	Adjustment. Add values in Column 7 for three preceding periods to value for period in question and divide by 4.5. The adjustment is limited in application to magnitudes of - 7,000 cfs and + 11,000 cfs, (see paragraph 41). The adjustment is also held constant during the winter and early spring; the value during this period is dependent upon the value of the adjustment during the third quarter of December, which was + 7,000 cfs.	$\frac{26 + 23 + 15 + 12}{4.5} = 17$
9.	Adjusted Supply Indicator. Add value in Column 8 to that in Column 6.	- 22 + 7 = - 15
10.	With adjusted Supply Indicator (Column 9) for previous period and end of period level (Column 16) for previous period, enter the appropriate Basic Rule Curve (Plate 1A or 1B) and read discharge from horizontal scale.	With elevation of 244.02 and adjusted supply indicator of - 15, basic regulated discharge from basic curve is 229.
11.	Seasonal Adjustment. These data are tabulated on Plate 3 for each period.	
12.	Seasonal Adjusted Outflow is obtained by adding value in Column 10 to that in Column 11.	229 + (- 8) = 221
13.	Discharge with limitations. The limitations are tabulated on Plate 3. There are three types of maximum limitations and two types of minimum limitations. For January 4, only two limitations may apply: a minimum designated (M) and a maximum designated (L). Since the seasonal adjusted outflow 222 (Column 12) exceeds the maximum limitation 220L (derived from Plate 2 with elevation 243.94), use 220L. For April 1, three limitations may apply: a minimum (M) and two maxima (L) and (P). The (L) from Plate 2 is 280L and the (P) maximum is 248 plus the supply indicator (Column 6) of March 4 of - 22, which gives 226P. The seasonal adjusted outflow is 221, therefore use 221. For June 1, four limitations may apply: two minima (M) and (P) and two maxima, (L) and (P). The (L) from Plate 2 is 304L and since the Lake St. Louis regulated outflow (298) for the previous period does not exceed 345, the maximum (P) is not applicable. The (M) is 190M and the minimum (P) 237 - 15 = 222P with a maximum limit of (225 - 1/6 I) or 214. The seasonal adjusted outflow is 232 which is greater than the minima and less than the maximum, therefore use 232. For October 2, three limitations may apply: two minima (M) and (P) and a maximum (L). The (M) is 193M, the (P) is 247 - 18 = 229 with a maximum of (225 - 1/6 I) which is (225 - 3) or 222P. Since the seasonal adjusted flow, 217, is less than minimum (P) 222, use 222P.	
14.	Change in Storage, Column 2 minus Column 13.	273 - 221 = + 52
15.	Change in Storage in Feet, use conversion Table on Plate 4.	+ 52 = + 0.16 feet
16.	End of Period Water Level. Add value in Column 15 to end of previous period level.	244.02 + 0.16 = 244.18
17.	Mean for Period. Average of end of current and previous period level.	$\frac{244.02 + 244.18}{2} = 244.10$
18.	Recorded adjusted Lake Ontario outflows were determined as described in paragraphs 22 and 23.	
19.	Recorded adjusted Lake St. Louis outflows were determined as described in paragraphs 24 and 25.	
20.	Mean outflows from Lake St. Louis with Lake Ontario regulated under Plan 1958-D. Add difference between values in Columns 19 and 18 to value in Column 13.	(278 - 225) + 221 = 274

NOTE: These computations were made to a higher degree of accuracy using an electronic computer and therefore totals may not agree exactly due to rounding.

TABLE D-3

REGULATION OF LAKE ONTARIO

PLAN 1958-D

REGULATION PERIOD 1937	SUPPLY DURING PERIOD	SUPPLY INDICATOR AT END-OF-PERIOD -- 1000 CFS: 16.5 X WEIGHTED SUPPLY = "KO"	WEIGHTED SUPPLY "O"	WEIGHTED NORMAL SUPPLY	SUPPLY INDICATOR	ADJUSTMENT OF SUPPLY INDICATOR AT END-OF-PERIOD -- 1000 CFS: CHANGE IN SUPPLY INDICATOR IN THREE MONTHS	ADJUSTMENT	ADJUSTED SUPPLY INDICATOR	UNDER PLAN 1958-D — OUTFLOWS FROM LAKE ONTARIO -- 1000 CFS: FROM BASIC CURVE	SEASONAL ADJUSTMENT	SEASONAL ADJUSTED	WITH LIMITATIONS	CHANGE IN STORAGE: 1000 CFS	FEET	WATER LEVELS OF LAKE ONTARIO: END OF PERIOD	MEAN FOR PERIOD	RECORDED ADJUSTED OUTFLOWS - 1000 CFS: FROM LAKE ONTARIO	FROM LAKE ST. LOUIS	MEAN OUTFLOW FROM LAKE ST. LOUIS WITH LAKE ONTARIO REGULATED UNDER PLAN 1958-D
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Jan 1	249	3299	200	234	- 34	+ 7	+ 7	- 27	180	0	180	210[M]	+ 39	+ 0.12	243.40	243.34	201	247	256
2	287	3386	205	234	- 29	+ 12	+ 7	- 22	180	- 6	174	210[M]	+ 77	+ 0.24	243.64	243.52	207	256	259
3	306	3487	211	233	- 22	+ 17	+ 7	- 15	183	- 6	177	210[M]	+ 96	+ 0.30	243.94	243.79	210	265	265
4	277	3553	215	233	- 18	+ 21	+ 7	- 11	228	- 6	222	220[L]	+ 57	+ 0.18	244.12	244.03	213	259	266
Feb 1	244	3582	217	233	- 16	+ 20	+ 7	- 9	235	- 6	229	229	+ 15	+ 0.05	244.17	244.14	212	273	290
2	233	3597	217	233	- 15	+ 20	+ 7	- 8	238	- 6	232	232[P]	+ 1	0	244.17	244.17	217	252	267
3	231	3610	219	233	- 14	+ 22	+ 7	- 7	239	- 6	233	233[P]	- 2	- 0.01	244.16	244.16	215	246	264
4	270	3662	222	233	- 11	+ 26	+ 7	- 4	240	- 6	234	234[P]	+ 36	+ 0.11	244.27	244.22	222	255	267
Mar 1	237	3677	223	233	- 10	+ 28	+ 7	- 3	245	- 6	239	237[P]	0	0	244.27	244.27	221	262	278
2	203	3657	222	235	- 13	+ 26	+ 7	- 6	246	- 6	240	238[P]	- 35	- 0.11	244.16	244.22	219	264	283
3	222	3657	222	237	- 15	+ 23	+ 7	- 8	241	- 6	235	235[P]	- 13	- 0.04	244.12	244.14	222	250	263
4	200	3636	220	242	- 22	+ 15	+ 7	- 15	238	- 6	232	232	- 32	- 0.10	244.02	244.07	216	246	262
Apr 1	273	3688	223	246	- 22	+ 12	+ 7	- 15	229	- 8	221	221	+ 52	+ 0.16	244.18	244.10	225	278	274
2	258	3723	226	249	- 23	+ 6	+ 7	- 16	233	- 10	223	223	+ 35	+ 0.11	244.29	244.24	226	306	303
3	322	3819	231	252	- 21	+ 1	+ 7	- 14	232	- 12	220	220	+102	+ 0.32	244.61	244.45	226	301	295
4	311	3899	236	254	- 18	0	+ 7	- 11	242	- 14	228	228	+ 83	+ 0.26	244.87	244.74	231	326	323
May 1	286	3948	239	257	- 18	- 2	+ 7	- 11	250	- 16	234	234	+ 52	+ 0.16	245.03	244.95	237	336	333
2	256	3965	240	258	- 18	- 3	- 1	- 19	254	- 18	236	236	+ 20	+ 0.06	245.09	245.06	239	344	341
3	310	4035	244	260	- 15	- 1	- 1	- 16	237	- 20	217	217	+ 93	+ 0.29	245.38	245.24	245	337	309
4	263	4053	246	261	- 15	- 4	- 2	- 17	254	- 20	234	234	+ 29	+ 0.09	245.47	245.42	246	310	298
Jun 1	247	4055	246	262	- 16	- 6	- 3	- 19	252	- 20	232	232	+ 15	+ 0.05	245.52	245.50	247	300	285
2	247	4056	246	262	- 16	- 3	- 3	- 19	245	- 20	225	225	+ 22	+ 0.07	245.59	245.56	247	291	269
3	277	4087	248	263	- 15	0	- 3	- 18	246	- 20	226	226	+ 51	+ 0.16	245.75	245.67	245	283	264
4	246	4085	248	263	- 15	+ 7	0	- 15	254	- 20	234	234	+ 12	+ 0.04	245.79	245.77	246	278	266
Jul 1	231	4069	247	262	- 15	+ 7	+ 2	- 13	265	- 18	247	247	- 16	- 0.05	245.74	245.76	247	273	273
2	228	4050	245	262	- 17	+ 6	+ 4	- 13	266	- 16	250	250	- 22	- 0.07	245.67	245.70	244	265	271
3	232	4037	245	261	- 16	+ 5	+ 6	- 10	264	- 14	250	250	- 18	- 0.06	245.61	245.64	248	266	268
4	233	4025	244	259	- 15	+ 3	+ 5	- 10	266	- 12	254	254	- 21	- 0.07	245.54	245.58	249	267	272
Aug 1	226	4007	243	258	- 15	+ 3	+ 4	- 11	265	- 10	255	255	- 29	- 0.09	245.45	245.50	243	263	275
2	243	4007	243	256	- 13	+ 5	+ 4	- 9	262	- 8	254	254	- 11	- 0.03	245.42	245.44	244	262	272
3	192	3956	240	254	- 14	+ 1	+ 3	- 11	263	- 6	257	257	- 65	- 0.20	245.22	245.32	241	265	281
4	221	3938	239	252	- 13	+ 2	+ 2	- 11	257	- 4	253	253	- 32	- 0.10	245.12	245.17	238	257	272
Sep 1	186	3885	235	250	- 15	+ 1	+ 2	- 13	255	- 2	253	253	- 67	- 0.21	244.91	245.02	234	250	269
2	186	3836	232	248	- 16	0	+ 1	- 15	249	0	249	249	- 63	- 0.20	244.71	244.81	234	248	263
3	170	3773	229	246	- 17	- 2	0	- 17	243	+ 2	245	245	- 75	- 0.23	244.48	244.60	233	249	261
4	194	3738	227	244	- 17	- 2	- 1	- 18	233	+ 2	235	235	- 41	- 0.13	244.35	244.42	226	244	253
Oct 1	193	3705	224	243	- 18	- 3	- 2	- 20	226	+ 2	228	228	- 35	- 0.11	244.24	244.30	225	243	246
2	159	3639	221	241	- 20	- 3	- 2	- 22	215	+ 2	217	222[P]	- 63	- 0.20	244.04	244.14	223	243	242
3	239	3658	222	239	- 17	- 1	- 2	- 19	203	+ 2	205	222[P]	+ 17	+ 0.05	244.09	244.06	223	241	240
4	241	3677	223	238	- 15	0	- 2	- 17	217	+ 4	221	222[P]	+ 19	+ 0.06	244.15	244.12	225	253	250
Nov 1	192	3646	221	237	- 16	- 1	- 1	- 17	226	+ 4	230	230	- 38	- 0.12	244.03	244.09	225	258	263
2	268	3693	224	236	- 12	+ 1	0	- 12	224	+ 6	230	230	+ 38	+ 0.12	244.15	244.09	221	260	269
3	192	3661	222	235	- 13	+ 1	0	- 13	235	+ 6	241	241	- 49	- 0.15	244.00	244.08	225	290	306
4	210	3649	221	235	- 14	- 1	0	- 14	231	+ 8	239	239	- 29	- 0.09	243.91	243.96	227	278	290
Dec 1	223	3651	221	235	- 14	+ 1	0	- 14	228	+ 8	236	236	- 13	- 0.04	243.87	243.89	224	263	275
2	175	3605	218	235	- 17	- 1	0	- 17	227	+ 8	235	235	- 60	- 0.19	243.68	243.78	224	259	270
3	234	3620	219	234	- 15	+ 2	0	- 15	207	+ 6	213	215[J]	+ 19	+ 0.06	243.74	243.71	219	252	248
4	165	3566	216	234	- 18	- 1	0	- 18	219	+ 6	225	225	- 60	- 0.19	243.55	243.64	214	245	256

