Report

OF THE

INTERNATIONAL JOINT COMMISSION

UNITED STATES AND CANADA

ON THE

Preservation and Enhancement of Niagara Falls

WASHINGTON 1953 OTTAWA

INTERNATIONAL JOINT COMMISSION

UNITED STATES	CANADA
A. O. STANLEY, Chairman	A. G. L. McNAUGHTON, Chairman
ROGER B. McWHORTER	GEORGE SPENCE
EUGENE W. WEBER	J. LUCIEN DANSEREAU
Jesse B. Ellis, *Secretary*	E. M. Sutherland, *Secretary*

Counsel

On behalf of Government of United States	*On behalf of Government of Canada*
William R. Vallance	Kenneth J. Burbridge

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LETTER OF TRANSMITTAL

The following letter was sent to the Secretary of State, Washington, D.C., by the Secretary of the United States Section of the International Joint Commission, and to the Secretary of State for External Affairs, Ottawa, Canada, by the Secretary of the Canadian Section of the International Joint Commission:

12 May, 1953.

Sir,

I have the honour to transmit a copy of Report of the International Joint Commission to the Governments of Canada and the United States of America on remedial works necessary to preserve and enhance the scenic beauty of the Niagara Falls and River, dated 5 May, 1953.

Under the Reference of 10 October, 1950, the Commission was directed by the two Governments to investigate and make a report containing recommendations concerning the nature and design of the remedial works necessary to enhance the beauty of the Falls in the Niagara River, in accordance with the objectives in the Final Report of 11 December, 1929, by the Special International Niagara Board, and bearing in mind the provisions of the Treaty of 27 February, 1950, respecting the uses of the waters of the Niagara River; recommendations concerning the allocation of the task of construction of remedial works; and estimate of the costs of such remedial works.

Copies of the Report of the International Niagara Falls Engineering Board (Main Report and Appendices A, B, C, D, E, F, G, H and J) are enclosed.

I have the honour to be,

Sir,

Your obedient servant,

JESSE B. ELLIS,
Secretary, United States Section

E. M. SUTHERLAND,
Secretary, Canadian Section
INTERNATIONAL JOINT COMMISSION

and Canada of such recommendations the construction shall be undertaken pursuant thereto under the supervision of the International Joint Commission and shall be completed within four years after the date upon which the United States of America and Canada shall have approved the said recommendations. The total cost of the works shall be divided equally between the United States of America and Canada.

ARTICLE III

The amount of water which shall be available for the purposes included in Articles IV and V of this Treaty shall be the total outflow from Lake Erie to the Welland Canal and the Niagara River (including the Black Rock Canal) less the amount of water used and necessary for domestic and sanitary purposes and for the service of canals for the purposes of navigation. Waters which are being diverted into the natural drainage of the Great Lakes System through the existing Long Lac-Ogoki works shall continue to be governed by the notes exchanged between the Government of the United States of America and the Government of Canada at Washington on October 14 and 31 and November 7, 1940, and shall not be included in the waters allocated under the provisions of this Treaty.

ARTICLE IV

In order to reserve sufficient amounts of water in the Niagara River for scenic purposes, no diversions of the water specified in Article III of this Treaty shall be made for power purposes which will reduce the flow over Niagara Falls to less than one hundred thousand cubic feet per second each day between the hours of eight a.m., E.S.T., and ten p.m., E.S.T., during the period of each year beginning April 1 and ending September 15, both dates inclusive, or to less than one hundred thousand cubic feet per second each day between the hours of eight a.m., E.S.T., and eight p.m., E.S.T. during the period of each year beginning September 16 and ending October 31, both dates inclusive, or to less than fifty thousand cubic feet per second at any other time; the minimum rate of fifty thousand cubic feet per second to be increased when additional water is required for flushing ice above the Falls or through the rapids below the Falls. No diversion of the amounts of water, specified in this Article to flow over the Falls, shall be made for power purposes between the Falls and Lake Ontario.

ARTICLE V

All water specified in Article III of this Treaty in excess of water reserved for scenic purposes in Article IV may be diverted for power purposes.

ARTICLE VI

The waters made available for power purposes by the provisions of this Treaty shall be divided equally between the United States of America and Canada.

INTERNATIONAL NIAGARA FALLS ENGINEERING BOARD.

Upon receipt of the Reference the Commission created the International Niagara Falls Engineering Board, composed of Engineers drawn from the technical agencies of Canada and the United States, and directed it to make the necessary investigation of the Niagara Falls and River, and thereafter prepare a report setting forth the Board's findings and recommendations. The Board was directed to include in its report preliminary designs of the recommended remedial works, an estimate of the cost of such works and recommendations concerning the allocation of tasks of construction of the remedial works as between Canada and the United States. The Board's report, dated 1 March, 1953, is attached hereto and constitutes a part of the Commission's report to the two Governments.

INTERNATIONAL JOINT COMMISSION

Report to the Governments of the United States of America and Canada on Remedial Works Necessary to Preserve and Enhance the Scenic Beauty of the Niagara Falls and River.

This report to the Governments of the United States of America and Canada, with recommendations, is submitted pursuant to a Reference to this Commission embodied in identical letters dated October 10, 1950, and signed by the Under Secretary of State of the United States and the Acting Secretary of State for External Affairs for Canada. The full text of the Reference is quoted below:

"I have the honour to inform you that the Governments of Canada and the United States of America have agreed to request the International Joint Commission to investigate and make a report containing:

(1) Recommendations concerning the nature and design of the remedial works necessary to enhance the beauty of the Falls in the Niagara River by distributing the waters so as to produce an unbroken crestline on the Falls, in accordance with the objectives envisaged in the final report submitted to Canada and the United States of America on December 11, 1929, by the Special International Niagara Board and bearing in mind the provisions for the diversion of the waters of the Niagara River and the apportionment thereof, which have been agreed upon by the two Governments in the Treaty of February 27, 1950, respecting the uses of the waters of the Niagara River.

(2) Recommendations concerning the allocation of the task of construction of remedial works as between Canada and the United States of America, having regard to the recommendations made under paragraph (1).

(3) An estimate of the costs of such remedial works.

In the conduct of its investigations, and otherwise in the performance of its duties under this reference, the International Joint Commission may utilize the services of engineers and other specially qualified personnel of technical agencies of Canada and the United States, and will so far as possible, make use of information and technical data which has been acquired by such technical agencies or which may become available during the course of the investigation, thus avoiding duplication of effort and unnecessary expense."

The Treaty referred to in paragraph (1) of the Reference respecting the uses of the waters of the Niagara River was signed at Washington, D.C. on February 27, 1950, approved by the Canadian Parliament on June 14, 1950, consented to by the United States Senate on August 9, 1950, and put into force by an exchange of ratifications at Ottawa on October 10, 1950.

In the preparation of this report the Commission has been particularly concerned with Articles II to VI inclusive of the Treaty, which read:

ARTICLE II

The United States of America and Canada agree to complete in accordance with the objectives envisaged in the final report submitted to the United States of America and Canada on December 11, 1929, by the Special International Niagara Board, the remedial works which are necessary to enhance the beauty of the Falls by distributing the waters so as to produce an unbroken crestline on the Falls. The United States of America and Canada shall request the International Joint Commission to make recommendations as to the nature and design of such remedial works and the allocation of the task of construction as between the United States of America and Canada. Upon approval by the United States of America

(a) The Chippawa-Grass Island Pool level would drop as much as four feet below its present normal elevation, thereby exposing considerable areas of the river bed presently covered, particularly in the vicinity of the head of Goat Island. The general lowering of this Pool would result in some lowering of levels of Lake Erie.

(b) The lowering of the Chippawa-Grass Island Pool level would reduce the flow over the American Falls well below that necessary for a satisfactory scenic spectacle.

(c) Under future maximum permissible diversions the flow over Horseshoe Falls during tourist season days would be concentrated towards the center leaving unsatisfactory conditions at the flanks; and during the non-tourist season and the night hours of the tourist season, the flow over the Horseshoe Falls would be so concentrated near the center of the crest as to leave the flanks dry.

(d) The necessary change in the Chippawa-Grass Island Pool level to increase the flow over the Falls from 50,000 to 100,000 cubic feet per second and vice versa, would require so much time that only a small part of the extra diversion authorized at night during the tourist season could be used. Moreover, the lowering of the Pool would slightly reduce the output of existing power plants.

OBJECTIVES.

In conducting the studies for this report it was considered imperative that the remedial works be designed to improve the distribution of flow along the crest of the Horseshoe Falls, maintain the present satisfactory conditions at the American Falls, and control the levels of the Chippawa-Grass Island Pool. The maintenance of the present relationship between river flow and Pool level is considered essential. Such regulation would preserve the existing conditions and appearance of the Niagara River upstream from the Pool and would ensure that Lake Erie levels and corresponding outflows would remain unaffected, thus protecting interests upstream which otherwise might be affected adversely by a general lowering or rapid variation in the Pool level. In addition, adequate flow down the American Rapids and over the Falls would be assured. Full advantage could be taken of the additional water available for power diversions in the night hours of the tourist season as well as at all other times. Therefore, it is considered that the remedial works should ensure:

(a) A dependable flow of water over the American Falls and in the vicinity of Three Sisters Islands, approximating the satisfactory flow under existing conditions;

(b) A dependable adequate flow over both flanks of the Horseshoe Falls sufficient to provide an unbroken crestline;

(c) Maintenance of the present relationship between the total river flow and the level of the Chippawa-Grass Island Pool; and,

(d) Ability to meet promptly the changes in permissible power diversions while assuring flows of either 50,000 or 100,000 cubic feet per second over the Falls.

INVESTIGATION AND STUDY PROCEDURE.

As contemplated in the Reference the detailed surveys and studies necessary for the design of remedial works to meet the objectives outlined above were accomplished by calling on the appropriate agencies in both countries. The International Niagara Falls Engineering Board appointed a working committee consisting of representatives of the agencies having regularly assigned responsibilities for the types of work involved. The regular field organizations of the appropriate agencies were asked to perform the various types of surveys and studies needed, thus ensuring that the services of specialists available in both countries were utilized on various aspects of the problem as required.

Description of the Niagara Falls Area.

The Niagara River, about 36 miles in length, connects Lake Erie and Lake Ontario. The river carries the outflow from the four upper lakes of the Great Lakes system averaging about 200,000 cubic feet per second. The fall from lake to lake is 326 feet, about half of which is concentrated at Niagara Falls, 21.6 miles below the head of the river.

In the one-mile reach immediately above the Falls, the river drops about 50 feet through cascades and rapids. Goat Island divides the river into two parts, the larger leading to the Horseshoe Falls on the Canadian side and the smaller to the American Falls.

The distance from shore to shore at Horseshoe Falls in 1200 feet but the total length of crest around the "horseshoe" is 2500 feet. The central portion of the crest has been receding faster than the flanks, with the result that in the last 100 years the crest length has increased about 100 feet. The depth of water flowing over the crest near each shore is less than one foot and this portion of the falling sheet of water usually appears white. Toward the center of the Horseshoe the crest depth increases to a maximum of 12 feet and the falling sheet of water has a darker, greenish appearance.

The American Falls has a relatively low flow distributed quite evenly along its 1100 feet of crest and has receded very slowly as compared with the Horseshoe Falls.

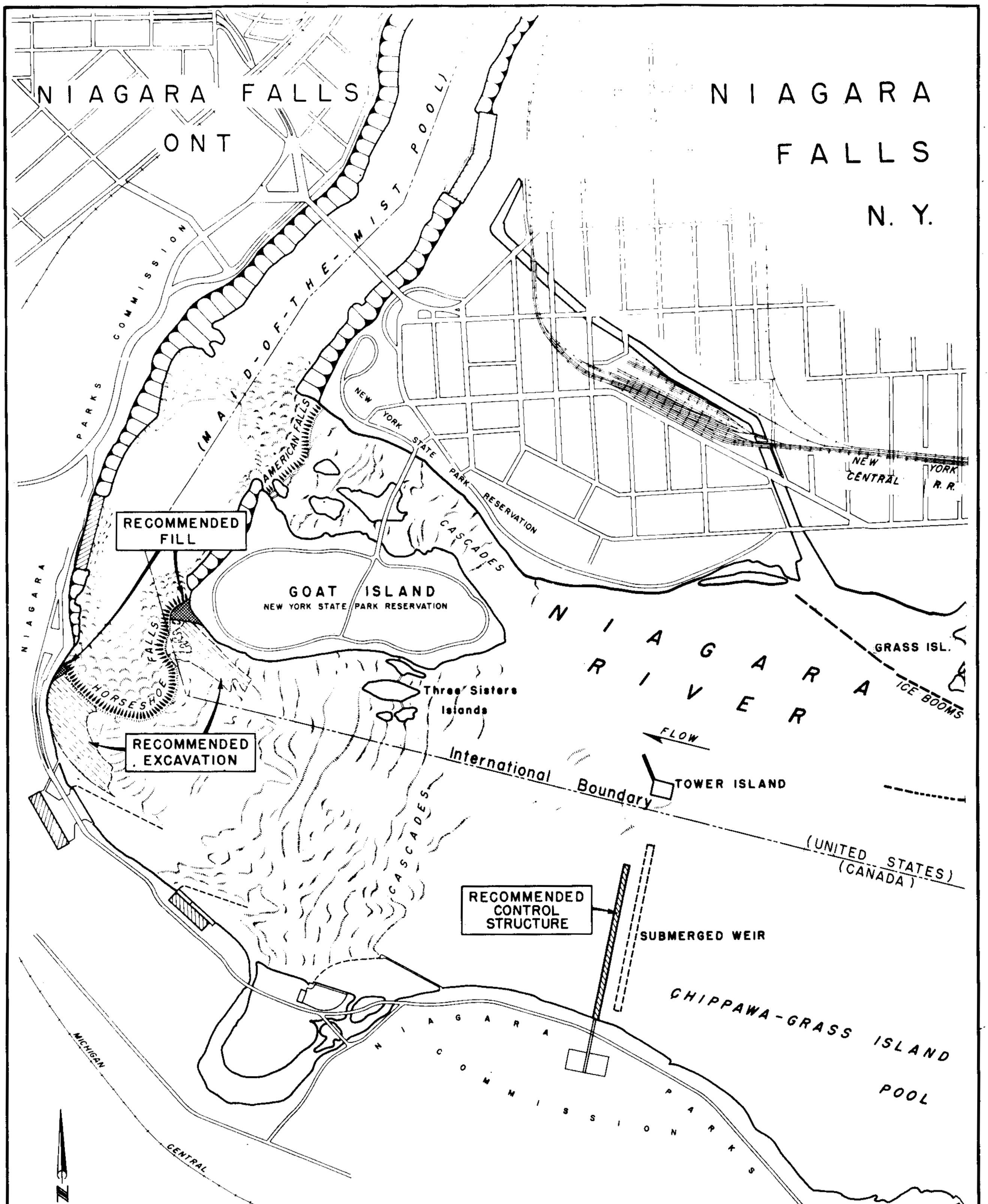
Nature and Extent of the Problem.

The vast storage capacity of the upper Great Lakes results in an unusually uniform flow in the Niagara. This flow and the concentration of fall at Niagara have created a scenic spectacle of unusual beauty and a hydroelectric power resource of great value. Both Canada and the United States have given attention over the years to the preservation and use of these assets.

In the Boundary Waters Treaty of 11 January, 1909, the two countries agreed to permit diversion of up to 56,000 cubic feet per second of the Niagara River flow for power purposes. To forestall possible adverse effects on the scenic beauty, a Special International Niagara Board was formed in 1926 to consider the problem. The Board recommended early construction of an initial phase of remedial works and outlined the further measures to be considered for preservation of the beauty of the falls under conditions which would permit more complete utilization of the hydroelectric potential.

With the growing need for power for defense activities the Governments of Canada and the United States concluded agreements in 1940 and 1941 to utilize on a temporary basis an additional 26,500 cubic feet per second of Niagara flow for power purposes. Pursuant to these agreements the initial phase of remedial works recommended by the Special International Niagara Board was accomplished by construction of a submerged weir in the Niagara River about one mile above the Horseshoe Falls during the period 1942 to 1947. The weir has substantially compensated for the lowering effect of the power diversions on the Chippawa-Grass Island Pool and has greatly increased the flow over the American Falls; but of course it has not improved the conditions on the flanks of the Horseshoe Falls.

In 1944 and 1948 the earlier agreements were modified to provide for small additional temporary diversions, and discussions which led to the Treaty of February 27, 1950, were commenced. By means of this Treaty the two Governments put into effect a revised permanent schedule of permissible power diversions under which the flow over the Falls may be reduced to not less than 100,000 cubic feet per second during the daylight hours of the tourist season and to not less than 50,000 cubic feet per second at any other time. Analyses and tests by the Board indicated that under these flow conditions the following objectionable conditions would result if remedial works were not provided:



PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

LOCATION PLAN OF RECOMMENDED REMEDIAL WORKS

INTERNATIONAL JOINT COMMISSION

The unusual river conditions at and in the vicinity of Niagara Falls, including high velocities of flow, great turbulence, and the risk that workmen might be swept downstream and over the Falls, made determination of water surface elevations, configuration of the riverbed, and hydraulic measurements extremely difficult. Nevertheless, by ingenious methods including use of helicopters, balloons, echo sounders, and searchlights, together with extra precautions with normal surveying equipment, thorough field surveys were made and adequate physical data for the design of the remedial works were obtained as described in the accompanying report of the Board.

The major phase of the engineering studies necessary for design of the remedial works was accomplished by means of hydraulic model studies. In order to cover all aspects of the problem and to utilize fully the available technical forces in both countries, two models were built. One model was constructed by the Corps of Engineers at its Waterways Experiment Station at Vicksburg, Mississippi. This model covered the entire upper Niagara River from Lake Erie to and including the Falls. The other model was constructed by The Hydro-Electric Power Commission of Ontario at Islington, near Toronto. This model was built to cover at the largest practicable scale the Falls proper and the Cascades and Pool area immediately above the Falls.

By use of the two models, complementary in coverage and providing a means of checking various tests, the full range of river conditions and numerous possible variations of remedial works were analysed and tested. The Commission is convinced that use of this important engineering tool made possible the design of the remedial works in a minimum of time and with maximum assurance of their adequacy.

As the model tests and design of remedial works neared completion, the Commission invited representatives of parks commissions and other interested agencies in both Canada and the United States to witness tests at the Islington model under typical conditions to be expected with and without the proposed remedial works. As a result of these demonstrations, representatives of these interests in general expressed their concurrence in the proposals for remedial works to preserve and enhance the scenic beauty of the Falls.

RECOMMENDED PLAN OF REMEDIAL WORKS.

The recommended plan of remedial works was developed as described in Section V of the Board's report. The complete plan consists of three separate works which, in the opinion of the Board, are necessary to ensure that the terms and intent of the 1950 Treaty will be fully met:

(a) A Chippawa-Grass Island Pool control structure.

(b) An excavation in the Horseshoe Cascades lying immediately upstream from the Canadian flank, and a crest fill 100 feet long on the Canadian flank extending out from the shore.

(c) An excavation in the Horseshoe Cascades lying immediately upstream from the Goat Island flank, and a crest fill 300 feet long on that flank extending out from the shore.

The location of the Chippawa-Grass Island Pool structure is shown in general on Plate 3 and in detail on Plate 6 of the Board's report. The structure would extend out from the Canadian shore some 1,500 feet into the river on a line parallel with the present submerged weir and 200 to 250 feet downstream therefrom. With the exception of an approach fill adjacent to the Canadian shore, the structure would consist entirely of piers and movable control gates.

The excavation in the Horseshoe Cascades in the area upstream from the Canadian flank will tap the deep stream that flows down the Canadian side of the Cascades and divert flow to the Canadian flank in quantities adequate to cover the flank and preserve the spectacle under all future conditions. The extent and grade of the excavation are shown in detail on Plate 7, the

Falls by the diversion of water from the deep channels leading into the central portion of the Horseshoe will reduce the rate of recession in the central portion.

CONCLUSIONS.

(a) Engineering studies and model tests show conclusively that remedial works are required to prevent impairment of the scenic beauty of Niagara Falls and River under flow conditions to be expected when withdrawals are made for power purposes to the extent permissible under the Treaty of February, 1950.

(b) Hydroelectric power works already under construction and scheduled for completion and operation within the next few years could not be fully utilized without detrimental effects on the beauty of the Falls unless remedial works are provided.

(c) In view of the urgent need for the power to be produced by generating facilities already under construction and other facilities to be constructed, initiation as soon as possible this year and completion within four years, of the remedial works authorized by the 1950 Treaty is a matter of urgency in the national interest of both countries.

The objectives for preservation and enhancement of Niagara Falls as contemplated by the 1950 Treaty can best be accomplished by construction of the remedial works described in this report and hereinafter recommended.

RECOMMENDATIONS.

In response to specific requests of the two Governments as set forth in the Reference, the Commission submits the following recommendations:

1. *Recommendations concerning the nature and design of the remedial works necessary to preserve and enhance the scenic beauty of the Niagara Falls and River.*

The Commission recommends the construction of the remedial works described in this report and in the Board's report which is attached hereto and made a part hereof, with such minor modifications as the Commission may deem advisable at the time of construction, the works to include:

(a) A Chippawa Grass Island Pool control structure, extending out from the Canadian shore approximately 1550 feet into the Niagara River, parallel to the existing submerged weir and about 225 feet downstream therefrom;

(b) An excavation in the Horseshoe Cascades lying immediately upstream from the Canadian flank of the Horseshoe Falls and a crest fill on that flank about 100 feet long; and,

(c) An excavation in the Horseshoe Cascades lying immediately upstream from the Goat Island flank of the Horseshoe Falls and a crest fill on that flank about 300 feet long.

2. *Recommendations concerning the allocation of the task of construction of the remedial works as between Canada and the United States of America.*

The Commission recommends that the task of construction be divided between the two countries in such manner that each country would construct, generally, those portions of the works which lie within its national boundaries. On this basis, Canada would construct the Chippawa-Grass Island Pool control structure and the excavation and crest fill on the Canadian flank of the Horseshoe Falls; and, the United States would construct the excavation and crest fill on the Goat Island flank of the Horseshoe Falls, including the small amount of excavation on the Canadian side of the Boundary.

estimated quantity involved being some 64,000 cubic yards of rock. As shown on Plate 7, the crest fill of 100 feet on the Canadian flank adjacent to the Canadian shore would extend upstream about 100 feet where it would merge with the present shoreline. It is contemplated that a concrete retaining wall, faced with stone to blend into the surroundings, would enclose this fill. Inside the wall, fill would be placed to the grade of the adjacent improved park area, and the whole landscaped to provide an attractive area for viewing the Cascades and Falls at close range.

The excavation in the Horseshoe Cascades on the Goat Island flank will divert an adequate volume of flow over that flank under all future conditions in a manner similar to that on the Canadian side. The extent and grade of this excavation is shown in detail on Plate 7, the estimated quantity involved being 24,000 cubic yards of rock. The 300 foot crest fill adjoining Goat Island would merge with the existing shoreline about 300 feet upstream. The extent of this fill is shown in detail on Plate 7. A concrete retaining wall suitably faced with rock would surround the fill which would be so graded as to be accessible from Goat Island. This area, suitably landscaped, would provide a much needed vantage point from which to view the Cascades and Falls. This fill is very similar to an improvement which it is understood has been under consideration by the Niagara Frontier State Park Commission.

RESULTS TO BE EXPECTED FROM REMEDIAL WORKS.

From the exhaustive and comprehensive series of engineering studies and model tests carried out on the proposed plan of remedial works at both Vicksburg and Islington, the Commission is confident that the proposed plan would fulfill the terms and intent of the 1950 Treaty. By operation of the gates in the proposed Chippawa-Grass Island Pool control structure, the same Pool level would be maintained in the future, under power diversions permitted by the 1950 Treaty, as would result from conditions above Niagara Falls since the completion in 1947 of the existing submerged weir, and under present power diversions. Such regulation would preserve the regimen of the river in the Chippawa-Grass Island Pool and upstream thereof and would ensure that Lake Erie levels and outflows would remain unaffected. Such regulation also would maintain sufficient flow over the American Falls to preserve the present satisfactory appearance which has prevailed since completion of the existing submerged weir in 1947. Adequate and scenically satisfactory flow conditions would exist at the head of Goat Island and in the vicinity of the Three Sisters Islands.

