ST. LAWRENCE WATERWAY PROJECT

MESSAGE
FROM
THE PRESIDENT OF THE UNITED STATES
TRANSMITTING
A REPORT OF THE CHAIRMAN OF THE UNITED STATES ST. LAWRENCE COMMISSION UPON THE DEVELOPMENT OF SHIPWAY FROM THE GREAT LAKES TO THE SEA

JANUARY 3, 1927.—Read; referred to the Committee on Commerce and ordered to be printed, with illustrations

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1927
MESSAGE

To the Congress of the United States:

Herewith is presented for the information of the Congress a report made to the President by a commission appointed to advise on the development of a shipway from the Great Lakes to the sea.

The White House, January 3, 1927.

Calvin Coolidge.
The President,
The White House, Washington, D. C.

Dear Mr. President: This commission appointed by you on March 14, 1924, to advise upon development of shipway from the Great Lakes to the sea has directed me to transmit to you their conclusions.

The necessity and feasibility of this undertaking has been the subject of much previous study and report. Under arrangements in 1919 between the United States and Canada, the International Joint Commission made an investigation of river improvement between Montreal and Lake Ontario, setting out its conclusions and recommendations in a report under date of January 6, 1922. That commission strongly indorsed the plan for the improvement of the St. Lawrence River and recommended that before the project should be actually undertaken the engineering features should receive "that further and complete study that its magnitude and importance demand."

In accordance with this recommendation, and upon the appointment of the present commission, and also a like body by Canada known as the National Advisory Committee of Canada, it was agreed between the two Governments that a joint board of six engineers should be created to further exhaustively examine the subject. This joint engineering board has now completed an exhaustive investigation of all the engineering features involved in the lake and river development. Its report is herewith submitted.

By the river and harbor act approved March 3, 1925, the Board of Engineers of the United States Army was directed to make an examination and survey as to the feasibility and cost of a waterway from the Great Lakes to the Hudson River and a further inquiry was requested by the resolution of the Committee on Rivers and Harbors of the House dated May 26, 1926. This work was completed and reports made to Congress December 6, 1926.

In order that the commission might have complete data as to the economic aspects of the problem, the Department of Commerce at the request of this commission undertook a full examination of the features and questions involved, and their report will be transmitted to you within a few days.

These investigations and reports combine to present a most exhaustive development of all of the important facts as to the subject.

This commission has also had the advantage of a large amount of other data and the personal study of its own members. Its conclusions are as follows:

1. The construction of a shipway of sufficient depth to admit ocean shipping from the Atlantic to the Great Lakes will lessen the economic handicaps of adverse transportation costs to a vast area in the interior of the continent. Within the United States it embraces
all or large portions of the States of Ohio, Indiana, Kentucky, Illinois, Iowa, Missouri, Kansas, Nebraska, North and South Dakota, Montana, Wisconsin, Minnesota, Michigan, Pennsylvania, and New York. It includes a large part of Canada. Within this area there are more than 40,000,000 inhabitants who gain their livelihood from its basic industries. It produces a vast surplus both from agriculture and manufactures, much of which demands long transportation. There is a reciprocal inflow of commodities from its neighbors.

These sections have always been under natural transportation disadvantages in the exportation and importation of commodities. But the building of the Panama Canal artificially created a still further dislocation of its competitive relations and beyond this the necessary increase in railway rates following the war have shifted greatly the economic position of the mid continent to the great detriment of that area.

The problem has thus become one of wide importance not only because of the fundamental advantages of elimination of great wastes in transportation costs but also because of the necessity for readjustment of adverse competitive relations of all the industries and agriculture throughout the mid continent.

This becomes apparent if we cease to think of distance merely as a matter of miles and consider it in terms of cost. If we take as a unit of measurement the cost in cents of carrying a ton of staple goods at present rate, taking the cheapest route in each case, we find that before the war New York was 1,904 cents away from San Francisco, while now it is only 1,680 cents away. Chicago, which was 2,610 cents away from the Pacific coast before the war, is to-day 2,946 cents away. In other words, Chicago has moved 336 cents away from the Pacific coast, while New York has moved 224 cents closer. A similar calculation will show that in the same period, since ocean rates have remained about the same, Chicago has moved 594 cents away from the markets of the Atlantic seaboard and South America. The same ratios apply to the other mid-west points. The increased transportation costs to world markets from the mid continent have had serious results to agriculture. The rate increases affecting this section of from 6 to 18 cents per bushel upon grain have not been accompanied by similar increases in many agricultural countries which compete with it, since they possess greater accessibility to the seaboard, and sea rates are about the same as before the war. Thus this increase in American rates has been in large degree a deduction from the receipts of farmers in the mid continent. With the completion of such a shipway as the St. Lawrence, the freight rates on grain to world markets would be substantially reduced and as a consequence the price levels of all grain in the Lakes transportation area would be increased accordingly. Much the same type of economic reaction would affect other commodities and industries. It has been estimated that the values in a single year to the farmers alone would equal the capital cost of the waterway. Thus the economic importance of the improvement would be far greater than the savings made upon the actual tonnage transported, important though that would be.

The interior States which are affected by this situation have not been neglectful of the benefits to be derived by the bringing to them of ship transportation to the sea. Eighteen of them have associated together by acts of their legislatures, under the name of the Great
Lakes-St. Lawrence Tidewater Association. They represent nearly two-fifths of our population. They have made their own independent investigation and have concluded and declared that the opening of the Great Lakes to ocean-going vessels through the St. Lawrence is a major public necessity in the economic interest of their communities.

There can be no disagreement in the opinion that this section of the United States is entitled to an equalization in transportation advantages as far as possible, nor as to the benefits which would inevitably flow to it if ship access to the ocean is afforded.

2. Three different routes for such a shipway have been put forward:

(a) By reconstruction of the present canal from Lake Ontario to the Hudson, making use of the new Welland Canal now being constructed by the Canadian Government to connect Lake Ontario and Lake Erie. The United States has treaty protection of equal treatment in the use of the Welland.

(b) By developing an “all-American” route, which would include the Lake Ontario-Hudson project plus a new ship canal on the south side of Niagara which would duplicate the new Welland Canal.

(c) By utilizing the St. Lawrence River as a joint undertaking with Canada.

3. Both the initial and ultimate depth of the shipway involves many technical and financial questions. A depth of 30 feet in the permanent structures will provide for almost any contingency for many years to come and for purposes of comparison in costs a depth of canals which will permit of ships of 25 feet of draft has been adopted. Such a depth will admit 88 per cent of all ships now entering American ports. After making full allowance for the seasonal variations in the volume of traffic to be handled, the capacity of a waterway of this depth, with a chain of single locks, is estimated at 30,000,000 tons per annum. The capacity can be increased to any reasonable amount that may be desired by the construction of additional locks paralleling those first installed.

4. It is estimated by the Department of Commerce that the following tonnages are at present available for transportation, of which, say 80 per cent, represents exports and imports as distinguished from internal traffic:

<table>
<thead>
<tr>
<th>Ontario-New York route</th>
<th>St. Lawrence route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum estimate</td>
<td>15,000,000</td>
</tr>
<tr>
<td>Maximum estimate</td>
<td>20,000,000</td>
</tr>
<tr>
<td>Median</td>
<td>17,500,000</td>
</tr>
</tbody>
</table>

5. The reports of the United States engineers of December 6, 1926, estimate the cost of constructing the Lake Ontario-Hudson route at $506,000,000; the all-American route at $631,000,000 (both estimates without interest during construction). No consequential relief by water power can be developed upon these routes. The net cost to the joint governments of the improvement of the St. Lawrence route upon procedure indicated below would be upon the joint engineers’ estimates of between $123,000,000 and $148,000,000, from
which some further reductions should be made from further reali-
zation upon hydroelectric power.

6. The development of the St. Lawrence waterway is necessarily
also a development of the huge hydroelectric power from the great
rapids which now obstruct navigation on the river. The complete
practicable power development of the river will provide a total of
about 5,000,000 installed horsepower of which about 2,250,000 lies
in the upper rapids along the international section between New
York State and the Province of Ontario, the remainder lying in the
lower rapids and wholly within the Dominion of Canada. This is
not only the largest possible hydroelectric power development upon
the continent but the reports of the engineers indicate that the
capital outlay per horsepower is less than most of the hydroelectric
installations now in progress in the United States. The inevitable
development of the river for power would in itself compass the major
construction for the shipway, since the dams necessary for develop-
ment of power create a series of pools in place of the present rapids
which, with the supplement of locks and short canals, become the
shipway. The development of these vast power resources are in-
evitable in the interest of the populations in that region. Their
development will eventually create a shipway on this route even if
other routes were undertaken.

7. There is estimated to be a requirement in the Province of
Ontario and in New York and New England States (by the time of
completion) for all the power which can be developed in the inter-
national section. Various private or public bodies are now seeking
the privilege of this development and we may assume for purposes
of estimation that its construction can be undertaken outside of the
Federal and Dominion Governments. The cost of providing the locks
and canals around this power development in the international sec-
tion (assuming proper enlargement of channel for winter operation
of power) is estimated at from $22,400,000 to $34,000,000, depending
upon details of the plans as to whether two dams or one are con-
structed. The improvement of the river from Lake Ontario down to
these power dams and below this point as far as the lower rapids is
estimated at less than $3,000,000. Thus the development of the
power in the international section with the above comparatively
minor expenditure would carry the shipway a total of 141 miles, out
of the total of 183 miles from Lake Ontario to Montreal, or taking
it to within 42 miles of tidewater.

8. This last 42-mile stretch embraces the two lower sets of rapids,
and the full power from these sources apparently will not be in
economic demand at so early a date, and therefore the construction
of the shipway could either be undertaken around these rapids inde-
pendently of power development or by adopting plans which would
give some 400,000 immediate horsepower and will provide important
preparation for further installment of 2,350,000 horsepower later on.
The first alternative should cost about $97,500,000 and the second
about $161,000,000. From the latter there must be deducted the
income value from 400,000 horsepower which would be equivalent to
a capital value of at least $50,000,000, and beyond this the completion
of the power development would further realize values which should
further reimburse expenditure upon this section. The second alter-
native should provide rather better navigation and is recommended
by the joint board of engineers.
9. Thus the total investment in the St. Lawrence by the joint Governments on the above basis of procedure would be from $123,-000,000 to $198,000,000, depending upon details of the plan. The latter sum, previously pointed out, would be reduced to an effective net of $148,000,000 from immediate power income and still further reduced by the returns from future power development. There are other alternative methods of handling the problem but this will serve to illustrate the costs. If other agencies than the Federal and Dominion Governments were not able to undertake the construction of power dams in the international section, and if it were necessary to consider their installation as part of the financial project, the returns from the power developed should reimburse its cost and perhaps something in addition. The whole St. Lawrence undertaking is, of course, a joint one between the United States and Canada. There is as yet no understanding between the two countries as to the proportion in which this cost would have to be shared, but obviously the share of either Government would be less than the totals shown above, which would also be subject to reduction through further power realization.

10. It is estimated that maintenance plus interest at 4½ per cent on the all-American route would be $36,000,000 per annum, upon the Ontario-Hudson route $28,770,000 upon this plan of development of the St. Lawrence route, say $10,000,000 after deduction of power returns from power actually developed as above. These charges applied to the estimated annual medial tonnages is as follows:

<table>
<thead>
<tr>
<th>Route</th>
<th>Per ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>All American</td>
<td>$2.06</td>
</tr>
<tr>
<td>Lake Ontario-Hudson</td>
<td>1.64</td>
</tr>
<tr>
<td>St. Lawrence</td>
<td>0.43</td>
</tr>
</tbody>
</table>

11. There are other important considerations in comparison of routes. The amount of restricted and therefore retarded navigation through actual canals would be 137 miles on the all-American route, 128 miles on the Ontario-Hudson route, 21 to 25 miles on the St. Lawrence. The operating season free from ice is practically the same. The St. Lawrence route requires 9 locks compared with 20 on the Ontario-Hudson, and the St. Lawrence route will be obstructed with 8 bridges compared with 54 on the Ontario-Hudson. The actual distance by the St. Lawrence from lake ports to northern European points would be less by 625 miles as compared with the Ontario-New York route. The actual distance from lake ports to New York would be greater by 1,550 miles and to South Atlantic points from 540 to 1,350 miles by the St. Lawrence, but these items are more than compensated for by better navigation and lesser fixed charges.

12. It is estimated that the construction of the waterway upon the St. Lawrence will require 8 years, but 10 years may be assumed as a minimum period even if all international questions, legislation, administrative, and financial problems were rapidly overcome.

13. While the commission deprecates the injection of the idea that military advantages by either route are to be seriously considered in connection with any relationships with our most friendly neighbor, the Chief of Engineers has discussed this feature as follows:

The military advantages of the proposed waterway across the State of New York are not sufficient greatly to affect the consideration of a matter involving hundreds of millions of dollars. It will be noted that many points of both routes are so close to the border as to make them subject to possible destruction in case of war.

S. Doc. 183, 69–2—2
14. On the American side the State of New York has a special interest in the power developments of the international section and the coordination of these improvements with the State should be undertaken. Owing to the navigational and international character of the river the Federal Government has an interest and must necessarily assent to and negotiate power-development questions from the American side.

15. There has been some feeling that the construction of the St. Lawrence waterway will injure the interests of our eastern States by decreasing terminal business of lake and seaboard cities; will divert traffic from American railways and endanger our commercial and financial control of American exports and imports over this route. Of first importance is the fact that the total estimated tonnage available to-day for the waterway amounts to under 4 per cent of the present tonnage carried by the American railway systems which now connect the Lakes with seaboard. It comprises less than 12 per cent of the sea shipments now moving through the affected American seaports. The natural increase in population and traffic would quickly recover such amounts theoretically before the earliest possible completion of the waterway. Our facilities are already much taxed, and another route does not mean a duplication of capital outlays. It is certain that American cities, of which New York is the center point, would remain the financial and commercial centers of America's foreign trade regardless of the route of traffic. It may be observed that the completion of the Welland Canal now in construction will divert some tonnage from present routes and terminals to lower Lake Ontario and that the development of the power on the borders of New York State will still further divert tonnage by opening this route 141 miles farther to within 42 miles of tidewater at Montreal.

In the wider view, the increased prosperity of the mid continent, the relief of many of their present economic difficulties, and development of huge water power for stimulation of industry and commerce in New York and New England shall add to the prosperity of the country as a whole and thereby benefit every citizen and every city.

The conclusions of this commission are therefore:

First. The construction of the shipway from the Great Lakes to the sea is imperative both for the relief and for the future development of a vast area in the interior of the continent.

Second. The shipway should be constructed on the St. Lawrence route, provided suitable agreement can be made for its joint undertaking with the Dominion of Canada.

Third. That the development of the power resources of the St. Lawrence should be undertaken by appropriate agencies.

Fourth. That negotiations should be entered into with Canada in an endeavor to arrive at agreement upon all these subjects. In such negotiations the United States should recognize the proper relations of New York to the power development in the International Section.

Yours faithfully,

HERBERT HOOVER,
Chairman United States St. Lawrence Commission.
REPORT OF JOINT BOARD OF ENGINEERS ON ST. LAWRENCE WATERWAY PROJECT

1. The joint board of engineers appointed by the Governments of the United States and Canada presents herein its report on the improvement of the St. Lawrence River between Lake Ontario and Montreal, and on related questions referred to it by the two countries.

2. The report is subdivided into the following parts:
   Part I. Constitution of board; Instructions to board; General description of Great Lakes and St. Lawrence; Prior reports; Work done by board.
   Part II. The Great Lakes; Existing diversions and their effects; Remedial measures; The cost of improving the lake channels to conform to the improvement of the St. Lawrence.
   Part III. Improvement of the St. Lawrence above Montreal; The plans recommended by the board for improvement for navigation and power.
   Part IV. The St. Lawrence at and below Montreal; Effect of diversions; Remedial measures; Effect of the proposed improvement of the upper St. Lawrence on the lower river.
   Part V. Specific answers to questions contained in the instructions to the board.

PART I

CONSTITUTION OF THE BOARD

3. The President of the United States appointed on March 14, 1924, a national committee of nine members, designated as the St. Lawrence Commission of the United States, having as its chairman the Hon. Herbert Hoover, Secretary of Commerce, to act as an advisory committee to the Government on all questions that might arise in the consideration of the project for the improvement of the St. Lawrence.

4. The Government of Canada on May 7, 1924, appointed a national advisory committee of nine members, having as its chairman the Hon. George Perry Graham, Minister of Railways and Canals, to advise that Government on the matters relating to the project.

5. Following a recommendation of the International Joint Commission in a report on the improvement of the St. Lawrence River, dated December 19, 1921, it was agreed by the two countries that a joint board of engineers, consisting of three members representing Canada and three members representing the United States, should be constituted to review the plans then formulated and to report on additional related matters referred to it with the mutual approval of the two countries.

6. The United States Government designated as members of the United States section of the board and as advisers to the St. Lawrence
Commission of the United States the following officers, assigned to that duty by order of the War Department dated April 2, 1924:

Maj. Gen. Edgar Jadwin, Chief of Engineers (then Colonel, Corps of Engineers).

Col. William Kelly, Corps of Engineers.

Lieut. Col. George B. Pillsbury, Corps of Engineers.

7. The Government of Canada appointed on recommendation of the privy council, approved by the Governor General May 7, 1924, the following members of the Canadian section of the board, who also act as advisers of the National Advisory Committee of Canada:

Mr. Duncan W. McLachlan, of the Department of Railways and Canals, Ottawa.

Mr. Olivier O. Lefebvre, chief engineer, Quebec Streams Commission, of Montreal.


8. The instructions to the joint board of engineers were agreed to by the two Governments by an exchange of notes dated February 4 and March 17, 1925, and are as follows:

The Governments of Canada and the United States have accepted the recommendation made by the International Joint Commission in its report dated December 19, 1921, that the question of the development of the St. Lawrence River for navigation and for the supply of power be referred to an enlarged joint board of engineers.

It is desired that the new board should review the report dated June 24, 1921, made by the late Mr. W. A. Bowden and Col. W. P. Wooten, and that it should extend its inquiries to certain additional matters with a view to supplying the technical information likely to be relevant to the proposals made in the report of the International Joint Commission above referred to. The new board is therefore charged at this time with reporting upon the following:

1. Is the scheme for the improvement of the St. Lawrence waterway, presented by the board in its report of June 24, 1921, practicable, and does it provide to the best advantage, at this time and ultimately, for the development of the capacities and possibilities of the waterway?