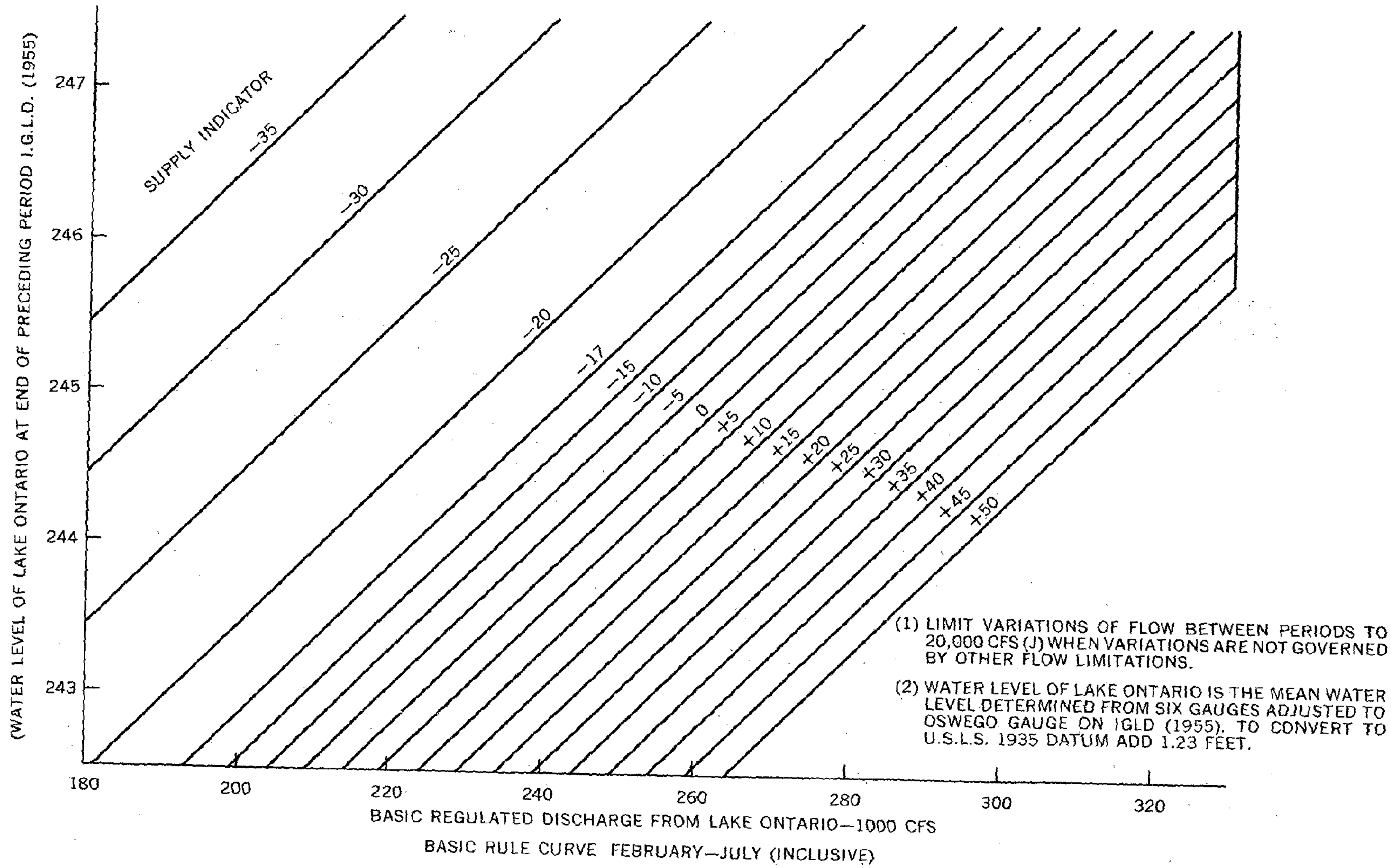


Figure D-1

REGULATION OF LAKE ONTARIO PLAN 1958-D

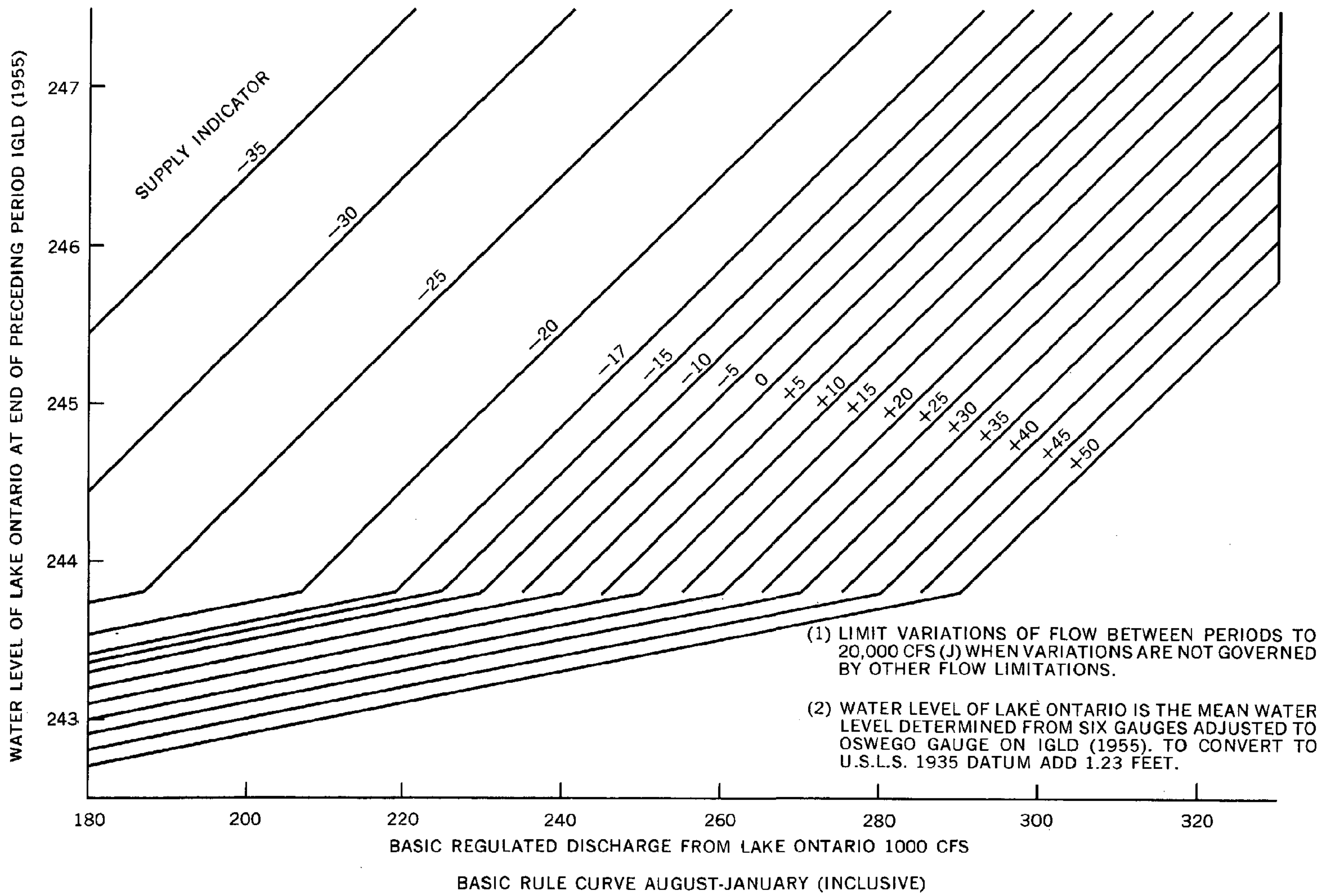
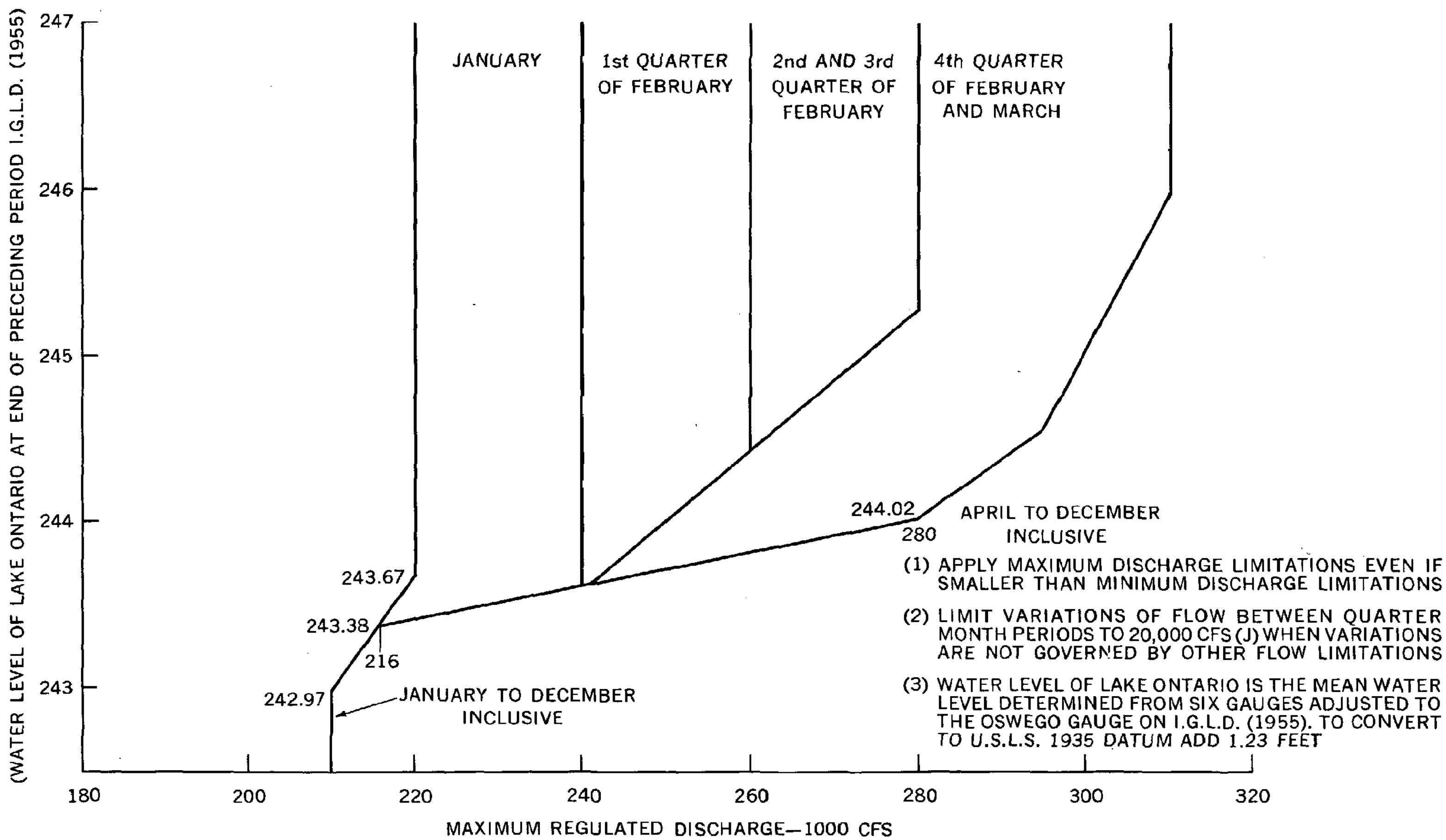