The design of the control structure is such that a total flow over the Falls of either 50,000 or 100,000 cubic feet per second as specified in the 1950 Treaty may be produced expeditiously at any time through the full range of Chippawa-Grass Island Pool levels without affecting the level of the Pool, thereby making available for power purposes the maximum amount of water. The control structure sluices equipped with gates which lower to open can be expected to pass low and normal runs of ice while maintaining proposed Pool levels, but in the event of an unusually heavy ice run, it is envisaged that all sluices would remain fully open during the run to minimize any obstruction to the floes. During such periods, which are usually of short duration, the normal regulation of the Pool would be suspended as the safe passage of ice is the more important consideration.

The proposed plan of excavations and crest fills in the Horseshoe Falls Cascades would ensure that in the daytime of the tourist season, when a minimum of 100,000 cubic feet per second is to be discharged over the Falls, an unbroken crestline on the Horseshoe Falls would extend from shore to shore and the intensity of flows on the flanks would always be sufficient to produce a very satisfactory scenic spectacle. In the other periods of the year, when a flow over the Falls as low as 50,000 cubic feet per second is permitted by the 1950 Treaty, these works would ensure that an unbroken crestline would always exist, and that the intensity of flow would be such that an impressive spectacle would result. The increasing of the flow over the flanks of the Horseshoe

As soon as cost data and other essential information are available in sufficient detail, a supplemental report on costs incurred through March 31, 1953, for remedial works will be submitted to the two Governments. On the basis of incomplete information now available, it appears that such costs might aggregate about two and one-half per cent of the estimated construction cost.

DIVISION OF COSTS.

Under the provisions of Article II of the Treaty the cost of the remedial works and the expense of operating and maintaining them are to be borne by the United States and Canada in equal moieties.

Signed this fifth day of May, 1953.

A. O. STANLEY

A. G. L. MCNAUGHTON

ROGER B. MCWHORTER

GEORGE SPENCE

EUGENE W. WEBER

J. LUCIEN DANSEREAU

3. The Commission further recommends that the construction of the proposed remedial works be initiated at the earliest possible moment and be pressed to completion as rapidly as possible. It is especially important that construction of the Chippawa-Grass Island Pool control structure be commenced immediately and that it be constructed to its ultimate length of approximately 1550 feet unless during the course of construction the status of prospective additional power diversion should permit consideration of a shorter structure initially. The excavation and fill on either flank of the Horseshoe Falls should be started as soon as possible and substantially completed before work is begun on excavation and fill on the other flank in order to minimize temporary adverse effects on the scenic spectacle during the construction period.

4. The Commission also recommends that the two Governments authorize it to establish a Control Board to supervise the operation of the proposed control structure to ensure accomplishment of its intended purposes and to ensure that the levels of the Niagara River and Lake Erie will not be adversely affected. These functions, deemed properly within the purview of the Commission, are closely related to the function of determining the amount of water available for the purposes of the Treaty of February 27, 1950. Accordingly, it would seem desirable and in the public interest that the representatives of the United States and Canada to be designated pursuant to Article VII of the Treaty be appointed by the Commission to serve also as members of the Control Board which the Commission desires to establish and hold responsible for the operation of the Chippawa-Grass Island Pool control structure.

Cost Estimates.

The construction cost of the remedial works (not including the comparatively small amount of pre-construction costs) is estimated to total $17,536,000 at July 1952 construction cost levels. A breakdown of this estimate is shown below:

Chippawa-Grass Island Pool Control Structure, 1550 Feet Long	$14,594,000
Excavation and Fill in the Cascades on the Canadian Flank of the Horseshoe Falls	1,582,000
Excavation and Fill in the Cascades on the Goat Island Flank of the Horseshoe Falls	1,360,000
Total	$17,536,000
Estimated Annual Cost of Operation and Maintenance of the Remedial Works	$100.000

Certain preliminary costs have been incurred under the terms of the Reference for surveys of the Niagara River between Lake Erie and the Falls and for other field investigations; also for two hydraulic models simulating the Niagara River above the Falls, one at Islington, Ontario, and the other at Vicksburg, Mississippi, and for much experimental work accomplished by the use of these models in connection with the design of the remedial works hereinbefore recommended; and for office studies and other activities incidental to determination of the most suitable types of remedial works. Inasmuch, however, as a part of this preliminary cost, particularly the costs incurred in connection with the hydraulic models, is chargeable to power development in both Canada and the United States, the duty of segregating the part thereof properly chargeable to remedial works, and determining the Canadian and United States costs properly chargeable thereto, is a duty which now devolves upon the Commission.

1 March, 1953.

TO: THE INTERNATIONAL JOINT COMMISSION

UNITED STATES AND CANADA

The International Niagara Falls Engineering Board submits herewith its report "Preservaton and Enhancement of Niagara Falls", dated 1 March, 1953, pursuant to the Commission's reference to the Board dated 16 January, 1951. This report concludes with recommendations for the type, location and timing of remedial and control works and for the division between the two countries of the task of constructing these works.

Respectfully submitted,

Members for the United States

COLONEL WENDELL P. TROWER,
Division Engineer,
Great Lakes Division,
Corps of Engineers,
Chicago, Illinois.

FRANCIS L. ADAMS,
Chief, Bureau of Power,
Federal Power Commission,
Washington, D.C.

Members for Canada

T. M. PATTERSON,
Assistant Chief,
Water Resources Division,
Department of Resources and Development,
Ottawa, Ontario.

G. A. LINDSAY,
Special Adviser to the Minister,
Department of Transport,
Ottawa, Ontario.

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

Report

to

The International Joint Commission

by

The International Niagara Falls Engineering Board

March 1, 1953

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PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

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2. In a reference dated October 10, 1950, the Governments of Canada and United States of America requested the International Joint Commission to investigate and make a report containing:

"(1) Recommendations concerning the nature and design of the remedial works necessary to enhance the beauty of the Falls in the Niagara River by distributing the waters so as to produce an unbroken crestline on the Falls, in accordance with the objectives envisaged in the final report submitted to Canada and the United States of America on December 11, 1929, by the Special International Niagara Board and bearing in mind the provisions for the diversion of the waters of the Niagara River and the apportionment thereof, which have been agreed upon by the two Governments in the Treaty of February 27, 1950, respecting the uses of the waters of the Niagara River.

"(2) Recommendations concerning the allocation of the task of construction of remedial works as between Canada and the United States of America, having regard to the recommendations made under paragraph (1).

"(3) An estimate of the costs of such remedial works."

3. The reference continues:

"In the conduct of its investigations, and otherwise in the performance of its duties under this reference, the International Joint Commission may utilize the services of engineers and other specially qualified personnel of technical agencies of Canada and the United States, and will so far as possible, make use of information and technical data which has been acquired by such technical agencies or which may become available during the course of the investigation, thus avoiding duplication of effort and unnecessary expense."

4. TERMS OF REFERENCE FROM INTERNATIONAL JOINT COMMISSION. — Under the authority thus given it, the Commission created the International Niagara Falls Engineering Board, all members of which were drawn from the technical agencies of the two governments. In the letter of reference from the International Joint Commission, the International Niagara Falls Engineering Board was directed to undertake the engineering investigation of the Niagara Falls and River necessary under the terms of the Treaty and to submit an adequate report to the Commission including preliminary designs of the recommended remedial works and an estimate of cost thereof. The Commission also desired the Board's recommendations concerning the allocation of tasks of construction of the remedial work as between Canada and the United States. The Board appointed a Working Committee and assigned to it the task of conducting the necessary investigations and compilation of data.

5. COMPOSITION OF INVESTIGATION BODIES. — The International Niagara Falls Engineering Board is composed of two representatives from each government. Colonel Wendell P. Trower, Division Engineer, Great Lakes Division, Corps of Engineers, and Mr. Francis L. Adams, Chief, Bureau of Power, Federal Power Commission are the United States members*. Mr. T. M. Patterson, Assistant Chief, Water Resources Division, Department of Resources and Development, and Mr. Guy A. Lindsay, Special Adviser to the Minister, Department of Transport, are the Canadian representatives*.

6. The Board appointed a Working Committee which comprises Colonel Philip R. Garges, District Engineer, Buffalo District, Corps of Engineers (who succeeded Colonel H. W. Schull, Jr.), and Mr. W. R. Farley, Chief of the Division of Licensed Projects, Bureau of Power, Federal Power

*Previous members of the board were: For the United States, Brigadier General W. E. Potter and Brigadier General C. H. Chorpening, Corps of Engineers, and Mr. Robert de Luccia, Federal Power Commission; and for Canada, Mr. Norman Marr, Department of Resources and Development.

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

SECTION I

INTRODUCTION

1. Authority. — A treaty concerning the uses of water of the Niagara River between the United States and Canada was signed at Washington, D.C. on February 27, 1950, approved by the Canadian Parliament on June 14, 1950, ratified by the United States Senate on August 9, 1950, and put into force by an exchange of ratifications between the two governments on October 10, 1950. The initial paragraph of the treaty states that the two governments recognize "their primary obligation to preserve and enhance the scenic beauty of the Niagara Falls and River". Article II of the treaty states "The United States of America and Canada agree to complete in accordance with the objectives envisaged in the final report submitted to the United States of America and Canada on December 11, 1929, by the Special International Niagara Board, the remedial works which are necessary to enhance the beauty of the Falls by distributing the waters so as to produce an unbroken crestline on the Falls. The United States of America and Canada shall request the International Joint Commission to make recommendations as to the nature and design of such remedial works and the allocation of the task of construction as between the United States of America and Canada . . . " Articles III, IV, V and VI are quoted in full below to furnish a clear understanding of the provisions for the diversion of the waters of the Niagara River which must be considered in investigating remedial works which are necessary to enhance the beauty of the Falls:

> "*Article* III. The amount of water which shall be available for the purposes included in Articles IV and V of this Treaty shall be the total outflow from Lake Erie to the Welland Canal and the Niagara River (including the Black Rock Canal) less the amount of water used and necessary for domestic and sanitary purposes and for the service of canals for the purposes of navigation. Waters which are being diverted into the natural drainage of the Great Lakes System through the existing Long Lac-Ogoki works shall continue to be governed by the notes exchanged between the Government of the United States of America and the Government of Canada at Washington on October 14 and 31 and November 7, 1940, and shall not be included in the waters allocated under the provisions of this Treaty."

> "*Article* IV. In order to reserve sufficient amounts of water in the Niagara River for scenic purposes, no diversions of the water specified in Article III of this Treaty shall be made for power purposes which will reduce the flow over Niagara Falls to less than one hundred thousand cubic feet per second each day between the hours of eight a.m., E.S.T., and ten p.m., E.S.T., during the period of each year beginning April 1 and ending September 15, both dates inclusive, or to less than one hundred thousand cubic feet per second each day between the hours of eight a.m., E.S.T., and eight p.m., E.S.T., during the period of each year beginning September 16 and ending October 31, both dates inclusive, or to less than fifty thousand cubic feet per second at any other time; the minimum rate of fifty thousand cubic feet per second to be increased when additional water is required for flushing ice above the Falls or through the rapids below the Falls. No diversion of the amounts of water, specified in this Article to flow over the Falls, shall be made for power purposes between the Falls and Lake Ontario."

> "*Article* V. All water specified in Article III of this Treaty in excess of water reserved for scenic purposes in Article IV may be diverted for power purposes."

> "*Article* VI. The waters made available for power purposes by the provisions of this Treaty shall be divided equally between the United States of America and Canada."

(d) *"Preservation of Niagara Falls."*

This report is a summarized statement of the operations of the United States Lake Survey Office under appropriation "Preservation of Niagara Falls" from June 29, 1906 to June 29, 1911. The report was prepared September 30, 1911 by Lt. Col. C. S. Riche, Corps of Engineers, the officer in charge of the "Survey of the Northern and Northwestern Lakes" in accordance with his instructions.

(e) *"Preservation of Scenic Beauty of Niagara Falls and of the Rapids of Niagara River."*

This exhaustive report was prepared by Col. Albert B. Jones, (then Lieutenant), Corps of Engineers, United States Army, August 26, 1919, and was published as Appendix "C" in the "Report on Investigation of Water Diversion from Great Lakes and Niagara River", by Col. J. G. Warren, Division Engineer, Lakes Division, Corps of Engineers, United States Army, August 30, 1919. Col. Jones' report exhaustively analyzed the conditions at Niagara with the objective of ascertaining what could be done to repair the existing damage to the beauty of the rapids and Falls and how much additional water might be permitted to be diverted, contingent upon the construction of remedial works, without injury to the scenic values.

(f) *"Report on Investigation of Water Diversion from Great Lakes and Niagara River."*

This report dated August 30, 1919 by Col. J. G. Warren, comments on the report of Col. A. B. Jones referred to above, and discusses the preservation of scenic beauty of Niagara Falls and the rapids of Niagara River, the problem of Niagara Falls, the character of the Horseshoe Falls, the erosion of the Horseshoe Falls, the Horseshoe Falls remedial works, the American Falls remedial works, the present effects of diversion on the Falls and rapids, and the allowable diversion around the Falls and rapids.

(g) *"Report of Board of Engineers for Rivers and Harbors."*

In a report dated August 24, 1920, the Board of Engineers for Rivers and Harbors, Brig. Gen. H. Taylor, Senior member reviews the report of the Division Engineer, Col. J. G. Warren, referred to above.

(h) *"Scenic Effects and Water Diversion."*

The Thirty-seventh Annual Report of the Commissioners for the Queen Victoria Niagara Falls Park for the fiscal year ending November 30, 1922, under the caption "Scenic Effects and Water Diversion" reviewed the early history of power development on the Canadian side of the Niagara River and the progress up to that date, which included the placing in operation of four generators in the Queenston-Chippawa plant. The report gives particular consideration to the question of preserving the scenic beauty of the Falls and river.

(i) *"The Preservation and Improvement of Niagara Falls and Rapids" by Special International Niagara Board, published in Canada as "The Preservation of Niagara Falls."*

This report, submitted to the Governments of the United States and Canada on December 11, 1929, (hereinafter referred to as "the 1928 report" for the purpose of brevity), covered a study of what quantity of water might be diverted for power and other purposes consistent with the preservation of the scenic beauty of the Falls and river. It recommended that the United States and Canada agree to the immediate construction of the initial remedial works recommended by the Board. This recommendation was approved by Canada but failed of ratification by the United States. By an exchange of notes dated October 27, 1941, the Governments of the United States and Canada agreed to commence the construction of remedial work in the Niagara River above Niagara Falls in 1942. Construction of a submerged weir in the Chippawa-Grass Island Pool, as part of the remedial works recommended by the Board, was approved by the President of the United States on January 27, 1942, and by the Prime Minister of Canada on February 28, 1942. Actual construction took place between 1942 and 1947, as explained in paragraph 17 below.

Commission, from the United States; Dr. Otto Holden, Assistant General Manager-Engineering, Hydro-Electric Power Commission of Ontario, and Mr. C. G. Cline, Senior Assistant Engineer, Water Resources Division, Department of Resources and Development, from Canada. The Board recognizes and acknowledges the major contribution that the Committee and its assistants made throughout the study and in the preparation of the report.

7. The engineering facilities and equipment of the U.S. Corps of Engineers at Buffalo, N.Y., the U.S. Lake Survey Office, the Waterways Experiment Station at Vicksburg, Miss., The Hydro-Electric Power Commission of Ontario, and the Canadian Departments of Resources and Development and of Transport were available to the Working Committee for its investigations. The Niagara-Mohawk Power Corporation, the Niagara Frontier State Park Commission at Niagara Falls, N.Y., and the Niagara Parks Commission, Niagara Falls, Ont., were helpful in furnishing data and otherwise co-operating.

8. Purpose and scope of this report. — The purpose of this report is to make recommendations concerning the nature and design of remedial works necessary to preserve and enhance the scenic beauty of Niagara Falls by distributing the flow of Niagara River waters so as to produce an unbroken crestline in accordance with the instructions from the International Joint Commission. The Board interpreted the instructions to include works to compensate for the effects of additional diversions for power purposes on water levels above the Cascades and the consequent effects on the scenic spectacle of the Cascades and Falls. There is recommended herein a plan that would accomplish these objectives together with recommendations as to the allocation of tasks of construction between the two governments.

9. Previous investigations into the preservation of Niagara Falls. — Many earlier investigations have been made into the conditions at the Falls which have had a bearing on their recession and preservation. Among the more important of the previous investigations are the following:

(a) *"Notes on the Retrocession of Niagara Falls."*

This report was prepared by J. C. K. Laflamme, Professor of Geology, Laval University, Quebec, November 9, 1905, at the request of the Canadian Section of the International Waterways Commission. The purpose of the report was to determine whether the cataract would continue to recede at a rate equal to that observed since 1842.

(b) *"Report of the American Members of the International Waterways Commission Regarding the Preservation of Niagara Falls."*

This report, dated March 19, 1906, was prepared following and in accord with a resolution of the Senate and House of Representatives of the United States. The report reviewed the then existing and prospective diversions from the Falls and river and recorded what action was, in the Commissioners' opinion, necessary and desirable to prevent the further depletion of water flowing over Niagara Falls.

(c) *"Preservation of Niagara Falls."*

This report, covering the investigatory work of the United States Lake Survey along the Niagara River during the years 1906, 1907 and 1908, was prepared by F. C. Shenehon, Principal Assistant Engineer, and under a covering report, dated November 30, 1908, by Major C. Keller, Corps of Engineers, was presented to the Chief of Engineers, United States Army. The investigation was undertaken under allotments from the Congressional appropriation of June 29, 1906, with a view to ascertaining the effects of diversions from the Niagara River upon Lake Erie, the river, Falls and rapids. It had also the purpose of ascertaining the amounts of water being diverted by the different companies on the United States side of the river.

SECTION II

DESCRIPTION

11. GENERAL AREA. — The Niagara River carries the surplus water of the upper Great Lakes seaward from Lake Erie to Lake Ontario. The mean flow of the river is about 200,000 cubic feet per second and because of the immense storage capacity of the upper lakes the flow is remarkably steady although it does vary somewhat from day to day, from season to season and from year to year. The normal flow is increased by a few thousand cubic feet per second which are diverted into Lake Superior from the Albany River watershed in Canada; and it is reduced by somewhat similar amounts diverted by the Chicago Sanitary and Ship Canal from Lake Michigan into the Mississippi River, and by the Welland Canal and the New York State Barge Canal directly into Lake Ontario. Detailed figures for the flow in the river and in these various diversions are given in Section III.

12. The Niagara River drops from a mean elevation of 572 feet above sea level at Lake Erie to 246 feet at Lake Ontario. This drop of 326 feet in a river with such a great discharge is primarily responsible for giving the river its unique character. The total length of the river is 36 miles but because of the nature of the geological formation most of the drop occurs in an eight-mile distance between Chippawa and Queenston, about half of it at the Falls and an additional 140 feet in the rapids above and below the Falls. This concentration of fall in a relatively short distance, combined with the great and steady flow of the river, makes possible the economical development of hydro-electric power.

13. The Falls of the Niagara and the surroundings constitute one of the most famous scenic wonders of the world, exciting the awe and admiration of all beholders. For more than two centuries they have been attracting visitors from every part of the globe and in ever increasing numbers.

14. UPPER NIAGARA RIVER. — The Niagara River flows north out of the northeast corner of Lake Erie near Buffalo Harbour through a funnel-shaped entrance much obstructed by shoals. For the first two miles, it is little more than 1,500 feet wide with a maximum depth of 20 feet and velocities as high as eight miles per hour. The Peace Bridge crosses near the head of the river and the International Railway Bridge spans it two miles farther downstream. This part of the river is paralleled by the Black Rock Canal, with a lift of some five feet, which permits the passage of vessels between Buffalo Harbour and the Niagara River near the foot of Squaw Island.

15. Below Squaw Island, the river widens and the current decreases. Two miles below the island, the river is divided into two channels by Grand Island, the Canadian channel being 10 miles long and the American, or Tonawanda channel, 13 miles long. The current in both channels is moderate and both are navigable. Two high-level bridges cross the Tonawanda channel, connecting Grand Island with the mainland. A 21-foot channel has been dredged in the river from the Black Rock Canal to Tonawanda and a 12-foot channel from there to docks at Conners Island, Niagara Falls, N.Y. The New York State Barge Canal starts from the Niagara River at Tonawanda and connects with Lake Ontario at Oswego and the Hudson River near Albany. The water it diverts from the Niagara River is returned to Lake Ontario.

16. The four miles of river from the lower end of Grand Island to the head of the Cascades, opposite the upstream end of Goat Island, is known as the Chippawa-Grass Island Pool. Here the river flows in a westerly direction, as shown on Plate 3. At present, there are three intakes diverting water from the Pool for power purposes: the Adams and Schoellkopf intakes near Grass

10. INVESTIGATION BY PRESENT BOARD. — The study of the present Board required the securing of definite information as to the physical and hydraulic conditions in the Cascades and at the crest of the Falls. Unique methods of surveying were used to obtain much needed physical data in heretofore inaccessible areas. These data were used to construct two models of the Niagara River: one by the Corps of Engineers at the Waterways Experiment Station at Vicksburg, Miss.; and the other by The Hydro-Electric Power Commission of Ontario at its Islington Service Center. Studies were made on these models of the effects of various diversions and locations and types of remedial and compensating works. The results of these studies, the recommended remedial and compensating works, estimates of costs, and recommendations as to the allocation of the task of construction between the United States and Canadian Governments are presented in the following sections and appendices.

adds greatly to the appearance. The colour is uniform wherever the depth is greater than five feet. This matter of the colour of the Falls is discussed in considerable detail in Appendix D of the 1928 report.

21. The Horseshoe Falls is at the head of a gorge that has been formed by the recession of the Falls. As explained in detail in Appendix E of the 1928 report, the upper layers of rock at the crest are of limestone, hard and resistant, whereas the lower layers are chiefly shales and sandstones, comparatively weak and easily eroded. As the softer rock is worn away below, the hard upper beds are undermined and from time to time sections break away and the crest is modified. In the central portion of the Horseshoe, the rate of recession was 4.2 feet per year from 1842 to 1905-06 and 3.2 feet per year from 1905-06 to 1927. Plate 4 shows a maximum recession of 50 feet from 1927 to 1950, which is at the rate of 2.2 feet per year. These figures indicate that the rate has been less since 1906 than it was during the preceding 60 years. In the 1928 report, it was noted that the tendency would be for the rate of recession to decrease in the future, except possibly during the following 50 years, mainly because the limestone strata are thicker upstream and because the two main streams which once actually joined near the toe of the Horseshoe are being separated more and more as the Falls recede. The increase in the diversion for power from 10,000 cubic feet per second in 1906 to about 85,000 in 1949 has made a corresponding decrease in the flow over the Falls. This reduction in Falls flow, coincident with the reduction in the rate of recession, is confirmation of the theory that the rate of recession varies with the flow over the Falls.

22. Since the American and the Horseshoe Falls parted company as the latter receded upstream, the recession at the American Falls has been very slow. The relatively small flow is distributed very evenly along the 1,100 feet of crest so that the discharge per foot rarely exceeds 20 cubic feet per second as compared with a maximum of 200 at the Horseshoe. This small rate of flow is not sufficient to cut through the sandstone stratum at the foot of the Falls so that the masses of rock that fell from the cliff accumulated to form a talus on this shelf. The undermining of the capping limestone, which is essential to maintain the vertical character of the Falls, is still continued by the action of the falling water and wind-driven spray. Until 1931 the crest of the Falls had not receded much faster than the weathering of the adjacent dry walls of the gorge. On January 17, 1931, a large mass of rock fell near the center of the Falls. This sudden recession extended along the crest for 300 feet with a maximum depth of 70 feet, as shown by the space between the 1927 and 1950 crestlines on Plate 5. The debris piled on top of the original talus and increased its height at this point by some 25 feet.