2. What alternative scheme, if any, would be better adapted to secure the ends desired, due consideration being given—
   (a) To any special international or local interests having an importance justifying exceptional consideration; and
   (b) To the extent and character of the damage through flooding and the probable effect of the works upon the formation of ice and the consequent effect on the flow of the river?

3. Should the estimates of cost be revised, and if so, what are the revised estimates of cost having regard to alternative schemes?

4. In order to assist either Government to allocate the amounts chargeable to navigation and power, what would be the respective estimated costs for improving the river for navigation alone and for power alone?

5. To what extent may water levels in the St. Lawrence River at and below Montreal, as well as the river and lake levels generally, be affected by the execution of the project?

6. (a) To what extent and in what manner are the natural water levels in the St. Lawrence River and on the Lakes affected by diversions authorized by license by either Canada or the United States from or in the St. Lawrence River watershed?
   (b) By what measures could the water levels or navigable depths affected by the diversions referred to in section 6 (a) be restored, and what would be the cost thereof?
   (c) How much power could be developed on the St. Lawrence River with the water diverted from the watershed referred to in section 6 (a) under—
      (1) The plans recommended?
      (2) Alternative plans providing for a full practical development of the river?
      (d) Without considering compensation by the present relative diversions of water from the Niagara River and from Lake Erie, and without prejudice to a future consideration thereof, what works, if any, could be constructed to recover
on the St. Lawrence River the amount of power determined under section 6 (c), and what would be the cost of such works?

7. Having regard to economy of construction and maintenance, expedition of construction, and efficiency of operation—
   (a) Which of the works should be constructed under the technical supervision of an international board and what other works, if any, might advantageously be constructed under such supervision?
   (b) Which of the works should be maintained and operated by an international board and what other works, if any, might advantageously be so maintained and operated?

8. What, if any, readjustments in the location of the international boundary are necessary or desirable to place power structures belonging to either country within its borders, as recommended by the International Joint Commission?

9. If the board is of the opinion that it would be advantageous to provide in the first instance for channel depths other than 25 feet, but less than 30 feet, for what draft of vessel should provision be made?

10. Having regard to the recommendation of the International Joint Commission that the new Welland Ship Canal should be embodied in the scheme and should be treated as a part thereof, and to the fact that if a greater depth than 21 feet be adopted for the initial project depth of the St. Lawrence, such greater depth would not be available to the upper lake ports without further work in the navigation channels in the Lakes, what would be the cost of improving the main navigation channels between and through the Lakes, so as to provide, without impairing the present lake levels for (a) a depth of 25 feet and (b) for such other depth not exceeding 30 feet as may be determined by the board to be that for which it would be most advantageous to provide on the St. Lawrence River?

11. What is the time required to complete the proposed works, the order in which they should be proceeded with, and the progress which should be made yearly toward the completion of each in order to secure the greatest advantage from each of the works and from the development of the waterway as a whole?

It is desired that the report be accompanied by such drawings as are necessary for showing the location and general character of the works proposed.

It is also desired that in the preparation of the report due regard be had to any diversions from or in the St. Lawrence River watershed which, at the date of the report, are authorized by license by either Canada or the United States.

It is desired that the board report from time to time on the matters referred to it as the progress of its inquiries permits, and that these inquiries be so prosecuted that, if practicable, the board should have reported on all such matters by the end of April, 1926.

9. Funds for the work of the Canadian section of the joint board were voted by the House of Commons of Canada yearly as required. Funds for the American section were provided by the deficiency act of March 4, 1925, which made available for that purpose, under the direction of the President, not exceeding $275,000 of funds appropriated for maintenance and improvement of river and harbor works.

DESCRIPTION

10. The Great Lakes are the source of the St. Lawrence, and form with it a waterway system extending from the interior of the continent to the sea. Lake Superior, the uppermost and largest of the Great Lakes, discharges into Lake Huron through the rapids of St. Marys Falls and the St. Marys River. Lake Michigan is connected with Lake Huron by the wide and deep Straits of Mackinac. Lake Huron discharges into Lake Erie through the St. Clair River, Lake St. Clair, and the Detroit River. Lake Erie discharges into Lake Ontario through the Niagara River. From Lake Ontario the St. Lawrence flows 533 miles northeast to Father Point, which marks its transition into the Gulf of St. Lawrence. The first 116 miles of the river is on the international boundary between Canada and the United States.
States; the remainder of its course is through Canadian territory.
The city of Montreal is 183 miles downstream from Lake Ontario.

11. The distances by the ordinary vessel routes from Duluth, Minn., and Port Arthur, Ontario, at the head of Lake Superior, to Kingston, Ontario, at the head of the St. Lawrence, are, respectively, 1,160 and 1,038 statute miles. The distance from Chicago to the head of the St. Lawrence is 1,067 miles.

12. The fall at mean stages between Lake Superior and Lake Huron is 21 feet. Lake Michigan and Lake Huron are at the same level. The fall from Lake Huron to Lake Erie averages 8.5 feet, taken up in the slopes of the connecting rivers. The fall from Lake Erie to Lake Ontario is 326 feet, of which approximately 165 feet is concentrated in the drop at Niagara Falls proper. The fall from Lake Ontario to Montreal Harbor averages approximately 226 feet, and from Montreal to the sea about 20 feet, the latter distributed through the 160 miles of river between Montreal and Quebec.

13. Navigation from Lake Superior to Lake Huron passes through the locks at St. Marys Falls. Channels have been excavated through the St. Marys River above and below the locks, and through the St. Clair River, Lake St. Clair, and the Detroit River, to afford a minimum depth of 20 feet at the lake levels that have been adopted as the standard for improvements. The extreme low stages reached by the Lakes during the last few years have been generally below these levels, with the result that the channel depths are less than 20 feet. In the latter part of the navigation season of 1925 the depth available was 18 feet, and at no time during that year did the maximum draft that could be carried from Lake Superior to Lake Erie exceed 19 feet.

14. The dredged channels between Lake Superior and Lake Erie aggregate nearly 100 miles in length. Their cost, for capital account only, including the costs of the locks in the St. Marys River, has been as follows:

<table>
<thead>
<tr>
<th></th>
<th>United States (to June 30, 1926)</th>
<th>Canada (to Mar. 31, 1925)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expended by the United States</td>
<td>$44,721,319.69</td>
<td>$5,560,009.00</td>
</tr>
<tr>
<td>Total</td>
<td>50,281,328.69</td>
<td></td>
</tr>
</tbody>
</table>

15. Navigation from Lake Erie to Lake Ontario passes through the Welland Canal, constructed and operated by the Dominion of Canada. The present Welland Canal affords a depth of 14 feet at normal lake levels. The new Welland Ship Canal, under construction by Canada, is 25 miles in length, with seven locks each having a lift of 46½ feet, and one guard lock. The portions of this canal first excavated were given a depth of 25 feet; the later contracts provide for a depth of 27 feet. The depth over the sills of the locks is 30 feet, to provide for subsequent enlargement of the canal reaches. The cost of the new Welland Ship Canal to March 31, 1925, has been $50,772,092.77, and the estimated total cost when completed is $114,526,484. These figures do not include interest during construction.

16. Navigation on the St. Lawrence River from Lake Ontario to Montreal is provided by isolated channel improvements and a series of side canals around the rapids (also constructed and operated by Canada), which afford 14 feet depth.
17. The channels between Montreal and the sea have been dredged to a depth of 30 feet and a project to provide a 35-foot depth is about half completed.

18. Navigation on the Great Lakes and the St. Lawrence at the present time falls into three categories:
   (a) Lake navigation, operating normally on 20-foot draft, on and between all of the lakes except Ontario.
   (b) Canal navigation, operating normally on 14-foot draft, between Lake Erie ports and Montreal through the Welland Canal, Lake Ontario, and the St. Lawrence.
   (c) Deep-sea navigation from Montreal to the ocean.

19. The completion of the new Welland Ship Canal will open Lake Ontario to lake navigation, which will then be separated from deep-sea navigation by the 183 miles of the St. Lawrence above Montreal.

20. The present lake commerce is upward of 100,000,000 tons per annum. The bulk cargoes, principally iron ore, coal, and grain, are moved in a special class of vessels developed for that purpose, of great length in proportion to their draft, so designed that they can be loaded and unloaded rapidly by special machinery installed for that purpose at terminal ports.

21. The present canal commerce through the Welland and St. Lawrence Canals is carried by smaller vessels of similar design. These vessels are relatively high powered, to meet the swifter currents on the St. Lawrence. This commerce has been increasing rapidly in recent years; that on the St. Lawrence canals amounted to 6,206,988 tons in 1925. Nearly all of the grain reaching Montreal Harbor in recent years is transported by this route.

22. The average dates of opening and closing navigation on the interconnecting channels of the Great Lakes and on the St. Lawrence River during the last 20 years have been as follows:
   - Great Lakes above Welland Canal, April 18 to December 19.
   - Welland Canal, April 18 to December 16.
   - St. Lawrence canals above Montreal, April 26 to December 9.

23. The part of the St. Lawrence with which this report is particularly concerned lies between Lake Ontario and Montreal. The river here runs in deep slow-flowing reaches and lake-like expansions, readily improved for navigation, with intervening reaches of rapids and swift currents. For the first 67 miles from Lake Ontario the river is a deep slow-flowing stream. It then passes through the remaining 49 miles of the international border in a succession of rapids and swift water. Leaving the border, the river expands into the quiet waters of Lake St. Francis. From this lake it drops in a succession of rapids to Lake St. Louis, and from Lake St. Louis drops through more rapids to Montreal Harbor.

24. As it is fed from the great reservoirs formed by the Lakes, the St. Lawrence has a remarkably steady flow. The mean discharge out of Lake Ontario during the past 66 years has been 246,000 cubic feet per second, the maximum average discharge for any month 318,000 cubic feet per second, and the minimum average discharge for any month 174,200 cubic feet per second. Except where affected by ice gorging in winter, the fluctuations in the river surface nowhere
exceed a few feet. The bed and banks are not subject to erosion and the river is free from silt.

25. Geologically, the St. Lawrence is a new river. Rock surfaces exposed indicate the passage of the continental glaciers across the valley, and the bed of the swifter portions is paved with bowlders from them, mingled with those formed from the country rock. The rock itself, as determined by borings, is generally uniform in contour, but is broken by valleys and ridges which strike across it northward. These are sometimes intersected by depressions from preglacial drainage. In the upper reaches the rock disclosed by borings is crystalline limestone of a firm character and close texture, mostly quite suitable for supporting hydraulic structures. Between Lakes St. Francis and St. Louis the rock is a hard limestone and a hard sandstone, equally sound. In the lower reaches around Lachine and Montreal there are igneous intrusions amongst limestone and shale which, while providing firm foundations, would require special protection against scouring.

26. The main banks and islands of the river are formed of mixtures of clay, sand, gravel, and bowlders, lying or deposited on the rocky floor of the valley. These materials are mixed in strata and irregular bodies but, in general, tight enough to form fairly watertight foundations for hydraulic structures under low heads. The high points on both islands and mainland are capped with extensive but shallow bowlder deposits.

PRIOR REPORTS

27. On the 21st of January, 1920, the Governments of the United States and Canada referred to the International Joint Commission, created by the treaty of the 11th of January, 1909, between the Governments of the United States and Great Britain, questions relating to the improvement of the St. Lawrence River between Lake Ontario and Montreal for the purpose of making it navigable for deep-draft vessels and securing the greatest beneficial use of the water for power.

28. Each of the Governments also designated an engineer to cooperate in the surveys necessary to plans for improvement and in the preparation of plans and estimates. These engineers were instructed to submit the surveys, plans, and estimates to the International Joint Commission.

29. Col. William P. Wooten, Corps of Engineers, United States Army, was designated as the engineer for the United States, and the late Mr. W. A. Bowden, chief engineer, Department of Railways and Canals, was designated as the engineer for Canada, these officers receiving identical instructions from their respective Governments.

30. Their report was submitted to the International Joint Commission on June 24, 1921. It is hereinafter referred to in this report as the report of 1921. The salient conclusions and recommendations in that report are as follows:

1. That the physical conditions (on the St. Lawrence) are favorable for improvements for navigation which will be permanent and will have very low upkeep costs.

2. That improvement of the entire reach from Montreal to Lake Ontario for navigation alone is feasible, but the loss of the power
that can be generated as a by-product in some reaches is not warranted.

(3) That the development of nearly all the potential power in the river, amounting to approximately 4,100,000 horsepower, can be made as coordinate parts of schemes for the improvement of navigation.

(4) That the simultaneous development of such a vast quantity of power is not a sound economic procedure, as a market to take this output is not now in existence and can not be expected to spring into being at once.

(5) That the sound method of procedure is to improve for navigation along those reaches where side canals and locks can most economically be used and where the development of the power at some future time is not interfered with by the proposed improvements, and in that part of the river where the construction of locks and dams offers the most feasible means of improving navigation to provide for the development of the incidental power obtainable as a result of the heads created by the dams.

(6) That the improvements undertaken afford a navigation channel 25 feet in depth, with lock sills 30 feet in depth, so built as to permit the eventual enlargement of the channel to that depth.

(7) That the improvement be secured by the combined development for navigation and for power of the rapids section on the international boundary, side canals around the other rapid sections, and the necessary channel excavation elsewhere.

31. The estimated cost of the entire work to provide a 25-foot channel and to develop 1,464,000 horsepower was as follows:

First division. Side canal from Montreal Harbor to deep water in Lake St. Louis $55,783,000
Second division. Side canal from deep water in Lake St. Louis to deep water in Lake St. Francis 36,590,000
Third division. Channel dredging in Lake St. Francis 1,158,000
Fourth division. Combined navigation and power development in international section, with annual power output of 1,464,000 horsepower (total installed capacity approximately 1,850,000 horsepower) 159,097,200
Fifth division. Navigation improvement above rapid section 100,000

Total 252,728,200

32. The estimated cost of increasing the navigable depth throughout the entire stretch to 30 feet at a later date was $17,986,180.

33. The report considered, but did not recommend, plans for power development in the first and second divisions, respectively.

34. Of the total estimated cost of the project, $159,097,200 was for the combined navigation and power development on the international section of the river. A head of 74 feet was to be developed by a dam across the river at the Long Sault Rapids. A second dam was to be constructed 23 miles upstream at Ogden Island, just upstream from Morrisburg, to provide navigation through the upper rapids of the reach, afford control over the flow of the river, and insure suitable winter operation. The head of approximately 8 feet available at this dam in summer was not to be developed. The main dam and related structures were, however, to be so designed that they could be raised subsequently so as to utilize fully whatever
head the operation of the works might show to be economically practicable.

35. It was estimated that if the improvements were carried on simultaneously it would be possible to complete them in eight years from the time the work was begun, if funds were made available as fast as needed.

36. The report pointed out that the construction of the upper dam proposed (at Ogden Island) and the enlargement of the discharge capacity of the upper reaches of the river would afford control over the level of Lake Ontario and the flow in the St. Lawrence River. This control can be so exercised as to raise the mean level of the lake without causing it to fluctuate beyond the limits previously reached. The studies made did not show, however, that any very great increase in the natural low-water flow can be made for the benefit of either power or navigation in Montreal Harbor or the ship channel below.

37. The engineers of the two countries united in all of the recommendations contained in the report of 1921, except as to the program of regulation of the levels and outflow from Lake Ontario which should be put into effect after the project was completed, each submitting a program regarded as most suitable to that end. The essential difference between the two was that the program proposed by the Canadian engineer provided for a greater restriction of the winter flow, with a view to creating more desirable ice conditions. With this restriction it was not possible to secure quite as favorable results from regulation as would be afforded by the program proposed by the United States engineer.

38. The plans presented in the report of 1921 were made the subject of public hearings before the International Joint Commission. At these hearings several alternative plans were presented for the consideration of the commission, especially with relation to the development of power in the international section.

39. The report of the International Joint Commission included the following recommendations:

(1) That the Governments of the United States and Canada enter into an arrangement by way of treaty for a scheme of improvement of the St. Lawrence River between Montreal and Lake Ontario.

(2) That the new Welland Ship Canal be embodied in said scheme and treated as a part thereof.

(3) That the proposed works between Montreal and Lake Ontario be based upon the report of the engineering board (report of 1921) but that before any final decision is reached the report of the board, together with such comments, criticisms, and alternative plans as have been filed with the commission, be referred back to the board enlarged by other leading members of the engineering profession, to the end that the whole question be given that further and complete study that its magnitude and importance demand, and that after completion the administrative features of the improvement be carried out as set forth in recommendations 7 and 8 hereof.

(4) That there shall be an exhaustive investigation of the extent and character of the damage through flowage involved in the plan of development finally adopted.

(5) That, assuming the adoption of the plans of the engineering board, or of other plans also involving a readjustment of the international boundary, in order to bring each of the power houses on its own side of the boundary, appropriate steps be taken to transfer to one country or the other, as the case may be, the slight acreage of submerged land involved.

(6) That Canada proceed with the works necessary for the completion of said new Welland Ship Canal in accordance with the plans already decided upon by that country.
(7) That such "navigation works" as do not lie wholly within one country or are not capable of economic and efficient construction, maintenance, and operation within one country as complete and independent units be maintained and operated by a board hereinafter called "the international board," on which each country shall have equal representation.

(8) That such "navigation works" as lie wholly within one country and are capable of economic and efficient construction, maintenance, and operation as complete and independent units be maintained and operated by the country in which they are located with the right of inspection by the said international board to insure economy and efficiency.

(9) That "power works" be built, installed, and operated by and at the expense of the country in which they are located.

(10) That, except as set forth in recommendation (11), the cost of all "navigation works" be apportioned between the two countries on the basis of the benefits each will receive from the new waterways: Provided, That during the period ending five years after completion of the works—and to be known as the construction period—the ratio fixing the amount chargeable to each country shall be determined upon certain known factors, such as the developed resources and foreign and coastwise trade of each country within the territory economically tributary to the proposed waterway, and that that ratio shall be adjusted every five years thereafter and based upon the freight tonnage of each country actually using the waterway during the previous five-year period.

(11) That the cost of "navigation works" for the combined use of navigation and power over and above the cost of works necessary for navigation alone should be apportioned equally between the two countries.

WORK DONE BY THE JOINT BOARD OF ENGINEERS

40. A program of the field work and office investigations to be undertaken, respectively, by the two sections of the board was adopted at a meeting held at Ottawa April 13-16, 1925. This embraced surveys of the sections of the river not previously covered in detail, and borings to determine foundation conditions at sites of proposed structures, with a special examination by shafts and borings at the site of the dam proposed in the report of 1921 at the Long Sault Rapids.