Figure D-2
REGULATION OF LAKE ONTARIO PLAN 1958-D



MAXIMUM OUTFLOW LIMITATIONS AS RELATED TO WATER LEVELS

Figure D-3
REGULATION OF LAKE ONTARIO PLAN 1958-D

ANNEX E

DESCRIPTION OF LAKE SUPERIOR REGULATION PLAN SO-901

Control of the levels and outflows of Lake Superior is provided by the existing control works at the head of the St. Marys River Rapids and by hydro-electric and navigation facilities which divert water around the rapids. The fundamental principle of Plan SO-901 is to manipulate the St. Marys River flow in such a way as to keep the levels of Lakes Superior and Michigan-Huron at relatively the same position with respect to their mean level while attempting to satisfy the criteria and other requirements established to protect the various interests. This is accomplished while adhering to selected maximum and minimum outflow limitations. To assess the degree to which the plan satisfied the criteria as well as other requirements, the plan was tested over the selected study period (1900-1967).

The basis of the plan is a linear relationship between the beginning-of-month elevations of Lake Superior and Lakes Michigan-Huron representing the range of events in which neither lake is in a more favorable condition. This is expressed by the following equation:

$$S = \overline{S} + (H-\overline{H})\ {}^{\sigma_S}/_{\sigma_H}$$

where S = beginning-of-month Lake Superior elevation for the given month

H = beginning-of-month Lakes Michigan-Huron elevation for the given month

$\overline{S}$ = average (1900-1967) beginning-of-month Lake Superior elevation for the given month

$\overline{H}$ = average (1900-1967) beginning-of-month Lakes Michigan-Huron elevation for the given month

σ_S = standard deviation of beginning-of-month Lake Superior elevation

σ_H = standard deviation of beginning-of-month Lakes Michigan-Huron elevation

The parameters $\overline{S}$, $\overline{H}$, σ_S and σ_H were derived from the basis-of-comparison data for each month of the year.

The operation of the plan is such that if, at any time, the existing Lake Superior water level is in excess of that defined by the above relationship, i.e., statistically, the level on Lake Superior is greater than that on Lakes Michigan-Huron, the outflow from Lake Superior is adjusted upward from its long-term average for the following months. Conversely, if conditions produce Lake Superior level values below those defined by the relationship, the outflow is adjusted downward from its long-term average. In this manner, there is a continual balancing of the levels between the two lakes.

The amount by which the outflow is adjusted from its long-term average is dependent upon how quickly it is desired to bring the levels on the two lakes into the balanced relationship. The basic operating equation then becomes:

$$Q_1 = \overline{Q} + A \left[S - \{ \overline{S} + (H - \overline{H}) \sigma_S / \sigma_H \} \right]$$

where Q_1 = initial outflow calculations in cfs

$\overline{Q}$ = long-term average (1900-1967) outflow in cfs

A = rate of adjustment (200,000 cfs/ft.)

Once the initial outflow has been determined, it is checked against the various outflow limitations. The regulated outflow is equal to the initial outflow only if it falls between the maximum and minimum outflow limitations. The limitations are described below.

The maximum outflow during the open-water period (May-November) is limited to the discharge capacity of the 16 gates of the Control Works plus an assumed 65,000 cfs diversion through the power and navigation facilities. The maximum monthly outflow during the winter period (December-April) shall not be greater than 85,000 cfs in order to lessen the possibility of flooding caused by ice conditions downstream of the St. Marys River Rapids. Whenever the initial outflow computed from the above relationship is less than 65,000 cfs, a minimum release of 55,000 cfs is employed, which is the minimum at any time. In addition to the above limitations, the change in outflow from month to month is limited to a maximum of 30,000 cfs.

A sample computation is presented in Table E1 and an explanation of the procedure is given in Table E2. Figures E1 through E12 illustrate the Plan SO-901 Rule Curves for the months of January through December.

TABLE E1

SAMPLE COMPUTATION SHEET FOR LAKE SUPERIOR REGULATION PLAN SO-901

Month	Beginning-of-month Water Level: Lake Superior	Beginning-of-month Water Level: Lake Michigan-Huron	Operating Parameters					Initial Outflow	Applicable Limitation	Preliminary Regulated Outflow	Gate Setting	Supply 1000 cfs	Change in Storage		Lake Superior Water Level: End of Monthly Period	Lake Superior Water Level: Mean	Actual Outflow
	S	H	$\bar{Q}$	$\bar{S}$	σ_S	$\bar{H}$	σ_H	Q_1 1000 cfs	1000 cfs	Q_R 1000 cfs		N	ΔN 1000 cfs	ΔN feet			Q_F 1000 cfs
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1900																	
JAN	601.51	577.51	70	600.26	0.46	577.54	1.04	322	85	85	3	-17	-100	-0.30	601.21	601.36	83
FEB	601.21	577.36	70	600.02	0.45	577.47	1.02	318	85	85	3	49	- 33	-0.10	601.11	601.16	82
MAR	601.11	577.56	69	599.86	0.45	577.46	1.01	311	85	85	3	- 6	- 88	-0.26	600.85	600.98	82
APR	600.85	577.55	69	599.79	0.46	577.63	1.06	287	85	85	3	129	+ 47	+0.14	600.99	600.92	82
MAY	600.99	577.84	75	600.03	0.50	577.98	1.06	281	112	112	15	132	+ 20	+0.06	601.05	601.02	112
JUN	601.05	578.04	79	600.39	0.51	578.26	1.09	231	Max	114	16	83	- 31	-0.09	600.96	601.00	114
JUL	600.96	578.19	85	600.64	0.51	578.45	1.12	173	Max	113	16	205	+ 90	+0.27	601.23	601.10	115
AUG	601.23	578.57	84	600.78	0.47	578.45	1.14	164	Max	116	16	226	+108	+0.32	601.55	601.39	118
SEP	601.55	578.69	85	600.84	0.46	578.34	1.13	199	Max	119	16	266	+145	+0.43	601.98	601.76	121
OCT	601.98	578.67	82	600.83	0.45	578.15	1.08	268	Max	124	16	82	- 41	-0.12	601.86	601.92	123
NOV	601.86	578.64	84	600.70	0.44	577.91	1.08	256	Max	121	16	- 2	-122	-0.36	601.50	601.68	120
DEC	601.50	578.57	70	600.51	0.43	577.75	1.06	202	85	85	3	-46	-129	-0.38	601.12	601.31	83