23. It should be pointed out that this sudden fall of rock was not caused by the increase in flow due to the submerged weir, because it occurred 10 years before the weir was started. It is a dramatic illustration of the fact that the recession at both Falls occurs as sudden breaks, of greater or lesser extent, rather than as a steady grinding away of the crest. On that account, the amount of erosion observed during a period of 10 or 20 years, or even more, might not give a reliable measure of the actual mean rate of recession.

24. Maid-of-the-Mist Pool. — The Niagara Gorge extends for seven miles downstream from the Horseshoe Falls to the foot of the escarpment at Queenston where it is thought that the Falls originated. The upper two and one-quarter miles of river extending downstream from the Falls to the railway bridges is known as the Maid-of-the-Mist Pool. It has a fall of only five feet and is navigable for practically the entire distance. Soundings show maximum depths of from 150 to 187 feet, though there are spots where great masses of rock come within a few feet of the surface. The elevation of the water in the Pool is regulated by the constriction in the channel at the head of Whirlpool Rapids.

Island on the United States side of the river, and the intake for the Sir Adam Beck No. 1 plant at Chippawa on the Canadian side. Present planning for plants based on the increased diversions permissible under the Treaty of 1950 contemplates taking the water from this Pool. Just below the Chippawa intake, work has been started on the intake for the Sir Adam Beck No. 2 plant. The intake for the plant to be built on the United States side of the river is to be located near Conners Island.

17. During the years 1942 to 1947, the submerged weir mentioned in paragraph 9(i) was built near the lower end of the Pool in the main channel leading to the Horseshoe Falls as shown on Plate 3. The weir was built by dropping large blocks of rock from a cableway 2,600 feet long spanning this part of the river. One tower of the cableway was erected on the Canadian shore and the other on an artificial island, known as Tower Island, which was built in shallow water 2,000 feet upstream from the upper end of Goat Island and connected with it by a temporary causeway. The weir was built to restore the major portion of the lowering of the Chippawa-Grass Island Pool which had been caused by diversions. It has improved intake conditions, especially during ice runs, and has increased the flow over the American Falls. The mean elevation of the crest of the weir is 553.5 feet above mean tide at New York (U.S.L.S. 1935 datum) and at ordinary stages there are six feet of water flowing over the crest. Full details of the design and construction of the weir are given in a report titled "Niagara River Remedial Works, Submerged Weir", dated September 1, 1948, which was submitted by a construction subcommittee to the United States St. Lawrence Advisory Committee and the Canadian Temporary Great Lakes-St. Lawrence Basin Committee.

18. NIAGARA CASCADES AND FALLS. — Goat Island divides the river into two channels, each half a mile long, one leading to the Horseshoe Falls, the other to the American Falls. In each channel, the water flows over ledges of limestone, scattered boulders and broken rock to form cascades and rapids with a total drop of about 50 feet. The uppermost ledge of rock acts as a natural weir to control the flow of water over it. Before the construction of the submerged weir, only five percent of the total flow over these ledges went down the channel leading to the American Falls, but this proportion was nearly doubled by the building of the weir.

19. At the head of the Cascades, the channel leading to the Horseshoe Falls is 3,200 feet wide but at the Falls the distance between the two shores is only 1,200 feet. In some places there are depths of from 6 to 12 feet but there are also several small islands and a number of shoals due to the irregular distribution of the ledges and boulders. In particular, there is a large central shoal dividing the flow into two main channels, one near each shore, which converge toward the central part of the Horseshoe. The Ontario Power Company, the Toronto Power Company and the Canadian Niagara Power Company plants have their intakes along the Canadian shore, the Ontario near the head of the Cascades and the other two farther downstream, as shown on Plate 3.

20. At the Horseshoe Falls, there is a straight drop of about 160 feet. The crest still retains the shape of a somewhat distorted horseshoe, from which it derives its name. The distance from shore to shore, as mentioned above, is 1,200 feet but the total length of the crest measured around the Horseshoe is 2,500 feet. The crest has been lengthening gradually and in the past 100 years this increase has amounted to as much as 100 feet, because the central portion has been receding faster than the ends. Near each shore, the depth of water flowing over the crest is less than one foot and the normal colour of the falling sheet of water is white, except when the water is discoloured after storms or heavy rains. Toward the center of the Horseshoe, the depth increases to a maximum of 12 feet with a discharge of 200 cubic feet per second per foot of crest. As the depth at the crest increases to four or five feet, a greenish colour mingles with the white and

not be very thick, "shelving" may take place. "Shelving" is the result of cakes riding over or diving beneath those already lodged, thereby forming a jam of considerable depth. During cold weather, the jam is consolidated and strengthened and may cause some reduction in the flow of the river. During mild weather, the jam loosens and may break up and go down stream, especially if there is a strong westerly wind. Some winters there may be a run of ice during January or February but other winters most of the ice may remain in the lake until April or early May. A heavy accumulation of ice at the eastern end of the lake is a potential hazard and its sudden discharge down the river by a change in weather may cause disastrous jams farther downstream. However, commonly the ice is fed down the river more or less gradually, so that the carrying capacity of the river is not exceeded and little difficulty results. Some springs, an easterly wind may blow much of the ice toward the west end of the lake where it may disintegrate.

32. A light run of ice may be carried downstream and over the Falls without being held up at any point. With a westerly wind, much of the ice will be blown into the Tonawanda channel. With a heavy run or a strong southwesterly wind, ice may collect along the United States side of the river in the Chippawa-Grass Island Pool and at times this has caused a temporary reduction in the power output at the Adams and Schoellkopf plants on that side of the river. At the Chippawa intake on the Canadian side there has been no trouble from ice.

33. At ordinary river stages, there is an average depth of six feet of water over the submerged weir. Thin fields of ice pass freely over it but heavy masses lodge temporarily on the crest and tend to collect more ice behind them.

34. At the three power plants with intakes in the rapids above the Horseshoe Falls along the Canadian shore there is usually some trouble with ice every winter, the Toronto Power plant having the least trouble and the Canadian Niagara Power plant the most. At this latter plant, intake conditions were improved by the construction of a gathering weir in 1936-37 which extends 900 feet from shore out to swift, deep water.

35. Practically every winter, ice that has come over the Falls collects in the Maid-of-the-Mist Pool opposite the American Falls to form what is known as the "Ice Bridge". The ice often extends upstream almost to the foot of the Horseshoe Falls but it rarely extends as far downstream as the Schoellkopf power plant except when it is breaking up and moving downstream. On two occasions, April 9, 1909 and January 28, 1938, ice and water flowed in through the windows and flooded the Ontario Power plant. Also, on the latter date, the ice rose so high it destroyed the International Railway Company Bridge. The footings for the present Rainbow Bridge have been set at a much higher elevation to escape damage from ice.

36. When ice is running in the river, there is always the possibility that anything that prevents the free flow of the ice into Lake Ontario, such as an upstream wind, may cause the start of a jam either on the shoals or farther upstream between Niagara-on-the-Lake and Queenston. If the ice run is heavy and the weather continues cold, this jam may build up beyond the Queenston-Lewiston Bridge and remain in place for weeks. Several times the jam has extended upstream past the Sir Adam Beck No. 1 power plant and in 1909 it reached above the Whirlpool. This causes a considerable rise in the tailwater at the plant with a proportionate reduction in output but the interior of the plant has never been flooded. Ice conditions on the Niagara River have been discussed in greater detail in Appendix G of the 1928 report.

25. Two power plants have been built beside the Pool and discharge their tailwater directly into it: the Ontario plant on the Canadian side near the Horseshoe Falls and the Schoellkopf plant on the United States side below the Rainbow Bridge. Three other plants discharge into the Pool through tunnels: the tunnel from the Toronto plant discharges behind the curtain of the Horseshoe Falls, that from the Canadian Niagara between the Falls and the Ontario Power plant, and that from the Adams station, on the United States side of the river, a short distance upstream from the Rainbow Bridge.

26. Whirlpool and Rapids. — The Whirlpool Rapids and the Whirlpool differ from the rest of the Gorge because the present river at this point intersects an old channel, probably formed by a river in glacial time and later filled with glacial drift. The present river, by re-excavating this unconsolidated material causes a marked enlargement at this juncture thereby forming the present Whirlpool. In the Whirlpool Rapids, in a distance of less than a mile from the railway bridges to the Whirlpool, the river drops 50 feet with maximum velocities of 30 feet per second. The water dashes over huge masses of rock and forms great breakers and standing waves. However, in spite of the high velocities, there is little erosion in the rapids at present, probably because the blocks of rock are too great to be moved by the current.

27. The Whirlpool is a basin 1,700 feet long and 1,200 feet wide, with a maximum depth of 125 feet. Here the river makes a right-angled turn. The water enters the Whirlpool at high velocity and most of the flow rushes past the outlet to the far side of the Pool, makes a complete circuit counter-clockwise, and escapes through the narrow outlet by passing under the incoming stream. The cables of the Spanish Aero-car span the Whirlpool to give passengers a view of the Whirlpool and Rapids.

28. Below the Whirlpool, there is another two miles of rapids with a drop of 40 feet. At Niagara Glen opposite Foster's Flats, the river is only 300 feet wide and is shallow and turbulent. Below this point, the river becomes wider and deeper with diminishing velocity so that the stream is comparatively quiet by the time it reaches the Queenston-Lewiston Bridge. The Sir Adam Beck No. 1 power plant is located one mile above the bridge and just above this plant, the No. 2 plant is under construction. The new plants to be built on the United States side are to be located in this part of the river also.

29. Lower Niagara River. — At Queenston the river emerges from the Gorge. It spreads out to a width of 2,000 feet and is navigable for the six miles from the Queenston-Lewiston Bridge to Lake Ontario at Niagara-on-the-Lake. The main channel where it enters the lake is 30 feet deep but it is narrow and crooked and is surrounded by large areas of sand bars where the depth is only 10 to 15 feet.

30. Ice conditions. — Usually by the last week in December, the temperature of the surface water in Lake Erie and the Niagara River drops to freezing and ice starts to form. The amount of ice and the amount of trouble resulting from it depends upon the temperature, and the force and direction of the wind, but very little difficulty has been experienced from ice that forms in the river. Ice formed on Lake Erie during periods of low temperature is sometimes broken up by natural causes and carried towards the head of the river by the set of the current and the action of the prevailing winds. A strong wind from the west or southwest usually raises the elevation of the water at Buffalo and this allows the ice to pass over the shoals and go down the river. This is the ice which causes the greatest difficulty in the Falls region.

31. However, if the water level at Buffalo remains normal, much of the ice will lodge on the shoals and gradually build up a jam at the head of the river. While ice cakes themselves may

Additional water is diverted from Lake Erie through the upper part of the canal for the operation of the DeCew Falls plant of The Hydro-Electric Power Commission of Ontario. Present diversions average about 7,500 cubic feet per second of which 1,100 is for operation of the canal and 6,400 for power generation. These rates are used for the purpose of this report.

42. POWER DIVERSIONS. —

(a) *Prior to 1950 Treaty.* — Prior to the signing of the 1950 Treaty, diversions for power were made above the Cascades for the Schoellkopf and Adams plants on the United States side of the river and for the Sir Adam Beck No. 1 (formerly Queenston) plant on the Canadian side. Additional Canadian diversions for the Toronto, Canadian-Niagara, and Ontario plants were made in the Cascades reach. The DeCew plant obtained water diverted from Lake Erie via the Welland Canal. Diversions were limited by the 1909 Treaty to 36,000 cubic feet per second by Canada and 20,000 by the United States. Under the exigencies of World War II, temporary additional diversions were authorized in 1940, 1941, 1944 and 1948. These authorizations, which increased the allowable diversions to 56,500 cubic feet per second by Canada and to 32,500 by the United States, were sufficient to permit all the plants on the Niagara River to operate at full capacity. If present power and other diversions referred to in paragraphs 38 to 41, inclusive, had been in effect during the whole period from 1860 to 1951, the average flow over the Falls would have been 124,000 cubic feet per second during the tourist season and 111,000 during the non-tourist season.

(b) *Intermediate period.* — For the purposes of this report, the intermediate period is defined as the period between the completion of the current construction of the Canadian Sir Adam Beck No. 2 plant scheduled to deliver power in 1954 and the completion of the proposed Conners Island-Lewiston plant not yet authorized. Capacity diversions or the maximum water demand through Canadian power plants during this intermediate period will be about 100,000 cubic feet per second of which 64,000 will be diverted through plants whose intakes are located in the Chippawa-Grass Island Pool and 36,000 through the plants with intakes in the Cascades. Capacity diversions through United States plants would be 32,500 cubic feet per second as at present. With these capacity diversions, the flow over the Falls will be 100,000 cubic feet per second for 92 percent of the tourist season days and somewhat higher for the remaining eight percent. The flow over the Falls will be 50,000 cubic feet per second for 16 percent of the non-tourist season and tourist season nights and above 50,000 cubic feet per second for 84 percent of the time. The average flow over the Falls will be 101,000 cubic feet per second during the tourist season days and 70,000 cubic feet per second at all other times.

(c) *Future period.* — The future period for the purposes of this report is defined as the period following the completion of the proposed Conners Island-Lewiston plant. At that time, capacity diversions through United States plants would be about 100,000 cubic feet per second, all of which would be diverted from the Chippawa-Grass Island Pool. Capacity diversions through Canadian plants would also be about 100,000 cubic feet per second, of which 64,000 will be diverted through plants whose intakes are located in the Chippawa-Grass Island Pool and 36,000 through plants with intakes in the Cascades, the same as for the intermediate period. Capacity diversions by all power plants, about 200,000 cubic feet per second, could take place whenever the discharge of the Niagara River exceeded 300,000 cubic feet per second during tourist season days and 250,000 at other times. Since the flow of the Niagara River, after allowing for authorized diversions above the power intakes, infrequently exceeds 250,000 cubic feet per second, the diversions for power, in general, would be limited to the flow in excess of Treaty requirements for flow over the Falls rather than by the capacity of the power facilities. Accordingly, the diversions for power would be limited so as to result in a flow over the Falls of 100,000 cubic feet per second during the tourist season days and 50,000 cubic feet per second during the remainder of the time.

FLOW AND HYDRAULICS OF NIAGARA RIVER

SECTION III

37. General characteristics of flow. — The flow of the Niagara River varies with the level of Lake Erie due to the presence of a rock ledge at the lake outlet at Buffalo which acts as a submerged weir. Due to the large area of the watershed and the immense storage capacity of the upper lakes, the Niagara River has a more uniform flow than most streams. However, fluctuations of lake level and river flow do occur throughout the year due to seasonal variations in the inflow. Also, there are long term fluctuations which are due to the abundance or deficiency of precipitation in the watershed of the upper lakes over a period of several years as is evidenced by the present high lake levels and the low levels during the drought years of the 1930's. The annual cycle is quite regular but there does not seem to be any predictable regularity in the long term fluctuations. In addition, temporary fluctuations in discharge occur which are caused mainly by changes in the velocity and direction of the wind and by differences in barometric pressure at the two ends of Lake Erie. The natural flow of the river is modified to a small degree by diversions into and from the watershed of the upper lakes. Diversions from the Albany River watershed into Lake Superior are made by The Hydro-Electric Power Commission of Ontario from the Ogoki River and at Long Lake. Water is diverted from Lake Michigan into the Mississippi River through the Chicago Sanitary and Ship Canal (Illinois Waterway). Also, the flow of the Niagara River is decreased by the diversion of water from Lake Erie into Lake Ontario through the Welland Canal and the New York State Barge Canal. Diversions for power at Niagara Falls reduce the flow through the Cascades and over the Falls. Each of these diversions is described briefly in the following paragraphs and more fully in Appendix A which includes also the records of past diversions.

38. Long Lake - Ogoki River. — Diversions into Lake Superior from the Hudson Bay watershed via the Long Lake project and Ogoki project began in 1939 and 1943, respectively. Water diverted from the Ogoki River is retained in Lake Nipigon until required for generation of power in Nipigon River. The water diverted from Long Lake is used at a power development in Aguasabon River. Diversions have averaged 5,000 cubic feet per second in recent years and this rate is used for the purpose of the design of remedial works in this report.

39. Chicago Sanitary and Ship Canal. — The Chicago Sanitary and Ship Canal between the Chicago River and the Des Plaines River forms a portion of the Illinois Waterway connecting Lake Michigan and the Mississippi River. The flow of water in the canal is controlled by a dam and gates at Lockport, Illinois. The annual average diversion from Lake Michigan through the Chicago Sanitary and Ship Canal is limited, by the decree of the United States Supreme Court on April 21, 1930, to 1,500 cubic feet per second in addition to domestic pumpage. Present total diversions are approximately 3,100 cubic feet per second and this rate is used for the purpose of the design of remedial works in this report.

40. New York State Canals. — The New York State Barge Canal forms a shallow draft connection between Lake Erie, Lake Ontario, and the Hudson River. Water is diverted from the Niagara River at Tonawanda and returned to Lake Ontario. While no record of diversions is kept, it is estimated that the amount of diversion during the navigation and winter seasons is 1,100 and 750 cubic feet per second, respectively. These rates are used for the purpose of this report.

41. Welland Canal. — The Welland Canal between Port Colborne on Lake Erie and Port Weller on Lake Ontario forms a deep draft connection between the two lakes. The summit is at the level of Lake Erie and water is diverted from the lake for the operation of the canal.

54. A reservoir below the model contains the water supply which is pumped up to a constant head tank and released into three channels at the upstream end of the model through three pipes, each of which is equipped with controlling and measuring devices. These channels represent the three parts into which the river is divided by Grand and Navy Islands and the flow through each channel is kept regulated to the proper proportion of the total river flow as determined by current meterings on the prototype. The water, after it flows through the model, is returned to the reservoir to be used again. A more detailed description of this model and of the verification tests of the portion above the Cascades is given in Appendix E; the verification of the Cascades section of both models is described in Appendix F.

55. Appearance of models. — Because of the great width of the river and the relatively shallow depth, it was necessary to distort the vertical scale of both models in order to reproduce the proper flow pattern and to enable depths to be measured with greater accuracy. To reproduce the proper river bed roughness in the area above the Cascades, a wire screen was fitted to the bed of each model. In the Cascades area, it was found necessary to embed small, upright metal strips to give the required degree of roughness so as to reproduce a turbulence similar to that in the prototype. These mechanical additions, while necessary for hydraulic reasons, mar the appearance of the models. This unavoidable limitation must be kept in mind when comparing the appearance of model and prototype. The model is an instrument, primarily, for measuring distribution of flow, not for direct comparison of natural beauty. If the model shows a certain flow over the Falls, the best way to judge the corresponding appearance is to inspect photographs showing the same flow, or nearly the same, in the prototype.

56. Effects of increased diversions. — Following the satisfactory verification of the two models, tests were made to determine the conditions which would exist under future increased diversions permitted under the Treaty of 1950 if no remedial works were constructed. These tests are reported in detail in Appendices D and E. The conditions which the model tests indicate would occur without remedial works under future maximum permissible diversions outlined in paragraph 42 (c) are described in paragraph 62.

43. THE USE OF HYDRAULIC MODELS. — In previous reports, investigators were of the opinion that it is practicable to design and construct works in the Cascades with a view to redistributing the flow over the crest of the Falls. However, there was serious difference of opinion as to the utility of hydraulic models for making such designs and in particular about the possibility of making surveys of the river bed in this area unless it could be unwatered. There was even some doubt whether experiments upon an accurate model could be expected to give more than a general idea of the effects which would follow any given design of remedial works, especially where weirs were involved. Because of this, the 1928 report recommended a step by step process of construction of a combination of submerged weirs and excavations with observation of the results after each step to guide in the design of the next step.

44. In recent times, however, the hydraulic model has gained recognition as a new and valuable tool of engineering design. Successful methods and techniques have been developed and an impressive record of accomplishment has proven the reliability of conclusions drawn from model studies. Where applicable, such studies constitute a reliable method of solving hydraulic problems at a minimum expenditure of time and money.

45. The advantage of using this new tool in the investigation of the Niagara remedial works was evident. Any given river flow, past, present or future, could be simulated at will. Remedial works in miniature could be inserted in the model and their performance studied under the full range of river conditions. It was necessary to settle two important questions: (1) future conditions in the river if no remedial works were constructed; (2) the location and design of remedial works that would correct these conditions so as to preserve and in some measure enhance the beauty of the Falls. The Engineering Board was of the opinion that only by model tests could reliable information of this nature be obtained.

46. In view of the far-reaching importance of the matters at issue and because of the uniqueness and complexity of the problem, it was realized that using two models would offer many advantages. The preservation of Niagara Falls is an international matter and both countries must be satisfied as to the validity of the solution proposed. Also, it would be unwise not to make use of all the facilities available in both countries. The use of two models, similar but not exactly the same, would make possible a constant check on test findings and assure the certainty and accuracy of the results obtained. Other advantages of two models are indicated in paragraph 49.

47. SURVEYS. — The problems of obtaining the water surface and river bed surveys for the models were unprecedented. Conventional survey methods coupled with the use of an echo sounder were suitable for the section of the river from Lake Erie to near the head of the Cascades but the section from there to the crest of the Falls required a totally new approach because the great width of the river combined with a drop of 50 feet in less than a mile with the consequent high velocities and turbulence made ordinary survey methods impossible. The problem was solved by developing unusual survey methods which combined modern science with ingenuity in making use of helicopters, balloons and searchlights, as described in detail in Appendix B.

48. HYDRAULIC STUDIES. — In addition to the surveys referred to above, it was necessary to have accurate information on the hydraulic characteristics of the prototype so that the models could be adjusted to perform in the same manner. The factors affecting the levels at each of the existing automatic gauge installations were studied and equations were derived which expressed the levels in terms of these factors. It was then possible to determine water surface profiles under various river discharges and amounts of diversions. This study is described in detail in Appendix C. In this same appendix there is also a study of the division of flow around Goat Island.

62. The most important change since the 1928 report is the increase in authorized diversions for power made imminent by the 1950 Treaty. Upon completion of the new power developments made possible by the Treaty, the flow over the Falls may be reduced to 100,000 cubic feet per second during the daylight hours of the tourist season and to 50,000 cubic feet per second at other times as indicated in paragraph 42 (c). Tests on the models under these flow conditions, presented in detail in Appendices D and E, indicate that without additional remedial works the following conditions would occur:

(a) The Chippawa-Grass Island Pool level would drop as much as four feet below its present normal elevation, thereby exposing considerable areas of the river bed presently covered, particularly in the vicinity of the head of Goat Island. During the tourist season days, the drop would vary from zero to three feet depending on river discharge, and during the non-tourist season and the tourist season nights from two to four feet. The general lowering of this Pool would result in some lowering of levels of Lake Erie.

(b) Because of the lowering of the Pool level, the flow over the American Falls would drop well below that necessary for a satisfactory scenic spectacle. Under present conditions with an average river discharge of 200,000 cubic feet per second, the flow over the American Falls is about 11,500 cubic feet per second. Under future maximum permissible diversions, the flow over the American Falls with the same river discharge would be only 4,600 cubic feet per second during the tourist season days and 2,500 cubic feet per second at other times.

(c) Under future maximum permissible diversions the Horseshoe Falls would have a flow of only about 95,000 cubic feet per second during tourist season days, making the conditions at the flanks unsatisfactory. During the non-tourist season and the night hours of the tourist season, the flow over the Horseshoe Falls would be only 47,000 cubic feet per second at average river discharge leaving the flanks dry. Even under existing conditions the flow over the Horseshoe Falls averages 105,000 cubic feet per second for which flow the flanks are inadequately covered.