41. The Canadian Department of Railways and Canals, having available the data collected for the report of 1921, continued investigations on the St. Lawrence River through the years 1922 and 1923 until the appointment of this board in the spring of 1924. Through the remainder of that year the Canadian section of the board further continued these investigations, and in April, 1925, after the adoption of the board’s program, both of the sections vigorously prosecuted extensive surveys and discharge meterings, together with numerous borings, completing these in the summer of 1926. The United States section devoted itself mainly to surveys and borings in the international section, including the special work at dam sites around Long Sault Rapids. The two sections together have made upward of 400 borings, covering the most critical portions of the St. Lawrence River between the Galop and Lachine Rapids; these included a set of borings across the river in the swift water at the head of the Cedars Rapids. The Canadian section carried out in November and December of 1924 and 1925 an extended set of temperature measurements to determine the rate of loss of heat in the river, and in February and March, 1926, a set of experiments to determine the resistance of ice as bearing on the design of dams in the river.

42. Each section employed a competent and extensive engineering force in office and field to carry out its investigations. The office staff of the United States section was maintained at the United States
Lake Survey, Corps of Engineers, United States Army, at Detroit, and the Canadian at the Department of Railways and Canals at Ottawa. The United States section engaged the services of the engineering firm of Viele, Blackwell & Buck as consulting engineers on features relating to power development.

43. The board had available for its use a large volume of data obtained from other sources. This consisted not only of topographic and hydraulic information concerning the lakes and river but a great number of boring determinations as well as construction and price data useful for estimating purposes. The various departments of the Canadian and United States Governments contributed a large part of this. Other sources of information were the reports of the United States Board of Engineers on Deep Waterways of 1900 and the Georgian Bay Canal survey of 1908, and data supplied by the St. Lawrence Power Co., the Canadian Light & Power Co., and the Montreal Light, Heat & Power Consolidated, and by the Hydro-electric Power Commission of Ontario which for several years has carried on extensive investigations in the vicinity of Morrisburg and the Long Sault Rapids. The board has had a special advantage with respect to navigation cost data in the current prices established on the New Welland Ship Canal, a similar work now under construction. The board has also received much valuable data from operating power companies and manufacturers of hydraulic and electrical machinery in both countries.

44. The board held frequent meetings at various points on the river and Great Lakes to study and discuss the problems involved in the improvement.

45. The results of these various investigations are set forth in appendixes to this report.

PART II

IMPROVEMENT OF LEVELS AND OUTFLOW OF THE GREAT LAKES

46. This part of the report deals with:
   (a) The extent to which the levels of the Great Lakes are affected by diversion of water. (Question 6a of the instructions to this board.)
   (b) The feasible measures for raising the levels of the Lakes to correct the effect of authorized diversions and to reduce the cost of improving the lake channels. (Questions 6b and 10.)
   (c) The extent to which the outflow from the Lakes can be improved by the manipulation of their levels. (Question 6d.)
   (d) The cost of deepening the channels through and between the Lakes. (Question 10.)

DESCRIPTION

47. The Great Lakes serve two great economic uses—as navigation routes of vital concern to the two countries and as a reservoir to equalize the flow of the St. Lawrence River.

48. The supply of water to the Great Lakes is furnished by the inflow of the many relatively small rivers of their drainage basins, increased by the rainfall on the Lakes themselves and decreased by the evaporation from the lake surfaces. The total area of the
drainage basins of the Lakes is approximately 300,000 square miles, of which nearly one-third is occupied by lake surface. Computations show that the average supply received from the land areas about equals that received as rainfall on the Lakes, but that roughly 40 per cent of this total gross supply is lost by evaporation. The net supply varies widely. The records show rates of net supply to the whole lake system exceeding 800,000 cubic feet per second for a month; and they also show months during which the evaporation from the Lakes exceeded the water received from all sources, with a consequent negative net supply. The average monthly net supply for the months of April and May is at a rate exceeding 500,000 cubic feet per second; and the average net supply for the month of November is at a rate of less than 20,000 cubic feet per second.

49. Notwithstanding this wide variation in supply, the monthly mean outflow from the Lakes during the past 65 years has ranged between the narrow limits of 318,000 and 174,000 cubic feet per second. But even this minimum was due partly to ice retardation. The minimum monthly mean discharge with open-river conditions was 194,000 cubic feet per second.

50. The Lakes absorb the great variations in supply because of the rise and fall of their levels. When the supply is high, they rise and store water; when it is low they fall and deliver the stored water. The average annual rise and fall of the various Lakes due to the seasonal variations in supply is from 1 1/4 to 2 feet; but extreme variations in seasonal supply have caused fluctuations in lake levels ranging from 2.67 feet on Lake Superior to over 4 feet on Lake Ontario. Extreme high and low lake levels are reached at the ends of periods of excessive or deficient supply extending over several years. The maximum ranges of the monthly mean levels of the various Lakes since 1860 vary from 3.5 feet on Lake Superior to a little more than 6 feet on Lakes Michigan and Huron.

51. The period of low rainfall occurring during the past few years has brought down the levels of the Lakes, and with other factors mentioned later has created record low levels on Lakes Michigan, Huron, and Erie. The rains of the summer of 1926 have, however, started the levels upward, and the Lakes will return to their ordinary levels if the increased rainfall continues.

DIVERSIONS AND OUTLET ENLARGEMENTS AFFECTING LAKE LEVELS

52. It is evident that as the level of a lake falls, that of its outlet river will fall also, and the discharge capacity of the outlet river will be reduced. When water is diverted from the outlet, the lake levels will be steadily lowered with respect to their natural levels until the discharge capacity of the outlet has been reduced by an amount corresponding to the diversion, after which the effect of the diversion on lake levels ceases to increase. Thus, at means stages of Lake Erie, a fall of 6 inches in its level will reduce the discharge capacity of its outlet, the Niagara River, by 11,000 cubic feet per second. After a diversion of 11,000 cubic feet per second has lowered Lake Erie by 6 inches, it will be balanced by the reduced outflow, and from then on the lake levels will remain substantially 6 inches below the levels that they would have if the diversion were not in existence.
53. The relation between the volume of flow of the various outlet rivers and the elevation of their water surface, or stage, has been accurately determined by repeated current-meter measurements made during the past quarter century, and the amounts by which the various existing diversions have affected the lake levels can be stated with assurance.

54. The time required for the decreasing outflow to reach an equilibrium with the decreased supply due to a diversion depends on the area of the lake in relation to its outlet capacity. Under present conditions, approximate equilibrium is reached on Lakes Erie and Ontario in about a year, but several years are required to establish this equilibrium on the great reservoir formed by the combined areas of Lakes Michigan and Huron.

55. It is obvious that any enlargement of the outlet channel will lower the level of a lake in the same manner as a diversion of water.

56. The levels of the Great Lakes have been affected by the following artificial factors:

(a) The operation of the regulating works constructed to correct for the power diversions in the St. Marys River at the outlet of Lake Superior.

(b) The diversion of the Chicago Sanitary District from Lake Michigan.

(c) Diversions from Lake Erie for power and navigation through the Welland Canal and from the Niagara River.

(d) Changes in the discharge capacity of the St. Clair River at the outlet of Lake Huron, and of the St. Lawrence River affecting Lake Ontario.

57. Effect of regulating works, St. Marys River.—The extensive diversions of water for power development at St. Marys Falls, amounting to approximately 50,000 cubic feet per second, has made necessary the installation of gates across the river, at the head of the falls, to control the outflow and levels of Lake Superior. The gates are operated and the diversions are controlled by an International Board of Control in accordance with conditions laid down by the International Joint Commission, May 26 and 27, 1914. Their operation substitutes artificial for natural control of the levels of Lake Superior, and has, in general, increased the levels of that lake at low water and somewhat diminished those at high water. The control of the outflow of Lake Superior for power and for navigation at St. Marys Falls has, therefore, in general, been beneficial rather than injurious in its effect on the levels of Lake Superior.

58. The operation of these regulating works has affected somewhat the levels of the other lakes, since the controlled discharge from Lake Superior into them is at times greater than the natural discharge and at times less. A computation shows that the maximum effect since the regulation was begun was reached in 1922 and 1923, when Lakes Michigan and Huron were lowered by 4 1/2 inches and Lakes Erie and Ontario by 3 inches. From 1923 to 1925 the release of water from Lake Superior was in excess of the outflow that would have occurred under natural conditions, with the consequence that by January, 1926, the other lakes were slightly higher than they would have been had there been no regulation of Lake Superior.

59. Diversion of Chicago Sanitary District.—The diversion by the Sanitary District of Chicago of an average yearly flow of 8,500 cubic
feet per second from Lake Michigan through the Chicago Drainage Canal into the basin of the Mississippi River has been authorized by the United States under the terms of a revocable permit issued by the Secretary of War, effective March 3, 1925. The permit was issued subject to the conditions, among others, that the sanitary district should construct extensive sewage purification works and control works in the river, within five years, and provides that the authorization shall terminate on December 31, 1929, unless specifically extended. The estimated cost of the sewage purification works required under the permit is $92,000,000. It is reported that these works are 46 per cent completed.

60. The diversion by the sanitary district authorized by the permit is exclusive of the water pumped by the city of Chicago into its water-supply system and thence passing through the sewers into the drainage canal. The amount so diverted in 1924 was reported as about 1,200 cubic feet per second. The permit was made contingent upon the adoption by the city of Chicago of an extensive program for metering its water service and the execution of this program within 10 years. The metering, which is estimated to cost $15,000,000, will reduce the amount of water diverted through the city water-supply system and will expedite the sewage purification by reducing the volume to be treated.

61. The official reports of the War Department show that the total diversion, including that diverted via the water-supply system, has averaged 8,660 cubic feet per second during the past five years. The Secretary of War, in issuing the permit, informed the sanitary district that the diversion of water should be reduced to reasonable limits with utmost dispatch. It was appreciated that the desired reduction could not be made instantaneously, but the conditions required under the permit were drawn with a view to making a substantial reduction by the time the permit expires.

62. The diversion of the Chicago Sanitary District authorized by license by the United States is taken in the present report as the diversion of 8,500 cubic feet per second specifically authorized in the permit issued by the Secretary of War.

63. There is a small diversion from Lake Huron into the Black River, which discharges into the St. Clair River below the head of the latter. Its effect on lake levels is negligible.

64. Diversions from Lake Erie.—On the Welland Canal, in addition to the water required for lockages, etc., diversions for power purposes aggregating the equivalent of a total of 2,050 cubic feet per second have been authorized by the department of railways and canals of the Dominion of Canada. The best measurements available indicate a total present average flow of 3,100 cubic feet per second for both navigation and power. More water will be required for the large locks of the new deep-draft canal now under construction. The board is informed by the chief engineer, department of railways and canals of the Dominion of Canada, that the total average flow will not exceed 5,000 cubic feet per second after the new canal is put in operation.

65. On the Niagara River a diversion for navigation purposes through the Black Rock Canal, operated by the United States to carry lake shipping past the rapids at the head of the river, has a small effect on the levels of Lake Erie. There is a diversion of ap-
proximately 1,500 cubic feet per second through the New York State Barge Canal, including 275 cubic feet per second for power purposes. This water is drawn from the Niagara River at Tonawanda below the rapids at the head of the river and is discharged into Lake Ontario. Its effect on lake levels is negligible. The effect of the considerable diversions for power on the Niagara River has been compensated for, at least to a large degree, by intake structures and the deposit of excavated material. The effect of the power diversions on the levels of Lake Erie, if any, is also regarded as negligible.

66. The diversions via the Welland Canal and the Black Rock Canal affect not only the levels of Lake Erie but also to a small degree the levels of Lakes Michigan and Huron.

67. Changes in outlet rivers.—The St. Clair River (the outlet of Lake Huron) is the one outlet of the Great Lakes system whose discharge capacity is not controlled by a natural weir of rock. The river has a sand and gravel bed. Any change in the slope of the river has an effect on the level of Lake Huron. At the entrance from Lake Huron it is contracted in a deep and narrow channel known as the Port Huron Rapids, changes in the cross-sectional area of which have a much greater effect than those of any other similar length of the river. There is every reason to believe that this contraction was formed by the drift of beach gravel from Lake Huron.

68. A detailed analysis of all available gauge records made by the United States Lake Survey indicates that between 1890 and 1900 discharge capacity of the St. Clair River increased possibly to the extent of 0.34 foot of stage of Huron. The question has been raised as to whether this was due to the dredging of navigation channels in the river. Most of such dredging was done, however, through the delta of the St. Clair, where the river flows with a flat slope through a number of channels into Lake St. Clair, and the extent of the dredging was insufficient to produce any sensible increase of the discharge capacity of the river as a whole. A more probable explanation of the apparent increase in discharge capacities during that period is the natural erosion of the gravel bed of the Port Huron Rapids.

The discharge measurements subsequent to 1899 afford a more definite basis for determining the changes in the discharge capacity of the river since that year. The shoaling caused by the wrecks of two schooners in the Port Huron Rapids in 1900 reduced the discharge capacity by 0.1 foot of stage, leaving a net change of 0.24 foot to that date. No further change is indicated by the discharge measurements until after 1908.

69. The computations of the United States Lake Survey show that between 1908 and 1925 the discharge capacity again enlarged to the extent of 0.38 foot of stage, and that this increase occurred in the contracted section near the head of the river. Its computations show no indication of any sensible increase in the discharge capacity except in this section. They do not show that the dredging done for the improvement of navigation during this period (embracing the removal of a shoal opposite Port Huron to the depth required for navigation), or the dredging of gravel for commercial purposes downstream from this contracted section, which has been permitted by both the United States and Canada, has sensibly affected the discharge capacity of the river.
70. In order to improve the navigable depth to the Point Edward docks, at the foot of the Port Huron Rapids, the Department of Public Works of the Dominion of Canada authorized the licensees of the Province of Ontario to dredge gravel in this contracted section. The records of the Province show a total of 1,519,000 cubic yards dredged from this locality during the period. A survey made in 1925 disclosed that this dredging had been carried on by the licensees and others to such an extent as to create a material enlargement of the cross-sectional area of the river through a distance of about 6,000 feet, such enlargement for about one-half this distance amounting to more than 30 per cent of the original area. This survey showed an apparent removal of 2,400,000 cubic yards. The computed effect of the enlargement is 0.29 foot and agrees reasonably closely with the observed increase in the discharge capacity during the period. The survey showed that the narrow section above the location of the dredging had contracted during the period, leaving this dredging as the only assignable cause of the increase in the discharge capacity of the river.

71. From the above figures, the total effect of the enlargement of the discharge capacity of the river is taken at 0.6 foot of stage.

72. Precise information as to the effect of gravel dredging in the part of the river below Point Edward can not be given at the writing of the report, but a joint survey is being made by the officers of the two countries covering the uppermost 6 miles of the river. From this survey further information will become available in regard to this matter.

73. The Detroit River has a wide sill of ledge rock across its lower reaches. The enlargement of the natural channels through this section of the river was commenced in 1876 and has been progressive since that time. In the lack of contemporaneous discharge measurements the effect of the earlier excavation can not be determined, but the amount of this excavation is insufficient to have caused any material increase in the discharge capacity of the St. Clair-Detroit outlet as a whole. In 1907 the excavation of a new straight channel, known as the Livingstone Channel, was begun, but in the execution of the work the excavated material was so deposited as to compensate for the enlargement. The discharge measurements and computations made by the United States Government engineer in charge of the improvement since the opening of the channel have convinced the board that the compensation for all channel excavation since 1901 was accomplished.

74. The Niagara River has had various minor contractions by bridge piers, shore encroachments, etc., and enlargements through the dredging of gravel for commercial purposes. Recent discharge measurements show that these have so closely balanced each other that the discharge capacity of the river has been substantially unchanged.

75. In the St. Lawrence River the works undertaken by the Canadian Government in connection with the present 14-foot navigation included the closure of a minor channel at the head of the Galop Rapids by what is known as the Gut Dam. This work was undertaken for the purpose of improving navigation at the rapids but caused a reduction in the discharge capacity of the outlet of Lake Ontario, which, in addition to counteracting minor channel enlarge-
ments made in the same period, raised the levels of the lake by some-what more than 0.4 foot.

76. The estimates of the cost of the channels of specified depths through and between the Lakes, hereinafter presented, are based on the premise that the lake levels will not be lowered by the further enlargement of their outlets through the dredging of sand and gravel for commercial purposes. The control of this dredging to prevent injurious enlargements is now being considered in correspondence between the two countries.

77. Omitting the small and varying changes resulting from the regulation of Lake Superior, the effect of the various diversions and outlet changes is found to be as follows. The minus sign indicates a lowering of lake levels and the plus sign a raising of lake levels.

<table>
<thead>
<tr>
<th>Cause</th>
<th>Amount of diversion, cubic feet per second</th>
<th>Effect in feet on levels of Lakes</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Michigan and Huron</td>
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<td>Authorized diversions:</td>
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</tr>
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<td>Chicago Sanitary District</td>
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<td>-0.5</td>
</tr>
<tr>
<td>Power diversions, Welland Canal</td>
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<td>-0.025</td>
</tr>
<tr>
<td>All present diversions and outlet changes:</td>
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<td></td>
</tr>
<tr>
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<td>-0.5</td>
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<tr>
<td>Welland Canal</td>
<td>3,100</td>
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</tr>
<tr>
<td>Black Rock Canal</td>
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</tr>
<tr>
<td>Changes in St. Clair River outlet—</td>
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<td></td>
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<tr>
<td>Prior to 1908</td>
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<tr>
<td>Subsequent to 1908</td>
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<tr>
<td>Gut Dam</td>
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</tr>
<tr>
<td>Total</td>
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<td>-0.6</td>
</tr>
</tbody>
</table>

1 Upon the opening of the new Welland Ship Canal the lowering of the level of Lake Erie will be increased to 0.7 foot.

**IMPROVEMENT OF LAKE LEVELS AND OUTFLOW**

78. *Compensating and regulating works.*—The levels of the Great Lakes can be raised by works in their outlet rivers, which may be wholly in the form of fixed weirs and contractions or may be provided with sluice gates. The first of these have come to be termed “compensating works,” while the second are termed “regulating works.”

79. The effect of compensating works is to raise both the high and low lake levels in substantially the same degree, the fluctuation of levels remaining unchanged. After the lake levels have adjusted themselves to the new regimen of the outlet, the outflow from the lake will likewise be substantially the same as if the compensating works had not been built. By operating the gates of regulating works, the discharge from a lake, and consequently the levels of the lake, can be controlled within limits to be discussed later.