TABLE E2

Explanation of Sample Computation Sheet for Lake Superior Regulation Plan SO-901

Column Number	Procedure
1	Regulation period for Lake Superior is one month.
2 and 3	Beginning-of-month water levels of Lakes Superior and Michigan-Huron. For Lake Superior the beginning-of-month level equals the computed end-of-month level of the previous month (Col. 16). The beginning-of-month Lakes Michigan-Huron levels are computed by routing the net total supplies, which include the actual Lake Superior outflows, through the lake.
4-8	Operating parameters derived from the basis-of-comparison data for each month of the year.
9	Initial outflow determination (e.g., July 1900)

$$Q_1 = \overline{Q} + A \left[S - \{ \overline{S} + (H - \overline{H}) \sigma_S / \sigma_H \} \right]$$

$$= 85 + 200 \left[600.96 - \{600.64 + (578.19 - 578.45)\frac{0.51}{1.12} \} \right]$$

$$= 85 + 200 \left[600.96 - \{600.64 - 0.26 \times \frac{0.51}{1.12} \} \right]$$

$$= 85 + 200 \left[600.96 - (600.64 - 0.12) \right]$$

$$= 85 + 200 (600.96 - 600.52)$$

$$= 85 + (200 \times 0.44) = 85 + 88 = 173$$

10 Applicable limitation - maximum and minimum outflows are determined from the following limitations:

(a) maximum winter outflow = 85,000 cfs

(b) maximum summer outflow = 65,000 cfs plus 16 gates of the compensating works open

(c) minimum outflow (all months) = 55,000 cfs

(d) variation in flow between regulation periods limited to 30,000 cfs unless governed by other limitation

(e) any time the initial outflow determination is less than 65,000 cfs the regulated outflow will be 55,000 cfs

TABLE E2 (continued)

11	Preliminary regulated outflow equal to the initially determined outflow or that governed by the applicable limitation.
12	Gate Setting - Using the beginning-of-month Lake Superior water level and the Lake Superior Gate Rating Curve determine the gate setting that will result in a flow closest to the preliminary regulated outflow (Q_R). In winter, if Q_R equals 85,000 cfs, the gate setting should be that which results in outflow closest to, but less than, 85,000 cfs.
13	Supply - Total basin supply to Lake Superior = net basin supply plus 5,000 cfs constant diversion into Lake Superior.
14	Change in storage = Column 13 - Column 18.
15	Change in storage in feet = Column 14 x 0.00296.
16	End-of-Period Water Level: - Add value in Column 15 to previous end-of-period level.
17	Monthly Mean Water Level: - Average of current and previous end-of-period water levels.
18	Actual Outflow: - Computed from Gate Rating Curve and monthly mean level. This is a trial and error calculation and change in storage (Cols.14 and 15) must be adjusted along with actual outflow.

For example, consider July 1900:

$Q_R = 113$ $N = 205$

$\Delta N = N - Q_R = 205 - 113 = 92$ or 0.27'

E.O.P. level = 600.96 + 0.27 = 601.23

Mean level = (600.96 + 601.23)/2 = 601.10

From Gate Rating Curve $Q_F = 115$

Recompute $\Delta N = 205 - 115 = 90$ or 0.27'

E.O.P. level = 600.96 + 0.27 = 601.23

Mean level = 601.10

Recheck Gate Rating Curve $Q_F = 115$

Repeat above procedures as many times as necessary to obtain correct outflow and change in storage.

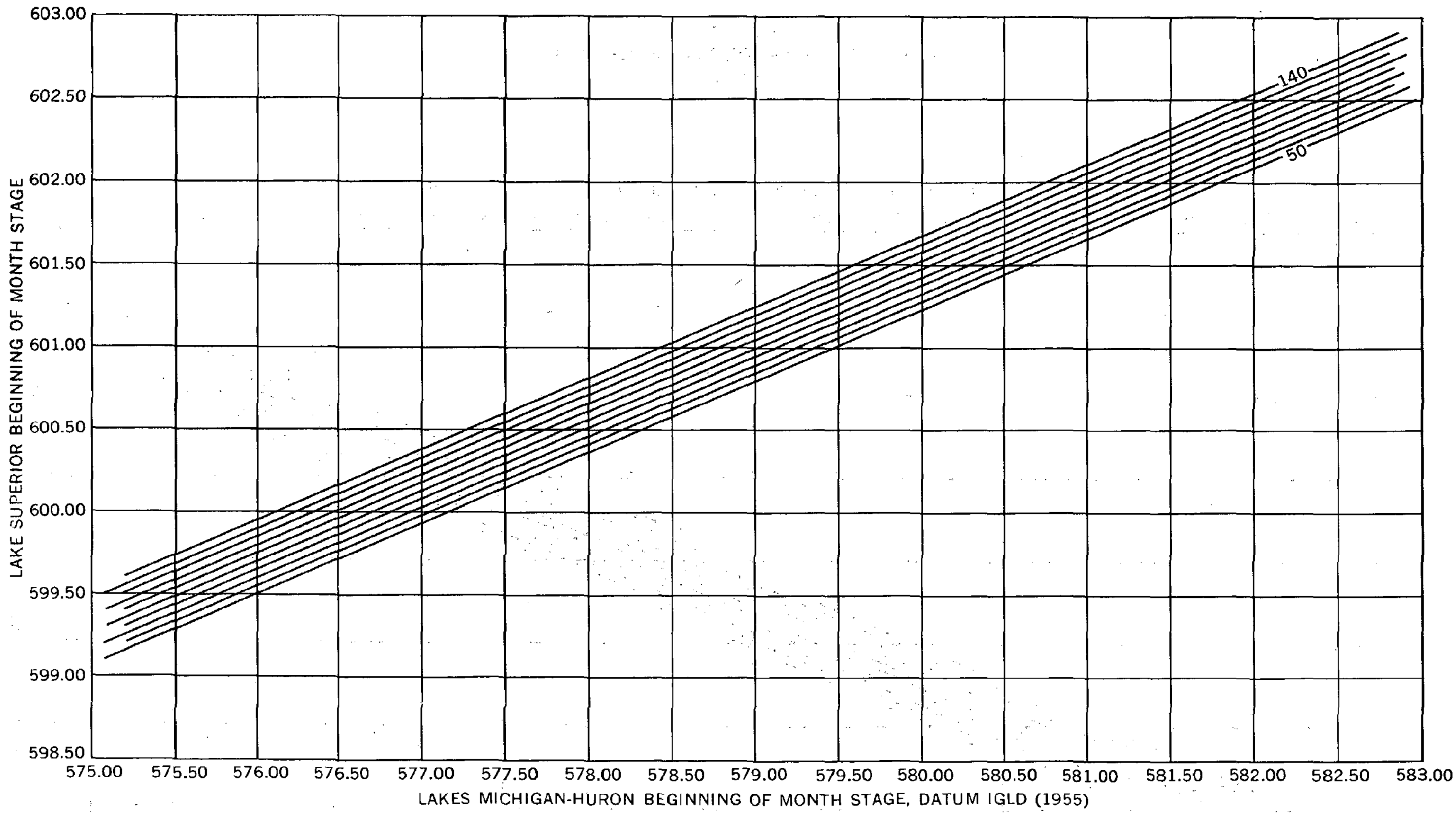


Figure E-1
PLAN SO-901 JANUARY RULE CURVE
(10 TCFS INCREMENTS)

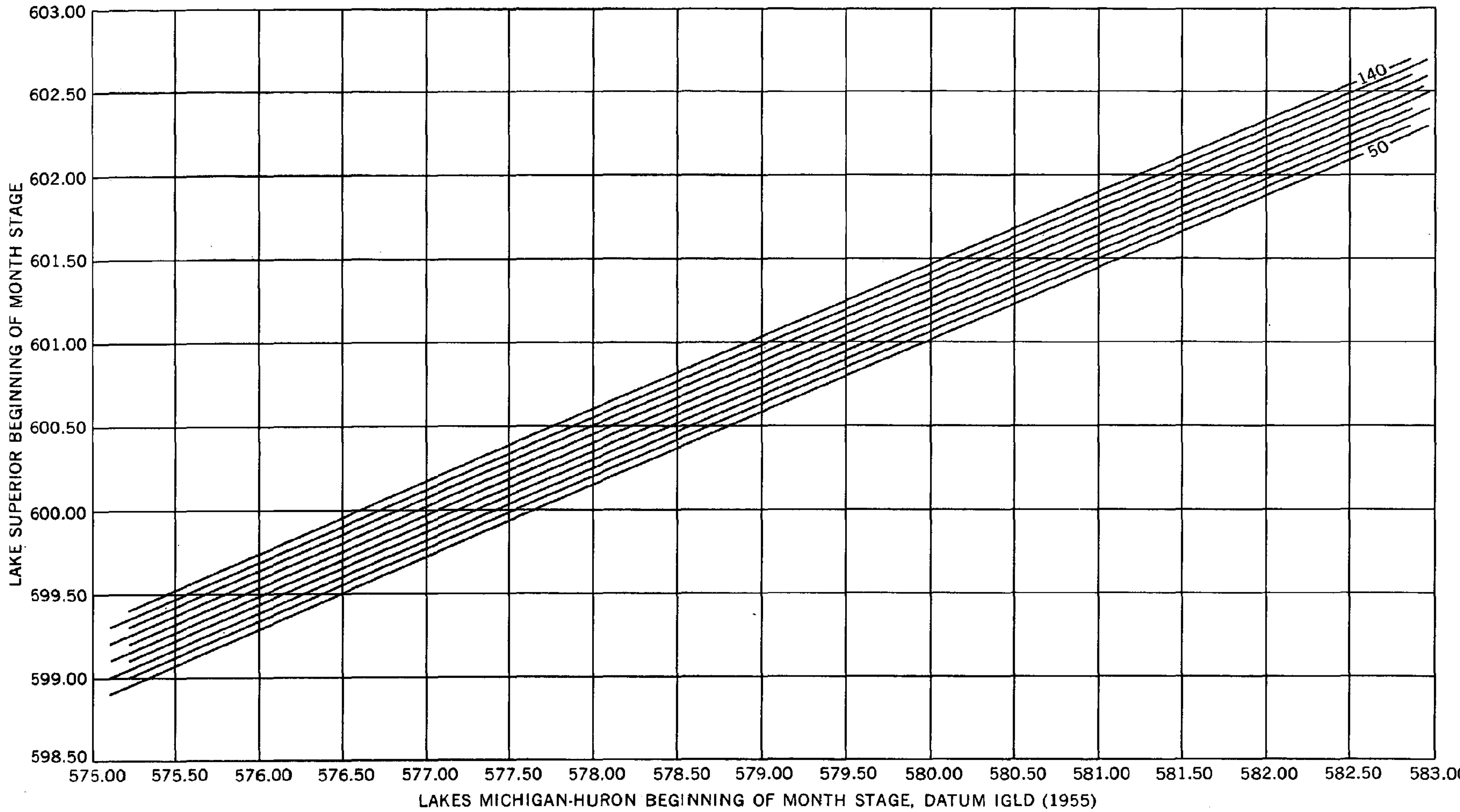


Figure E-2
PLAN SO-901 FEBRUARY RULE CURVE
(10 TCFS INCREMENTS)