(d) The necessary change in the Chippawa-Grass Island Pool level to increase the flow over the Falls from 50,000 to 100,000 cubic feet per second and vice versa, would require so long a period that only a small part of the extra diversion authorized at night during the tourist season by the Treaty of 1950 could be used. Experiments on the Vicksburg model indicate that while about one-half the required change could be accomplished in the first hour, it would require about 12 hours for the complete change. Accordingly, after about one to two hours of the extra night-time diversions, it would be necessary to start reducing the diversions in order to build up the Pool to the level required for a flow of 100,000 cubic feet per second over the Falls by 8:00 a.m. the following morning. In addition, the lowering of the Pool which would result would affect adversely the output of existing power plants withdrawing water from the Pool by reducing head-water levels.

63. Views of the International Niagara Falls Engineering Board. — The present International Niagara Falls Engineering Board considers it to be imperative to provide works that will improve the distribution of flow along the crest of the Horseshoe Falls and to control the levels of the Chippawa-Grass Island Pool. The maintenance of the present relationship between river flow and Pool level is considered essential. Such regulation would preserve the existing conditions and appearance of the Niagara River upstream and would ensure that Lake Erie levels and outflows would remain unaffected, thus protecting interests upstream who otherwise might be affected adversely by a general lowering or rapid variation in the Pool level. In addition, adequate flow over the American Rapids and Falls would be assured. Full advantage could be taken of the additional water available for power diversions in the night hours of the tourist season. Therefore, the Board considers that satisfactory remedial works should ensure the following:

52. The horizontal scale of the Vicksburg model is 360 feet to one foot and the vertical scale, 60 feet to one foot. The model is 260 feet long and has a maximum width of 125 feet. It represents the Niagara River from two miles above the Peace Bridge to one mile below the Falls. The model reproduces accurately the flow entering the river from Lake Erie and also the division of water around Grand Island. The construction of this model and the verification of the portion above the Cascades are described in greater detail in Appendix D; the verification of the Cascades section is described in Appendix F.

53. THE ISLINGTON MODEL. — Late in 1950, a building was erected at Islington to house the Islington model. The floor of the model consists of a reinforced concrete slab with supports running down to hardpan to prevent settlement or any disturbance due to the action of frost. Plywood templates, shaped to the correct contours of the river bottom, were set upright on the floor slab, sand was compacted between them to within three inches of the top and then a shell of concrete was poured to bring the model flush with the tops of the templates. The model is 95 feet long, 37 feet wide and four feet high and represents a section of river from the lower end of Grand Island to the Rainbow Bridge to a scale of 250 feet to one foot horizontally and 50 feet to one foot vertically.

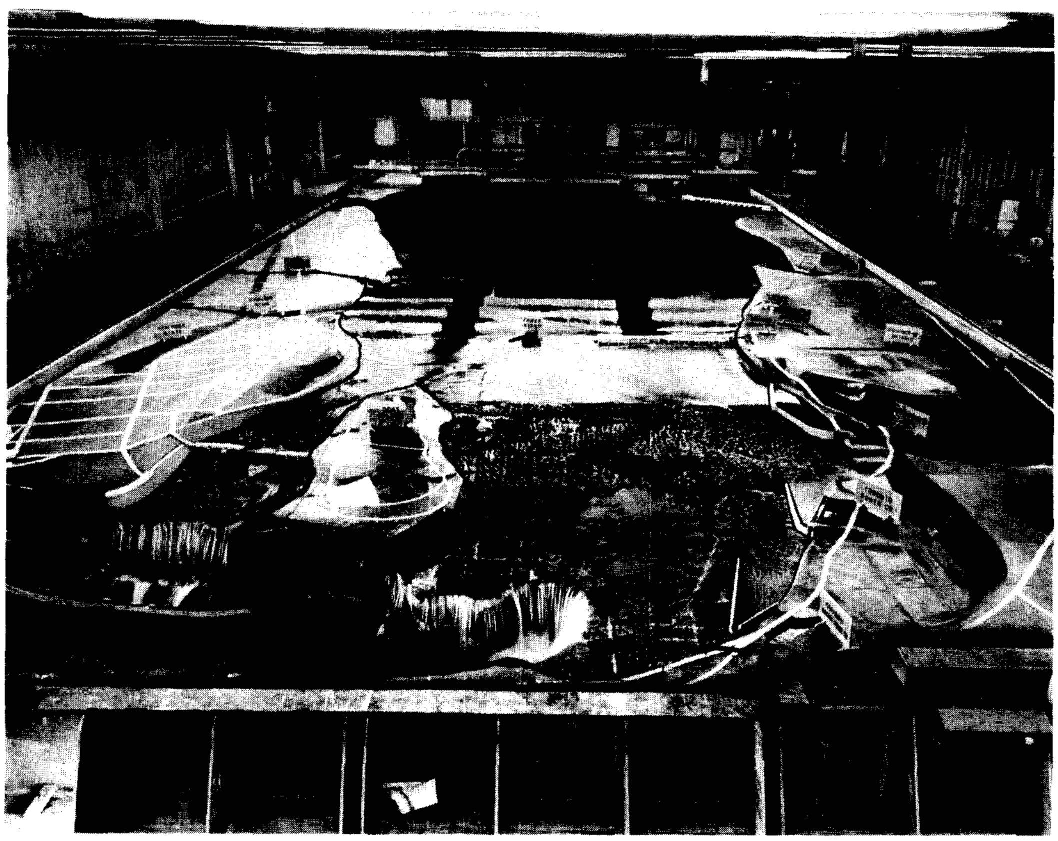


Figure 2. THE ISLINGTON MODEL

SECTION V

TYPE AND LOCATION OF REMEDIAL WORKS CONSIDERED

65. GENERAL LOCATION OF REMEDIAL WORKS STUDIED. — The remedial works considered for Niagara Falls divide naturally into two different but not unrelated groups. The first group consists of works designed to preserve the present range of levels in the Chippawa-Grass Island Pool and to maintain an adequate flow over the American Falls while the function of the works in the second group is to improve the distribution of flow along the crest of the Horseshoe Falls. The works in the first group would be located in the Pool upstream from the head of the Cascades; those in the second group, in the Cascades upstream from the Horseshoe Falls.

66. REMEDIAL WORKS IN THE CHIPPAWA-GRASS ISLAND POOL. — To remedy conditions in the Chippawa-Grass Island Pool as described in paragraphs 60, 61 and 62, the remedial works to be located in the Pool should be capable of performing the following functions:

(a) Regulate the Pool under future conditions of diversion to the same levels that now exist for the same total river flow.

(b) Maintain sufficient flow over the American Falls to preserve its present satisfactory appearance.

(c) Regulate the combined flow over the two Falls to 50,000 or 100,000 cubic feet per second as required, at any normal Pool level, without any change in the level of the Pool.

(d) Pass ice with a minimum of obstruction.

(e) Provide sufficient flow over the area around the Three Sisters Islands and the area upstream from Goat Island to preserve their appearance.

67. The only type of structure that could successfully fulfill all these requirements is one with movable gates. Any alternative scheme is open to serious objections. A fixed overflow weir similar in principle to the present submerged weir but farther downstream or with a higher crest elevation, would not satisfy requirements (c) and (d), paragraph 66. Similarly, dredging a channel from deep water in the Pool to the head of the channel leading to the American Falls, while it would satisfy requirement (b), would certainly not satisfy the others.

68. The Board recognizes the advantage of locating this control structure as near to the downstream end of the Pool as possible. Such a location would keep the appearance of most of the Pool unchanged and would materially assist in covering the Three Sisters Island area and the area upstream from Goat Island with an adequate flow of water. Also all power plants with intakes located upstream from the control structure would benefit from the regulated Pool levels.

69. REMEDIAL WORKS IN THE CASCADES. — In considering the works that would be required to remedy the deficient flow near the two ends of the Horseshoe Falls under the minimum flows stipulated in the 1950 Treaty, it is evident that water must be diverted from the two deep channels which converge near the center of the Horseshoe and be directed to the two flanks.

70. It appeared to the Board that it should investigate three types of works which it was considered might accomplish this purpose, as follows:

(a) Excavations on the flanks extending far enough into the stream and far enough upstream to divert water to the flanks.

(b) Submerged weirs built into the deep channels to intercept the necessary flow and divert it to the two flanks of the Horseshoe.

(c) Various combinations of items (a) and (b).

SECTION IV

CONDITIONS TO BE IMPROVED

57. REFERENCE IN TREATY OF 1950. — The 1950 Treaty calls for the completion in accordance with the objectives envisaged in the final report submitted to the United States and Canada on December 11, 1929 by the Special International Niagara Board, of the "remedial works which are necessary to enhance the beauty of the Falls by distributing the waters so as to produce an unbroken crestline on the Falls".

58. VIEWS OF THE SPECIAL INTERNATIONAL NIAGARA BOARD. — The Special International Niagara Board's objective was to remedy the following conditions which prevailed at the time of its report in 1928:

(a) The flow over the Goat Island shelf at the United States flank of the Horseshoe Falls was deficient and would eventually cease altogether unless restored and maintained by remedial works.

(b) The flow over the Canadian flank of the Horseshoe Falls was deficient and was becoming more so. The conditions at the flanks were caused by the natural upstream movement of the central portion of the Horseshoe and by diversions of water for power and other purposes.

(c) The flow in a few other parts of the rapids above the Horseshoe Falls, particularly in the vicinity of the Three Sisters Islands, was not sufficient to maintain the unique spectacle of the rapids in its full grandeur.

(d) The flow in the rapids above the American Falls was deficient, leaving exposed ledges to mar the spectacle, especially at low river stages.

(e) The flow over the American Falls at low stages was so small as to give a marked impression of thinness.

59. CHANGES IN CONDITIONS SINCE 1928 REPORT. — The present Board concurs in general with the views of the Special International Niagara Board. However, several important changes have occurred since 1928 which have altered to a considerable extent the problems involved in preserving and enhancing the scenic beauty of the Falls. These changes are described in the following paragraphs.

60. International agreements in 1940, 1941, 1944 and 1948 authorized temporary increases in diversion of water for power from the 56,000 cubic feet per second permitted by the Boundary Waters Treaty of 1909, up to a total of 89,000 cubic feet per second. These agreements were in effect until superseded by the 1950 Treaty. The two 1941 agreements authorizing increases in diversions of water for power recognized the need for the immediate construction of remedial works. Pursuant to the above agreements, the two governments authorized in 1942 the construction of the submerged weir in the Chippawa-Grass Island Pool which was one of the remedial works envisaged in the 1928 report. The increased diversions had the effect of reducing the flow over both Falls. Construction of the weir was commenced in 1942 and completed in 1947. The weir had the effect of restoring the major portion of the lowering of the Chippawa-Grass Island Pool which had been caused by the diversions, and improving the flow over the American Falls and in the vicinity of the Three Sisters Islands; however, it resulted also in a small further decrease in the flow over the Horseshoe Falls, thus making the conditions at the flanks somewhat more unsatisfactory.

61. The continuing recession of the Horseshoe Falls, resulted in a lengthening of its flanks, and a reduction in the intensity of the flow of water in these areas.

requirements for the flow over the crest as mentioned in paragraph 64 were met. Each set of tests was carried out both with and without the fills at the two ends of the crest as mentioned in paragraph 71.

77. Of the excavation schemes tested, the best was found to be one consisting of two excavations, one on the Canadian flank designated CE in Appendices G and H and one on the Goat Island flank designated R17, and with 100 feet of fill at the Canadian end of the Horseshoe Falls and 300 feet at the Goat Island end. This scheme proved to be entirely satisfactory. For a combined flow over the two Falls of 100,000 cubic feet per second, the intensities of flow mentioned in paragraph 64 were exceeded on both flanks. For a flow of 50,000 cubic feet per second, there was a complete curtain of water from shore to shore. Lesser amounts of excavation at either flank were sufficient to produce the required intensity of flow for 100,000 cubic feet per second but did not give the unbroken crestline for 50,000 cubic feet per second.

78. As a result of the tests with weirs, two alternative schemes were developed which gave the required crest flow. One scheme involved two weirs, one upstream from each flank and no excavation. The second included two similar weirs and also some excavation. Both schemes included the fills at the two ends of the crest. However, both schemes required weirs which were so high as to give a distinctly artificial appearance. It is evident that the construction hazards would be greater for weirs than for excavations alone because weirs must extend farther into the river. The weirs would be subjected to the impact from large masses of ice moving at high velocity and it is probable that they would require maintenance which would involve expensive unwatering. Economic studies showed that the weir schemes would be as costly as the excavation scheme mentioned in paragraph 77. Consequently the schemes involving weirs were rejected.

(a) A dependable flow of water over the American Falls and Rapids and in the vicinity of Three Sisters Islands, approximating the satisfactory intensity experienced under existing conditions.

(b) A dependable and ample flow of water over both flanks of the Horseshoe Falls to provide an unbroken crestline, the intensity of the flank flows to be such as to satisfy the requirements given in detail in paragraph 64 below.

(c) Maintenance of the present relationship between the total river flow and the level of the Chippawa-Grass Island Pool.

(d) Ability to meet promptly the changes in permissible power diversions while assuring flows of either 50,000 or 100,000 cubic feet per second over the Falls.

64. Flows over flanks of Horseshoe Falls. — The Board has given consideration to the flows that should exist over the flanks of the Horseshoe Falls to preserve and enhance the scenic beauty of the Falls under future flow conditions. Recognition has been given to the suggestion in the 1928 report that the intensity of flow over the Goat Island flank should approximate, while that over the Canadian flank should be somewhat greater than the flow over the American Falls under low water conditions. The Board has accordingly adopted the following criteria for judging the suitability of remedial works:

(a) When the total flow over the Falls is 100,000 cubic feet per second, the remedial works should produce a flow per foot of crest length of six to eight cubic feet per second over the Goat Island flank and 10 to 12 cubic feet per second over the Canadian flank.

(b) When the total flow over the Falls is 50,000 cubic feet per second, the remedial works should produce an unbroken curtain from shore to shore.

with stone to blend into the surroundings, would enclose this fill. Inside the wall, fill would be placed to the grade of the adjacent improved park area, and the whole landscaped to provide an attractive area for viewing the Cascades and Falls at close range.

84. Excavation in Cascades upstream from Goat Island flank. — The extent and grade of this excavation is shown in detail on Plate 7, the estimated quantity involved being 24,000 cubic yards of rock. The function of this excavation is to divert an adequate volume of flow over the Goat Island flank under all future conditions in a manner similar to that on the Canadian side. Tests on the model have indicated that the cofferdam location should be as shown on Plate 7.

85. Goat Island flank crest fill. — On the Goat Island flank of the Horseshoe Falls, the proposed 300-foot crest fill adjoining Goat Island would merge with the existing shoreline about 300 feet upstream. The extent of this fill is shown in detail on Plate 7. A concrete retaining wall suitably faced with rock would surround the fill which would be so graded as to be accessible from Goat Island. This area, suitably landscaped, would provide a much needed vantage point from which to view the Cascades and Falls. This fill is very similar to an improvement which it is understood is under independent consideration by the Niagara Frontier State Park Commission.

86. Estimated construction costs. — The basis of design and estimates and the detailed estimate of construction costs at July 1952 price levels for each feature are given in Appendix J. While four types of gates were investigated, only the estimate for the "Bascule" type is given in Appendix J, (Table J-1). A summary of the total construction costs for each feature of the proposed plan follows:

FEATURE	ESTIMATED COST
Chippawa-Grass Island Pool control structure (Bascule type)	$14,594,000.00
Canadian flank excavation and crest fill	1,582,000.00
Goat Island flank excavation and crest fill	1,360,000.00
Estimated total	$17,536;000.00

87. Estimated annual costs. — It is estimated that an annual cost of about $100,000 would be incurred in the operation and maintenance of the Chippawa-Grass Island Pool control structure. No operation or maintenance should be required in the other features of the proposed remedial works, and it is proposed that the filled areas be transferred to the Parks authorities for development as they see fit for use as observation areas.

88. Results to be expected from proposed plan. — From the exhaustive and comprehensive series of model tests carried out on the proposed plan of remedial works at both Vicksburg and Islington, the Board is confident that the proposed plan would fulfill the terms and intent of the 1950 Treaty. By operation of the gates in the proposed Chippawa-Grass Island Pool control structure, the same Pool level would be maintained in the future, under power diversion permitted by the 1950 Treaty, as would result from conditions above Niagara Falls since the completion in 1947 of the existing submerged weir, and under present diversions for power. Such regulation would preserve the regimen of the river in the Chippawa-Grass Island Pool and upstream thereof and would insure that Lake Erie levels and outflows would remain unaffected. Such regulation also would maintain sufficient flow over the American Falls to preserve the present satisfactory appearance which has prevailed since completion of the existing submerged weir in 1947. Adequate and scenically satisfactory flow conditions would exist at the head of Goat Island and in the vicinity of the Three Sisters Islands.

71. Also it appeared to the Board that a moderate shortening of each flank by fills at the ends should be investigated. Such fills suitably retained and landscaped would be valuable improvements in themselves, as they would provide exceptionally fine vantage points from which the Falls and Cascades could be viewed at close range. In addition, they would help to intensify the flow at the flanks and reduce the amount of other work required.

72. General outline of model studies of remedial works. — In the studies of the remedial works on both models, the general procedure was to study first the control structure in the Chippawa-Grass Island Pool and then the remedial works near the Horseshoe Falls, because the design and location of the upper works has some effect on the lower ones. A detailed description of these studies and of the results obtained is given in Appendices G and H and the findings are summarized in the following paragraphs.

73. Model studies of control structure in Chippawa-Grass Island Pool. — It was considered that the best location for the control structure would be somewhere between the line of the present submerged weir and the head of the Cascades. Tests were carried out with gated dams located both on the line of the submerged weir and at several locations farther downstream. These tests indicated that the performance at all these various locations was essentially the same. From the standpoint of feasibility and economy of construction, the dam should be located between 200 and 250 feet downstream from the submerged weir and on a line parallel with the weir. The tests indicated that it should start from the Canadian shore because the deep channel which must be intercepted to provide efficient control lies near this shore. It is in this channel that the existing submerged weir was placed. The deeper channel also offered less likelihood of ice grounding in the channel in the vicinity of the dam.

74. Intensive testing was done to determine the optimum length of this control structure. Structures extending from the Canadian shore for various lengths were tested, including one extending across the whole river. In all these tests the entire control structure consisted of piers with sluices 100 feet in width between them, sills at elevation 553.5 and with a movable gate in each sluice. Also, in certain tests in which the dam extended only part way across the river, experiments were made by adding a short structure extending out from the United States shore into the channel leading to the American Falls.

75. In general the results obtained were as follows:

(a) For the main control structure to be built out from the Canadian shore, a minimum length of 1,550 feet would be necessary to keep the Pool at the same levels as exist at present for the same river flow, which is the requirement stated in paragraph 66 (a) and would be sufficient to permit the flow over the Falls to be changed from 100,000 to 50,000 cubic feet per second, and vice versa, without a change in Pool level which is the requirement stated in paragraph 66 (c).

(b) Although not necessary for Pool control, a structure some 450 feet in length near the United States shore composed entirely of gates without intervening piers was found to be of some value in controlling the flow into the channel leading to the American Falls, especially at high river flows. However, it was concluded that the cost would be out of proportion to the resulting benefits and that this feature did not warrant further consideration.

76. Model studies of remedial works in Cascades. — In an effort to find successful remedial schemes utilizing submerged weirs, 11 different designs were tested in the Cascades above the flanks of the Horseshoe Falls, some with weirs alone and some with weirs in combination with excavation. Also schemes involving excavation without weirs were developed and tested. In general, the tests commenced with small amounts of excavation and these were progressively increased until the

SECTION VII

TIMING AND ALLOCATION OF TASK OF CONSTRUCTION OF PROPOSED REMEDIAL WORKS

92. Timing of remedial works construction. — Two periods have been defined in this report with respect to the increased power diversions permitted by the 1950 Treaty. These have been designated the "intermediate period" and the "future period" and are defined in Section III of the report. In the intermediate period, the new diversions would be confined to those utilized by the Sir Adam Beck-Niagara Generating Station No. 2, now under construction, while in the future period the new diversions would include also those utilized by the proposed Conners Island-Lewiston plant. The new Sir Adam Beck plant is scheduled to begin delivering power in 1954 and be fully completed by the end of 1955 or early in 1956. The proposed plan of remedial works is designed for the future period, when all permissible diversion will be fully utilized. It was established in this investigation that of the 1,550 feet of control structure required in the Chippawa-Grass Island Pool for the future period, 1,200 feet would be sufficient for the necessary regulation in the intermediate period.

93. The Board wishes to emphasize the urgency of commencing construction of the control structure at the earliest possible date. The 1950 Treaty provides that the recommended remedial works shall be completed within four years after the date upon which Canada and the United States of America shall have approved the recommendations of the International Joint Commission as to the nature and design of remedial works. It is the opinion of the Board that the remedial works can be completed within the four year period. Diversions of water for power are now governed by the terms of the 1950 Treaty. Without the control structure or equivalent effect from temporary construction works, the level of Chippawa-Grass Island Pool will be lowered by increased diversions with respect to present relationship between total river flow and the level of the Pool, with consequent impairment of the appearance of the American Falls. The lowering of the Chippawa-Grass Island Pool will also increase current velocities and reduce depths for navigation in the river above the Falls. It is the Board's opinion that the schedule for construction of the control structure should be co-ordinated with the increasing diversions so as to reduce to a minimum any adverse effects of these increased diversions. To do this, it is necessary that construction of the control structure be commenced at the earliest practicable date in order to meet the schedule for increased diversions. In addition, by an early start, advantage may be taken of construction plant and facilities now available adjacent to this site, thus assuring efficient and economical construction. It is also the Board's opinion that when the construction of the 1200 linear feet of control structure required for the intermediate period nears completion, consideration may be given to deferring completion of the structure to its ultimate length until the dates of increased United States diversions are known. The Board is of the further opinion that a more precise determination of the ultimate length of the control structure should be based on operating experience with completed increments of the structure.

94. The remedial works in the Cascades, that is, the excavations and fills, are required during the intermediate period to enable the additional power diversions authorized by the 1950 Treaty to be utilized without adversely affecting the scenic beauty of the Horseshoe Falls. With the expected diversions during the intermediate period as set forth in paragraph 42, a Falls flow of 100,000 cubic feet per second, the minimum flow permitted in the daytime tourist season by the 1950 Treaty, would occur for 92 percent of the tourist season days and would be exceeded during the remaining eight percent. The minimum Falls flow of 50,000 cubic feet per second would occur for 16 percent of the non-tourist season and tourist season nights and would be exceeded for 84 percent of the time. Since it would be advisable that only one of the excavations be under way at one time and since each would require one construction year, the work should commence as soon as practicable.

SECTION VI

DESCRIPTION OF PROPOSED PLAN OF REMEDIAL WORKS

79. GENERAL DESCRIPTION OF PROPOSED PLAN. — The proposed plan of remedial works was developed by model tests as described in Section V. The total plan consists of three separate works which, in the opinion of the Board, are necessary to ensure that the terms and intent of the 1950 Treaty will be fully met. The three works, whose general location is as shown on Plate 3, are enumerated briefly below and described fully in the paragraphs which follow:

(1) A Chippawa-Grass Island Pool control structure.

(2) An excavation in the Horseshoe Cascades lying immediately upstream from the Canadian flank, including a 100-foot crest fill on the Canadian flank.

(3) An excavation in the Horseshoe Cascades lying immediately upstream from the Goat Island flank, including a 300-foot crest fill on the Goat Island flank.

80. CHIPPAWA-GRASS ISLAND POOL CONTROL STRUCTURE. — The location of the proposed structure is shown in general on Plate 3 and in detail on Plate 6. The structure would extend out from the Canadian shore some 1,550 feet into the river on a line parallel with the present submerged weir and 200 to 250 feet downstream therefrom. With the exception of an approach fill adjacent to the Canadian shore, the strucure would consist entirely of piers and movable control gates.