80. *Regulation of Lake Ontario.*—The regulation of Lake Ontario is an inherent part of the plans for the improvement of the St. Lawrence River for navigation and power, proposed in Part III of this report, since these plans include a major enlargement of the rock sill at the head of the Galop Rapids, which now controls the outflow from the lake, and provide for the control of outflow by sluice gates. The program for the regulation of Lake Ontario recommended by the board is presented in Appendix B.
81. Regulation of other lakes.—Since regulating works are already in operation at the outlet of Lake Superior, as a consequence of the large power diversions at St. Marys Falls, there remains only the consideration of compensating or regulating works at outlet of Lake Huron (controlling also the levels of Lake Michigan) and of Lake Erie.

82. A widespread belief has arisen among members of the engineering profession as well as among the public at large that a remedy for low lake levels and discharges can be found through a comprehensive system of regulation of these lakes. The board has given the question searching study, and has turned to compensating works in the outlets of Lakes Huron and Erie only after it was found that the results that can be secured from regulating works are entirely incommensurate with their cost.

83. Limitations on lake regulation.—To many of the persons concerned in the levels of the Great Lakes, the apparent remedy for such low-water levels as are now occurring is the construction of regulating works across their outlets, with gates which can be closed at low-water periods to hold back the water which now runs out in excess of the supply, and which can be opened when the supply again becomes normal. It is the excess discharge during low-water periods, however, that furnishes the bulk of the flow of the Niagara and St. Lawrence Rivers. There have been times when, for two months consecutively, practically all of the water flowing out of the Lakes into the St. Lawrence came from the recession of lake levels. The lake levels would therefore have to be allowed to recede, when the rainfall is deficient, to maintain the natural low-water flow in the Niagara and St. Lawrence Rivers.

84. Similarly, when the lakes reach high stages, it is not possible to hold back more water for storage against a future low supply without raising the Lakes to such extent as would do great damage to industries and lands on the lake shores.

85. The operation of regulating works must therefore be limited to holding back water in storage when the supply is in excess of the requirements of the Niagara and St. Lawrence Rivers, and the stages of the Lakes are at the same time such that the water can be stored without risk of causing excessively high levels. The water stored can subsequently be used for maintaining the outflow of the Niagara and St. Lawrence during periods of deficient supply without drawing down the Lakes as far as they would fall under present conditions.

86. The lake levels can be raised by compensating works to the extent regarded as justifiable with respect to high lake levels. With regulating works the range of stage can be reduced, so that, with the same high levels, the low levels will be higher than those secured by compensating works.

87. Regulation for lake navigation.—To determine the extent of the benefit a program of regulation was formulated by the board, which was designed to secure, with as complete a control over the outflow of the Lakes as is at all practicable, the maximum improvement in lake levels and at the same time assure a minimum discharge of 176,000 cubic feet per second out of Lake Erie and 200,000 cubic feet per second into the St. Lawrence River. The natural discharge heretofore has fallen below these figures but 5 and 15 per cent of the time, respectively. This program was then applied to conditions that actually occurred on the Lakes during the period
from 1894 to 1925, inclusive. Considering only the levels affecting navigation and eliminating the fluctuation in the natural stages which were due to progressively increasing diversions and outlet enlargements, the results are as follows:

<table>
<thead>
<tr>
<th>Lake</th>
<th>Range of stage if regulated</th>
<th>Range in stage if not regulated</th>
<th>Gain by regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior</td>
<td>Feet</td>
<td>Feet</td>
<td>Feet</td>
</tr>
<tr>
<td>Michigan-Huron</td>
<td>2.4</td>
<td>2.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Erie</td>
<td>2.8</td>
<td>3.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Ontario</td>
<td>2.8</td>
<td>4.2</td>
<td>1.4</td>
</tr>
</tbody>
</table>

88. The minimum cost of regulating works necessary to put the program into effect is estimated at $36,400,000. The cost of securing the same improvement in lake channels and harbors by compensating works supplemented by dredging is $13,400,000, it being assumed that the dredging is undertaken in both bases as a part of the comprehensive project for channel enlargement. It is clear, therefore, that the construction of regulating works for the benefit of lake navigation is not economically justified.

89. Moreover, regulation works in the St. Clair River will necessarily be a burden to its present intensive water traffic. A preliminary investigation indicates that the control over the discharge of the river necessary to regulation could be obtained by a series of works each with an open navigable pass having a width, depth, and current velocity suitable for navigation, and the estimate of $36,400,000 is based on such a scheme. The scheme involves the maintenance of many miles of channel at the predetermined dimensions necessary to accomplish the result, and its practicability is not assured. It would certainly afford a waterway less convenient for navigation than are the present free channels. The somewhat more expensive plan that has been advanced, of works in which locks would be provided to pass vessels at the regulating works, would be more certain of operation but would inflict a serious loss on present commerce through the delay of lockage. The total delay for each vessel passage, including the time lost in approaching the lock and delays awaiting lockage, would be approximately one hour. The aggregate economic loss resulting from such a delay to the great vessel movement through the waterway would be in the vicinity of $1,000,000 per annum.

90. Furthermore, an analysis of the outflow from the Lakes afforded by the program of regulation tested shows that, while the lowest outflow would be somewhat increased, the discharge would be held down to a lower flow than now occurs for nearly half the time in order to build up the lake levels. As explained in Appendix B, a prolongation of the periods of low discharge disproportionate to the increase in the minimum discharge is an inevitable consequence of the restricted discharge capacity of the lake system. Aside from the effect on the future development of power, such long-continued low discharges would have serious consequences in reducing the water levels in Montreal Harbor.
91. Various modified programs for regulations were tried out but all with the same result; such improvement in lake levels as could be secured was at a cost greatly in excess of the saving effected in future channel and harbor dredging and at the expense of prolonging the periods of low flow in the St. Lawrence.

92. Regulation for power.—While the general regulation of the Great Lakes is clearly inadvisable for the purposes of improving the lake levels for lake navigation, there remained a question whether it might be justifiable for the purpose of increasing the flow for power on the St. Lawrence. A study was made, therefore, to determine the results that could be expected if the operation of the works was directed toward that end instead of toward reducing the fluctuations in the levels of the Lakes. While the outflow could thus be redistributed to increase the primary power potentially available, no program of regulation was found that would increase materially the total output of plants with an installed capacity sufficient to utilize the mean flow of the river. The advisability of undertaking the regulation for the benefit of the power on the St. Lawrence depends, therefore, wholly on the nature of the market for power that may develop as the installation of power works proceeds. The regulation of Lake Ontario alone will afford a sufficient control over the flow of that river for the advantageous development of power until at least the enormous amounts available without further regulation are absorbed. There is, therefore, no present justification for the great expenditure necessary to provide regulating works in the interest of power production.

93. General aspects of regulation.—Regulation works could be administered to serve either of two divergent purposes. They could be used to decrease the fluctuations in the lake levels for the benefit of navigation and of riparian interests on the Lakes at the expense of the outflow into the St. Lawrence; or they could be used to improve the outflow into the St. Lawrence for the benefit of power production and of navigation in the lower river at the expense of the levels of the Lakes. The predominant interests concerned in the levels of the Great Lakes are in the United States; the predominant interests concerned in the outflow into the St. Lawrence are in Canada. Lake regulation might therefore create points of difference between various interests in the two countries. It is not even possible to fix in advance a definite allocation of such benefits as might accrue from lake regulation, because any program of regulation must be based on past experience as to the supply of water to the lake system. If a future deficiency in supply should exceed past records in extent and duration, the question would arise whether the emergency should be met by holding back water in the Lakes at the expense of the St. Lawrence, or whether the navigable depth in Montreal Harbor is to be maintained at the expense of lake navigation.

94. The regulation of Lake Superior has been satisfactory to the two countries for the reason that the fluctuations introduced in discharge from that lake are absorbed in the great reservoir formed by Lakes Michigan and Huron without greatly affecting the levels of the latter or materially affecting the discharge of the Niagara and the St. Lawrence Rivers. The recent great deficiency in supply to Lake Superior, which was not anticipated when the program for regulation was drawn up, gave rise, therefore, to no special complications. The regulation of Lake Ontario, proposed as a necessary part of the
improvement of the St. Lawrence, affects but one lake only, which has but 8 per cent of the area of the Great Lakes system. Its regulation will not affect in any substantial manner divergent national interests and is a relatively minor problem whose solution offers no serious difficulties. The regulation of the Lakes as a whole is an entirely different matter.

95. **Compensating works.**—The investigations made by the board show that it is advisable to construct compensating works in the Niagara and St. Clair Rivers to counteract the effect of all diversions and outlet enlargements on the levels of Lakes Michigan, Huron, and Erie.

96. The works proposed in the Niagara River are located just above the contracted section of the river at Fort Erie, and in effect merely prolong this contracted reach. A longitudinal dike, approximately one-half mile in length, is to be constructed to secure the required contraction. It is to be connected with the Canadian shore by a weir with its crest slightly below low-water level, which will force practically all of the flow through the contraction at low lake levels and a less proportion of the flow at high lake levels. The structures will not interfere with the free passage of ice nor with such light-draft navigation as follows the river instead of using the Black Rock Canal. In view of the approaching opening of the new Welland Ship Canal, with an increased diversion for its operation, they are designed to raise the low levels of Lake Erie by 0.7 foot and the high levels by a slightly less amount. Should the amounts of the present or prospective diversions be reduced, the works can be altered at small cost to balance the reduced diversion. The cost of these works is estimated at $700,000.

97. The works proposed on the St. Clair River are a series of submerged rock sills with crests 30 feet below the low-water stage of the river. It has been shown in paragraph 77 that present diversions and outlet enlargements have lowered the levels of Lakes Michigan and Huron by 1.15 feet. The board regards it as safe to restore them to the extent of 1 foot. The back-water effect of the compensating works proposed in the Niagara River is computed as 0.15 foot on Lake Huron. It is estimated that 31 sills in the St. Clair River will secure the remaining 0.85 foot of compensation proposed at a cost of $2,700,000.

98. This form of compensating works is selected primarily for the reason that the sills will not reduce the navigable width of this important waterway nor will they increase the cost of providing a channel depth of 30 feet. While these works once built can not be altered readily to meet a future reduction in the amount of the Chicago diversion, yet, on account of the commercial value of the gravel in the river bed, it would not be costly to again enlarge the capacity of the river to meet such a reduction.

99. To avoid an unwarranted reduction in the flow of the Niagara and St. Lawrence Rivers while the Lakes are being raised by the compensating works, the construction on the Niagara River should be spread over two years and on the St. Clair River over four years' time, and the prosecution of the latter should be suspended during any extreme low-water periods that may occur at the time they are undertaken.
100. The proposed compensating works will counteract not only the effect of diversions authorized by license in the United States and Canada but also the effect of outlet enlargements, diversions for navigation, and diversions not covered by license. The lake levels could be restored by similar but less extensive works to the extent that they have been reduced by diversions authorized by license in the two countries. The cost of such works would be nearly proportional to the amount of compensation of level effected, and is estimated as follows:

<table>
<thead>
<tr>
<th>Diversion compensated for</th>
<th>Cost of works in Niagara River</th>
<th>Cost of works in St. Clair River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago Sanitary District</td>
<td>$400,000</td>
<td>$1,350,000</td>
</tr>
<tr>
<td>Power diversions, Welland Canal</td>
<td>$100,000</td>
<td></td>
</tr>
</tbody>
</table>

COST OF DEEPENING CHANNELS THROUGH AND BETWEEN THE LAKES

101. An uncompensated enlargement of the navigation channels through the St. Clair and Detroit Rivers would slightly increase the discharge capacity of these rivers, and hence will tend to lower the levels of Lakes Michigan and Huron. On the Detroit River an enlargement can be compensated by the deposit of the excavated material. On the St. Clair River some additional compensating works will probably be required. The cost of these, to counterbalance the excavation of a channel to a depth of 25 feet, is estimated at $200,000.

102. The cost of improving the channels between Lake Erie and Lake Superior to secure a depth of 25 feet below the levels which past experience indicates will be available 99 per cent of the time during the navigation season, after compensating works have been constructed, is as follows:

<table>
<thead>
<tr>
<th>25-foot channel</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of compensating works</td>
<td>$3,600,000</td>
</tr>
<tr>
<td>Cost of excavation</td>
<td>41,100,000</td>
</tr>
<tr>
<td>Total</td>
<td>44,700,000</td>
</tr>
</tbody>
</table>

The present project for the new Welland Ship Canal, when completed, will give this depth of 25 feet between Lake Erie and Lake Ontario.

103. The estimates are based on the deepening of present channels, with such minor enlargements and straightening as experience with these channels has proved necessary. The lake levels on which the depths are based are:

- Lake Superior: 601
- Lakes Michigan and Huron: 579
- Lake St. Clair: 573.75
- Lake Erie: 571

The estimates do not include a new lock in the St. Marys River, since the available depth in two locks last built by the United States, the Davis and Fourth Locks, is 24 feet when Lake Huron is at the level chosen as a basis for this improvement. The additional depth
provided in the 25-foot channels is no more than is required for safe and convenient navigation.

104. The estimates show that a saving of approximately $1,250,000 will be effected in providing channels 25 feet in depth through and between the Lakes by including compensating works in the project as proposed rather than by securing the depth by dredging only. The construction of these compensating works will afford also increased depth in all the harbors, large and small, on Lakes Michigan, Huron, and Erie, and will reduce the cost of improving such harbors as may be deepened to correspond with the enlarged interlake channels. Moreover, without compensating works, the low-water depth in the Davis and Fourth Locks at St. Marys Falls will be but 23 feet. The construction of compensating works is therefore fully justified.

105. The costs of channels 27 and 30 feet deep, respectively, through and between the Lakes at the same lake levels as those on which the channel 25 feet deep is based, are as follows:

<table>
<thead>
<tr>
<th>Channel Depth</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 feet</td>
<td></td>
</tr>
<tr>
<td>Compensating works, Niagara and St. Clair Rivers</td>
<td>$3,700,000</td>
</tr>
<tr>
<td>Channel excavation, Lake Erie to Lake Superior</td>
<td>54,900,000</td>
</tr>
<tr>
<td>Lock in St. Marys River</td>
<td>6,500,000</td>
</tr>
<tr>
<td>New Welland Ship Canal, in addition to present project</td>
<td>1,100,000</td>
</tr>
<tr>
<td>Total</td>
<td>66,200,000</td>
</tr>
</tbody>
</table>

| 30 feet      |                       |
| Compensating works, Niagara and St. Clair Rivers | $3,800,000 |
| Channel excavation, Lake Erie to Lake Superior | 75,900,000 |
| Lock in St. Marys River | 6,500,000 |
| New Welland Ship Canal, in addition to present project | 14,100,000 |
| Total        | 100,300,000            |

The studies made by the board relating to lake levels and outflows and to works for their control will be given at length in Appendix B.

PART III

THE IMPROVEMENT OF THE ST. LAWRENCE RIVER

106. This part of the report sets forth the plans presented by the board for the improvement of the St. Lawrence River for navigation and power between Lake Ontario and Montreal Harbor.

DESCRIPTION

107. For convenience of reference, the board will use the following names to designate the five sections into which this part of the river naturally divides itself. In order downstream these are:

The Thousand Islands section (fifth division of the report of 1921), embracing the deep, lake-like reaches of the river, 67 miles in length, from Lake Ontario to the first swift water at Chimney Point, 3 miles downstream from Ogdensburg, N. Y., and Prescott, Ontario.

The International Rapids section (fourth division of the report of 1921), embracing the 48 miles of rapids and swift water between Chimney Point and the head of Lake St. Francis.
The Lake St. Francis section (third division of the report of 1921), extending 26 miles through that lake to the end of deep water at its foot.

The Soulanges section (second division of the report of 1921), embracing the 18 miles of rapids and shoal water from Lake St. Francis to Lake St. Louis.

The Lachine section (first division of the report of 1921), embracing Lake St. Louis and the rapids and shoals from this lake to Montreal Harbor, a length of 23 miles.

108. The first two sections lie along the international boundary, between the Province of Ontario and the State of New York. The remaining three lie in the Province of Quebec. The improvement of the Thousand Islands section and of the Lake St. Francis section is solely a question of excavating channels for navigation. The other three sections can be improved for power in addition to navigation.

General Features of Plans

Navigation

109. Fundamental principles.—The plans have been prepared in accordance with the recognized principle that the interests of navigation on the St. Lawrence are paramount. A full observance of this principle does not interfere with the beneficial use of the flow of the river for power generation. On the contrary, the improvement of the rapid sections of the river for the joint benefit of navigation and power affords, as a rule, much better navigation than could be secured by the improvement now economically justifiable in the interest of navigation alone.

110. In accordance with its instructions, the schemes presented by the board are designed to provide to the best advantage, at this time and ultimately, for the development of the capacities and possibilities of the waterway. The magnitude of the interests in the two countries that would be affected by the improvements if the project be adopted have been fully considered. The board has visualized the fullest ultimate development of the navigable capacity of the waterway commensurate with cost. The endeavor has been made to provide the maximum amount of open-river navigation with a minimum of locks and of canal navigation. For the initial improvement it has adopted the minimum standards hereinafter set forth, but the plans are so drawn that the navigation improvements can be enlarged at the least economic loss as the traffic justifies further improvement. Plans that would restrict the best eventual development of the waterway for navigation have therefore been discarded.

111. Channel depth.—Conforming to the tenor of the instructions, the estimates are based on navigation channels 25 feet in depth. The sills of all locks and fixed structures are placed at 30 feet depth to permit of the future enlargement of the waterway. The board has given careful consideration to the question whether it would be advantageous to provide initially for a channel depth other than 25 feet (question 9 of instructions). A majority of the Canadian section favor the initial excavation to a depth of 27 feet. This is the depth to which the new Welland Ship Canal is being carried under the
present contracts and to which the sections of the canal previously excavated can be enlarged at relatively small cost. A majority of the United States section regard the depth of 25 feet as sufficient initially, in the view that a project for a greater depth through the interlake channels above Lake Erie is not foreseen for a long period. To afford full information on which to base the determination of this broad question of economic policy, the board presents in the summaries at the end of this part of the report the estimates of the additional cost of excavating the channels initially to 27 feet, of the saving effected with an initial depth of 23 feet, and of the cost of subsequently enlarging the channel from 25 feet to 30 feet. Estimates for channels 23 feet deep are included, since such channels would accommodate comfortably all shipping that can use the existing interlake channels above Lake Erie. The designs herein presented and the alignment of the channels are not affected by the depth to which the channels are excavated initially.