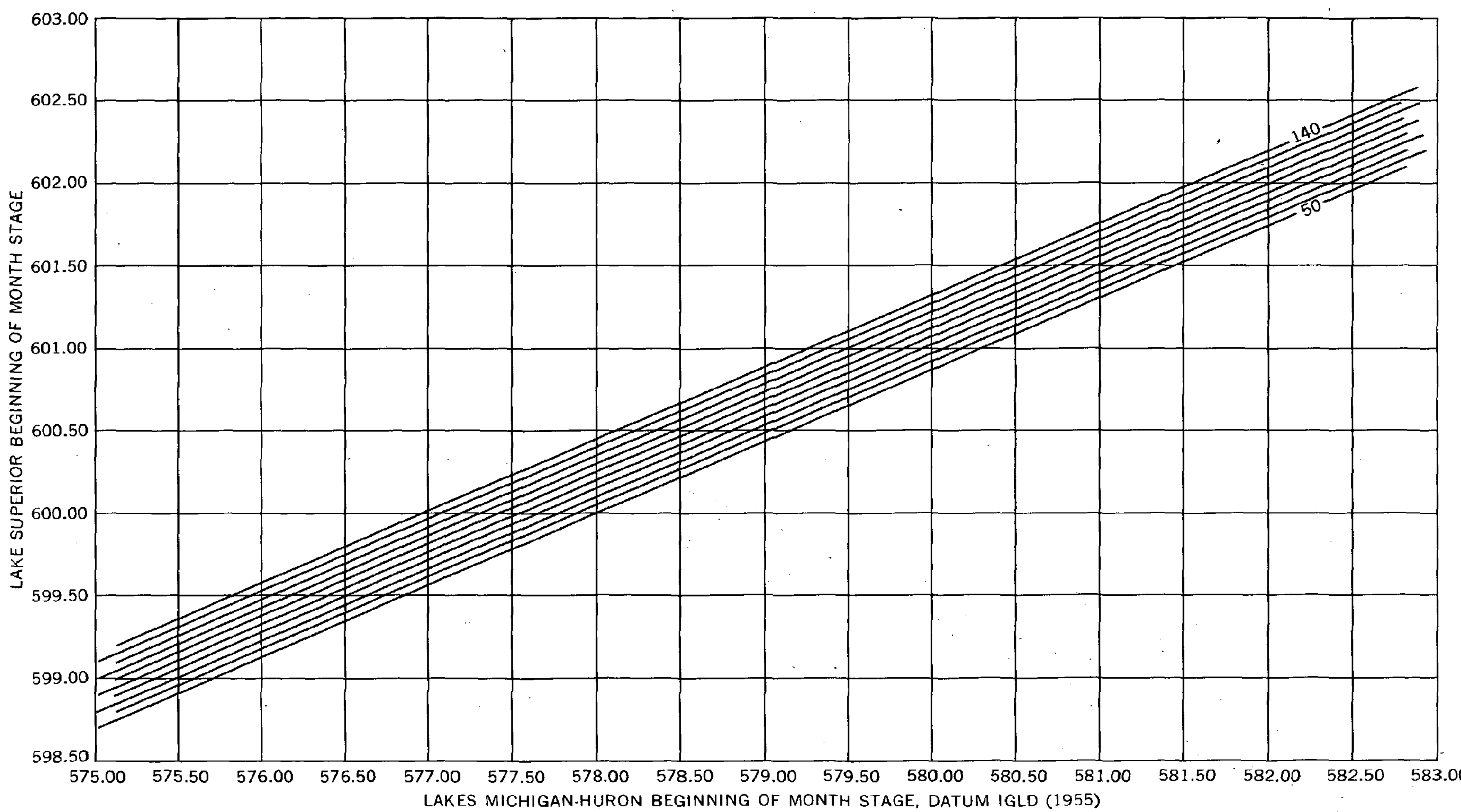


Figure E-3
PLAN SO-901 MARCH RULE CURVE
(10 TCFS INCREMENTS)

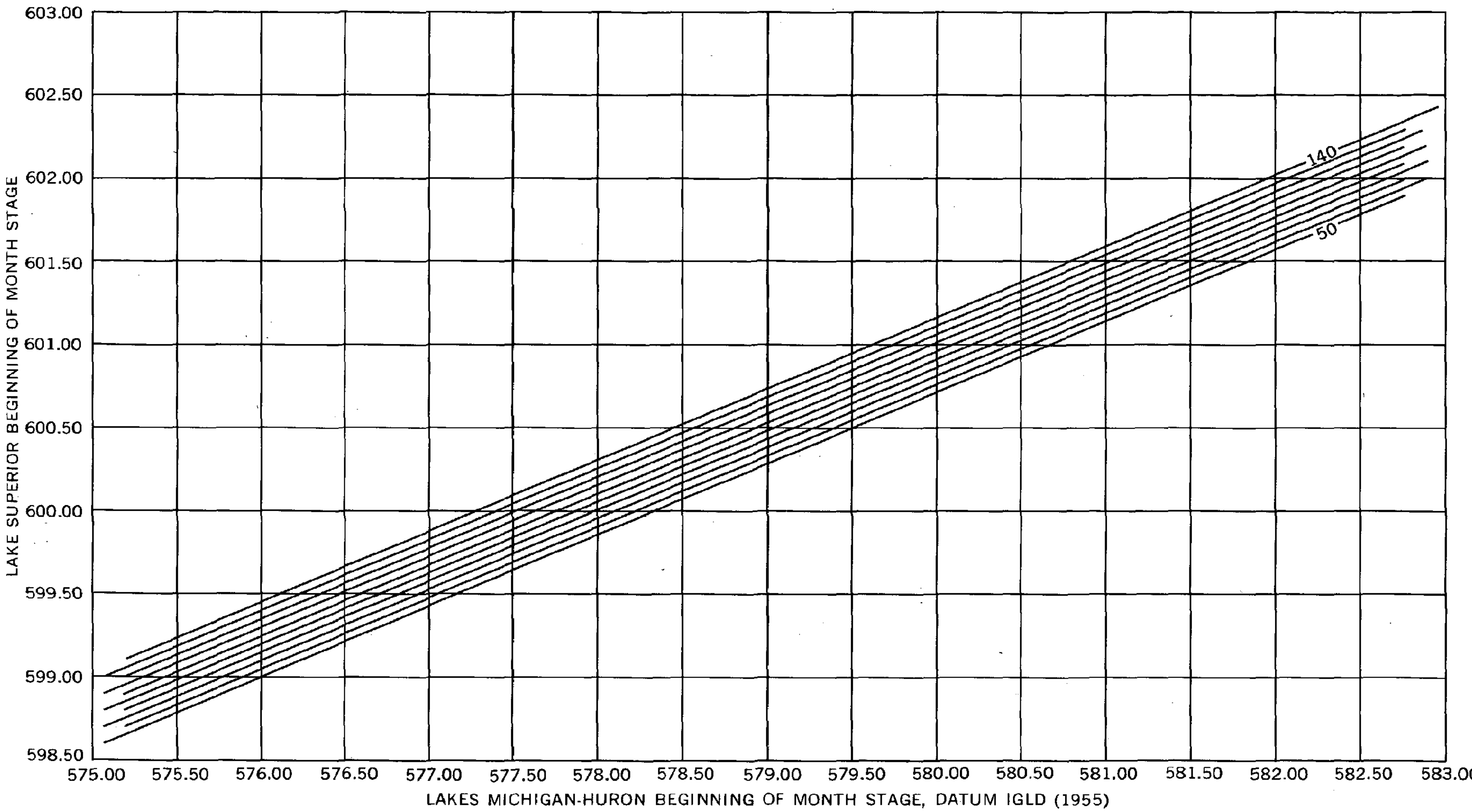


Figure E-4
PLAN SO-901 APRIL RULE CURVE
(10 TCFS INCREMENTS)