81. On Plate 6 is shown the general arrangement of the control structure tested in the models and considered desirable by the Board. Shown on the plate are thirteen 100-foot wide sluices, the minimum width considered desirable in passing ice during ice runs. However, it is the total length of structure rather than the particular sluice widths that governs the degree of Pool control that can be obtained. The final selection of sluice and pier widths will be governed by economic and structural considerations when the structure is designed in detail. Four types of gates for the control structure were investigated by the Board, and while each has its individual merits, the "Bascule" type, which lowers to open, is considered functionally most suitable to the conditions peculiar to the Niagara River, and is the type shown on Plate 6 and covered by the estimates in paragraph 86. The other three types investigated are shown on Plate J-1, Appendix J. It is the opinion of the Board that a service deck spanning the piers is essential for access, operation and maintenance. For aesthetic considerations, the operating machinery should be enclosed in the piers and the service deck might take the form of a series of flat arches. It is contemplated that this structure would be constructed in stages, each including as many complete sluices as could be built in one construction season. Unwatering would be necessary for each stage but cofferdams would be confined to one stage at a time.

82. EXCAVATION IN CASCADES UPSTREAM FROM CANADIAN FLANK. — This excavation would lie in the Horseshoe Cascades in the area upstream from the Canadian flank. Its purpose would be to tap the deep stream that flows down the Canadian side of the Cascades, and divert flow to the Canadian flank in quantities adequate to preserve the spectacle under all future conditions. The extent and grade of the excavation are shown in detail on Plate 7, the estimated quantity involved being some 64,000 cubic yards of rock. On Plate 7 is shown the location of the cofferdam found necessary on the models to dewater the area and enable the excavation to be performed in the dry.

83. CANADIAN FLANK CREST FILL. — As shown on Plate 7, the crest fill of 100 feet on the Canadian flank adjacent to the Canadian shore would extend upstream about 100 feet where it would merge with the present shoreline. It is contemplated that a concrete retaining wall, faced

SECTION VIII

CONCLUSIONS AND RECOMMENDATIONS

96. CONCLUSIONS. — The Board concludes that the objectives for preservation and enhancement of Niagara Falls, as set forth in the 1950 Treaty, can best be accomplished by the construction of a control structure at the head of the Cascades and by construction of remedial works on the flanks of the Horseshoe Falls of the nature and extent described in Section VI of this report. No lesser plan would be adequate.

97. The construction costs of these works are estimated to total $17,536,000, at July 1952 construction cost levels. The subdivision of this total amount among the various items is given in Section VI and in detail in Appendix J. The annual cost of operation and maintenance is estimated to be approximately $100,000.

98. RECOMMENDATIONS. —

(a) The Board recommends the construction of remedial works shown in general on Plate 3 and in detail on Plates 6 and 7 and described in Section VI of this report with such minor modifications as are deemed advisable at the time of construction.

(b) The Board strongly recommends that the construction of the remedial works in the Cascades above the Horseshoe Falls, and the Chippawa-Grass Island Pool control structure be started without delay.

(c) The Board recommends that the task of construction be divided between the two countries on the basis that each country would construct, generally, those portions of the work that lie within their national boundaries. On this basis, the United States would construct the excavation and crest fill on the Goat Island flank of the Horseshoe Falls (including the small amount of excavation on the Canadian side of the boundary), while Canada would construct the excavation and crest fill on the Canadian flank of the Horseshoe Falls and also the Chippawa-Grass Island Pool control structure.

INTERNATIONAL NIAGARA FALLS ENGINEERING BOARD:

T. M. PATTERSON

Assistant Chief, Water Resources Division, Department of Resources and Development, Ottawa, Canada.

Canadian Member

COLONEL WENDELL P. TROWER

Division Engineer, Great Lakes Division, Corps of Engineers.

United States Member

GUY A. LINDSAY

Special Adviser to the Minister, Department of Transport, Ottawa, Canada.

Canadian Member

FRANCIS L. ADAMS

Chief, Bureau of Power, Federal Power Commission, Washington, D.C.

United States Member

89. The design of the control structure is such that Falls flows of either 50,000 or 100,000 cubic feet per second as specified in the 1950 Treaty may be produced expeditiously at any time through the full range of Chippawa-Grass Island Pool levels without affecting the level of the Pool, thereby making available for power purposes the maximum amount of water. The control structure sluices equipped with gates which lower to open can be expected to pass low and normal runs of ice while maintaining proposed Pool levels, but in the event of an unusually heavy ice run, it is envisaged that all sluices would remain fully open during the run to minimize any obstruction to the floes. During such periods, which are usually of short duration, the normal regulation of the Pool would be suspended as the safe passage of ice is the more important consideration.

90. The proposed plan of excavations and crest fills in the Horseshoe Falls Cascades would ensure that in the daytime of the tourist season, when a minimum of 100,000 cubic feet per second is to be discharged over the Falls, an unbroken crestline on the Horseshoe Falls would extend from shore to shore and the intensity of flows on the flanks would always be sufficient for a satisfactory scenic spectacle as defined in paragraph 64. In the other periods of the year, when a Falls flow as low as 50,000 cubic feet per second is permitted by the 1950 Treaty, these works would ensure that an unbroken crestline would always exist, and that the intensity of flow would be such that an impressive spectacle would result. In Plates 8, 9, and 10 are shown the expected distributions of flow along the crest of the Horseshoe Falls for both these periods under minimum, average, and maximum river flows, respectively. These plates also show the distributions that would exist if no remedial works were provided. It will be noted that the flow over the Horseshoe Falls is larger for the minimum river flow than for the maximum river flow. This is due to the regulation of the Pool level resulting in an increase in flow over the American Falls and a corresponding reduction in the Horseshoe Falls flow. The increasing of the flow over the flanks of the Horseshoe Falls by the diversion of water from the deep channels emptying into the central portion of the Horseshoe will reduce the rate of recession in the central portion.

91. The Board considers that the results to be expected from its proposed remedial works as described in paragraphs 88 to 90 inclusive will fulfill the objectives set forth in paragraph 63.

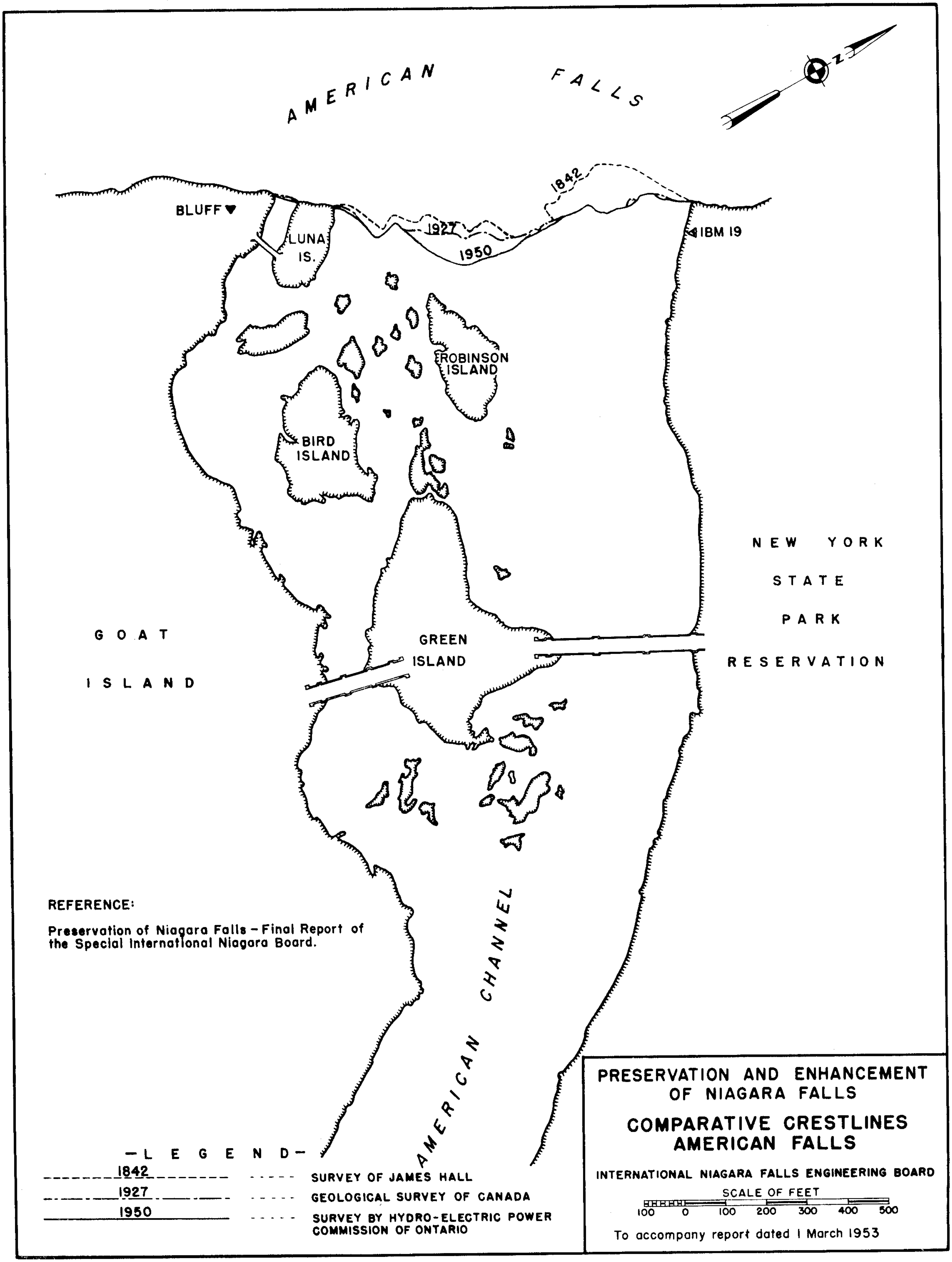

AMERICAN FALLS
N
1842
1927
1950
BLUFF
LUNA IS.
IBM 19
ROBINSON ISLAND
BIRD ISLAND
GREEN ISLAND
GOAT ISLAND
NEW YORK STATE PARK RESERVATION
AMERICAN CHANNEL
REFERENCE:
Preservation of Niagara Falls – Final Report of the Special International Niagara Board.
—LEGEND—
1842 SURVEY OF JAMES HALL
1927 GEOLOGICAL SURVEY OF CANADA
1950 SURVEY BY HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS
COMPARATIVE CRESTLINES AMERICAN FALLS
INTERNATIONAL NIAGARA FALLS ENGINEERING BOARD
SCALE OF FEET
100 0 100 200 300 400 500
To accompany report dated 1 March 1953

PLATE 5

95. Allocation of task of construction. — It is the opinion of the Board that, in general, the most satisfactory division of the work would be for each country to assume the construction of that portion of the proposed remedial works that will lie within its own national boundaries. Because two of the main items will lie wholly within Canada and one, the excavation on the Goat Island flank, will lie almost entirely on the United States side of the boundary and will be accessible only from that side, it is recommended that the task of construction be divided as follows:

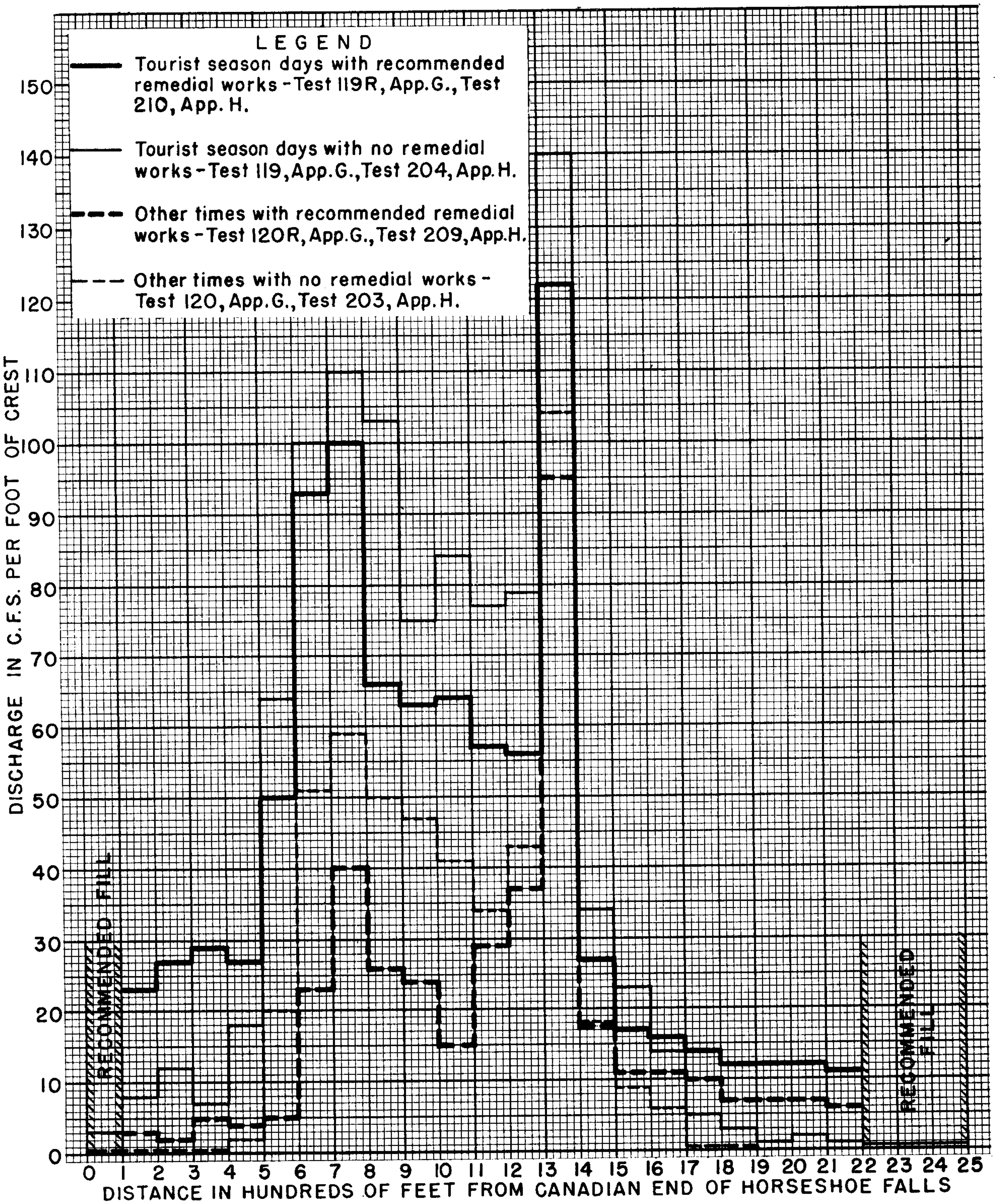
(a) Work to be done by Canada:

(1) Construction of the complete Chippawa-Grass Island Pool control structure, including all necessary cofferdams.

(2) Construction of the flank excavation in the Horseshoe Falls Cascades adjacent to the Canadian shore, including the necessary cofferdams and including also the 100-foot crest fill on the Canadian end of the Horseshoe Falls crest.

(b) Work to be done by the United States:

(1) Construction of the flank excavation in the Horseshoe Falls Cascades adjacent to Goat Island, including the necessary cofferdams, and including also the 300-foot crest fill adjacent to Goat Island.



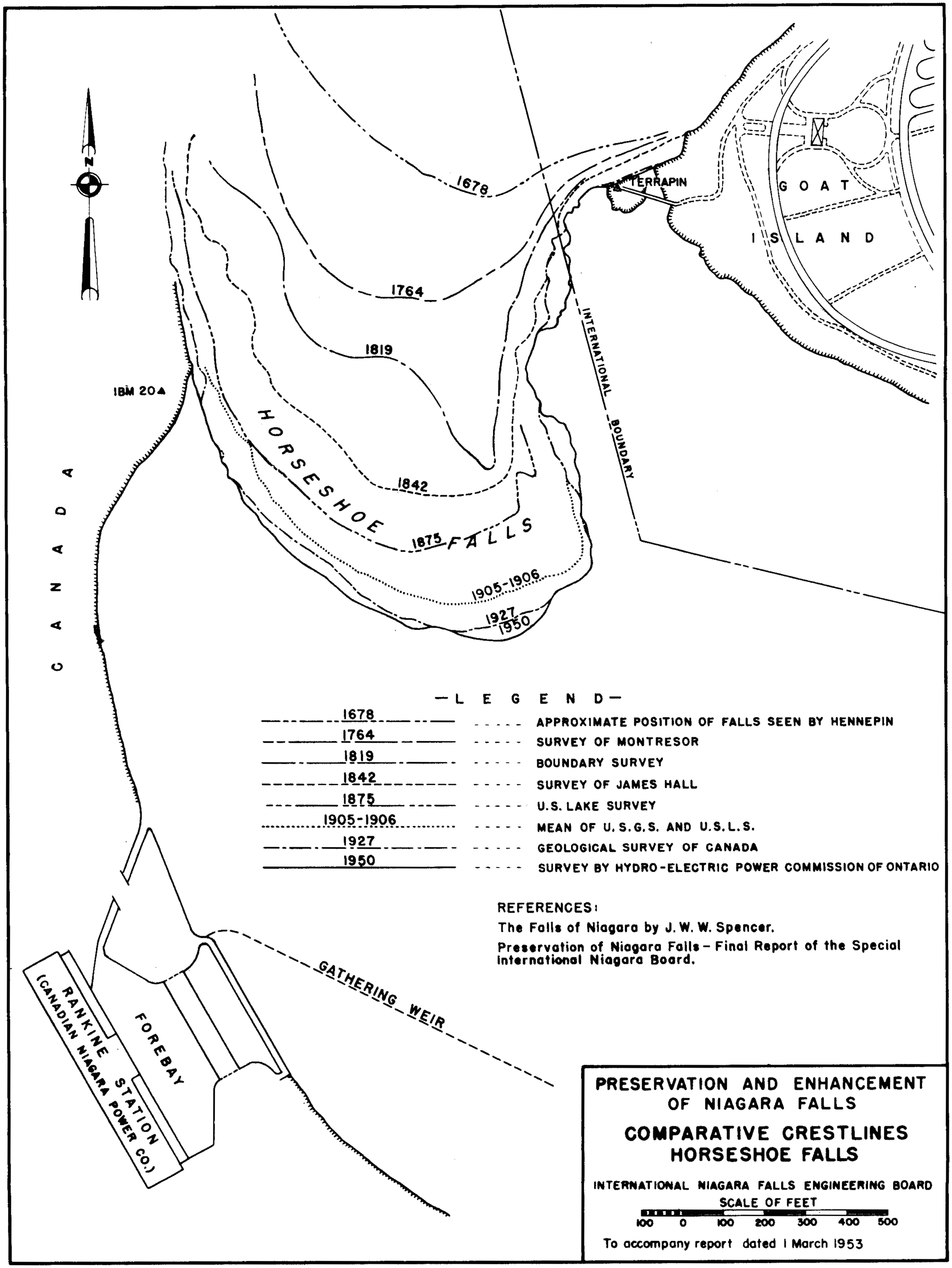
NOTE:- All data shown are means of measurements of same test on Islington and Vicksburg models.

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

HORSESHOE FALLS
CREST FLOW DISTRIBUTION
200,000 CFS RIVER FLOW

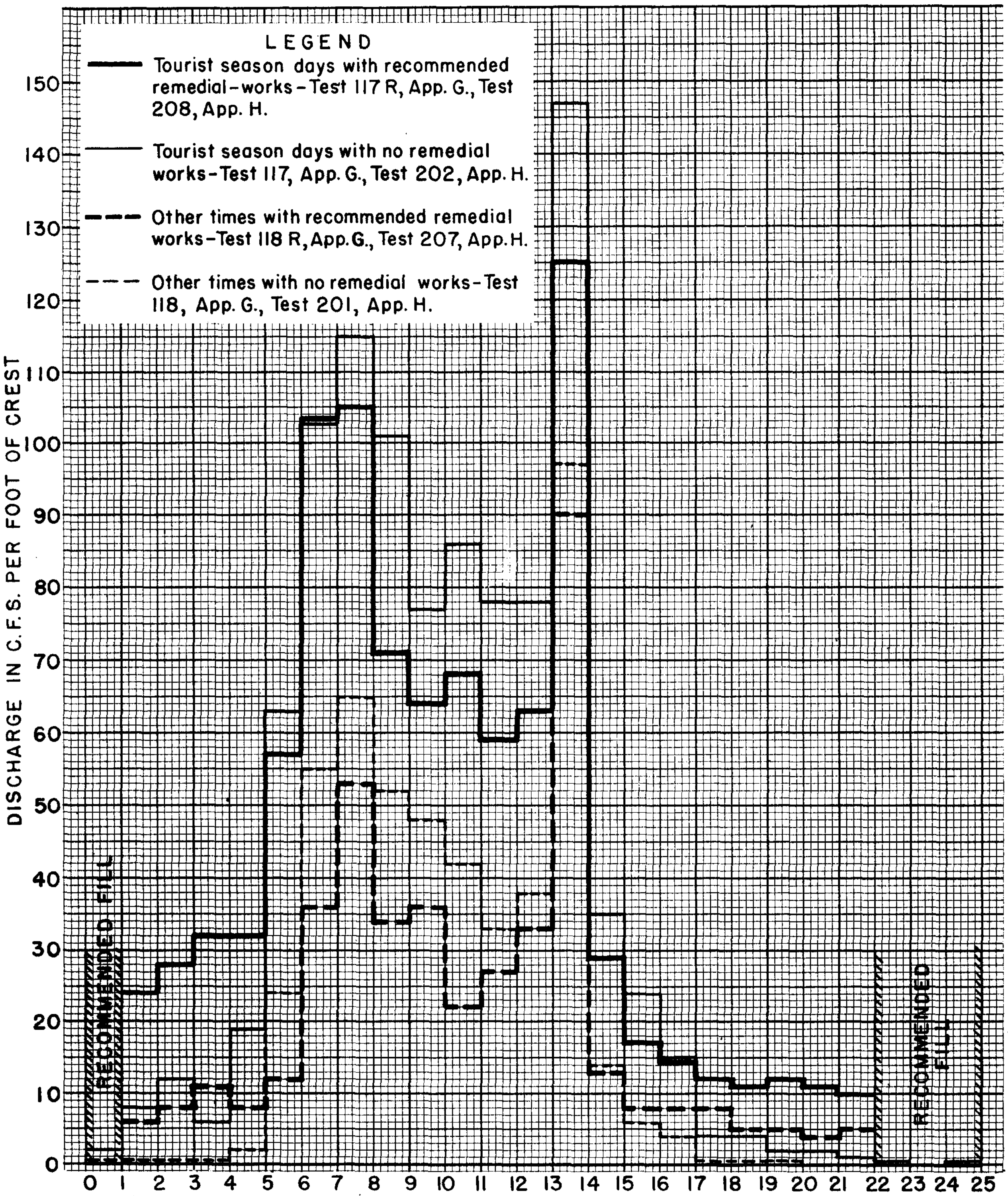
INTERNATIONAL NIAGARA FALLS ENGINEERING BOARD

To accompany report dated 1 March 1953



N
1678
1764
1819
1842
1875
1905-1906
1927
1950
HORSESHOE FALLS
TERRAPIN
GOAT ISLAND
INTERNATIONAL BOUNDARY
IBM 20
CANADA
GATHERING WEIR
FOREBAY
RANKINE STATION
(CANADIAN NIAGARA POWER CO.)
—LEGEND—
1678 ----- APPROXIMATE POSITION OF FALLS SEEN BY HENNEPIN
1764 ----- SURVEY OF MONTRESOR
1819 ----- BOUNDARY SURVEY
1842 ----- SURVEY OF JAMES HALL
1875 ----- U.S. LAKE SURVEY
1905-1906 ----- MEAN OF U.S.G.S. AND U.S.L.S.
1927 ----- GEOLOGICAL SURVEY OF CANADA
1950 ----- SURVEY BY HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
REFERENCES:
The Falls of Niagara by J. W. W. Spencer.
Preservation of Niagara Falls – Final Report of the Special International Niagara Board.
PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS
COMPARATIVE CRESTLINES HORSESHOE FALLS
INTERNATIONAL NIAGARA FALLS ENGINEERING BOARD
SCALE OF FEET
100 0 100 200 300 400 500
To accompany report dated 1 March 1953