112. To remove any confusion between the depth of the channels and the draft of the vessels which can use them, the board points out that channels 25 feet in depth are suitable for safe and convenient navigation by vessels of not to exceed 23 feet salt-water draft and channels 27 feet in depth by vessels of 25 feet salt-water draft. For vessels of this size fresh-water draft exceeds salt-water draft by from 6 to 7 inches.

113. The board recommends and has adopted the following standards for navigation improvements:

Channels for navigation have a minimum width of 450 feet, except in canal sections, where they have a bottom width of 200 feet (at 25-foot depth). Open channels are widened where advisable on account of cross currents and at bends and are both widened and deepened as required to afford suitable current velocities for navigation. The minimum radius of curvature of the channels is 5,000 feet.

The locks conform in dimension with those in the new Welland Ship Canal, and have chambers 859 feet in length between inner quoin posts and 766 feet between breast wall and fender. The clear width of the locks is 80 feet and the depth over the sills 30 feet. Duplicate sets of gates are so provided that two gates may always be closed against the upper level. Fenders will afford an additional safety precaution, and guard gates or emergency dams are provided when necessary to afford a means for stopping the flow that would result from the accidental destruction of any lock gates. The plans are so drawn that all locks can be duplicated as commerce requires additional facilities, and the estimates include the foundations for duplicating all flight locks, since these have less ultimate traffic capacity than single locks.

114. Capacity of waterway.—The 25-foot waterway as designed has an estimated traffic capacity of 24,000,000 tons per annum after any flight locks included in the adopted plans have been duplicated. Flight locks are included in alternative plans for the improvement of the Soulanges section only. With these alternative plans the initial capacity of the waterway would be 16,000,000 tons per annum until the duplicate locks of the flight were completed, after which the traffic capacity would be 24,000,000 tons, established by the capacity of the separate lock of the system having the highest lift.
115. *Power installations.*—The plans provide for an initial construction of power plants based on conservative estimates of the rate at which power can be marketed under restrictions as to exportation. The demand for power the world over is growing rapidly and the great potential power of the St. Lawrence River may well become an important factor in the economic welfare of the two countries. The board has therefore drawn its plans with especial view to the eventual utilization of the complete power resources of the river.

116. The various power houses have the capacity for the development of the maximum flow which the board considers as utilizable in the future. The interests of navigation require that the flow down the St. Lawrence be maintained at a high degree of uniformity and prevent the maximum use of water for power by fluctuating the hourly flow to meet the fluctuating power demand. An installed capacity well in excess of the minimum flow of the river has been provided, however, since the increasing value of power will justify its eventual development from the flow available during high-water periods only.

117. The ultimate installation proposed by the board in the International Rapids section is somewhat less than the installation proposed by some of the applicants for authority to develop power in this section. The excess installed capacity provided in the plans of these applicants would afford little return on account of the limits inherent in the regulation of flow required in the interests of navigation and of power downstream.

118. The initial installation of power machinery in each powerhouse will depend on the market available when the works are put in operation. For purposes of estimating the initial expenditures required, the initial installation is taken at 50 per cent of the eventual capacity of the power houses first constructed.

119. *Winter power operation.*—A full study has been given to the winter operation of power plants. The fundamental problem is found to be the maintenance of the winter discharge capacity of the river without excessive loss of head from gorging with ice, rather than the local problems of handling the ice at the power plants themselves.

120. The power sections of the river now have so rapid a current that (with an exception elsewhere noted in this report) they always run open throughout the winter. From the time that the water reaches the freezing point, in late December or early January, until the end of winter these exposed reaches are continuously losing heat and making ice in the form of frazil and anchor ice. Frazil is the term applied to the particles of ice forming in water where the current prevents the formation of a surface ice sheet. These particles agglomerate in pans of soft, snow-like ice, which float down the surface of the river. Anchor ice is the ice forming on the bed of the river, due to the loss of heat by radiation. It rises to the surface when loosened by the heat of the sun, and floats downstream in masses resembling frazil ice. The term “slush ice” is often applied to both. The masses of slush ice are carried down by the current and pack under and against the ice sheet formed over the quiet water at the foot of the reach, gorging the channels to such extent that
rises in the water level of from 10 to 30 feet occur in winter at the foot of each open section.

121. The construction of a dam in any of the power sections for the dual purpose of concentrating head for power development and of improving the river for navigation will, in the general case, create a deep slow-flowing pool, certain to freeze over early in the winter. The situation to be guarded against is the throttling of the river by the gorging of the channel at the upper end of this frozen pool. It is established by the board from measurements of the loss of heat from the river, confirmed by measurements of the ice actually formed, that, with the temperatures obtaining in the region, from 15 to 20 cubic feet of ice will be made in the course of a severe winter for every square foot of open water. It is found, however, that in all cases where the current velocity is as low as 2.25 feet per second the frazil and anchor ice consolidates on the surface when it meets an ice sheet, and extends this sheet upstream without the excessive gorging and throttling of the river that occur at higher current velocities. The plans for power development are therefore based on enlarging the upper reaches of the power sections by excavation where necessary to insure, with the discharges that must be maintained in winter, current velocities not exceeding 2.25 feet per second, except through short distances at the upper ends of the power reaches where the remaining area of open water could not produce enough ice to be of serious consequence. Such ice as may be formed in these short distances would be stowed in near-by enlargements of the river below.

With an ice sheet extending down to the intakes of the power houses, the operation of the power plants will be nearly, if not entirely, free from ice difficulties.

122. Modification of plans during construction.—In such an extensive project as that for the improvement of the St. Lawrence it is not possible, even in the time consumed by the board in its investigations, to arrive at the best possible design of all features of the project, both for navigation and for power. The estimates are based on safe and adequate structures and channels, but it is expected that the responsible authorities in charge of the construction will exercise the usual latitude in making such alterations as are found to be desirable in consequence of more detailed studies and the development of the art.

123. Datum plane used in report.—All elevations in this report are elevations above mean sea level. The precise reference planes used are described in Appendix C.

THOUSAND ISLANDS SECTION

[Fifth division of report of 1921]

124. This section, 67 miles in length, extends from Tibbetts Point, taken as marking the end of Lake Ontario, to Chimney Point, 3 miles downstream from the towns of Ogdensburg, N. Y., and Prescott, Ontario. The river is generally broad, deep, and slow flowing, with a total fall at mean stage of but about 1 foot. Between Clayton, N. Y. (mile 20), and Brockville, Ontario (mile 52), a number of granite reefs endanger navigation, and the narrow, deep channels through the Thousand Islands and the Brockville group require some straightening for safe and convenient navigation by deep-draft vessels.
The improvement proposed is the removal of 12 reefs and the cutting back of four projecting points, all to a depth of 25 feet below a datum plane corresponding to elevation 242.5 on Lake Ontario. The cost, determined from a detailed survey made by the present board, is $1,100,000. Details of the estimate are given in Appendix C.

125. The work recommended follows the same lines as that proposed in the report of 1921, but the estimated cost is greatly increased on account of the more accurate data secured since that report.

INTERNATIONAL RAPIDS SECTION

[Fourth division of report of 1921]

126. Description.—This section extends from Chimney Point (mile 67) to Colquhoun Island (mile 115), opposite St. Regis, at the head of Lake St. Francis, a distance of 48 miles. The river head runs in a succession of rapids, beginning with the Galop Rapids, near the head of the section, and ending with the Long Sault Rapids (miles 103 to 104), with the Rapide Plat, just above Morrisburg, about midway between. Swift currents predominate in the reaches between the rapids and extend to the middle of Cornwall Island (mile 111). The total fall through the section at mean river stage is 92 feet, of which approximately one-third occurs in the first 18 miles above the foot of the Rapide Plat, at Ogden Island, and the remaining two-thirds below that point. The present 14-foot navigation on the river is carried around the rapids by a series of side canals along the Canadian shore.

127. Prior plans.—The improvement proposed in the report of 1921 was the construction of a dam in the Long Sault Rapids which would raise the water level to elevation 231, creating a pool reaching into the Rapide Plat at Ogden Island. At Ogden Island a second dam with a lock was to be constructed, which with suitable channel enlargements would carry navigation through the upper part of the section. A canal along the Canadian shore 8 miles in length with two locks was to carry navigation from the pool formed by the lower dam back to the river at the town of Cornwall. The plan included the development of power at a Canadian and an American power house located at the foot of Barnhart Island, with a head of 74 feet and a total installed capacity of 1,777,360 horsepower. In addition, a second power plant with a capacity of approximately 60,000 horsepower, located near the head of Long Sault Island, was to develop the surplus head of 29 feet created in the diversion which feeds the power plant of the St. Lawrence River Power Co. at Massena, N. Y. The head available at the upper dam at Ogden Island, amounting to about 8 feet during the ice-free months, was not to be developed for power. It was estimated that most of this head would be absorbed in winter by the increased river slope due to ice conditions. The structures creating the lower pool were, however, to be so designed that the pool level could be raised to recover a part or all of the head lost at the Ogden Island Dam, if desired at a future time.

128. Plans proposed.—The present board concurs in the opinion that the improvement of the International Rapids section should include the development of power. Its length is such that a side canal for navigation would be extremely costly and would impose an unnecessary hindrance to shipping.
129. The board has given extended study to various plans for improving the river for power and navigation, including those presented by the Hydroelectric Commission of Ontario and others to the International Joint Commission in 1921 and those recently submitted by American corporations to the Water Power Commission of the State of New York.

130. The board is of the opinion that the plan presented in the report of 1921, although in a general sense practicable, should be modified to secure more dependable winter operation and to assure the fullest practicable utilization of power resources of the river.

131. Two plans meeting these requirements have been prepared by the board, one for a single-stage development, with a dam and power houses in the vicinity of Barnhart Island, at the foot of the reach, but with control gates at Galop Island at the head of the reach, except across the channel provided for navigation. The second scheme is for a two-stage development, with two pools, the upper pool formed by a dam and power house at Ogden Island, just above Morrisburg, and the lower pool (at normal elevation 224) by a dam and power houses at Barnhart Island.

132. With the single-stage development, navigation enters the pool through a free channel from the upper river and passes from the lower end of the pool through a canal, with two locks, on the United States side of the river which leads to the south channel at Cornwall Island, thence a free channel leads to Lake St. Francis. With the two-stage development navigation similarly enters the upper pool through a free channel, passes from the upper to the lower pool through a lock at Ogden Island, and from the lower pool to the south channel at Cornwall Island by a canal with two locks as in the single-stage scheme. The two-stage scheme requires one more lock than the single stage.

133. The levels of the pool of the single-stage development during the ice-free months, after the full estimated channel enlargements have been made, will vary normally between the limits of elevations 240 and 244, depending on the level of Lake Ontario and the flow of water as determined by the program of regulation. The tail-water elevation will be about elevation 157. Further channel enlargement below the power houses may lower the tail-water somewhat and add to the head, but the increased power made available is not considered in this report. The normal summer head at the power houses of the single-stage development will therefore be about 85 feet. The increased slope of the pool in winter due to ice retardation is expected to amount to about 6 feet and a rise of about 4 feet in the tail-water elevations is anticipated from the increased slopes below the power house, so that the net winter head expected is about 75 feet.

134. With the two-stage development the lower pool will be kept closely to elevation 224 both summer and winter, giving a summer head of 67 feet and a winter head of 63 feet. The summer levels of the upper pool at the Ogden Island power houses will range between elevations 241 and 245. On account of the slopes of the lower pool, the summer head at the Ogden Island power houses

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1 The plans provide for partly closing the navigable channel by control gates, leaving a free opening for navigation at least 450 feet in width.
will be about 17 feet. A winter head of 12 feet is expected. The plans and estimates provide for the utilization of a head of 21 feet temporarily during the period between the completion of the upper and lower plants, respectively.

135. The maximum flow which the board regards as eventually utilizable at the Barnhart Island power houses is 245,000 cubic feet per second at winter head. The equivalent capacity at summer head in the single-stage development will be 261,000 cubic feet per second and in the two-stage development 252,000 cubic feet per second. The utilization of such large flows will not be economically justified at the Ogden Island power houses of the two-stage development, and the ultimate installation at these power houses is based on a flow of 212,000 cubic feet per second at winter head, equivalent to 240,000 cubic feet per second at summer head. The installed capacity of the power houses of the single-stage development, based on the summer head and flow, and, including spares, is 2,326,000 horsepower. The installed capacity of the two-stage development on the same basis is as follows:

| Horsepower | Lower power house, Barnhart Island | 1,808,600 |
| Horsepower | Upper power house, Ogden Island | 406,400 |
| Total | 2,215,000 |

136. The fact must be appreciated that the additional capacity proposed in the single-stage development is not a measure of power which can be delivered. Except for the slightly less efficiency of the machinery of the Ogden Island power houses, which would not materially affect the total, the power that can be delivered depends on the flow of water available, which will be less than the installed capacity of the plants for a considerable part of the time.

137. As for winter operation, the pool formed by the single-stage development is so wide and deep as far upstream as Ogden Island that an ice cover will form over it promptly. The plans and estimates provide for the eventual enlargement of the constricted portions of the river from Ogden Island as far upstream as Lotus Island (at the foot of the Galop Rapids) to the extent necessary to secure current velocities not exceeding 2.25 feet per second in order to assure satisfactory ice conditions in winter. The contracted section from the foot of Lotus Island to the head of Galop Island, 2.5 miles in length, is to be given the area required for satisfactory navigation only and is expected to have an open channel in winter, but the extent of this open water would be too limited to be of serious consequence in winter operation.

138. The amount of channel enlargement required to assure satisfactory winter operation can not be predicted in advance with certainty. It is proposed to execute initially only such enlargement as is necessary to insure satisfactory navigation conditions and to prosecute this enlargement after the pool has been created, when dredging can be done more advantageously, until satisfactory winter operation is secured. The control of the head through the section afforded by the control gates at the Galop will afford a means for insuring the winter discharge capacity of the river during this period.

139. In the two-stage development some enlargement of the channels in the 8-mile reach between Ogden Island and Weavers Point
is required to secure the desired low current velocities to assure winter operation. Above Ogden Island the enlargement required will be identical with that required in the single-stage development. This enlargement must be completed before the complete scheme is put in operation in order to insure control of the winter flow and provide uninterrupted power at the Ogden Island plant.

140. It is assumed that proper control will be exercised over the ferries operating between Ogdensburg and Prescott to prevent the ice situation from being aggravated by the breaking up of the ice sheet between these towns and Galop Island by these agencies.

141. The cost of the single-stage development, including the full channel enlargement to insure satisfactory winter operation, is estimated at $235,000,000. The cost of the two-stage development is estimated at $264,600,000.

142. The United States section of the board recommends the single-stage development as affording better navigation by eliminating one lock, and slightly more power, at a cost $29,600,000 less than the cost of a two-stage development.

143. The Canadian section of the board recommends the two-stage development on the ground that it can be carried out in two parts, so that the power from the upper development can be developed and marketed before the whole of the improvement is completed. It believes that for this reason its over-all cost, including interest charges, will not be as greatly in excess of the single-stage development as appears from the comparative costs without interest charges. It believes that the control over the flow of the river will be better assured. The flowage of land will be reduced from about 28,000 acres to about 18,000 acres.2

144. Whatever plan be adopted, there is a choice of sites for the dam and power houses in the vicinity of Barnhart Island that create the pool of the single-stage development, or the lower pool of the two-stage development. A suitable site for the dam exists at the foot of the Long Sault Rapids, on an arc extending from the head of Barnhart Island to the foot of Long Sault Island and thence to the United States shore. With a dam at this site, the channel between Barnhart and Sheek Islands would be utilized as a forebay channel to the power houses, which would be located at the foot of Barnhart Island. This general arrangement was contemplated in the report of 1921. For the 224 two-stage development it is proposed to supplement the capacity of this forebay channel by utilizing also the channel known as Bergen Lake, between Sheek Island and the Canadian shore. The low banks prevent the use of this channel for that purpose at the high levels of the single-stage development.

145. With the dam built at the foot of Long Sault Island, the navigation canal from the pool would leave the river at the middle of Long Sault Island. It would be 6.9 miles long.

146. The second site for the dam is across the main river at the foot of Barnhart Island. The foundation rock is here quite deep. With a dam at this site the navigation canal would leave the river at Robinsons Bay, and its length would be reduced to 2.9 miles. The power houses would be adjacent to the dam. Two alignments for

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2 The above acreages include all lands the purchase of which is contemplated in the estimates. The area of land actually inundated at maximum emergency levels, including the inundated portions of islands, will be 22,000 acres and 12,000 acres, respectively.
the dam and power houses at this location are shown on the plans, either of which is regarded as satisfactory.

147. The United States section prefers the location for the dam at the foot of Barnhart Island, since it reduces the length of the navigation canal, reduces the chance of local ice difficulties in winter (since the section of the pool above the power houses is ample to insure a firm ice cover), and simplifies operation through the juxtaposition of the dam and power houses. The Canadian section prefers the location at the foot of Long Sault Island on account of the higher rock foundations there found, which it believes will lessen construction difficulties. The choice between the two locations is regarded as a matter of detail, to be settled by the constructing agencies after the general type of development has been determined.

148. The plans for the single-stage development submitted with this report show the dam across the main river channel at the foot of Barnhart Island. Those for the two-stage development show it at the foot of Long Sault Island. In the opinion of the board either location can be used with either development.

149. Whether the single-stage or the two-stage development is finally selected as best meeting the joint interests of the two countries, the board points out that the use of water at the power houses and the operation of the sluice gates, which with the wheels control the flow of the river, should be under the control of an international board. That board should be clothed with full authority to take such measures as will insure the regularity of flow that is necessary in the interest of navigation in the lower river, and of the power houses downstream; and to insure such flows as will maintain the levels of Lake Ontario within proper limits, while preserving the volume of flow required to prevent injury to navigation at and below Montreal.

150. Alternative plans considered.—Of the various alternative plans for the improvement of the International Rapids section submitted to the International Joint Commission in 1921, the one requiring especial consideration at this time is that for navigation and power development proposed by the hydroelectric commission on Ontario and designated as "Scheme B." This provided for a two-stage development broadly on the same lines as those proposed by the Canadian section herein, except that the lower pool was to be held at elevation 210, or 14 feet below the elevation proposed in this report. At this low elevation a large amount of excavation would be required to secure suitable channels for navigation through the lower pool; and an enlargement to secure the low velocities regarded as necessary for satisfactory ice-covered winter operation would be excessively costly and was not contemplated by the proponents. On the other hand, the higher head at the Ogden Island power plants, amounting to about 30 feet, reduced materially the cost per horsepower of development of the upper head.