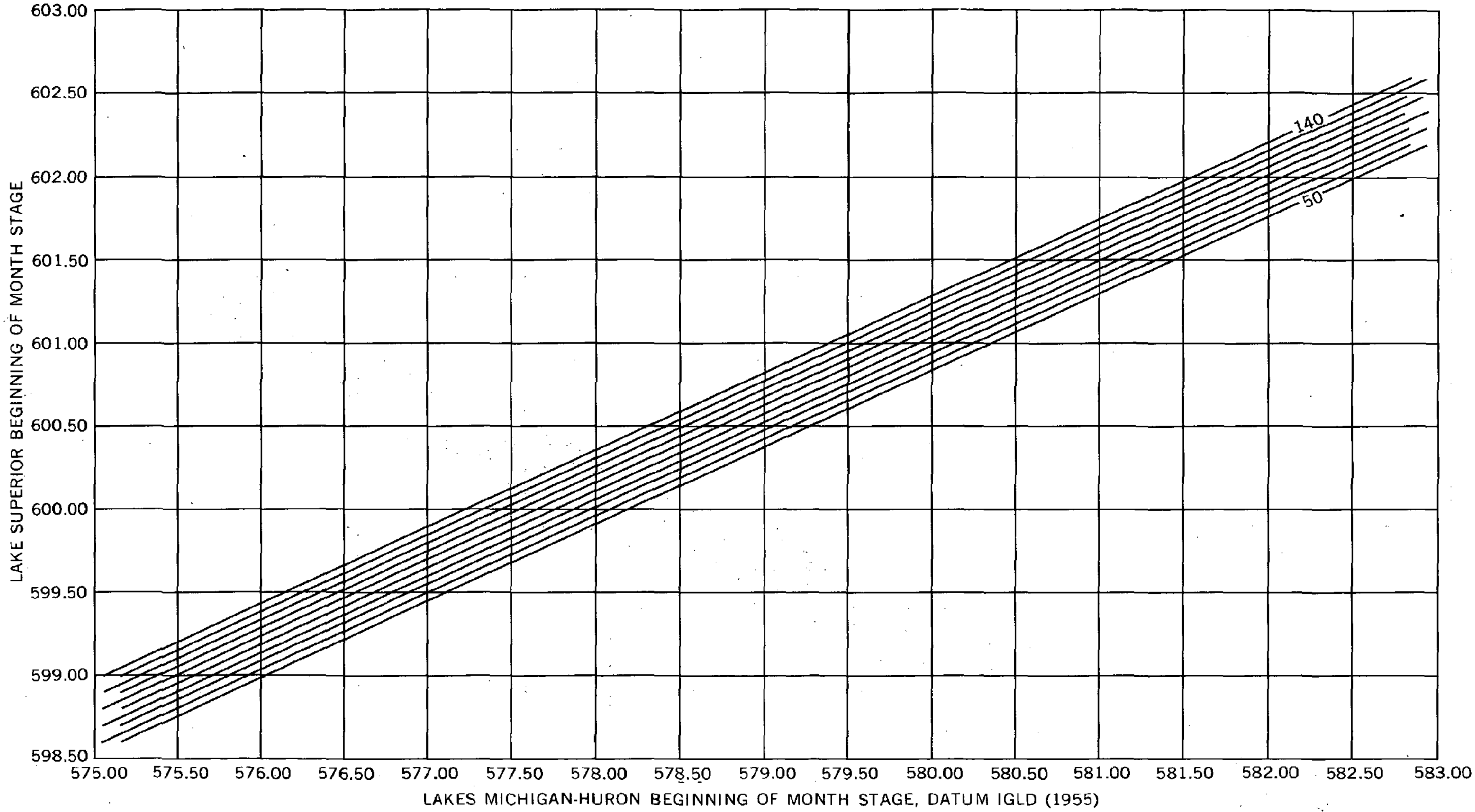


Figure E-5
PLAN SO-901 MAY RULE CURVE
(10 TCFS INCREMENTS)

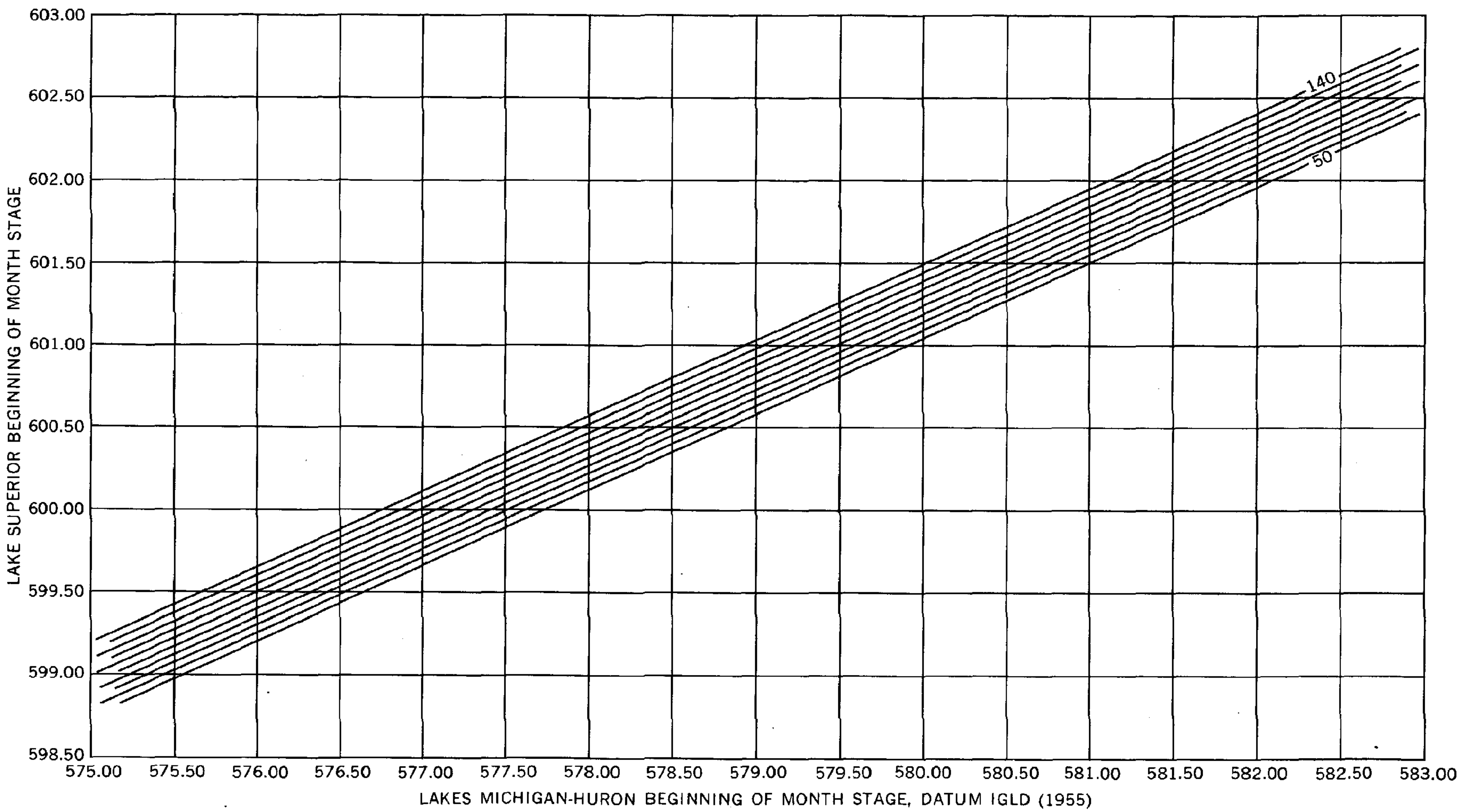


Figure E-6
PLAN SO-901 JUNE RULE CURVE
(10 TCFS INCREMENTS)

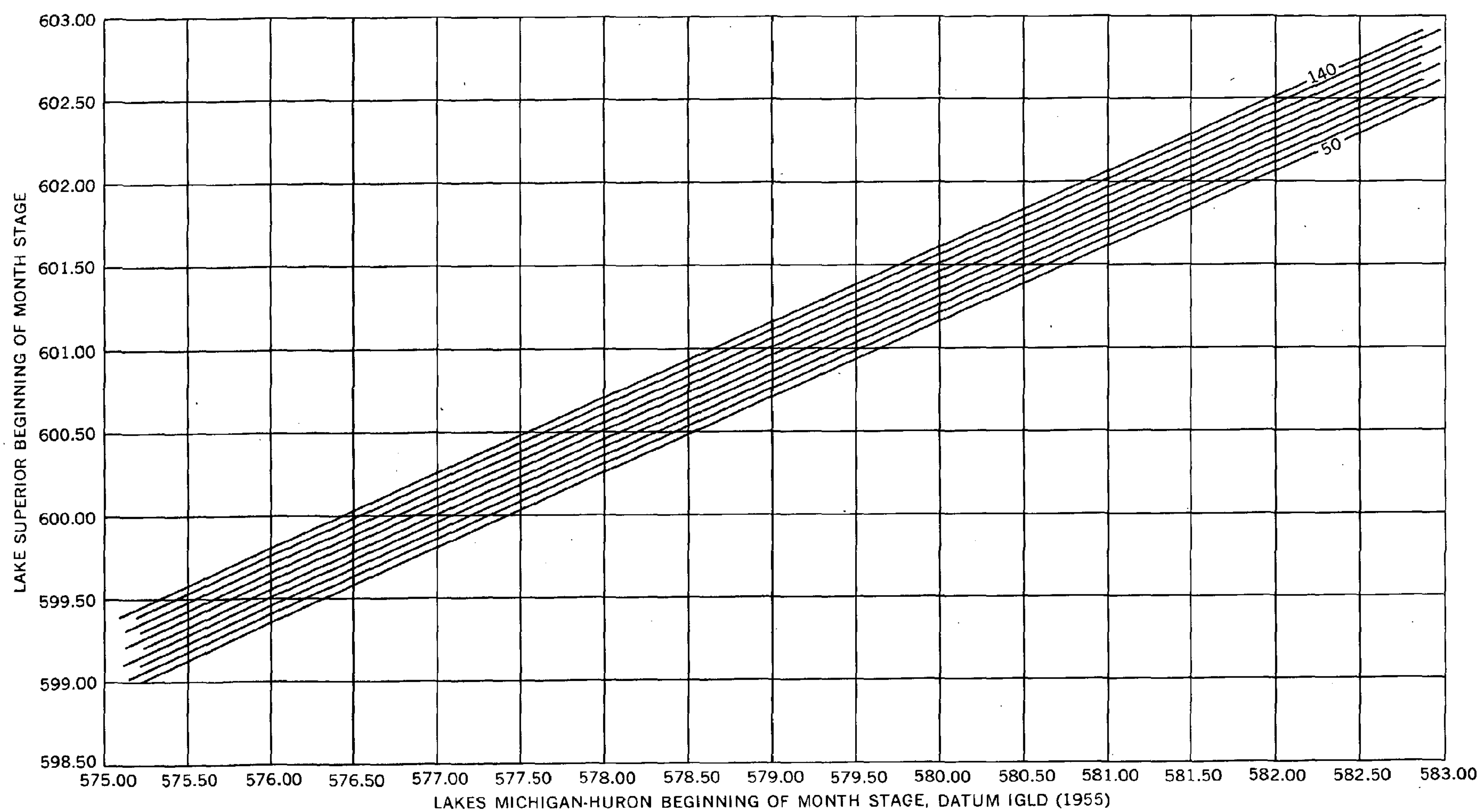


Figure E-7
PLAN SO-901 JULY RULE CURVE
(10 TCFS INCREMENTS)