PLATE 4



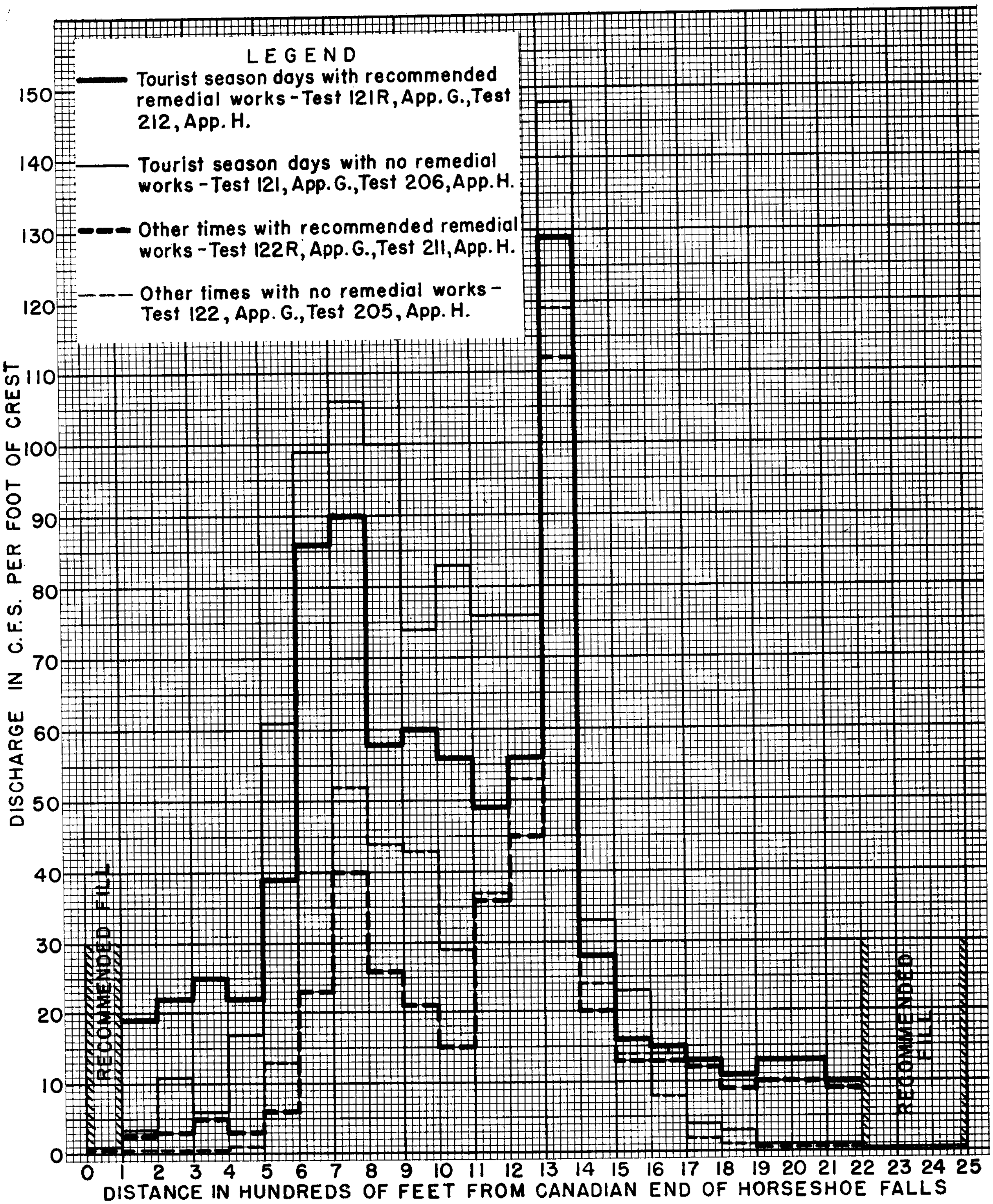
NOTE:-All data shown are means of measurements of same test on Islington and Vicksburg models.

PRESERVATION AND ENHANCEMENT
OF NIAGARA FALLS

HORSESHOE FALLS
CREST FLOW DISTRIBUTION
170,000 CFS RIVER FLOW

INTERNATIONAL NIAGARA FALLS ENGINEERING BOARD

To accompany report dated 1 March 1953



NOTE:- All data shown are means of measurements of same test on Islington and Vicksburg models.

PRESERVATION AND ENHANCEMENT
OF NIAGARA FALLS

HORSESHOE FALLS
CREST FLOW DISTRIBUTION
240,000 CFS RIVER FLOW

INTERNATIONAL NIAGARA FALLS ENGINEERING BOARD

To accompany report dated 1 March 1953

LIST OF PLATES

APPENDIX A

FLOW AND HYDRAULIC CONDITIONS IN THE NIAGARA RIVER

6. Discharge measurements. — The first measurements of record of the flow of the Niagara River were made by the U.S. Lake Survey in 1867, in the lower river near Youngstown. Velocities were determined by use of double floats. These early measurements were rejected when they were compared with results of measurements made many years afterwards using current meters and more refined techniques. The results of all discharge measurements on the Niagara River made between 1898 and 1925 by the U.S. Lake Survey, the Canadian Department of Resources and Development and the Niagara Falls Power Company are shown in Table A of Appendix F of the report on "The Preservation and Improvement of Niagara Falls and Rapids" published in Canada as "The Preservation of Niagara Falls" by the Special International Niagara Board (hereinafter referred to as "the 1928 report" for the purpose of brevity). The cross sections used for measuring discharge were the "International Bridge Section", located at the railway bridge between Fort Erie and Buffalo, the "Open Section" which was about 1,800 feet downstream of the International Bridge and the "Split Section" which was used to measure flows in the east and west channels around Grand Island. The record of discharges of the Niagara River from 1860 to 1925, as listed in the 1928 report, was computed from a formula derived from the above meterings.

7. In 1931 additional measurements of discharge were made by the U.S. Lake Survey at a new section established as the "Black Rock Section" in the general vicinity of the "Open Section". The U.S. Lake Survey made 141 measurements of the flow at the "Black Rock Section" covering a range in stage at Buffalo from 570.23 feet to 572.50 feet. The U.S. Lake Survey also made 14 measurements at the "Split Section" in 1931. The measurements at the "Split Section" and "Black Rock Section" are shown in Tables A-1, A-2 and A-3. Additional measurements of discharge were made in June and July 1952 by the U.S. Lake Survey in the general vicinity of the "Open Section", which confirm the present Niagara River discharge equation (1) given in paragraph 8 below. Final analysis and results of these measurements were not completed in time for inclusion in this report.

TABLE A-1

DISCHARGE MEASUREMENTS AT "SPLIT SECTION" — CANADIAN CHANNEL

MEASUREMENT		WATER SURFACE ELEVATION (1)		MEASURED DISCHARGE CFS
No.	Date, 1931	Buffalo ft.	International Bridge, ft.	
1	Sept. 21	571.38	566.32	102,490
2	Sept. 21	571.21	566.23	100,659
3	Sept. 21	571.36	566.28	102,858
4	Sept. 23	571.26	566.27	100,560
5	Sept. 23	571.07	566.16	97,614
6	Sept. 23	570.96	566.04	97,813
7	Sept. 25	571.12	566.10	100,560
8	Sept. 25	570.86	566.00	96,910
9	Sept. 25	570.91	565.94	96,908
10	Sept. 25	571.16	566.03	97,471
11	Sept. 29	571.14	566.14	98,867
12	Sept. 29	571.22	566.18	99,758
13	Sept. 29	571.21	566.18	100,932
14	Sept. 29	571.29	566.22	100,714

(1) U.S.L.S. 1935 Datum

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX A

FLOW AND HYDRAULIC CONDITIONS IN THE NIAGARA RIVER

CONTENTS

LIST OF TABLES

where Q_B is the discharge at Buffalo, which includes the water diverted at Tonawanda by the New York State Barge Canal and Q_M is the discharge from the Maid-of-the-Mist Pool, which must be increased by the amount of the diversions around the Pool to give the total flow of the river at Queenston. Buf. is the Buffalo gauge height, Bl. R. is the Black Rock gauge height and Morr. is the Morrison Street gauge height. Buffalo and Black Rock are Lake Survey gauges, now set at the Lake Survey datum of 1935. Morrison Street is maintained by the Water Resources Division of the Department of Resources and Development and 330 on the staff equals 330.35 Lake Survey datum of 1935.

9. A simpler formula derived by the U.S. Lake Survey, which gives practically the same discharges as Eq. (1) under present backwater conditions at Black Rock, is as follows:

$$Q_B = 3{,}665 \ (\text{Buf.} - 558.10)^{3/2} \qquad (3)$$

10. Discharge formulae for other lower river gauges have been derived by the Canadian Department of Resources and Development from Eq. (2) by gauge relations. Two of these are as follows:

$$Q_M = 730 \ (3A - 299.83)^{3/2} \qquad (4)$$

$$Q_M = 768 \ (\text{Whirl.} - 250.70)^{3/2} \qquad (5)$$

where Q_M is the discharge from the Maid-of-the-Mist Pool as above, 3A is the gauge height at the 3A lower river gauge of the Niagara Mohawk Power Corporation, set at Hydraulic datum, and Whirl. is the Whirlpool gauge set at the Lake Survey datum, 1903 adjustment. It might be mentioned that, for purposes of measuring the discharge, the datum of a gauge is of little importance as long as it remains unchanged.

11. It can be seen by comparing Eq. (3) with Eqs. (2), (4) and (5), that the change in stage at the Buffalo gauge for a given change in discharge is not as large as at the gauges in the Maid-of-the-Mist Pool and the Whirlpool. Gauges in the Chippawa-Grass Island Pool are rarely used for determining the flow of the river, particularly since the water level here is affected by changes in the power diversions. Whenever there is an ice jam at Buffalo, the stage-discharge relationship at Buffalo is disturbed and Eqs. (1) and (3) will not show the correct discharge. The water level near the lower end of the Maid-of-the-Mist Pool is not affected by ice except for a few minutes at a time when large masses of ice are moving downstream from the Pool. By neglecting these characteristic short, sharp peaks whenever they occur, the Morrison and 3A gauges, Eqs. (2) and (4), give reliable records during the winter as well as the summer. In 1909 the ice jam in the lower river extended upstream to the Whirlpool, and in 1925 it came within half a mile of the Whirlpool but except for such exceptional cases, the Whirlpool gauge, Eq. (5) gives a reliable record of discharge both winter and summer.

12. The record of flows over the Falls from 1927 to 1950 inclusive, as given in Table A-10 of this appendix, was based on the Morrison Street gauge record using Eq. (2).

13. DIVERSIONS FROM THE GREAT LAKES. — The flow of the Niagara River is modified by diversions from the Great Lakes Basin. In the past, diversions from the Great Lakes have occurred through four canals, namely,

Illinois and Michigan Canal

Chicago Sanitary and Ship Canal (Illinois Waterway)

New York State Canals

Welland Canal

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX A

FLOW AND HYDRAULIC CONDITIONS IN THE NIAGARA RIVER

1. SCOPE. — This appendix is concerned with the discharge of the Niagara River and all diversions from and into the river above Niagara Falls. Records of flow at the Falls, both as it occurred and as it would have been in nature, were synthesized from existing gauging records and records of power diversions. Duration curves for the flow of the Falls and Cascades for conditions prior to the effective date of the 1950 Treaty and under certain future conditions of development under the terms of the Treaty were prepared and are included in this appendix.

2. CHARACTERISTICS OF NIAGARA RIVER. — The Niagara River consists of a series of pools of relatively quiet water linked by rapids which form the spillways from the pools. The elevation of the water surface in each of the pools rises or falls as the discharge of the river increases or decreases. This means that in effect there is a submerged weir at the outlet of each pool and that the flow of the river can be determined by rating gauges in each of the pools, though some pools are more sensitive and more suitable for this purpose than others.

3. Lake Erie is the initial pool and the elevation of the water at the gauge in Buffalo Harbour is the main factor in determining the amount of water that will flow down the river and this, in turn, determines the elevation of the water at the gauges in the lower pools. Over a long period, the elevation of the water in Lake Erie and the flow of the Niagara River depend upon the amount of surplus water available, that is, upon the excess of runoff into the lake from all sources over the losses by evaporation and the amount of water diverted from the lake and river. The amount of this surplus varies from season to season and from year to year. It reaches a maximum each year some time during June or July and drops to a minimum during the winter. The actual quantities vary from year to year, though usually the swing from high to low, and vice versa, is gradual and extends over several years because of the great storage capacity of the upper lakes.

4. However, the flow of the Niagara River at any given instant depends, not upon the average elevation of Lake Erie, but upon the elevation at the Buffalo end of the lake. Thus upon the seasonal variations mentioned above, there are superimposed variations in river flow due to the fluctuation at Buffalo above and below the mean lake level. These fluctuations are caused mainly by variations in the velocity and direction of the wind and by differences in the barometric pressures over the lake. During a severe storm the water may rise or fall several feet at Buffalo within a few hours and this causes a corresponding increase or decrease in the flow of the river. However, during periods of fair weather, the fluctuations are small and after every storm the fluctuations tend to diminish and die out.

5. Because of the relatively small amount of fall from Lake Erie to the foot of Squaw Island near Black Rock, the rock ledge at the head of the river functions as a submerged weir: the discharge is controlled mainly by the headwater elevation as recorded at the Buffalo gauge but it is influenced to some extent by the tailwater elevation as recorded at Black Rock gauge. Temporary changes in elevation at Black Rock above or below the elevation that is normal for any given river discharge may be caused by sudden fluctuations in discharge. Permanent changes may be caused by dredging or other artificial changes in the river bed in the section of river between Black Rock and the lower end of the Chippawa-Grass Island Pool, such as the construction of intakes for power plants. Semi-permanent changes may be caused by changes in the power diversions in the Pool. The weirs at all the other pools function as ordinary broad-crested weirs and are not affected by the elevation of the tailwater.

16. NEW YORK STATE CANALS. — The diversion of water by the New York State Canals began in 1825, at which time water was taken at Bird Island opposite the foot of Porter Avenue, Buffalo, N.Y., at a point where the river surface has an elevation about 0.6 foot lower than Lake Erie. The water was carried by a canal to Tonawanda where it joined the canalized section of Tonawanda Creek. This diversion was ultimately discharged into Lake Ontario at various points. Between 1836 and 1862, the canal was widened and deepened, and larger locks were provided. In 1869-70, the Bird Island pier which separated the original canal from the Niagara River was extended upstream as far as Hudson Street, and in 1892 a further extension of 900 feet brought it to Maryland Street. Here the water is practically at the elevation of the lake. The New York State Barge Canal project was adopted in 1903 and completed in 1918. Since that time the diversion has been taken from the Niagara River at Tonawanda. No records of diversion are kept. Based on several flow measurements made in the period 1923 to 1927, it is estimated that the amount of diversion during the navigation and winter seasons is 1,100 cfs and 700 cfs, respectively, exclusive of 275 cfs diverted for power up to October 1928. The estimated monthly diversion from Niagara River from 1860 to 1917, inclusive, is given in Table 1, Appendix F of the 1928 report; from 1918 to 1926, inclusive, the monthly diversion is given in Table 2, Appendix F of the same report; and from 1927 to 1951, inclusive, the monthly diversion is given in Table A-9 of this present report.

17. WELLAND CANAL. — The original Welland Canal was built in 1829 between Port Dalhousie on Lake Ontario, and Port Robinson on the Welland River. This canal in conjunction with the Welland and Niagara Rivers furnished the first complete navigation between Lake Erie and Lake Ontario. The summit level which was about 8 feet higher than Lake Erie was supplied through a feeder canal from the Grand River, a tributary of Lake Erie, the river being dammed at Dunnville for that purpose. The canal was extended and deepened several times during the next 50 years and in 1881 the summit reach was lowered to Lake Erie level. This marked the beginning of diversion of water via the Welland Canal directly from Lake Erie. A portion of this diversion is used for power development at DeCew Falls. Table A-5 shows the mean yearly diversion from the Niagara River and Lake Erie through the Welland Canal for the period 1860 to 1926, inclusive, and the mean monthly and mean yearly diversions from 1927 to 1951, inclusive, are shown in Table A-6. These data do not include about 300 second-feet diverted from Lake Erie and discharged into the Welland River which is tributary to Niagara River, a short distance above the Falls.

TABLE A-2

DISCHARGE MEASUREMENTS AT "SPLIT SECTION" — AMERICAN CHANNEL

MEASUREMENT		WATER SURFACE ELEVATION (1)		MEASURED DISCHARGE CFS
No.	Date, 1931	Buffalo, ft.	International Bridge, ft.	
1	Sept. 22	571.52	566.43	77,131
2	Sept. 22	571.81	566.58	77,636
3	Sept. 24	571.03	566.28	67,435
4	Sept. 24	571.47	566.30	73,731
5	Sept. 24	571.44	566.33	73,295
6	Sept. 28	571.02	566.07	70,465
7	Sept. 28	571.03	566.04	71,543
8	Sept. 28	571.14	566.09	71,077
9	Sept. 30	571.04	566.09	70,915
10	Sept. 30	571.18	566.13	72,818
11	Sept. 30	571.25	566.17	72,821
12	Sept. 30	571.19	566.17	72,858
13	Oct. 1	571.70	566.78	74,779
14	Oct. 1	571.28	566.52	71,748

(1) U.S.L.S. 1935 Datum

TABLE A-3

1931 DISCHARGE MEASUREMENTS AT "BLACK ROCK SECTION"

Number of Measurements	Water surface elevation Buffalo, ft. (1)	Fall to International Bridge Ft.	Fall to Black Rock Ft.	Measured discharge cfs
5	572.33	5.23	5.18	199,700
6	571.94	5.20	5.15	191,200
10	571.80	5.15	5.10	187,700
10	571.69	5.17	5.13	185,000
10	571.62	5.11	5.07	183,200
10	571.56	5.07	5.03	183,300
10	571.48	5.07	5.03	181,100
10	571.39	5.08	5.04	179,000
10	571.34	5.04	5.00	178,800
10	571.21	5.03	4.99	176,600
10	571.07	4.98	4.94	174,300
10	570.91	4.97	4.93	170,700
10	570.80	4.96	4.92	169,200
10	570.73	4.93	4.89	166,600
6	570.60	4.87	4.83	164,500
4	570.39	4.92	4.88	160,600

(1) U.S.L.S. 1935 Datum

8. Discharge formulae of flow in Niagara River. — Two new discharge formulae of flow in Niagara River were derived by the U.S. Lake Survey from all the meterings referred to in paragraphs 6 and 7, for the gauges at Buffalo and Black Rock, and one for the Morrison Street gauge in the Maid-of-the-Mist Pool as follows:

$$Q_B = 1{,}954\ (\text{Buf.} - 556.73)^{3/2}\ (\text{Buf.} - \text{Bl. R.})^{0.3} \quad (1)$$

$$Q_M = 768\ (\text{Morr.} - 301.10)^{3/2} \quad (2)$$

18. Diversion into Great Lakes. — Diversions into Lake Superior from the Hudson Bay drainage basin via the Long Lake Project commenced in 1939 and via the Ogoki project in 1943. Measurements of these diversions are made at or near the divide between the Hudson Bay and Great Lakes drainage basins. In the case of the Ogoki diversion, the water is retained in Lake Nipigon until required for generation of power in Nipigon River and the monthly variation in the outflow from Lake Nipigon is fairly well equalized throughout the year. A similar equalization occurs in the Long Lake project where the water is used at a power development on Aguasabon River. The mean monthly and yearly recorded diversions are given in Table A-7.

TABLE A-7

MEAN MONTHLY DIVERSIONS FROM HUDSON BAY DRAINAGE BASIN IN C.F.S.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1939							105	365	369	190	0	0	171
1940	0	0	0	0	578	847	1,122	1,281	881	0	0	0	392
1941	212	723	612	668	1,489	1,621	1,402	1,216	1,288	1,205	1,737	1,550	1,144
1942	1,235	939	725	724	1,780	2,307	1,927	1,607	1,270	550	2,092	1,876	1,419
1943	1,466	1,143	866	705	1,607	2,281	3,152	4,209	5,053	5,468	5,316	4,530	2,983
1944	3,978	3,384	2,663	2,439	4,663	8,026	7,362	2,962	2,317	3,837	2,816	2,563	3,917
1945	2,882	2,052	1,937	2,574	3,608	7,113	8,696	6,388	3,767	3,733	3,980	3,697	4,202
1946	3,312	2,872	2,785	3,777	10,061	12,484	10,627	5,652	3,807	4,669	7,351	7,287	6,224
1947	5,075	3,990	2,950	2,425	7,635	8,500	9,845	5,180	4,950	4,035	3,390	3,720	5,141
1948	3,550	2,835	2,165	2,560	8,200	9,315	9,075	7,590	4,565	3,335	3,330	4,700	5,102
1949	3,705	3,435	3,515	4,855	10,265	10,430	5,435	4,745	3,610	3,645	4,595	4,940	5,265
1950	5,025	4,420	3,875	3,470	8,930	2,290	2,315	2,115	6,985	3,550	6,845	6,665	4,706
1951	4,755	3,725	3,065	2,550	4,645	2,970	3,575	4,700	3,980	7,575	7,540	9,440	4,877

19. Effect of diversions above the head of Niagara River. — The diversion of water from or into the Great Lakes above Niagara River does not produce a simultaneous and equal change in the flow of Niagara River. Because of the large storage area in Lakes Superior, Michigan, Huron and Erie, many months must elapse before the full effect of the diversion appears in the Niagara River. The effect on the flow of Niagara River of diversions through the Chicago Sanitary and Ship Canal, the Welland Canal, and Long Lake-Ogoki was determined in a manner similar to that described in the 1928 report, Appendix F for the Chicago Sanitary and Ship Canal. The Long Lake-Ogoki diversion was treated as a diversion directly into Lakes Huron-Michigan. No appreciable error is introduced by this assumption as diversions into Lake Superior are passed down to Lake Huron in a comparatively short time and with little modification due to the regulation of the levels of Lake Superior. The mean monthly effect in the flow of Niagara River due to each of the diversions for the period 1860 through 1926 is given in Table 1, Appendix F, of the 1928 report, and for the period 1927 to 1951 is given in Table A-8 below.

14. Illinois and Michigan Canal. — The Illinois and Michigan Canal extended from the South Branch of the Chicago River at Chicago, southwesterly to LaSalle where it entered the Illinois River. This canal was completed in 1848 and was used to supply water needed for operating locks and serving other needs of navigation. Soon after the opening of the canal it was found that the operation of the lift wheel, pumping water from the Chicago River into the summit level, was causing sufficient current in the South Branch of the Chicago River to make the water perceptibly cleaner. This led to an arrangement with the Canal Commissioners in 1865 by which it was agreed to pump water from the river at certain times for the relief of the City from the serious nuisance of a badly contaminated river. The pumping was done chiefly in the summer and early fall when river conditions were at their worst. This canal has fallen into disuse and poor repair and has been abandoned. The diversion of water through the canal ceased in 1910, and since that time such water as has been used in certain sections of the canal has been part of the diversion through the Chicago Sanitary Canal.

15. Chicago Sanitary and Ship Canal. — The Chicago Sanitary and Ship Canal forms the connection between the Chicago River and the Des Plaines River and is a portion of the Illinois Waterway connecting Lake Michigan and the Missisippi River. The flow of water in the canal is controlled by a bear trap dam and a group of sluice gates on the northwest side of the canal at Lockport, Illinois. This canal has been in continuous use since 1900. The annual average diversion from the Lake Michigan watershed through the Chicago Sanitary and Ship Canal is limited by the decree of the United States Supreme Court dated 21 April 1930 to 1,500 cubic feet per second in addition to domestic pumpage. The mean monthly and yearly diversions from 1900 through 1926 are shown in Appendix F of the 1928 report and from 1927 through 1951 are shown in Table A-4 of this present report.