151. The operation of this scheme was based on maintaining an open channel through the river during the winter, and only such channel enlargements were proposed as would be necessary for navigation.

152. The cost, on estimates paralleling those herein presented for a single-stage and two-stage development, would be $254,000,000.

153. The studies of the board, and its investigations of power plants operating under similar climatic conditions, show conclusively
that it is neither feasible nor desirable to maintain an open channel through this section in winter when it is improved for power. Even with the present current velocities the ice has at various times caught across the river in the quieter reaches of the section, starting an ice pack which quickly attained large proportions and raised the river level by as much as 10 feet. The likelihood of the ice catching to form ice jams would be increased after the river has been improved, on account of the greatly reduced current velocities. It is certain that an open channel through this 35-mile stretch could not be maintained without ice breakers; and all experience shows that a reasonable number of ice breakers could not be depended upon to keep open continuously so long a channel under these conditions. If, however, an open channel were maintained by such means, the accumulation of ice below the power houses of the lower pool at Barnhart Island would raise the tail-water level at these power houses to such an extent that their output would be greatly curtailed.

154. Other alternative plans presented to the joint commission in 1921 were for two-stage developments with the upper dam at Cleray Island (6 miles downstream from the foot of Ogden Island) and at Cat Island (10 miles downstream from the foot of Ogden Island). The further borings made at the Cleray Island site show that the foundation conditions are not as good as were first supposed, and the proponents of the Cat Island dam site now prefer a full single-stage development broadly on the lines of that proposed by the United States section herein.

155. Improvement for navigation only.—The least expensive method developed for improving the river for navigation alone is through the construction of a side canal on the American shore from the Galop Rapids to Ogden Island. Navigation would there enter a pool, with water level at elevation 220, to be formed by a dam at the head of the Long Sault Rapids, and from this pool pass to the south channel of the river at Cornwall Island through a canal on the same line as that proposed for the two-stage development. The navigation provided by such a plan would be far inferior to that provided by either the single or the two-stage developments, respectively, proposed. The estimated cost is $79,000,000.

156. Summary.—Two alternative schemes for the improvement of the international rapids section in the joint interest of navigation and power are presented by the board as best providing for the development of the capacity and possibilities of this section.

Their respective estimated costs are as follows:

(1) Single-stage development:
- Works solely for navigation ........................................ $22,000,000
- Works common to navigation and power .................. 106,500,000
- Works primarily for power—
  - Substructures and head and tail race excavation ...... 42,000,000
  - Superstructures and machinery ....................... 64,500,000
- Total cost (2,326,000 installed horsepower) .............. 235,000,000

Initial cost with installation of 1,163,000 horsepower (remaining installation deferred awaiting growth of market) ... 203,000,000
Estimated initial expenditure to open navigation and provide 1,163,000 installed horsepower before channels are enlarged to insure winter operation (see par. 137, 138) .... 190,000,000
Two-stage development:

**Upper pool—**
- Works solely for navigation: $8,093,000
- Works common to navigation and power: 53,726,000
- Works primarily for power:
  - Substructures, head and tail race excavation: 23,737,000
  - Machinery and superstructure: 33,829,000

**Lower pool—**
- Works solely for navigation: 25,388,000
- Works common to navigation and power: 37,130,000
- Works primarily for power:
  - Substructures, head and tail race excavation: 36,866,000
  - Machinery and superstructures: 45,777,000

Total cost (2,215,000 installed horsepower): $119,385,000

**LAKE ST. FRANCIS SECTION**

157. This section extends from Colquhoun Island opposite St. Regis (mile 115) to deep water at the foot of Lake St. Francis (mile 141). The currents through the lake are sluggish, and the total fall through the section is about 1 foot. While the lake contains many shoals, deep channels extend through it. The work proposed is the dredging necessary to secure a suitable channel. It is on substantially the same lines as was recommended in the report of 1921. The estimated cost, for a channel 25 feet deep below a datum plane having an elevation 151.5 at the head of the lake and 150.5 at its foot, is $980,000. The estimates differ by a small amount from those shown in the report of 1921, principally because the limits of the section are slightly changed to conform to the modifications of the project in the international rapids section.

**SOULANGES SECTION**

158. Description.—This section, 18 miles in length, extends from deep water in Lake St. Francis (mile 141) to deep water in Lake St. Louis (mile 159). The river falls from Lake St. Francis to Lake St. Louis in a succession of rapids, the Coteau Rapids at the head, the Split Rock and Cascades Rapids at the foot, and the Cedars
Rapids about midway. The total fall through the section at present mean stages of the two lakes is 83 feet.

159. Present 14-foot navigation passes through the Soulanges Canal, paralleling the river on the north.

160. There are a number of existing power developments in this section, which are described in Appendix C. The most important is that at the Cedars Rapids where a third of the low-water flow of the river is diverted through a headrace canal to a power house with an installed capacity of 197,000 horsepower, at 32-foot head.

161. Prior plans.—The improvement proposed in the report of 1921 was a lateral canal, 15 miles in length, for navigation only, on the south side of the river, designated as the Melocheville-Hungry Bay route. The report outlines a plan for navigation in conjunction with complete development of power, but contains the opinion that the rate of growth of the market for the large block of 1,560,000 horsepower afforded by the development was insufficient to justify its adoption.

162. Improvement for navigation and power.—The board finds that it is practicable and advantageous to combine the improvement for navigation in this section with the development of power on a progressive program of construction of power plants; only the first part of the power development being undertaken in conjunction with the works required to carry navigation through the section.

163. In brief, this plan provides for a dam at the head of the Cedars Rapids, which will create a pool having a level from $1 \frac{1}{2}$ to 5 feet below the level of Lake St. Francis. The shores of that lake are so low that the raising of its high-water levels would destroy large areas of agricultural land and, aside from the large cost involved, is highly undesirable. The plans therefore include an extensive enlargement of the discharge capacity of the Coteau Rapids to insure that the backwater slope will not raise the high levels of the lake. Navigation passes from Lake St. Francis to the pool by a canal around the Coteau Rapids, 3 miles in length with a low lift lock. Even with the enlargement proposed the currents in these rapids will be too swift for safe navigation, and especially for safe passage through the draw in the railroad bridge which here crosses the river. The canal has, however, been given such an alignment that it can be converted into an open channel when the traffic justifies the large additional cost. A second canal, 5 miles in length, with two lift locks, carries navigation from the pool to Lake St. Louis. These locks may be either in flight or separated by a short pool. The difference in cost in favor of the separate locks is small.

164. The first part of the power development is the generation of a total of 382,000 horsepower at a power house with 22-foot head incorporated in the dam. The present Cedars plant will be continued in operation, water being fed into the headrace through sluice gates.

165. The second part of the progressive development now envisaged is the installation of 500,000 horsepower at 75-foot head at a power house located on the shore of Lake St. Louis north of Cascades Point, and near the Chamberry Gully. It will be supplied through a headrace canal formed in part by the enlargement of the navigation canal.
166. The third part is the construction of a dam and power house with a 53-foot head, at the Cascades Rapids, at the foot of the section, which will develop a total of 974,000 horsepower. The present Cedars plant will then be put out of commission.

167. The estimated cost of these works is as follows:

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>First part, including navigation works</td>
<td>$103,945,000</td>
</tr>
<tr>
<td>Second part</td>
<td>$37,291,000</td>
</tr>
<tr>
<td>Third part</td>
<td>$63,816,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$205,052,000</strong></td>
</tr>
</tbody>
</table>

168. The installed capacities in these plants, including spares, at normal summer heads are:

<table>
<thead>
<tr>
<th>Part</th>
<th>Horsepower</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>404,300</td>
</tr>
<tr>
<td>Second</td>
<td>545,000</td>
</tr>
<tr>
<td>Third</td>
<td>1,030,400</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,979,700</strong></td>
</tr>
</tbody>
</table>

169. If but one-half of the hydroelectric machinery is installed when the first part of the program is initially constructed, leaving the other half to be installed as the demand for power develops, the initial expenditure required to open navigation and provide 202,000 horsepower becomes $92,000,000.

170. **Complete river development.**—An alternative scheme which affords the maximum open river navigation warrants description. In this scheme two dams with power houses would be constructed initially, the upstream dam substantially on the line of the dam proposed in the first part of the recommended scheme, and the second dam and power houses at the Cascades Rapids at the site of the structures forming the third part of the progressive power development therein contemplated. Navigation would pass from Lake St. Francis to the pool formed by the upstream dam as in the recommended scheme. From this pool it would pass through a short canal and lock to the pool formed by the Cascades dam and power houses, thence through a lock directly to Lake St. Louis. The 5-mile canal provided in the recommended scheme between the upper pool and Lake St. Louis thereby would be eliminated.

171. The pool of the Cascades Dam would be held at elevation 115, giving a 43-foot head between this pool and Lake St. Louis, instead of the 53-foot head contemplated in the third part of the recommended project. This change would reduce the difference of levels to a conservative lift for a single lock. The power houses at the upstream dam would be so located as to develop the remaining 30 feet of head available in the section.

172. The scheme would entail the reconstruction of the existing Cedars power plant as a part of the initial work instead of permitting a postponement until the last part of the power development program. Arrangement would have to be made to supply the present customers during the reconstruction period.

173. The total cost of this alternative scheme, with a complete eventual installed capacity of 1,948,000 horsepower, would be $194,317,000 exclusive of interest charges, or approximately $10,700,000 less than the cost with the plans recommended. On the other hand, the initial expenditure would exceed largely the initial expenditure required with the recommended plan. The initial
power installation must include, in addition to such new power as is provided, an installation of 207,000 horsepower to replace power lost at existing plants, this being 197,000 horsepower at the present Cedars plant, and 10,000 at other plants. The initial expenditure required to open navigation and to provide an installation of 404,300 horsepower of new power, together with this replacement of power at existing installations, would be $123,400,000, against the minimum initial expenditure of $103,945,000 required with the same installation of new power under the recommended plan. Unless power can be sold more rapidly than the board is led to believe, the interest charges on the $19,455,000 increased initial cost would overbalance the $10,700,000 difference between the ultimate costs of the completed projects indicated by the foregoing estimates. The scheme makes a maximum use of the river and merits serious consideration if a market for the large amount of power can be developed within a reasonable period.

174. Improvement for navigation alone.—The schemes studied by the board for providing navigation alone are:

(a) A lateral canal on the south side of the river extending from Hungry Bay to Melocheville, substantially as recommended in the report of 1921. Its estimated cost is now $33,640,000.

(b) A lateral canal on the north side of the river, so designed as to conform to an eventual combined improvement of the river for navigation and power on the lines recommended by the board. Essentially, this scheme embraces the construction of the upper and lower lateral canals proposed in the combined improvement, with a land canal connecting them, the latter to be abandoned when the river is improved for power. The estimated cost of the canal complete is $40,378,000.

The part of the land canal that would be abandoned for navigation would be used in part for drainage. Its estimated cost is $6,382,000. The estimated cost of the river connections is $1,922,000.

(c) A river improvement as proposed in the recommended scheme, with substructures for power plant, but without power installation. Its estimated cost is $78,515,000.

175. Conclusions.—The board unites in the view that the navigation improvement combined with the progressive development of power (pars. 162 to 169) hereinbefore set forth better provides for the present and future development of the waterway than any scheme for navigation alone, and is therefore the desirable scheme, if arrangements are made whereby power interests bear a fair proportion of the cost of the initial expenditure required.

176. If it be found impossible to arrange for such cooperation in meeting the initial cost, a majority of the Canadian section favor the construction of the lateral canal on the south side of the river (Melocheville-Hungry Bay project), which is the least expensive means for providing navigation. The United States section submits the view that a route designed to serve so large a territory will demand eventually the freer navigation of an open river. It believes, therefore, that even if arrangements can not be made for the participation of power development in the initial improvement, it will be better to adopt the river development (navigation scheme C) or a canal on the north side capable of conversion into a river development (navigation scheme B) rather than the Melocheville-Hungry Bay route,
the investment in which would largely be lost when a river development is adopted.

177. A detailed description of the works proposed in the combined navigation and power project recommended, including those necessary to prevent undue flowage, with detailed estimates of cost, and a discussion of alternative schemes and their relative economic values at various rates of power consumption, are given in Appendix C. A general analysis of the estimated cost of the initial part of the recommended combined navigation and power project is as follows:

| Works solely for navigation | $31,594,000 |
| Works common to navigation and power | $34,686,000 |
| Substructures, and head and tail race excavation | $13,079,000 |
| Superstructure and machinery | $24,586,000 |
| Total | $103,945,000 |
| Cost with initial installation of one-half of power machinery | $92,000,000 |

**LACHINE SECTION**

178. Description.—This section extends from deep water at the head of Lake St. Louis (mile 159) to Montreal Harbor (mile 183). The first 11 miles are through the deep water in the upper part of the lake; the next 4 miles are through the shoal water at its foot. From the foot of the lake, the river runs 5 miles with swift currents, through a channel badly obstructed with rock reefs, to the Lachine Rapids. It drops through these rapids to the La Prairie Basin, a wide expanse of shoal water, 5 miles in length; thence falls through a mile of shoal, swift-running channels, to Montreal Harbor. The total fall through the section is about 48 feet, of which 9 feet is between the upper end of Lake St. Louis and the head of the Lachine Rapids, 24 feet through these rapids, 4 feet through the La Prairie Basin, and 11 feet between the La Prairie Basin and Montreal.

179. The course of the river from Lake St. Louis to Montreal Harbor describes a wide bend to the south. The present 14-foot navigation passes through the Lachine Canal, which cuts through the city across this bend.

180. In this section the St. Lawrence begins to receive water from the Ottawa River. The Ottawa discharges into the Lake of Two Mountains, which lies just north of Lake St. Louis, and is at a slightly higher level. That lake discharges a part of the flow through two outlets into Lake St. Louis and the remainder into the St. Lawrence below Montreal, through two rivers lying to the north of the city. On account of the widely varying flow of the Ottawa, the range in the levels of Lake St. Louis is about 8 feet.

181. The winter rise of the river due to the ice gorging raises the water in the La Prairie Basin by 10 feet or more.

182. Prior plans.—The improvement proposed for this section in the report of 1921 was a side canal, 9 miles in length (10 miles to the end of the Lachine breakwater), with two lift locks and one guard lock, extending from the upper entrance to the present Lachine Canal across the bend in the river to a point on the shore 3 miles above Montreal Harbor (avoiding the built-up portion of the city), thence
along the shore to the harbor. The eventual increase in depth from the 25 feet provided in that report to 30 feet was to be secured by a dam in the Lachine Rapids, which would raise the low-water levels of Lake St. Louis and the upper canal level by 5 feet. The report considered, but did not recommend, an alternative project for combining navigation and power by constructing a dam and power works in the Lachine Rapids.

183. Plan recommended by board.—The board has examined with care the feasibility of utilizing the contracted section of the river above the Lachine Rapids for navigation, in connection with power development at these rapids, but finds that, without an excessive amount of costly excavation, the currents created by the concentration of the flow in the excavated channels would be excessive for navigation, even if the railroad bridge which here crosses the river were raised, at large cost, to provide overhead clearance. A side canal affords, therefore, the most suitable route for navigation between Montreal Harbor and Lake St. Louis.

184. The westward growth of the built-up sections of the city of Montreal has already encroached on a part of the route selected for the canal in the report of 1921. It is highly advisable to build the canal on a location that will not interfere with the future growth of the city and will eliminate the difficult problem inherent to the crossing of land and water traffic with the consequent inconvenience and delay to both. The route now proposed, therefore, follows close to the river bank throughout and consequently cuts off no area capable of urban development. Its length and its cost are substantially the same as on the route recommended in the report of 1921. The canal has three lift locks and a guard gate, instead of the two lift locks and the guard lock proposed in that report. But 4 miles are in land cut with minimum section. The remaining 6 miles (counting the length to the end of the Lachine Breakwater) have a minimum width of 300 feet. The additional lock assures the minimum alterations in sewerage and water supply systems, including the Montreal Aqueduct. When the project is adopted, details can be modified to conform to any projected changes in these public utilities.

185. The excavation of the upper level of the canal, and through the long shoals at the foot of Lake St. Louis, can be reduced by the construction of a control dam in the river at the head of the Lachine Rapids, above Heron Island, to raise the low-water levels of Lake St. Louis to elevation 71 during the navigation season. Since at low stages this would back the water up into the Lake of Two Mountains and slightly raise also the low-water levels of the latter, it is necessary to construct supplementary control works at the two northerly outlets of that lake (Mille Isles and des Prairies Rivers) in order to preserve the present distribution of the flow of the Ottawa and to prevent a reduction in the flow in the main channel of the St. Lawrence past Montreal. The cost of the entire system of control works is about $2,000,000 in excess of the saving in excavation costs; but these works will reduce the cost of a future development of power at the Lachine Rapids, besides being of benefit to local navigation on the two lakes. Their construction is therefore desirable, and is included in the plans of the initial improvement for navigation.

A detailed description of the improvement proposed is given in Appendix C. Its complete cost is estimated at $53,000,000.
186. **Power development.**—The board concurs in the views expressed in the report of 1921 that the feasible power production in this section is limited to the development of the head of a little more than 30 feet available above the foot of the Lachine Rapids. The winter rises of the river drown out the remaining head, and the upper level of a power development can not be carried below the foot of these rapids without causing widespread flood damage.

187. To assure the safe and dependable winter operation of a power development at the Lachine Rapids, the discharge capacity of the contracted reaches above these rapids should be so enlarged that the maximum winter current velocities will not create ice gorging. The alternative of a development based on maintaining an open channel through the river in winter is rejected as hazardous for the same reasons that such a proposal is rejected in the International Rapids section (par. 153).

188. The most feasible method of enlarging the discharge capacity of the river is found to be the construction of a deep, concrete-lined headrace canal on the south side of the river. The plans for improving the river for power provide, therefore, for a development in two parts. The first part is the construction of such a power canal along the south shore, from the foot of Lake St. Louis to the Lachine Rapids, designed to carry a flow of 120,000 cubic feet per second at so high a velocity that an ice cover can not catch across to form an ice jam. The water would be delivered to a power house on the south shore at the foot of the rapids, discharging into the La Prairie Basin, which would develop 391,000 horsepower.