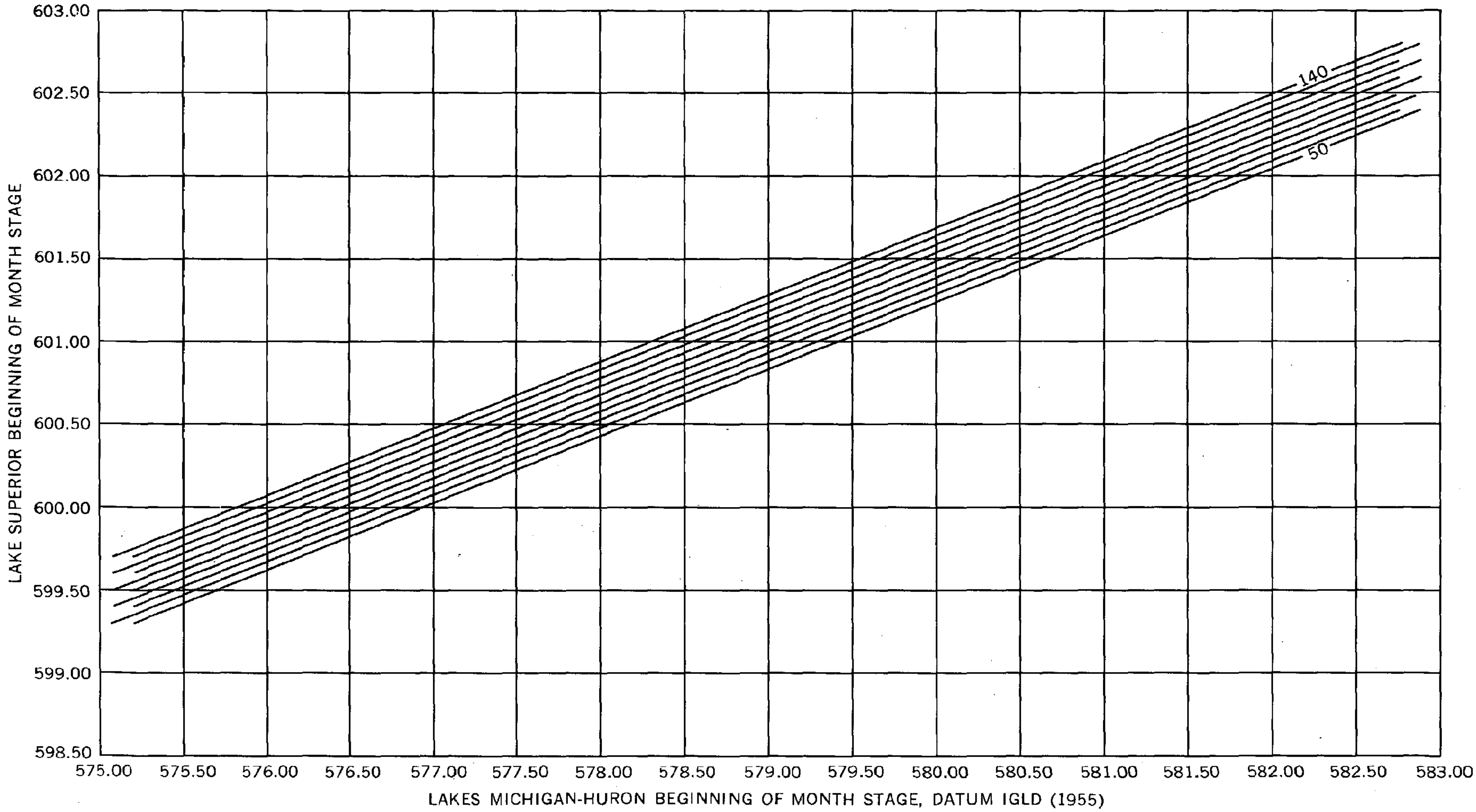


Figure E-8
PLAN SO-901 AUGUST RULE CURVE
(10 TCFS INCREMENTS)

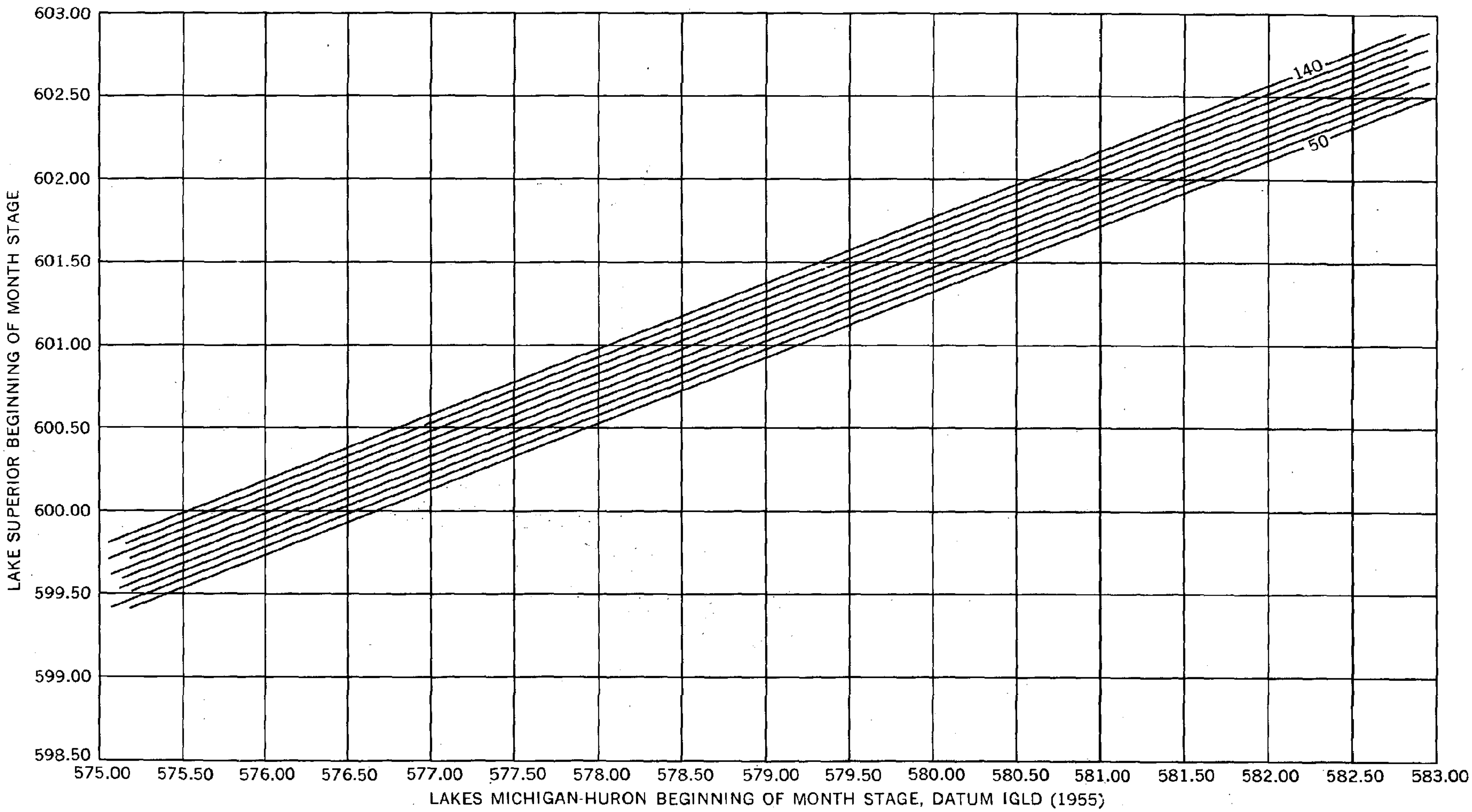


Figure E-9
PLAN SO-901 SEPTEMBER RULE CURVE
(10 TCFS INCREMENTS)