TABLE A-4

CHICAGO SANITARY AND SHIP CANAL—MEAN MONTHLY AND YEARLY DIVERSIONS IN C.F.S.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1927	8,520	7,850	9,110	7,840	6,790	6,555	7,835	9,115	10,045	9,795	10,245	7,675	8,448
1928	8,455	9,775	10,005	10,005	10,055	10,265	10,020	10,325	10,060	10,045	10,310	10,235	9,963
1929	10,105	10,170	7,790	6,470	5,785	10,035	9,080	9,475	11,015	11,435	11,070	10,135	9,381
1930	7,745	7,910	8,885	9,743	8,200	8,500	8,195	10,370	8,915	7,420	7,160	7,235	8,357
1931	8,120	7,655	7,575	7,565	7,990	8,355	7,945	9,005	8,815	8,770	8,455	7,905	8,180
1932	8,003	7,420	7,130	7,799	8,190	8,140	7,735	8,645	8,865	8,835	8,300	8,105	8,098
1933	7,120	6,820	7,660	8,195	7,225	8,545	8,925	8,750	8,525	7,690	8,095	7,965	7,960
1934	7,281	7,144	7,004	7,955	8,413	8,762	8,710	8,700	8,657	8,239	8,266	8,365	8,125
1935	8,312	8,325	8,235	8,375	8,291	8,214	8,024	7,732	7,217	7,824	8,752	7,734	8,086
1936	6,256	6,597	6,626	6,826	7,593	6,425	7,002	7,086	7,193	5,887	6,495	4,904	6,574
1937	6,257	5,599	5,437	6,305	5,815	6,724	7,303	7,675	6,921	7,171	7,388	7,252	6,654
1938	6,388	7,359	7,582	7,664	6,298	6,673	6,509	6,729	7,222	5,501	5,852	5,460	6,603
1939	2,901	3,949	3,169	2,695	2,605	4,211	2,873	2,899	2,826	3,018	2,816	3,465	3,119
1940	2,930	2,766	3,099	2,960	3,226	2,823	3,571	3,876	3,093	3,159	2,800	*4,937	3,270
1941	2,580	2,540	2,832	2,732	3,590	3,958	3,724	3,608	3,379	2,784	2,270	3,279	3,106
1942	2,734	3,447	2,924	2,859	3,077	3,111	3,285	3,547	3,733	2,841	2,750	2,936	3,103
1943	2,478	2,620	2,742	2,672	4,489	3,696	4,095	3,569	3,291	2,973	2,310	2,321	3,105
1944	3,206	2,633	3,179	3,126	3,022	3,330	3,278	3,316	3,081	3,136	3,346	2,993	3,137
1945	2,915	2,852	2,746	3,449	3,907	3,690	3,257	3,322	3,201	2,848	2,496	2,326	3,085
1946	2,846	2,886	3,019	2,589	4,099	3,579	3,774	3,516	3,200	2,653	2,713	2,256	3,095
1947	2,904	2,789	2,877	4,011	3,064	3,474	2,930	3,986	2,967	2,600	2,382	3,406	3,116
1948	2,586	2,506	3,096	2,361	2,896	3,453	3,918	4,446	3,992	3,132	2,475	2,821	3,140
1949	2,474	2,380	2,434	2,480	3,436	4,132	4,244	4,113	3,708	3,007	2,396	2,812	3,134
1950	2,500	2,551	2,601	2,981	2,482	3,930	4,053	3,990	3,750	2,951	2,397	3,088	3,106
1951	2,659	2,731	2,695	2,976	3,185	3,765	3,785	3,862	3,903	3,191	2,437	2,091	3,106

* The U.S. Supreme Court authorized an increase in diversion from Lake Michigan watershed from 1,500 C.F.S. to 10,000 C.F.S. in addition to domestic pumpage for one continuous period from an appropriate hour on Dec. 2, 1940 to the same hour on Dec. 12, 1940.

TABLE A-8

MONTHLY MEAN DECREASE IN FLOW OF NIAGARA RIVER DUE TO DIVERSIONS ABOVE HEAD OF RIVER, IN C.F.S. 1933 - 1938

Month	Welland Canal naviga- tion and power	Chicago Sanitary and Ship Canal	Long Lake and Ogoki increase	Net decrease	Month	Welland Canal naviga- tion and power	Chicago Sanitary and Ship Canal	Long Lake and Ogoki increase	decrease Net
				1933					
Jan.	2,100	8,500		10,600	July	2,100	8,400		10,500
Feb.	2,000	8,500		10,500	Aug.	2,200	8,400		10,600
Mar.	1,900	8,400		10,300	Sept.	2,300	8,400		10,500
April	2,000	8,400		10,400	Oct.	2,300	8,400		10,700
May	2,000	8,400		10,400	Nov.	2,300	8,300		10,600
June	2,000	8,400		10,400	Dec.	2,300	8,300		10,600
				1934					
Jan.	2,200	8,300		10,500	July	2,200	8,300		10,500
Feb.	2,200	8,300		10,500	Aug.	2,300	8,300		10,600
Mar.	2,100	8,300		10,400	Sept.	2,300	8,300		10,600
April	2,100	8,300		10,400	Oct.	2,300	8,300		10,600
May	2,200	8,300		10,500	Nov.	2,300	8,200		10,500
June	2,200	8,300		10,500	Dec.	2,300	8,200		10,500
				1935					
Jan.	2,200	8,200		10,400	July	2,200	8,200		10,400
Feb.	2,100	8,200		10,300	Aug.	2,200	8,200		10,400
Mar.	2,000	8,200		10,200	Sept.	2,200	8,200		10,400
April	2,100	8,200		10,300	Oct.	2,300	8,200		10,500
May	2,100	8,200		10,300	Nov.	2,300	8,200		10,500
June	2,100	8,200		10,300	Dec.	2,400	8,200		10,600
				1936					
Jan.	2,300	8,200		10,500	July	2,300	8,000		10,300
Feb.	2,200	8,100		10,300	Aug.	2,300	8,000		10,300
Mar.	2,100	8,100		10,200	Sept.	2,400	7,900		10,300
April	2,200	8,100		10,300	Oct.	2,400	7,900		10,300
May	2,200	8,000		10,200	Nov.	2,400	7,900		10,300
June	2,300	8,000		10,300	Dec.	2,500	7,900		10,400
				1937					
Jan.	2,400	7,800		10,200	July	2,400	7,700		10,100
Feb.	2,300	7,800		10,100	Aug.	2,500	7,600		10,100
Mar.	2,100	7,800		9,900	Sept.	2,500	7,600		10,100
April	2,200	7,700		9,900	Oct.	2,500	7,600		10,100
May	2,300	7,700		10,000	Nov.	2,500	7,500		10,000
June	2,300	7,700		10,000	Dec.	2,600	7,500		10,100
				1938					
Jan.	2,500	7,500		10,000	July	2,400	7,400		9,800
Feb.	2,400	7,500		9,900	Aug.	2,500	7,300		9,800
Mar.	2,200	7,400		9,600	Sept.	2,500	7,300		9,800
April	2,300	7,400		9,700	Oct.	2,500	7,300		9,800
May	2,300	7,400		9,700	Nov.	2,600	7,300		9,900
June	2,400	7,400		9,800	Dec.	2,600	7,200		9,800

TABLE A-5

WELLAND CANAL — MEAN YEARLY DIVERSIONS — 1860 TO 1926

Year	Yearly mean diversion cfs	Year	Yearly mean diversion cfs	Year	Yearly mean diversion cfs	Year	Yearly mean diversion cfs
1860	85	1880	85	1900	852	1920	2673
1861	85	1881	85	1901	883	1921	2486
1862	85	1882	185	1902	914	1922	2427
1863	85	1883	237	1903	945	1923	2434
1864	85	1884	288	1904	1048	1924	2279
1865	85	1885	340	1905	1151	1925	2252
1866	85	1886	392	1906	1254	1926	2326
1867	85	1887	443	1907	1348		
1868	85	1888	484	1908	1243		
1869	85	1889	526	1909	1538		
1870	85	1890	567	1910	1625		
1871	85	1891	609	1911	1701		
1872	85	1892	650	1912	1835		
1873	85	1893	670	1913	2065		
1874	85	1894	689	1914	1952		
1875	85	1895	709	1915	2188		
1876	85	1896	728	1916	2417		
1877	85	1897	759	1917	2584		
1878	85	1898	790	1918	2380		
1879	85	1899	821	1919	2503		

TABLE A-6

WELLAND CANAL — MEAN MONTHLY AND YEARLY DIVERSION IN C.F.S. — 1927 TO 1951

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly
1927	2240	2240	2260	2410	2460	2430	2400	2500	2480	2440	2490	2280	2386
1928	2090	2090	2060	2240	2290	2330	2300	2380	2350	2510	2530	2360	2294
1929	2350	2350	2300	2370	2390	2410	2460	2410	2350	2430	2440	2090	2362
1930	2070	2040	2000	2170	2540	2450	2430	2510	2540	2530	2290	1930	2292
1931	1730	1800	1800	2040	2280	2230	2090	2100	2150	2130	2260	1760	2031
1932	1560	1640	1540	1870	2390	2410	2390	2390	2420	2480	2400	1780	2106
1933	1590	1620	1510	1780	2420	2430	2450	2530	2600	2620	2570	2000	2177
1934	1800	1880	1800	1920	2500	2440	2500	2480	2380	2530	2570	1860	2222
1935	1770	1830	1620	2030	2430	2390	2100	2450	2550	2680	2700	2070	2218
1936	1870	1940	1750	2010	2650	2520	2540	2430	2540	2730	2790	2290	2338
1937	1670	1680	1970	2330	2660	2780	2660	2750	2820	2880	2770	2140	2426
1938	1950	1860	1810	2330	2730	2590	2580	2680	2810	2860	2880	2180	2438
1939	1920	1900	1920	2110	2500	2690	2590	2670	2760	2830	2920	2150	2413
1940	2040	2130	1990	2330	2980	3130	2920	3120	3100	3510	3220	2520	2749
1941	2310	2370	2260	2800	3199	3200	3170	2940	3080	3160	3530	2980	2916
1942	2610	2630	2450	3070	2960	3200	3240	3220	3040	3040	3050	2600	2925
1943	2510	2430	2560	2720	3040	3030	3040	2980	3250	4610	5070	4630	3323
1944	4420	4540	4660	4840	4230	5180	4780	5240	5200	5220	5240	3830	4782
1945	4790	4730	4510	4920	5230	5190	5110	5130	5190	4880	5150	3780	4884
1946	2160	4270	4300	4960	4980	4870	4810	5040	4950	5310	5450	5000	4675
1947	4900	4770	4790	5000	5200	5170	4460	4740	5120	5370	5260	5560	5028
1948	6000	5990	5920	5090	5070	5080	5090	5160	5100	5390	5420	6000	5443
1949	6710	6740	6730	5110	5180	5240	5130	5210	5370	5340	5350	5910	5668
1950	6830	7030	6950	5510	5300	5290	5240	5250	5300	6810	7760	7300	6214
1951	6760	5800	6050	7730	7810	7780	7690	7860	7900	7990	7930	7280	7382

TABLE A-8

MONTHLY MEAN DECREASE IN FLOW OF NIAGARA RIVER DUE TO DIVERSIONS FROM GREAT LAKES ABOVE HEAD OF RIVER, IN C.F.S. 1927-1951 (Cont'd.)

Month	Welland Canal naviga- tion and power	Chicago Sanitary and Ship Canal	Long Lake and Ogoki increase	Net decrease	Month	Welland Canal naviga- tion and power	Chicago Sanitary and Ship Canal	Long Lake and Ogoki increase	Net decrease
				1945					
Jan.	4,700	3,700	1,800	6,600	July	4,900	3,600	2,200	6,300
Feb.	4,700	3,700	1,900	6,500	Aug.	5,000	3,600	2,200	6,400
March	4,700	3,700	2,000	6,400	Sept.	5,000	3,600	2,300	6,300
April	4,800	3,600	2,000	6,400	Oct.	4,900	3,500	2,300	6,100
May	4,800	3,600	2,100	6,300	Nov.	4,900	3,500	2,400	6,000
June	4.900	3.600	2,100	6,400	Dec.	4,800	3,500	2,400	5,900
				1946					
Jan.	4,600	3,500	2,500	5,600	July	4,600	3,400	2,900	5,100
Feb.	4,400	3,500	2,600	5,300	Aug.	4,700	3,400	3,000	5,100
March	4,300	3,500	2,700	5,100	Sept.	4,700	3,400	3,100	5,000
April	4,400	3,500	2,700	5,200	Oct.	4,800	3,400	3,200	5,000
May	4,500	3,500	2,800	5,200	Nov.	4,900	3,400	3,200	5,100
June	4,600	3,400	2,900	5,100	Dec.	5.000	3.400	3.300	5.100
				1947					
Jan.	4,900	3,400	3,400	4,900	July	5,000	3,300	3,700	4,600
Feb.	4,900	3,400	3,400	4,900	Aug.	4,900	3,300	3,700	4,500
March	4,900	3,400	3,500	4,800	Sept.	4,900	3,300	3,800	4,400
April	4,900	3,300	3,500	4,700	Oct.	5,000	3,300	3,800	4,500
May	5,000	3,300	3,600	4,700	Nov.	5,000	3,300	3,900	4,400
June	5,000	3,300	3,600	4,700	Dec.	5,100	3.300	3,900	4,500
				1948					
Jan.	5,200	3,300	3,900	4,600	July	5,300	3,200	4,100	4,400
Feb.	5,400	3,300	4,000	4,700	Aug.	5,300	3,200	4,100	4,400
March	5,500	3,300	4,000	4,800	Sept.	5,200	3,200	4,200	4,200
April	5,400	3,300	4,000	4,700	Oct.	5,300	3,200	4,200	4,300
May	5,400	3,300	4,100	4,600	Nov.	5,300	3,200	4,200	4,300
June	5,300	3,300	4,100	4,500	Dec.	5,400	3,200	4,300	4,300
				1949					
Jan.	5,600	3,200	4,300	4,500	July	5,600	3,200	4,400	4,400
Feb.	5,800	3,200	4,300	4,700	Aug.	5,500	3,200	4,400	4,300
March	6,000	3,200	4,300	4,900	Sept.	5,400	3,200	4,500	4,100
April	5,900	3,200	4,300	4,800	Oct.	5,500	3,200	4,500	4,200
May	5,700	3,200	4,400	4,500	Nov.	5,500	3,200	4,500	4,200
June	5,600	3,200	4,400	4,400	Dec.	5,500	3,200	4,500	4,200
				1950					
Jan.	5,700	3,200	4,500	4,400	July	5,700	3,200	4,600	4,300
Feb.	5,900	3,200	4,500	4,600	Aug.	5,600	3,200	4,600	4,200
March	6,100	3,200	4,600	4,700	Sept.	5,500	3,200	4,600	4,100
April	6,000	3,200	4,600	4,600	Oct.	5,800	3,200	4,600	4,400
May	5,900	3,200	4,600	4,500	Nov.	6,100	3,100	4,600	4,600
June	5,800	3,200	4,600	4,400	Dec.	6,300	3,100	4,600	4,800
				1951					
Jan.	6,300	3,100	4,600	4,800	July	7,100	3,100	4,700	5,500
Feb.	6,300	3,100	4,600	4,800	Aug.	7,200	3,100	4,700	5,600
March	6,300	3,100	4,600	4,800	Sept.	7,300	3,100	4,700	5,700
April	6,500	3,100	4,700	4,900	Oct.	7,400	3,100	4,700	5,800
May	6,700	3,100	4,700	5,100	Nov.	7,500	3,100	4,700	5,900
June	7.000	3.100	4.700	5.400	Dec.	7,500	3,100	4,700	5,900

TABLE A-8

MONTHLY MEAN DECREASE IN FLOW OF NIAGARA RIVER DUE TO DIVERSIONS ABOVE HEAD OF RIVER, IN C.F.S. 1927 - 1951

Month	Welland Canal naviga-tion and power	Chicago Sanitary and Ship Canal	Long Lake and Ogoki increase	Net decrease	Month	Welland Canal naviga-tion and power	Chicago Sanitary and Ship Canal	Long Lake and Ogoki increase	Net decrease
				1927					
Jan.	2,400	8,300		10,700	July	2,400	8,300		10,700
Feb.	2,400	8,300		10,700	Aug.	2,400	8,300		10,700
Mar.	2,300	8,300		10,600	Sept.	2,400	8,300		10,700
April	2,300	8,300		10,600	Oct.	2,400	8,300		10,700
May	2,400	8,300		10,700	Nov.	2,400	8,300		10,700
June	2,400	8,300		10,700	Dec.	2,400	8,300		10,700
				1928					
Jan.	2,400	8,300		10,700	July	2,300	8,500		10,800
Feb.	2,300	8,300		10,600	Aug.	2,300	8,500		10,800
Mar.	2,200	8,400		10,600	Sept.	2,300	8,500		10,800
April	2,300	8,400		10,700	Oct.	2,300	8,500		10,800
May	2,300	8,400		10,700	Nov.	2,300	8,600		10,900
June	2,300	8,400		10,700	Dec.	2,400	8,600		11,000
				1929					
Jan.	2,400	8,600		11,000	July	2,400	8,800		11,200
Feb.	2,400	8,600		11,000	Aug.	2,400	8,800		11,200
Mar.	2,300	8,700		11,000	Sept.	2,400	8,800		11,200
April	2,400	8,700		11,100	Oct.	2,400	8,800		11,200
May	2,400	8,700		11,100	Nov.	2,400	8,800		11,200
June	2,400	8,700		11,100	Dec.	2,300	8,900		11,200
				1930					
Jan.	2,300	8,900		11,200	July	2,300	8,800		11,100
Feb.	2,300	8,800		11,100	Aug.	2,300	8,800		11,100
Mar.	2,200	8,800		11,000	Sept.	2,400	8,800		11,200
April	2,300	8,800		11,100	Oct.	2,400	8,800		11,200
May	2,300	8,800		11,100	Nov.	2,300	8,800		11,100
June	2,300	8,800		11,100	Dec.	2,300	8,800		11,100
				1931					
Jan.	2,200	8,800		11,000	July	2,100	8,700		10,800
Feb.	2,200	8,800		11,000	Aug.	2,100	8,700		10,800
March	2,100	8,800		10,900	Sept.	2,100	8,700		10,800
April	2,100	8,700		10,800	Oct.	2,100	8,700		10,800
May	2,100	8,700		10,800	Nov.	2,100	8,600		10,700
June	2,100	8,700		10,800	Dec.	2,100	8,600		10,700
				1932					
Jan.	2,000	8,600		10,600	July	2,100	8,500		10,600
Feb.	1,900	8,600		10,500	Aug.	2,100	8,500		10,600
Mar.	1,900	8,600		10,500	Sept.	2,200	8,500		10,700
April	1,900	8,600		10,500	Oct.	2,200	8,500		10,700
May	2,000	8,600		10,600	Nov.	2,200	8,500		10,700
June	2,000	8,600		10,600	Dec.	2,200	8,500		10,700

TABLE A-9

MONTHLY MEAN DIVERSIONS FROM NIAGARA RIVER BETWEEN ITS HEAD AND NIAGARA FALLS, IN C.F.S. 1927 - 1951 (Cont'd.)

Month	New York State Barge Canal	Niagara Mohawk Power Corp.	Canadian Niagara Power Co.	Hydro-Electric Power Commission of Ontario: Ontario Plant	Toronto Plant	Sir Adam Beck Plant No. 1	International Railway Co.	Total
				1929				
Jan.	700	19,995	9,764	7,116	2,985	14,791	209	55,560
Feb.	700	19,997	10,008	7,362	2,489	14,950	222	55,728
March	0	19,925	9,786	7,177	2,559	14,565	199	54,211
April	1,000	19,948	9,380	7,366	3,478	13,823	196	55,191
May	1,100	19,996	9,995	6,543	4,083	13,978	199	55,894
June	1,100	19,997	10,063	6,597	3,685	13,805	211	55,458
July	1,100	19,992	10,083	7,016	2,808	13,688	207	54,894
Aug.	1,100	19,997	9,888	7,277	3,422	14,189	209	56,082
Sept.	1,100	19,997	10,140	6,880	2,666	14,971	207	55,961
Oct.	1,100	19,998	10,162	6,467	2,801	14,131	197	54,856
Nov.	1,100	19,997	10,170	7,010	2,608	15,305	200	56,390
Dec.	775	19,905	9,679	6,897	2,344	14,311	195	54,106
				1930				
Jan.	700	19,998	9,990	7,009	2,900	14,517	226	55,340
Feb.	700	19,978	9,875	7,240	2,378	14,878	214	55,263
March	0	19,983	9,776	6,827	2,140	14,650	203	53,579
April	900	19,994	9,414	6,995	2,511	14,136	181	54,131
May	1,100	19,990	9,669	6,541	3,241	13,591	197	54,329
June	1,100	19,983	9,646	6,149	2,728	13,338	208	53,152
July	1,100	19,983	9,773	4,993	2,634	11,575	210	50,268
Aug.	1,100	19,997	9,974	5,104	2,424	11,919	209	50,727
Sept.	1,100	19,997	9,653	5,441	2,845	14,008	204	53,248
Oct.	1,100	19,965	9,340	5,067	3,774	14,258	196	53,670
Nov.	1,100	19,997	9,354	4,255	3,281	13,569	200	51,756
Dec.	800	19,997	9,255	4,376	3,735	13,386	210	51,759
				1931				
Jan.	700	19,997	9,226	4,707	3,683	13,185	225	51,723
Feb.	700	19,997	9,119	4,750	3,245	12,741	223	50,775
Mar.	0	19,997	9,018	2,542	3,365	12,798	216	47,936
Apr.	1,000	19,763	8,380	389	7,526	10,589	197	47,844
May	1,100	19,179	7,235	924	5,722	9,440	195	43,795
June	1,100	19,415	7,643	700	5,773	9,546	209	44,386
July	1,100	19,553	7,691	727	5,303	9,077	210	43,661
Aug.	1,100	18,711	8,024	563	563	10,456	211	39,628
Sept.	1,100	19,406	8,186	628	796	11,322	197	41,635
Oct.	1,100	19,712	8,524	929	806	11,419	182	42,672
Nov.	1,100	18,935	7,438	3,124	684	9,416	154	40,851
Dec.	900	18,369	6,510	3,051	1,263	9,489	158	39,740
				1932				
Jan.	700	17,735	5,866	3,213	1,445	9,298	159	38,416
Feb.	700	18,184	5,679	3,544	1,394	9,141	162	38,804
Mar.	100	18,635	5,821	4,252	1,369	9,305	160	39,642
Apr.	900	17,990	5,605	393	1,107	10,771	146	36,912
May	1,100	15,875	6,015	515	854	8,738	153	33,250
June	1,100	16,315	6,044	321	824	8,953	164	33,721
July	1,100	15,960	5,722	309	1,217	8,462	176	32,946
Aug.	1,100	17,009	6,090	327	771	8,996	173	34,466
Sept.	1,100	18,477	6,480	487	791	9,847	176*	37,358
Oct.	1,100	18,639	6,042	607	813	9,420		36,621
Nov.	1,100	18,240	5,388	668	812	9,091		35,299
Dec.	850	18,141	5,282	525	814	9,022		34,634

*Franchise expired Sept. 12. Mean diversion is for 12 days.

TABLE A-8

MONTHLY MEAN DECREASE IN FLOW OF NIAGARA RIVER DUE TO DIVERSIONS FROM GREAT LAKES ABOVE HEAD OF RIVER, IN C.F.S. 1927-1951 (Cont'd.)