189. A control dam in the river, with auxiliary structures at the outlets of the Lake of Two Mountains, is required with the first part of the development, to prevent the lowering of Lake St. Louis by the large diversion, and to secure the maximum allowable head at the power house. The main control dam in the river would be at the head of the Lachine Rapids, at the same location as the dam hereinbefore proposed to regulate the levels of Lake St. Louis for the benefit of navigation, and the normal regulated level of the lake would be at elevation 71 in both cases. The auxiliary control structures would be identical. The main control dam would, however, require a different design. The dam proposed in connection with navigation improvement is designed with wide openings to be left clear in winter in order to prevent the danger of the formation of an ice jam. With the power canal in operation the currents in the main river would be so reduced as to eliminate the danger of an ice jam, but the openings must be reduced to such dimensions as will afford safe and convenient winter operation of the gates. A dam constructed initially for navigation purposes would therefore require alterations when the first part of the power development is undertaken. The cost of these alterations is estimated at $281,000.

190. The estimated cost of this first part of the development is $88,131,000 if no control dam has been built for navigation purposes, and $81,247,000 if such a dam has been built, the latter figure including the necessary modifications in the dam.

191. The second part of the improvement for power is the development of 422,000 horsepower from the remaining flow of the river, at a power house to be constructed in the main river at the
foot of the Lachine Rapids, adjacent to the power house constructed in the first part of the development. The headrace to this power house would be formed by a longitudinal wall extending downstream from the control dam previously constructed to the new power house, and by opening the portion of the control dam between this wall and the south shore. The estimated cost of the second part of the development is $41,966,000.

192. If the first part of the power development be undertaken simultaneously with the navigation improvement, the estimated combined cost would be $133,358,000.

193. If the first part of the power development be undertaken subsequently to the navigation improvement, requiring the alteration of the control dam initially constructed for the latter purpose, the combined cost would be $134,247,000.

194. The economic saving from combining power development with the improvement of the Lachine section for navigation is therefore but $889,000, and this saving would be soon counterbalanced by the interest charges on the large investment necessary to secure it, unless the power could be marketed promptly at remunerative rates. For this reason, and on account of the high cost of developing power in this section as compared with its cost in the Soulanges section, the board does not include power development in its plans for the initial improvement of this section. The development of power can be undertaken when found economically justifiable from the standpoint of power production alone.

195. In summary, the estimates for this section are as follows:

Recommended project for navigation alone $53,000,000

Power alone:
First part, 435,000 installed horsepower $88,131,000
Second part, 488,000 installed horsepower 41,406,000
Total, 923,000 installed horsepower 129,537,000

Power subsequent to navigation:
First part, 435,000 installed horsepower 81,247,000
Second part, 488,000 installed horsepower 41,966,000
Total, 923,000 installed horsepower 123,213,000

GENERAL SUMMARY

LAKE ONTARIO TO MONTREAL HARBOR

196. In summary, the plans recommended by the board for the improvement of the river will provide to the best advantage for a navigation route through the 183 miles of river and lake from Lake Ontario to Montreal Harbor, with a total not exceeding 25 miles of restricted canal navigation, and with not more than 9 locks. It will be crossed by but 8 bridges. The plans include power houses with
an ultimate installed capacity of from 2,619,000 to 2,730,000 horsepower, and permit the eventual development with installed capacity of approximately 5,000,000 horsepower, which is the full power potentiality of the river.

197. The estimated expenditures required to open navigation with channels 25 feet in depth, with an initial power development having one-half the ultimate installed capacity of the power houses first constructed (the installation of the remainder being deferred to await the growth of the market), is as follows:

1. Total cost of improvement if with a single-stage development in the international rapids section (1,365,000 horsepower initially installed) $350,100,000

2. Above improvement before channels are enlarged to insure winter operation 337,100,000

(2) Total cost of improvement if with a two-stage development in the international rapids section (1,365,000 horsepower initially installed) 385,500,000

(2b) Above improvement if the initial power installation in the international rapids section is all made at the lower (Barnhart Island) plants 361,600,000

198. After all of the machinery in plants recommended by the board has been installed, these costs will become, respectively:

1. If with a single-stage development of the international rapids section (2,730,000 installed horsepower) 839,400,000

2. If with a two-stage development of the international rapids section (2,619,000 installed horsepower) 423,600,000

199. The board has considered it advisable to present alternative plans and estimates in several instances for the reason that a choice between them rests on broad questions of policy rather than upon strictly engineering considerations.

200. The estimated cost of additional channel excavation required to provide channels initially 27 feet deep from Lake Ontario to Montreal instead of 25 feet deep is $5,800,000.

201. The estimated saving in the cost of channel excavation through providing channels initially 23 feet deep instead of 25 feet deep is $5,350,000.

202. The estimated cost of subsequently enlarging to 30 feet in depth channels initially excavated 25 feet in depth is $24,400,000.

203. The estimated cost of additional works required to complete the full practicable development of power in the river, with works having an installed capacity of 2,500,000 horsepower, is approximately $225,000,000. The total eventual power installation visualized is therefore approximately 5,000,000 horsepower; and the total eventual cost of developing this power, and of providing navigation with channels 25 feet in depth, is in round numbers from $620,000,000 to $650,000,000, depending upon the form of improvement adopted in the international rapids section.
A general analysis of these costs is shown in the following tables:

**Table I.—Recommended plans with single-stage development in international power section**

<table>
<thead>
<tr>
<th>Section</th>
<th>(a)</th>
<th>(b)</th>
<th>(c)</th>
<th>(d)</th>
<th>(e)</th>
<th>(f)</th>
<th>(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thousand Islands</td>
<td>$1,100,000</td>
<td>$106,500,000</td>
<td>$106,500,000</td>
<td>$1,100,000</td>
<td>$1,100,000</td>
<td>$1,100,000</td>
<td></td>
</tr>
<tr>
<td>International Rapids</td>
<td>22,000,000</td>
<td>33,481,000</td>
<td>140,209,000</td>
<td>264,546,000</td>
<td>$1,100,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lake St. Francis</td>
<td>980,000</td>
<td>37,665,000</td>
<td>169,945,000</td>
<td>303,600,000</td>
<td>404,300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soulanges</td>
<td>31,594,000</td>
<td>34,686,000</td>
<td>55,000,000</td>
<td>92,000,000</td>
<td>33,481,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lachine</td>
<td>53,000,000</td>
<td>53,000,000</td>
<td>53,000,000</td>
<td>53,000,000</td>
<td>53,000,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>120,155,000</td>
<td>177,874,000</td>
<td>225,542,000</td>
<td>423,571,000</td>
<td>2,619,300</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Including $13,000,000 for channel enlargement to assure winter operation.

**Table II.—Recommended plans with two-stage development in international power section**

<table>
<thead>
<tr>
<th>Section</th>
<th>(a)</th>
<th>(b)</th>
<th>(c)</th>
<th>(d)</th>
<th>(e)</th>
<th>(f)</th>
<th>(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thousand Islands</td>
<td>$1,100,000</td>
<td>$140,209,000</td>
<td>$106,500,000</td>
<td>$1,100,000</td>
<td>$1,100,000</td>
<td>$1,100,000</td>
<td></td>
</tr>
<tr>
<td>International Rapids</td>
<td>33,481,000</td>
<td>37,665,000</td>
<td>169,945,000</td>
<td>264,546,000</td>
<td>2,215,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lake St. Francis</td>
<td>980,000</td>
<td>34,686,000</td>
<td>55,000,000</td>
<td>92,000,000</td>
<td>404,300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soulanges</td>
<td>31,594,000</td>
<td>34,686,000</td>
<td>55,000,000</td>
<td>92,000,000</td>
<td>404,300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lachine</td>
<td>53,000,000</td>
<td>53,000,000</td>
<td>53,000,000</td>
<td>53,000,000</td>
<td>53,000,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>120,155,000</td>
<td>177,874,000</td>
<td>225,542,000</td>
<td>423,571,000</td>
<td>2,619,300</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 This becomes $214,500,000 if installation is at Barnhart Island power houses.
2 This becomes $361,580,000 if initial installation in International Rapids section is at Barnhart Island power houses.

**Table III.—Estimated cost of additional works to complete the full practicable development of power in the river**

<table>
<thead>
<tr>
<th>Section</th>
<th>Installed horse-power</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soulanges section:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second part</td>
<td>545,000</td>
<td>$37,391,000</td>
</tr>
<tr>
<td>Third part</td>
<td>1,030,000</td>
<td>68,816,000</td>
</tr>
<tr>
<td>Lachine section:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First part</td>
<td>435,000</td>
<td>$8,247,000</td>
</tr>
<tr>
<td>Second part</td>
<td>488,000</td>
<td>41,906,000</td>
</tr>
<tr>
<td>Total</td>
<td>2,498,000</td>
<td>224,420,000</td>
</tr>
</tbody>
</table>

1 First part included in Tables I and II.
TABLE IV.—Estimated cost of improving the river for power alone, with power development as provided in the recommended joint navigation and power improvement (14-foot navigation maintained)

<table>
<thead>
<tr>
<th>Section</th>
<th>With the two-stage development of the International Rapids section</th>
<th>With the single-stage development of the International Rapids section</th>
</tr>
</thead>
<tbody>
<tr>
<td>International Rapids section</td>
<td>$231,800,000</td>
<td>$215,000,000</td>
</tr>
<tr>
<td>Soulanges section</td>
<td>77,172,000</td>
<td>77,172,000</td>
</tr>
<tr>
<td>Total</td>
<td>308,972,000</td>
<td>292,172,000</td>
</tr>
</tbody>
</table>

TABLE V.—Estimated cost of improving the river for navigation alone, under the least expensive alternative plan

<table>
<thead>
<tr>
<th>Section</th>
<th>Cost (Thousands)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thousand Islands section</td>
<td>$1,100,000</td>
</tr>
<tr>
<td>International Rapids section</td>
<td>79,000,000</td>
</tr>
<tr>
<td>Lake St. Francis section</td>
<td>980,000</td>
</tr>
<tr>
<td>Soulanges section</td>
<td>336,000</td>
</tr>
<tr>
<td>Lachine section</td>
<td>53,000</td>
</tr>
<tr>
<td>Total</td>
<td>167,720,000</td>
</tr>
</tbody>
</table>

TABLE VI.—Tabulated estimates of cost of providing channels of various depths from the head of the Great Lakes to Montreal, including the installation of 1,365,000 horsepower on the St. Lawrence and the entire cost of the New Welland Ship Canal

<table>
<thead>
<tr>
<th>Channel</th>
<th>23-foot depth</th>
<th>25-foot depth</th>
<th>27-foot depth</th>
<th>30-foot depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Lakes connecting channels</td>
<td>$41,100,000</td>
<td>$54,900,000</td>
<td>$68,900,000</td>
<td>$75,900,000</td>
</tr>
<tr>
<td>St. Mary River Locks</td>
<td>6,500,000</td>
<td>6,500,000</td>
<td>6,500,000</td>
<td>6,500,000</td>
</tr>
<tr>
<td>Compensating works</td>
<td>$3,400,000</td>
<td>3,600,000</td>
<td>3,700,000</td>
<td>3,800,000</td>
</tr>
<tr>
<td>Welland Canal</td>
<td>114,500,000</td>
<td>115,600,000</td>
<td>128,600,000</td>
<td>137,400,000</td>
</tr>
<tr>
<td>St. Lawrence River to Montreal</td>
<td>344,700,000</td>
<td>355,900,000</td>
<td>387,400,000</td>
<td>501,700,000</td>
</tr>
<tr>
<td>Total</td>
<td>462,600,000</td>
<td>509,300,000</td>
<td>556,600,000</td>
<td>635,100,000</td>
</tr>
</tbody>
</table>

1 Based on subsequent deepening from 25 feet.

PART IV

ST. LAWRENCE RIVER AT AND BELOW MONTREAL

205. This part of the report deals with the effect of the diversion of water from the Great Lakes system on the water levels at and below Montreal and with measures for restoring these levels. (Question 6.) It also considers the effect of the proposed improvement of the St. Lawrence on these levels. (Question 5.)

DESCRIPTION

206. Montreal Harbor is a highly developed port, with 9 miles of improved wharf frontage, grain elevators with a total storage capacity of 12,000,000 bushels, and an extensive warehousing system. The commerce through the port in 1925 amounted to 9,137,281 tons, including 166,000,000 bushels of grain.
The water levels in Montreal Harbor during the navigation season range generally between 18 and 28 feet above mean sea level, depending upon the flow of the St. Lawrence and the Ottawa Rivers, the higher stages being due to the spring floods in the Ottawa. In winter, the increased slope of the river due to ice retardation raises the water surface by from 10 to 20 feet, and ice jams occurring during the break-up season in April have raised the water to the stage of 52 feet above mean sea level.

207. The wharves in Montreal Harbor are of exceptionally massive construction, to resist damage by ice at the high winter and spring levels. They are built typically with high masonry walls founded on wooden cribbing. The vessel berths at the wharves in the upper portion of the harbor are generally excavated in rock. Extreme low-water levels, which would expose the wooden foundations of the wharves, with consequent danger of decay, are regarded as of serious consequence; and the berths at wharves can not be deepened readily to meet a reduction in the water levels.

208. Montreal lies 53 statute miles upstream from Lake St. Peter, a wide expanse of shallow water, which is the head of the tide in the St. Lawrence. Below the city of Quebec, 160 miles downstream from Montreal, the river is a tidal estuary, with its mean level substantially at mean sea level. The river below Montreal has been improved by dredging to afford a channel with 450 feet minimum width, 30 feet deep at water levels corresponding to a stage at the head of Montreal Harbor, 18.4 feet above mean sea level (low water of 1897 as modified). The water level rarely falls below this datum. This channel is now under enlargement to 35 feet depth. The expenditures by Canada on the improvement of the channel below Montreal, to March 31, 1925, have been as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dredging, field cost</td>
<td>$17,434,683.66</td>
</tr>
<tr>
<td>Plant, shops, surveys, etc</td>
<td>10,268,461.52</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>27,703,145.18</strong></td>
</tr>
</tbody>
</table>

Effect of diversion of water

209. An accurate determination of the relation between the river discharge past Montreal and the river stage is complicated by the fact that these stages are modified by the varying discharge of the tributaries entering the river below Montreal, including the main part of the discharge of the Ottawa, and are affected by the long period tidal fluctuations.

210. A detailed analysis of the relation between gauge heights and discharge, given in Appendix D, shows, however, that a diminution of the flow past Montreal reduces the water levels in the harbor, at the rate of 1 foot for each 23,000 cubic feet per second of flow. The authorized diversion of 8,500 cubic feet per second through the Chicago Drainage Canal reduces the levels in Montreal Harbor, therefore, by 0.37 foot. A similar analysis shows the following effects at points below Montreal:
211. The navigable depths of the channels below Montreal Harbor can be restored by dredging. An analysis of the gauge records shows that the dredging heretofore done has lowered the levels in Montreal Harbor at the rate of 0.15 foot for each foot of navigable depth gained, and has lowered the levels of the river between Varennes and Quebec by an average of 0.06 foot for each foot of navigable depth gained. The estimated cost of increasing the effective depths of the channel below Montreal by the amounts found in the foregoing tabulation, if done as a part of the present project for a general increase in depth and at the current costs of such dredging, is as follows:

<table>
<thead>
<tr>
<th>Locality</th>
<th>Statute miles below Montreal</th>
<th>Amount by which levels are lowered by diversion of 8,500 cubic feet per second</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montreal</td>
<td>0</td>
<td>0.37</td>
</tr>
<tr>
<td>Varennes</td>
<td>13</td>
<td>0.25</td>
</tr>
<tr>
<td>Sorel</td>
<td>45</td>
<td>0.28</td>
</tr>
<tr>
<td>Batiscan</td>
<td>100</td>
<td>0.24</td>
</tr>
<tr>
<td>Lotbiniere</td>
<td>117</td>
<td>0.24</td>
</tr>
<tr>
<td>Platon</td>
<td>125</td>
<td>0.17</td>
</tr>
<tr>
<td>Quebec</td>
<td>160</td>
<td>0.03</td>
</tr>
</tbody>
</table>

212. The navigable depths in Montreal Harbor can be restored by similar dredging. The estimated cost of this dredging necessary to compensate for a diversion of 8,500 cubic feet per second is as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,168,000 cubic yards dredging at 42.5 cents per cubic yard</td>
<td>$1,346,400</td>
</tr>
<tr>
<td>Plant, shops, surveys, etc., average proportional cost since beginning of work, 60 per cent</td>
<td>807,600</td>
</tr>
<tr>
<td>Total</td>
<td>2,154,000</td>
</tr>
</tbody>
</table>

213. The unit costs are based on the execution of the work as a part of a general project for deepening the harbor. The removal as a separate undertaking of the 5-inch layer required to compensate for the diversion would be much more expensive.

214. A comprehensive project for deepening the harbor would, however, require the reconstruction of a large amount of dock wall. An estimate of the part of the cost of reconstruction chargeable to the diversion of water obviously presents difficulties. This diversion is but a contributing cause to the need for enlargement, for there has been a loss of 1.15 feet in depth in the harbor since 1895 due to other causes. The older dock walls will require reconstruction in the not distant future on account of deterioration. The Canadian section of the board has prepared an estimate of $1,800,000 as the part of the cost of rebuilding dock walls due to the lowering of the levels by a diversion of 8,500 cubic feet per second, the details of which are set
forth in Appendix D. The American section accepts this estimate with the understanding that it is subject to further investigation and revision.

215. A study was made of the possibility of constructing contraction works in the river below Montreal Harbor to compensate for the effect of such a diversion. No substantial saving was indicated by this course.

216. In summary, the cost of restoring the navigable depths at and below Montreal to the extent that they have been affected by the authorized diversion of 8,500 cubic feet per second is as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dredging Montreal Harbor</td>
<td>$654,000</td>
</tr>
<tr>
<td>Reconstruction of dock walls, Montreal Harbor</td>
<td>1,800,000</td>
</tr>
<tr>
<td>Dredging below Montreal Harbor</td>
<td>2,154,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4,608,000</strong></td>
</tr>
</tbody>
</table>

217. The suggestion has been advanced that, instead of securing the desired channel depth at and below Montreal by further dredging, control works with twin locks could be constructed in the river below Montreal to raise the water levels to the extent required for that purpose. Such a structure must be so designed that it would not aggravate ice conditions in winter, and therefore would be costly. It would afford incidentally a complete remedy for the lowering of the water in Montreal Harbor due both to channel enlargement and to the diversion of water, and also would afford an opportunity for the fuller development of power, especially in the Lachine section, since the restrictions as to maintaining uniformity of flow could be made less stringent. The consideration of such a scheme is beyond the scope of the instructions to the board.