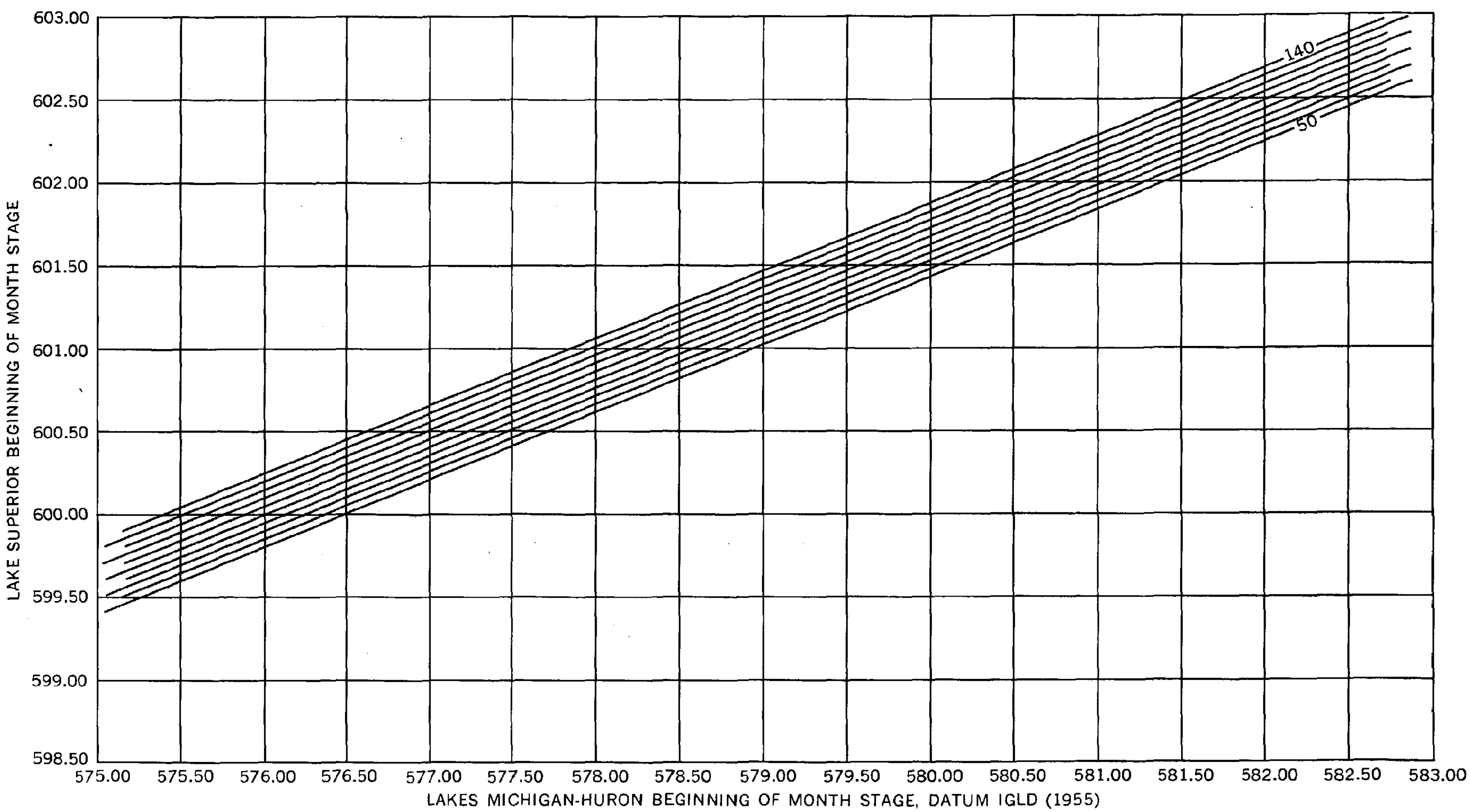


Figure E-10
PLAN SO-901 OCTOBER RULE CURVE
(10 TCFS INCREMENTS)

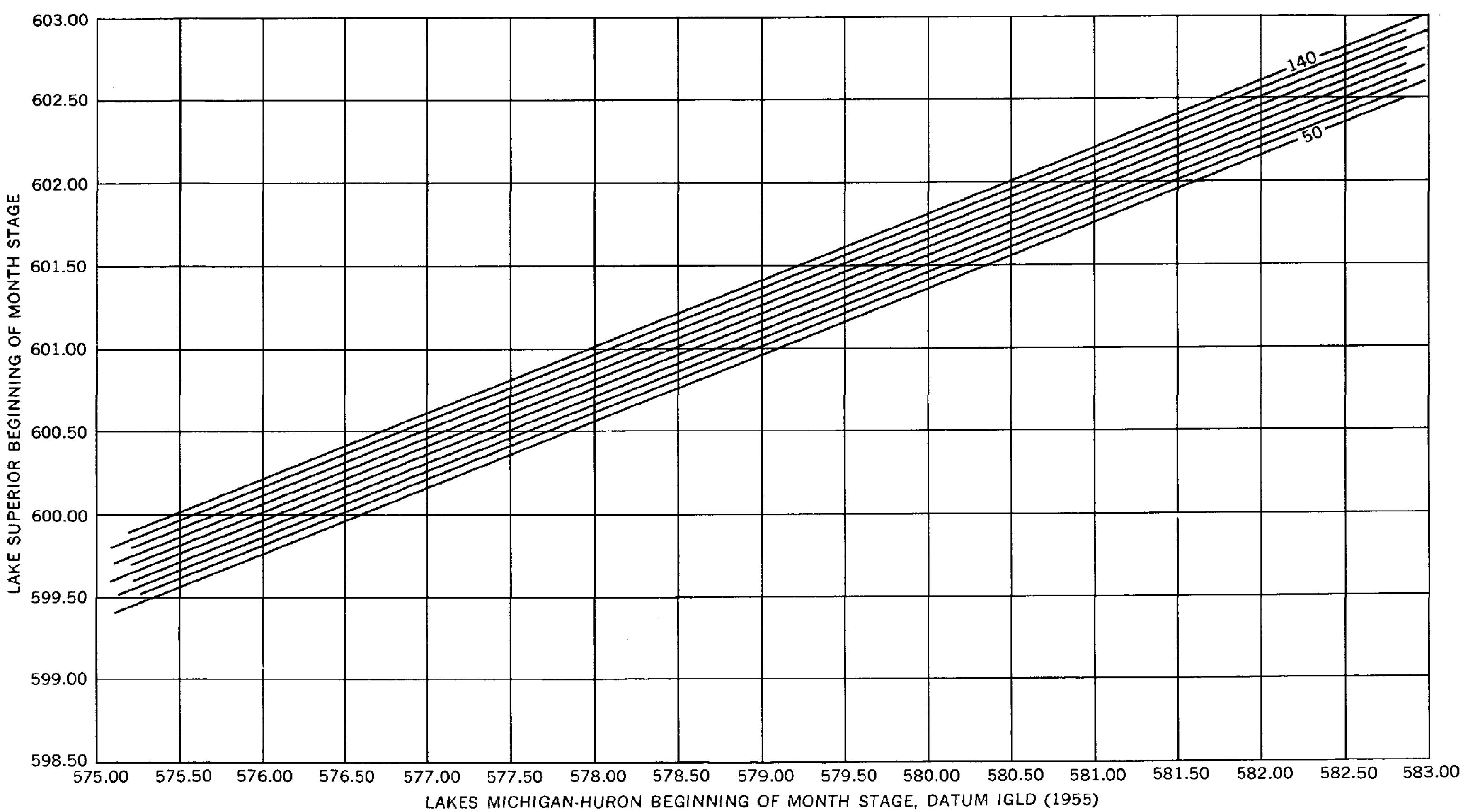


Figure E-11

PLAN SO-901 NOVEMBER RULE CURVE

(10 TCFS INCREMENTS)

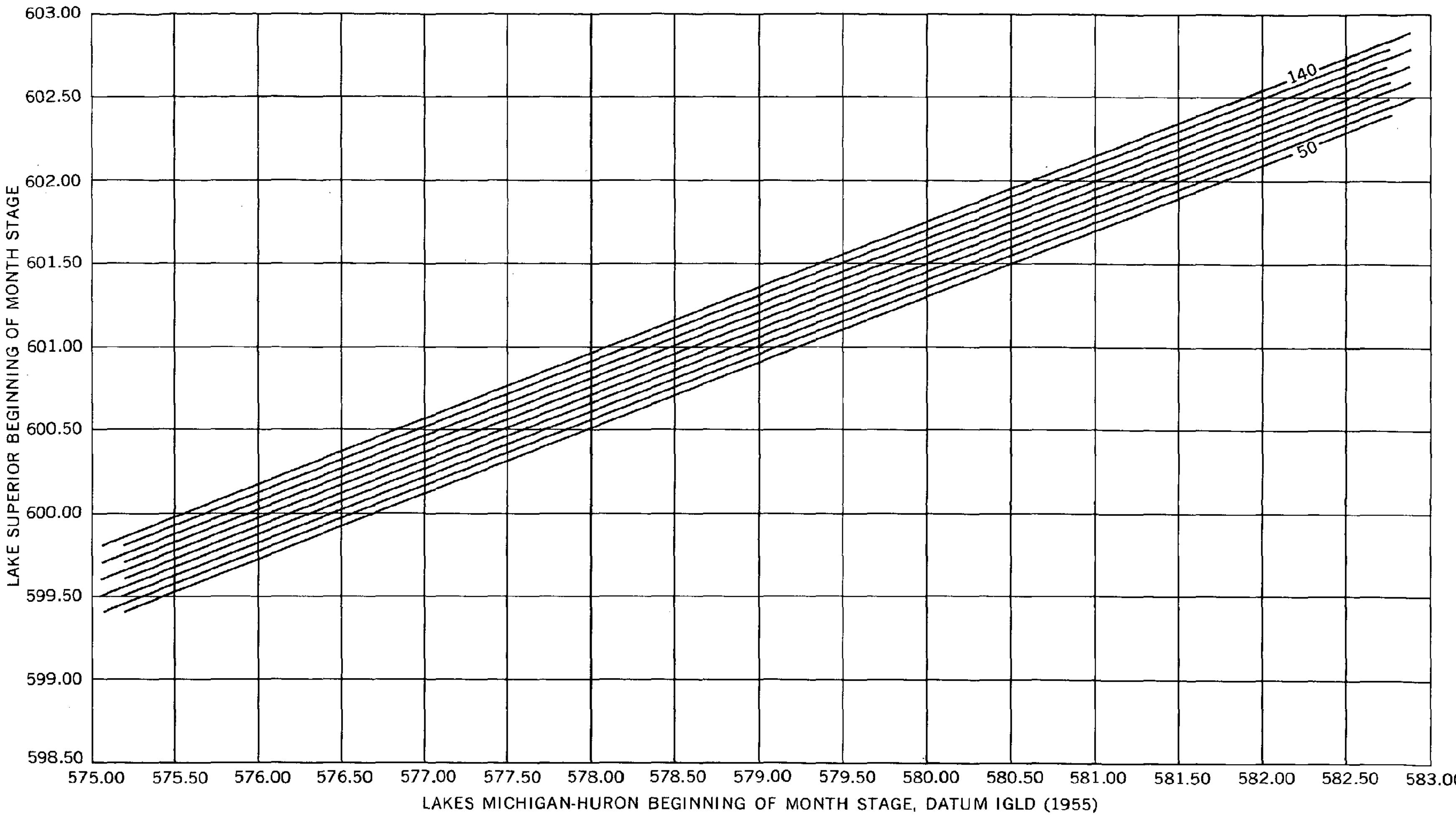


Figure E-12
PLAN SO-901 DECEMBER RULE CURVE
(10 TCFS INCREMENTS)