**EFFECT OF PROPOSED IMPROVEMENT OF THE ST. LAWRENCE RIVER**

218. The improvement of the St. Lawrence River could affect the water levels at and below Montreal to the extent only that the works might be so operated as to modify the rate of discharge of water down the river. The program for the regulation of Lake Ontario recommended by the board (Appendix B) is so drawn as to afford mean discharges during the critical months of September, October, and November at least equal to the discharges that occur in nature; and discharges in the first half of April, when the river has its maximum flood levels, no greater than those that would occur with equal frequency without regulation. There remains the possibility of the introduction of fluctuations in the discharge of the river through the fluctuations in the discharges through the power plants to meet their changing loads.

219. Any necessary uniformity of discharge past the various power structures can be secured by opening sluice gates as the power load and power house discharge diminishes. Power can be profitably generated at the various plants recommended by the board without causing any greater hourly and daily fluctuations in the water levels at Montreal than now occur from natural causes, and suitable Government supervision, both over the plants in the International section and over those in the Province of Quebec, can assure this result.

220. In short, all the works of the improvement of the St. Lawrence River must be so operated as to have no injurious effect on the water levels at and below Montreal.
FINDINGS ON QUESTIONS CONTAINED IN THE INSTRUCTIONS TO THE JOINT BOARD OF ENGINEERS

221. Answering specifically the questions contained in its instructions, the board finds:

QUESTION 1

Is the scheme for the improvement of the St. Lawrence waterway, presented by the board in its report of June 24, 1921 (herein referred to as the report of 1921), practicable and does it provide to the best advantage, at this time and ultimately, for the development of the capacities and possibilities of the waterway?

222. Answer. The scheme as presented in the report of 1921 is in its broad lines practicable, but should in the opinion of this board be modified to provide to the best present advantage, at this time and ultimately, for the development of the capacities and possibilities of the waterway.

QUESTION 2

What alternative scheme, if any, would be better adapted to secure the ends desired, due consideration being given—

(a) To any special international or local interests having an importance justifying exceptional consideration; and

(b) To the extent and character of the damage through flooding and the probable effect of the works upon the formation of ice and the consequent effect on the flow of the river?

223. Answer. The plans recommended by the present board are set forth in Part III of this report, and are described in detail in Appendix C.

224. The plans presented in the report of 1921 are altered in their broader features as follows:

225. In the International Rapids section (fourth division of the report of 1921) the plans now presented provide for the development of the entire power possibilities of the section, without subsequent alterations in the works. Two alternative schemes for accomplishing this result are presented, one for a two-stage development, the other for a single-stage development.

226. In the Soulanges section (second division) the board recommends a scheme for navigation correlated with a progressive development of power instead of a side canal for navigation only.

227. In the Lachine section (first division) the alignment of the navigation canal is changed to secure a minimum interference between land and water traffic, and a control dam to regulate the levels of Lake St. Louis has been included in the initial development.

228. The plans proposed have been drawn with full regard to all interests concerned. Flowage damage is inseparable from a practicable development of power on the St. Lawrence, since freedom from floods has led to the occupation of its banks almost to the waters’ edge. The plans have been drawn to reduce to a minimum the flowage consequent to the plans proposed. They have been prepared with special care to meet ice conditions affecting the flow of the river.
ST. LAWRENCE WATERWAY PROJECT

QUESTION 3

Should the estimates of cost be revised, and, if so, what are the revised estimates of cost having regard to alternative schemes?

229. Answer. The estimates should be revised. The estimates of the works proposed by this board, with hydroelectric machinery completely installed, exclusive of interest during construction, are as follows:

(1) If a single-stage development be adopted in International Rapids section—

| Works solely for navigation | $108,700,000 |
| Works common to power and navigation | 141,200,000 |
| Works primarily for power | 144,100,000 |
| **Total** | **394,000,000** |

Installed capacity 2,730,300 horsepower.

(2) If a two-stage development be adopted in the International Rapids section—

| Works solely for navigation | $120,200,000 |
| Works common to power and navigation | 125,500,000 |
| Works primarily for power | 177,900,000 |
| **Total** | **423,600,000** |

Installed capacity 2,619,000 horsepower.

230. The board considers that sound business management will dictate the initial installation of but a part of the hydroelectric machinery with its housing and accessories. With a total initial installation of 1,368,000 horsepower, the initial costs, including all features required for navigation and with complete channel enlargement for winter power operation, becomes respectively $350,100,000 and $385,500,000.

231. The plans presented by the board outline a subsequent complete development of the power resources of the river, by the construction of additional power works with an installed capacity of approximately 2,500,000 horsepower, at an additional cost of approximately $225,000,000.

232. The total ultimate development visualized on the St. Lawrence River by the board amounts therefore to approximately 5,000,000 horsepower at a total cost of from $620,000,000 to $650,000,000, including navigation works. Further details of estimates are given in Part III, paragraphs 200 to 204.

QUESTION 4

In order to assist either Government to allocate the amounts chargeable to navigation and power, what would be the respective estimated costs for improving the river for navigation alone and for power alone?

233. Answer. The estimated costs for the initial improvement of each river section: (a) On plans recommended by the board for both power and navigation, (b) on similar plans for the development of the same amount of power without any navigation works other than to maintain the existing 14-foot navigation, and (c) on alternative plans for practicable, though inferior, navigation through the power sections, are shown in parallel columns as follows:
(1) If a single-stage development is adopted in the international power section:

<table>
<thead>
<tr>
<th>Section</th>
<th>(a) Plans recommended</th>
<th>(b) Power alone</th>
<th>(c) Navigation alone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper international</td>
<td>$1,100,000</td>
<td></td>
<td>$1,100,000</td>
</tr>
<tr>
<td>International power</td>
<td>235,000,000</td>
<td>$213,000,000</td>
<td>$70,000,000</td>
</tr>
<tr>
<td>Lake St. Francis</td>
<td>980,000</td>
<td>77,172,000</td>
<td>980,000</td>
</tr>
<tr>
<td>Soulanges</td>
<td>103,945,000</td>
<td></td>
<td>33,640,000</td>
</tr>
<tr>
<td>Lachine</td>
<td>53,000,000</td>
<td></td>
<td>53,000,000</td>
</tr>
<tr>
<td>Total</td>
<td>304,925,000</td>
<td>290,172,000</td>
<td>167,720,000</td>
</tr>
</tbody>
</table>

(2) If a two-stage development is adopted in the international power section:

<table>
<thead>
<tr>
<th>Section</th>
<th>(a) Plans recommended</th>
<th>(b) Power alone</th>
<th>(c) Navigation alone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper international</td>
<td>$1,100,000</td>
<td></td>
<td>$1,100,000</td>
</tr>
<tr>
<td>International power</td>
<td>264,546,000</td>
<td>$231,800,000</td>
<td>$70,000,000</td>
</tr>
<tr>
<td>Lake St. Francis</td>
<td>980,000</td>
<td>77,172,000</td>
<td>980,000</td>
</tr>
<tr>
<td>Soulanges</td>
<td>103,945,000</td>
<td></td>
<td>33,640,000</td>
</tr>
<tr>
<td>Lachine</td>
<td>53,000,000</td>
<td></td>
<td>53,000,000</td>
</tr>
<tr>
<td>Total</td>
<td>423,571,000</td>
<td>308,972,000</td>
<td>167,720,000</td>
</tr>
</tbody>
</table>

**QUESTION 5**

To what extent may water levels in the St. Lawrence River at and below Montreal, as well as the river and lake levels generally, be affected by the execution of the project?

234. Answer. The irresponsible operation of the power works proposed by the board, or indeed of any power works, however designed, that develop fully the power resources of any section of the river, would affect injuriously the water levels in the St. Lawrence River at and below Montreal; but it is feasible to operate these works under Government supervision in such manner that they will neither lower the summer levels in the lower river nor raise the winter and spring levels. With such control the improvements proposed will have no injurious effect whatever on the water levels of the St. Lawrence at and below Montreal.

235. The high levels of Lake Ontario, of the upper reaches of the St. Lawrence River, extending 67 miles from that lake, and of Lake St. Francis and Lake St. Louis, will not be raised by the improvement. The low levels of Lake Ontario and of these upper reaches of the St. Lawrence will not be made lower. The low levels of Lake St. Francis will be raised about a foot and of Lake St. Louis about 5 feet. The dams proposed in the power reaches of the St. Lawrence will create material local changes in the levels of these reaches only.

236. The levels of the Great Lakes above Lake Ontario can not be affected by any works in the St. Lawrence proper. Works to restore the effects of channel enlargements and of diversions from lakes above Lake Ontario are dealt with under the replies to questions 6 (b) and 10.
ST. LAWRENCE WATERWAY PROJECT

QUESTION 6 (A)

To what extent and in what manner are the natural water levels in the St. Lawrence River and on the Lakes affected by diversions authorized by license by either Canada or the United States, from or in the St. Lawrence River watershed?

237. Answer. The diversion by the Chicago Sanitary District of 8,500 cubic feet per second from the lake basin through the Chicago Drainage Canal, authorized by license by the United States, lowers the water levels on the Great Lakes and the St. Lawrence River as follows:

<table>
<thead>
<tr>
<th>Foot</th>
<th>Lakes Michigan and Huron</th>
<th>Lake Erie</th>
<th>Lake Ontario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
<td></td>
<td>0.4</td>
</tr>
</tbody>
</table>

St. Lawrence River between Lake Ontario and Montreal:

<table>
<thead>
<tr>
<th>Foot</th>
<th>At Prescott</th>
<th>At Lock 25 (Iroquois)</th>
<th>At Lock 23 (Morrisburg)</th>
<th>At Lock 21 (Dickensons Landing)</th>
<th>At Lock 15 (Cornwall)</th>
<th>Lake St. Francis</th>
<th>Lake St. Louis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

St. Lawrence River at and below Montreal:

<table>
<thead>
<tr>
<th>Foot</th>
<th>At Montreal Harbor</th>
<th>At Varennes</th>
<th>At Sorel</th>
<th>At Batiscan</th>
<th>At Lotbiniere</th>
<th>At Platon</th>
<th>At Quebec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>37</td>
<td>35</td>
<td>28</td>
<td>24</td>
<td>24</td>
<td>17</td>
<td>0.03</td>
</tr>
</tbody>
</table>

238. The diversion of 2,080 cubic feet per second from Lake Erie via the Welland Canal for power use by corporations and municipalities authorized by license by Canada lowers the levels of the Great Lakes as follows:

<table>
<thead>
<tr>
<th>Foot</th>
<th>Lakes Michigan and Huron</th>
<th>Lake Erie</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.025</td>
<td>0.1</td>
</tr>
</tbody>
</table>

239. The foregoing are the only authorized diversions found by the board to affect appreciably the levels of the Lakes and the St. Lawrence. The effect of all diversions, including those for navigation purposes, and the effect of other factors, is described in Part II of this report.

QUESTION 6 B

By what measures could the water levels or navigable depths affected by the diversions referred to in section 6 (a) be restored, and what would be the cost thereof?

240. Answer. The water levels of Lakes Michigan, Huron, and Erie can be restored most advantageously by compensating works in the St. Clair and Niagara Rivers, which should, however, be so designed as to offset all existing diversions and outlet enlargements, as well as the diversions authorized by license. The total cost of these works is estimated at $3,400,000. The cost of similar but less extensive works designed to restore the effect of authorized diversions only is estimated as follows:
Compensated for:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost of works</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago diversion</td>
<td>$1,750,000</td>
</tr>
<tr>
<td>Power diversions, Welland Canal</td>
<td>$100,000</td>
</tr>
</tbody>
</table>

241. The effect of the Chicago diversion on the levels of Lake Ontario and of the St. Lawrence River above Montreal will be removed by the works provided for the improvement of this part of the St. Lawrence.

242. The effect of the Chicago diversions on the levels of the St. Lawrence River at and below Montreal can be restored by dredging and accessory works at estimated costs as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost of works</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dredging Montreal Harbor</td>
<td>$654,000</td>
</tr>
<tr>
<td>Reconstruction of dock walls, Montreal Harbor</td>
<td>1,800,000</td>
</tr>
<tr>
<td>Dredging below Montreal</td>
<td>2,154,000</td>
</tr>
</tbody>
</table>

Total: 4,608,000

QUESTION 6 C

How much power could be developed on the St. Lawrence River with the water diverted from the watershed referred to in section 6 (a) under—

1) The plans recommended?
2) Alternative plans providing for a full practicable development of the river?

243. Answer. The following amounts of 24-hour power could be developed on the St. Lawrence River with the authorized diversion of 8,500 cubic feet per second from the watershed through the Chicago Drainage Canal:

1) At the average heads available at the power plants initially recommended—

<table>
<thead>
<tr>
<th>Description</th>
<th>Horsepower</th>
</tr>
</thead>
<tbody>
<tr>
<td>In the international power section (82.5 feet average head)</td>
<td>70,125</td>
</tr>
<tr>
<td>In the Soulanges section (22 feet average head)</td>
<td>18,700</td>
</tr>
</tbody>
</table>

Total: 88,875

2) At the average heads available at the power plants recommended for the eventual full practicable development of the river—

<table>
<thead>
<tr>
<th>Description</th>
<th>Horsepower</th>
</tr>
</thead>
<tbody>
<tr>
<td>In the international power section (82.5 feet average head)</td>
<td>70,125</td>
</tr>
<tr>
<td>In the Soulanges section (75 feet average head)</td>
<td>63,750</td>
</tr>
<tr>
<td>In the Lachine Section (32 feet average head)</td>
<td>27,200</td>
</tr>
</tbody>
</table>

Total: 161,075

QUESTION 6 D

Without considering compensation by the present relative diversions of water from the Niagara River and from Lake Erie, and without prejudice to a future consideration thereof, what works, if any, could be constructed to recover on the St. Lawrence River the amounts of power determined under section 6 (c), and what would be the cost of such works?

224. Answer. The board finds that after the St. Lawrence River has been fully developed for power production no works can be constructed which would recover on the St. Lawrence the power lost by the diversion of water from the watershed.

QUESTION 7

Having regard to economy of construction and maintenance, expedition of construction, and efficiency of operation—

(a) Which of the works should be constructed under the technical supervision of an international board, and what other works, if any, might advantageously be constructed under such supervision?
(b) Which of the works should be maintained and operated by an international board, and what other works, if any, might advantageously be so maintained and operated?

245. Answer (a). *Construction of works.*—All dams, embankments, power-house substructures, water passages, gates, and channel enlargements within the international sections should be designed and constructed under the technical supervision of a single international authority.

246. The purpose of this is to make sure that the different parts of the works will not be so prosecuted as to interfere with each other and that safe and equitable regulation of both winter and summer flows of the river will be possible both during and after construction, as well as to secure uniformity, economy, and expedition by coordinating design and construction programs.

247. The same authority should coordinate for the entire river, from Lake Ontario to Montreal, the programs of construction and the channel dimensions and clearances for works necessary to secure through navigation.

248. Answer. (b) *Maintenance and operation of works.*—The board regards it as essential that an international control board be created with full power to regulate the use of water at the power plants in the international section in order that such use may be prevented from creating conditions harmful to navigation in any part of the St. Lawrence, and in order that the operation of the various power plants be conducted with full regard to the use of water at other power plants on the river.

All locks and other navigation structures will necessarily lie in the territory of one country or the other, and can be most advantageously maintained and operated by the usual government agencies of the two countries.

**QUESTION 8**

What, if any, readjustments in the location of the international boundary are necessary or desirable to place power structures belonging to either country within its borders, as recommended by the International Joint Commission?

249. Answer. Readjustments in the international boundary are necessary only in the International Rapids section and depend upon the plan adopted for the improvement of that section. A change in the boundary in the vicinity of Barnhart Island is necessary irrespective of whether the single-stage or the two-stage scheme be adopted in this section. If, with either of these general schemes, the dam is located at the foot of Long Sault Island and both power houses at the foot of the island, as shown on the plans of the two stage development, a change is necessary between turning points 10 and 14 to bring the power houses within the borders of the two countries. If, on the other hand, the dam and power houses are at the foot of Barnhart Island, with the United States power house on the mainland of the United States, as shown on the plans of the single-stage development, it is desirable to so change the boundary between turning points 10 and 21 as to bring all of Barnhart Island into Canadian territory. This island is separated from other American territory by the main channel of the St. Lawrence. The estimates
include the acquisition of the entire island in connection with power development, and the land remaining unsubmerged can, with this plan, be put to beneficial use only in connection with the Canadian power house located thereon.

250. With the two-stage scheme, a slight change is needed also in the boundary north of Ogden Island, to bring the power houses at that locality within the borders of the respective countries.

251. A detailed description of the necessary changes will be given in Appendix C.

QUESTION 9

If the board is of the opinion that it would be advantageous to provide in the first instance for channel depths other than 25 feet, but less than 30 feet, for what draft of vessel should provision be made?

252. Answer. As explained in paragraph 111, Part III, the board is not agreed on the advantage of any depth other than 25 feet.

QUESTION 10

Having regard to the recommendation of the International Joint Commission that the new Welland Ship Canal should be embodied in the scheme and should be treated as a part thereof, and to the fact that if a greater depth than 21 feet be adopted for the initial project depth of the St. Lawrence, such greater depth would not be available to the upper lake ports without further work in the navigation channels in the Lakes, what would be the cost of improving the main navigation channels between and through the Lakes, so as to provide, without impairing the present lake levels, for (a) a depth of 25 feet and (b) for such other depth not exceeding 30 feet, as may be determined by the board to be that for which it would be most advantageous to provide on the St. Lawrence River?

253. Answer. The cost of improving the main navigation channels between and through the Lakes, so as to provide a depth of 25 feet, including all compensating works constructed in furtherance of the work, is estimated at $44,700,000, not including the cost of the new Welland Ship Canal.

QUESTION 11

What is the time required to complete the proposed works, the order in which they should be proceeded with, and the progress which should be made yearly toward the completion of each in order to secure the greatest advantage from each of the works and from the development of the waterway as a whole?

254. Answer. It is estimated that the waterway can be opened to navigation in from seven to eight years from the time that active work has been begun. All works should be so prosecuted as to insure the completion of navigation works at the same time. A complete program for the prosecution of the work will be presented in Appendix G.

APPENDICES

255. The investigations by the board are set forth more fully in appendices, as follows:

Appendix A.—Field investigations.
Appendix B.—Lake levels and outflows.
Appendix C.—Detailed plans and estimates for the improvement of the St. Lawrence.
Appendix D.—River levels and discharges at and below Montreal.
Appendix E.—Ice formation on St. Lawrence.
Appendix F.—Experiments on strength of ice.
Appendix G.—Construction program.

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WASHINGTON, D. C., November 16, 1926.