Month	Welland Canal navigation and power	Chicago Sanitary and Ship Canal	Long Lake and Ogoki increase	Net decrease	Month	Welland Canal navigation and power	Chicago Sanitary and Ship Canal	Long Lake and Ogoki increase	Net decrease
				1939					
Jan.	2,500	7,200		9,700	July	2,400	6,800		9,200
Feb.	2,400	7,100		9,500	Aug.	2,500	6,700		9,200
Mar.	2,300	7,000		9,300	Sept.	2,500	6,600		9,100
April	2,300	7,000		9,300	Oct.	2,500	6,500		9,000
May	2,300	6,900		9,200	Nov.	2,500	6,500		9,000
June	2,300	6,800		9,100	Dec.	2,600	6,400		9,000
				1940					
Jan.	2,500	6,300		8,800	July	2,600	5,900	100	8,400
Feb.	2,400	6,300		8,700	Aug.	2,700	5,800	100	8,400
Mar.	2,300	6,200		8,500	Sept.	2,800	5,700	100	8,400
April	2,400	6,100		8,500	Oct.	2,800	5,700	100	8,400
May	2,500	6,000		8,500	Nov.	2,800	5,600	100	8,300
June	2,500	6,000	100	8,400	Dec.	2,900	5,500	100	8,300
				1941					
Jan.	2,800	5,500	100	8,200	July	2,900	5,100	200	7,800
Feb.	2,700	5,400	100	8,000	Aug.	2,900	5,100	200	7,800
Mar.	2,600	5,300	100	7,800	Sept.	2,900	5,000	300	7,600
April	2,700	5,300	200	7,800	Oct.	3,000	4,900	300	7,600
May	2,800	5,200	200	7,800	Nov.	3,000	4,900	300	7,600
June	2,800	5,200	200	7,800	Dec.	3,100	4,800	300	7,600
				1942					
Jan.	3,000	4,800	300	7,500	July	3,000	4,500	500	7,000
Feb.	2,900	4,800	400	7,300	Aug.	3,000	4,500	500	7,000
Mar.	2,800	4,700	400	7,100	Sept.	3,000	4,500	500	7,000
April	2,900	4,700	400	7,200	Oct.	3,000	4,400	500	6,900
May	2,900	4,600	400	7,100	Nov.	3,000	4,400	600	6,800
June	2,900	4,600	400	7,100	Dec.	3,000	4,300	600	6,700
				1943					
Jan.	2,900	4,300	600	6,600	July	2,900	4,100	900	6,100
Feb.	2,800	4,300	700	6,400	Aug.	2,900	4,100	900	6,100
March	2,800	4,200	700	6,300	Sept.	3,000	4,100	1,000	6,100
April	2,800	4,200	800	6,200	Oct.	3,200	4,000	1,000	6,200
May	2,800	4,200	800	6,200	Nov.	3,500	4,000	1,100	6,400
June	2,800	4,100	800	6,100	Dec.	3,800	4,000	1,100	6,700
				1944					
Jan.	3,900	3,900	1,200	6,600	July	4,500	3,800	1,500	6,800
Feb.	4,000	3,900	1,200	6,700	Aug.	4,600	3,800	1,600	6,800
March	4,100	3,900	1,300	6,700	Sept.	4,700	3,800	1,600	6,900
April	4,200	3,900	1,300	6,800	Oct.	4,700	3,700	1,700	6,700
May	4,300	3,900	1,400	6,800	Nov.	4,700	3,700	1,700	6,700
June	4,400	3,800	1,400	6,800	Dec.	4,700	3,700	1,800	6,600

TABLE A-9

MONTHLY MEAN DIVERSIONS FROM NIAGARA RIVER BETWEEN ITS HEAD AND NIAGARA FALLS, IN C.F.S. 1927 - 1951 (Cont'd.)

Month	New York State Barge Canal	Niagara Mohawk Power Corp.	Canadian Niagara Power Co.	Hydro-Electric Power Commission of Ontario: Ontario Plant	Hydro-Electric Power Commission of Ontario: Toronto Plant	Hydro-Electric Power Commission of Ontario: Sir Adam Beck Plant No. 1	International Railway Co.	Total
				1937				
Jan.	700	19,997	9,520	7,260	3,572	14,144		55,193
Feb.	500	19,997	9,730	7,360	3,467	14,522		55,576
Mar.	100	19,997	9,486	7,332	3,543	14,930		55,388
Apr.	900	19,997	9,952	7,211	3,238	14,789		56,087
May	1,100	19,997	10,093	6,981	3,977	13,236		55,384
June	1,100	19,997	10,241	7,531	4,449	13,209		56,527
July	1,100	19,997	10,140	7,108	5,004	12,781		56,130
Aug.	1,100	19,997	10,029	7,184	4,129	13,890		56,329
Sept.	1,100	19,971	10,065	7,317	3,144	14,948		56,545
Oct.	1,100	19,997	10,127	7,481	3,400	14,612		56,717
Nov.	1,100	19,997	9,618	7,535	3,381	14,173		55,804
Dec.	700	19,997	9,710	7,250	3,205	13,534		54,396
				1938				
Jan.	700	18,518	9,177	5,383	4,594	12,743		51,337
Feb.	600	19,618	9,172	Down	11,830	11,647		52,767
Mar.	0	19,997	9,210	137	11,030	11,756		52,130
Apr.	750	19,997	8,918	340	10,738	11,391		52,134
May	1,100	19,998	9,671	1,053	10,122	11,297		53,241
June	1,100	19,997	9,833	1,938	9,250	11,145		53,263
July	1,100	19,997	9,601	2,378	7,539	11,062		51,677
Aug.	1,100	19,982	9,507	4,842	2,464	11,706		49,601
Sept.	1,100	19,971	9,580	5,959	2,638	12,633		51,881
Oct.	1,100	19,997	9,660	5,926	2,632	13,006		52,321
Nov.	1,100	19,997	9,475	6,579	2,862	12,585		52,598
Dec.	750	19.997	9.363	6,227	2,771	12,589		51,697
				1939				
Jan.	700	19,998	9,482	6,123	2,590	12,523		51,416
Feb.	575	19,997	9,640	6,638	2,195	13,344		52,389
Mar.	0	19,997	9,554	6,103	2,169	12,439		50,262
Apr.	650	19,997	8,838	3,821	5,891	10,974		50,171
May	1,100	19,997	9,246	5,954	6,735	9,760		52,792
June	1,100	19,997	9,195	5,786	6,978	10,224		53,280
July	1,100	19,981	9,400	5,170	6,669	9,718		52,038
Aug.	1,100	19,997	9,639	5,702	6,596	10,786		53,820
Sept.	1,100	19,970	9,887	7,105	4,377	13,300		55,739
Oct.	1,100	19,996	9,681	7,526	4,332	13,907		56,542
Nov.	1,100	19,997	10,083	7,547	3,821	14,179		56,727
Dec.	750	19,997	10.251	7,760	3,146	14,396		56.300
				1940				
Jan.	700	19,260	10,006	8,209	3,006	14,509		55,690
Feb.	625	19,997	9,557	8,616	3,080	14,568		56,443
Mar.	0	19,996	10,233	8,463	2,504	14,615		55,811
Apr.	325	19,997	10,068	7,934	2,759	14,633		55,716
May	1,100	19,996	9,836	7,615	3,498	14,604		56,649
June	1,100	19,997	9,719	7,728	3,814	14,518		56,876
July	1,100	19,997	9,764	7,768	4,075	13,914		56,618
Aug.	1,100	19,997	10,070	8,732	3,440	13,612		56,951
Sept.	1,100	19,970	10,214	8,420	3,366	13,825		56,895
Oct.	1,100	19,996	10.247	8,556	3,181	13,905		56,985
Nov.	1,100	19,997	10,202	9,155	6,904	13,911		61,269
Dec.	700	19,997	9,931	9.326	6.983	14,095		61,032

20. Diversions between the head of Niagara River and Niagara Falls. — Power diversions above the Falls and diversions through the New York State Barge Canal for the period 1886 - 1926, inclusive, are summarized in Table 2, Appendix F, of the 1928 report, and for the period 1927 to 1951 are shown in Table A-9 below.

TABLE A-9

MONTHLY MEAN DIVERSIONS FROM NIAGARA RIVER BETWEEN ITS HEAD AND NIAGARA FALLS, IN C.F.S. 1927 - 1951

Month	New York State Barge Canal (1)	Niagara Mohawk Power Corp.	Canadian Niagara Power Co.	Hydro-Electric Power Commission of Ontario			International Railway Co.	Total
				Ontario Plant	Toronto Plant	Sir Adam Beck Plant No. 1 (2)		
				1927				
Jan.	975	19,714	8,791	6,859	3,393	13,589	196	53,517
Feb.	975	19,645	9,398	6,193	2,704	13,872	164	52,951
Mar.	600	19,601	9,064	6,548	3,028	12,947	194	51,982
Apr.	1,100	19,606	9,277	6,377	3,279	12,336	176	52,151
May	1,375	19,625	9,381	6,134	3,088	11,849	190	51,642
June	1,375	19,664	9,808	6,459	3,409	12,504	196	53,415
July	1,375	19,391	9,555	6,396	2,505	11,453	186	50,861
Aug.	1,375	19,649	9,850	6,655	2,969	12,713	183	53,394
Sept.	1,375	19,706	9,970	6,781	3,059	13,564	181	54,636
Oct.	1,375	19,709	10,072	6,630	3,280	13,968	181	55,215
Nov.	1,375	19,693	9,988	6,603	2,679	14,449	184	54,971
Dec.	975	19,654	9,942	6,606	2,719	14,276	198	54,370
				1928				
Jan.	975	19,709	9,709	6,770	2,492	14,273	210	54,138
Feb.	975	19,671	9,861	6,704	2,229	14,858	212	54,510
Mar.	500	19,698	9,686	6,681	2,583	14,477	206	53,831
Apr.	1,050	19,573	9,686	6,617	3,305	13,414	197	53,842
May	1,375	19,628	9,586	6,839	3,361	13,719	191	54,699
June	1,375	19,449	9,376	6,976	3,714	13,244	213	54,347
July	1,375	19,563	9,562	7,250	3,755	11,602	213	53,320
Aug.	1,375	19,661	9,856	6,726	3,244	13,629	211	54,702
Sept.	1,375	19,698	9,422	6,839	2,780	14,131	208	54,453
Oct.	1,100	19,993	10,076	6,544	3,032	14,824	195	55,764
Nov.	1,100	19,997	10,027	6,868	2,950	14,564	200	55,706
Dec.	700	19,960	10,034	6,830	2,575	14,368	209	54,676

(1) Period from Jan. 1927 to Sept. 1928 includes 275 cfs for power.
(2) Formerly called Queenston plant.

TABLE A-9

MONTHLY MEAN DIVERSIONS FROM NIAGARA RIVER BETWEEN ITS HEAD AND NIAGARA FALLS, IN C.F.S. 1927 - 1951 (Cont'd.)

Month	New York State Barge Canal	Niagara Mohawk Power Corp.	Canadian Niagara Power Co.	Hydro-Electric Power Commission of Ontario: Ontario Plant	Hydro-Electric Power Commission of Ontario: Toronto Plant	Hydro-Electric Power Commission of Ontario: Sir Adam Beck Plant No. 1	International Railway Co.	Total
				1945				
Jan.	700	30,719	10,284	10,519	13,678	15,015		80,915
Feb.	575	31,772	10,308	10,534	13,943	14,818		81,950
Mar.	50	31,552	10,500	10,583	13,871	15,234		81,790
Apr.	1,075	31,446	10,559	10,430	14,089	15,278		82,877
May	1,100	31,686	10,601	9,661	13,869	14,986		81,903
June	1,100	31,876	10,438	9,761	13,870	15,208		82,253
July	1,100	31,645	10,601	10,177	12,652	14,185		80,360
Aug.	1,100	31,365	10,575	9,681	13,680	14,387		80,788
Sept.	1,100	31,728	10,564	10,031	13,796	14,775		81,994
Oct.	1,100	31,587	10,548	10,630	13,258	14,907		82,030
Nov.	1,100	31,974	10,536	10,666	12,872	14,211		81,359
Dec.	850	31.943	10.496	10,724	14,111	14,176		82,300
				1946				
Jan.	700	31,872	10,512	10,609	14,224	14,576		82,493
Feb.	600	32,146	10.534	10,554	13,834	14,241		81,909
Mar.	0	31,557	10,531	10,175	13,335	14,293		79,891
Apr.	700	31,640	10,359	9,980	13,795	14,742		81,216
May	1,100	31,788	10,579	9,431	12,769	14,721		80,388
June	1,100	31,817	10,609	9,715	13,650	14,416		81,307
July	1,100	31,944	10,582	10,226	13,754	13,714		81,320
Aug.	1,100	32,127	10,626	9,786	14,248	14,042		81,929
Sept.	1,100	32,028	10,454	9,804	14,389	14,361		82,136
Oct.	1,100	31,793	10,109	10,699	13,983	14,522		82,206
Nov.	1,100	32,000	10,486	10,777	14,107	14,547		83,017
Dec.	700	31,948	10.586	10,805	13,860	14.527		82.426
				1947				
Jan.	700	31,074	10.284	10,289	14,366	14,245		80,958
Feb.	600	27,472	10,258	10,420	14,422	14,446		77,618
Mar.	75	31,745	9,722	10,630	14,724	14,520		81,416
Apr.	750	27,966	10,028	9,998	13,947	14,735		77,424
May	1,100	28,084	10,093	9.143	13,720	15,262		77,402
June	1,100	28,276	10.426	9,396	13,154	15,265		77,617
July	1,100	28,576	10,011	9,838	14,036	14,675		78,236
Aug.	1,100	31,507	10,629	10,083	14,639	14,266		82,224
Sept.	1,100	31,413	10,616	10,433	14,655	14,445		82,662
Oct.	1,100	31,796	10,523	10,631	14,745	14,035		82,830
Nov.	1,100	31,765	10,421	10,872	14,776	14,066		83.000
Dec.	800	31.861	10.536	10.798	14,502	14,290		82.787
				1948				
Jan.	700	31,413	10,218	10,512	14.331	14.215		81,389
Feb.	550	31,862	10,306	10,442	14,581	14,178		81.919
Mar.	0	31,555	10,430	10,470	14,042	14,642		81,139
Apr.	700	31,060	10,522	10,348	14,355	15,043		82.028
May	1,100	31,327	10.266	10,169	14,189	15,051		82,102
June	1,100	31,027	10.651	10,221	14,690	14,456		82.145
July	1,100	30,976	10,628	10,238	14,950	14,087		81,979
Aug.	1,100	31,166	10,636	10,155	14.817	13,963		81.837
Sept.	1,100	31,396	10,631	10.715	14.794	13.993		82.629
Oct.	1,100	31,440	10,539	10.482	14.987	14,029		82.577
Nov.	1,100	31,457	9.671	10,933	15,043	14,310		82.514
Dec.	225	31.017	10.192	11.000	14.430	14.362		81.226

TABLE A-9

MONTHLY MEAN DIVERSIONS FROM NIAGARA RIVER BETWEEN ITS HEAD AND NIAGARA FALLS, IN C.F.S. 1927 - 1951 (Cont'd.)

Month	New York State Barge Canal	Niagara Mohawk Power Corp.	Canadian Niagara Power Co.	Hydro-Electric Power Commission of Ontario: Ontario Plant	Hydro-Electric Power Commission of Ontario: Toronto Plant	Hydro-Electric Power Commission of Ontario: Sir Adam Beck Plant No. 1	International Railway Co.	Total
				1933				
Jan.	700	16,765	5,483	521	817	8,529		32,815
Feb.	625	16,907	5,758	566	821	10,118		34,795
Mar.	100	15,900	5,636	557	787	10,325		33,305
Apr.	1,000	15,150	5,184	500	680	10,278		32,792
May	1,100	18,234	5,829	594	746	9,044		35,547
June	1,100	19,680	7,768	669	819	8,840		38,866
July	1,100	19,825	9,351	712	4,177	8,310		43,475
Aug.	1,100	19,930	9,539	2,125	828	8,945		42,467
Sept.	1,100	19,994	9,397	4,320	911	9,173		44,895
Oct.	1,100	19,998	9,442	3,907	889	10,074		45,410
Nov.	1,100	19,996	9,685	5,192	878	11,668		48,519
Dec.	850	19,927	9,195	5,890	878	11,841		48,581
				1934				
Jan.	700	19,846	8,820	5,960	924	12,279		48,529
Feb.	700	19,924	7,825	6,963	1,659	14,223		51,294
Mar.	225	19,981	8,196	5,446	4,237	14,165		52,250
Apr.	650	19,522	6,198	708	7,197	10,124		44,399
May	1,100	19,952	8,651	1,416	9,706	8,431		49,256
June	1,100	19,998	8,708	2,881	9,640	8,502		50,829
July	1,100	19,995	8,103	3,456	8,745	7,903		49,302
Aug.	1,100	19,996	8,947	6,884	914	9,179		47,020
Sept.	1,100	19,961	8,914	6,849	939	8,808		46,571
Oct.	1,100	19,967	8,848	6,569	1,187	8,602		46,273
Nov.	1,100	19,944	8,523	6,338	1,281	9,459		46,645
Dec.	700	19,938	8,904	6,704	1,679	9,770		47,695
				1935				
Jan.	700	19,970	8,156	6,662	2,315	11,066		48,869
Feb.	700	19,997	7,977	7,176	1,232	12,615		49,697
Mar.	0	19,902	8,194	6,921	1,236	10,707		46,960
Apr.	850	19,772	7,691	6,290	1,196	10,170		45,969
May	1,100	19,795	8,575	7,079	1,159	9,282		46,990
June	1,100	19,956	8,168	7,416	1,167	9,244		47,051
July	1,100	19,908	8,240	5,447	2,656	8,655		46,006
Aug.	1,100	19,993	9,505	7,163	1,363	9,253		48,377
Sept.	1,100	19,971	9,510	7,416	1,632	10,444		50,073
Oct.	1,100	19,997	9,917	6,594	3,259	12,475		53,342
Nov.	1,100	19,998	10,013	6,686	3,459	14,478		55,734
Dec.	700	19,998	9,559	6,715	3,509	14,590		55,071
				1936				
Jan.	700	17,544	8,650	7,225	4,138	14,852		53,109
Feb.	625	15,337	6,037	8,469	7,300	13,218		50,986
Mar.	0	19,986	7,685	7,515	4,266	13,617		53,069
Apr.	850	19,997	8,896	7,263	3,097	13,058		53,161
May	1,100	19,995	9,518	6,531	3,303	13,108		53,555
June	1,100	19,997	10,162	6,968	3,621	13,044		54,892
July	1,100	19,994	9,628	6,932	3,994	12,843		54,491
Aug.	1,100	19,994	10,177	6,996	3,588	13,721		55,576
Sept.	1,100	19,970	10,161	7,451	3,387	13,956		56,025
Oct.	1,100	19,997	10,097	7,415	3,848	13,984		56,441
Nov.	1,100	19,997	10,048	7,339	3,982	13,787		56,253
Dec.	700	19,997	10,225	7,249	3,710	14,072		55,953

procedure followed in obtaining these data is explained in detail. For the period 1927 through 1951, the flow over the Falls was obtained by subtracting from the flow of the Niagara River at the Morrison Street gauge (outlet of the Maid-of-the-Mist Pool) all the diversions made at the Falls except those through the Sir Adam Beck No. 1 plant. The actual mean monthly flow over the Falls and also the flows that would have occurred had there been no diversions from or into the Great Lakes are listed in Table A-10 below for the period 1927 through 1951. Both sets of data for the 92-year period from 1860 to 1951 are shown graphically on Plates A-1 to A-3, inclusive.

TABLE A-10

SUMMARY OF DISCHARGE DATA — NIAGARA RIVER MONTHLY MEANS IN C.F.S. 1927-1951

Month	Actual flow over Falls	Additions for diversions		Flow which would have occurred had there been no diversion	Month	Actual flow over Falls	Additions for diversions		Flow which would have occurred had there been no diversion
		Above head of Niagara River (From Table 8)	Below head of Niagara River (From Table 9)				Above head of Niagara River (From Table 8)	Below head of Niagara River (From Table 9)	
				1927					
Jan.	122,300	10,700	53,500	186,500	July	144,700	10,700	50,900	206,300
Feb.	119,700	10,700	53,000	183,400	Aug.	138,300	10,700	53,400	202,400
Mar.	123,700	10,600	52,000	186,300	Sept.	132,900	10,700	54,600	198,200
Apr.	133,600	10,600	52,200	196,400	Oct.	127,300	10,700	55,200	193,200
May	143,900	10,700	51,600	206,200	Nov.	128,500	10,700	55,000	194,200
June	145,500	10,700	53,400	209,600	Dec.	148,600	10,700	54,400	213,700
				1928					
Jan.	139,600	10,700	54,100	204,400	July	155,000	10,800	53,300	219,100
Feb.	127,000	10,600	54,500	192,100	Aug.	148,600	10,800	54,700	214,100
Mar.	129,400	10,600	53,800	193,800	Sept.	144,300	10,800	54,500	209,600
Apr.	133,500	10,700	53,800	198,000	Oct.	139,200	10,800	55,800	205,800
May	140,500	10,700	54,700	205,900	Nov.	143,100	10,900	55,700	209,700
June	151,900	10,700	54,300	216,900	Dec.	145,500	11,000	54,700	211,200
				1929					
Jan.	137,700	11,000	55,600	204,300	July	182,700	11,200	54,900	248,800
Feb.	134,400	11,000	55,700	201,100	Aug.	172,900	11,200	56,100	240,200
Mar.	150,100	11,000	54,200	215,300	Sept.	164,600	11,200	56,000	231,800
Apr.	169,600	11,100	55,200	235,900	Oct.	159,400	11,200	54,900	225,500
May	188,800	11,100	55,900	255,800	Nov.	166,100	11,200	56,400	233,700
June	185,100	11,100	55,500	251,700	Dec.	160,300	11,200	54,100	225,600
				1930					
Jan.	165,400	11,200	55,300	231,900	July	173,300	11,100	50,300	234,700
Feb.	158,700	11,100	55,300	225,100	Aug.	161,800	11,100	50,700	223,600
Mar.	169,800	11,000	53,600	234,400	Sept.	156,200	11,200	53,200	220,600
Apr.	164,000	11,100	54,100	229,200	Oct.	148,100	11,200	53,700	213,000
May	178,800	11,100	54,300	244,300	Nov.	147,000	11,100	51,800	209,900
June	178,800	11,100	53,200	243,100	Dec.	142,800	11,100	51,800	205,700
				1931					
Jan.	134,700	11,000	51,700	197,400	July	140,300	10,800	43,700	194,800
Feb.	125,400	11,000	50,800	187,200	Aug.	141,400	10,800	39,600	191,800
Mar.	123,100	10,900	47,900	181,900	Sept.	136,800	10,800	41,600	189,200
Apr.	132,300	10,800	47,800	190,900	Oct.	132,400	10,800	42,700	185,900
May	140,900	10,800	43,800	195,500	Nov.	133,500	10,700	40,900	185,100
June	139,900	10,800	44,400	195,100	Dec.	135,900	10,700	39,700	186,300

TABLE A-9

MONTHLY MEAN DIVERSIONS FROM NIAGARA RIVER BETWEEN ITS HEAD AND NIAGARA FALLS, IN C.F.S. 1927 - 1951 (Cont'd.)

Month	New York State Barge Canal	Niagara Mohawk Power Corp.	Canadian Niagara Power Co.	Hydro-Electric Power Commission of Ontario: Ontario Plant	Hydro-Electric Power Commission of Ontario: Toronto Plant	Hydro-Electric Power Commission of Ontario: Sir Adam Beck Plant No. 1	Inter-national Railway Co.	Total
				1941				
Jan.	700	19,997	9,644	9,144	7,412	14,281		61,178
Feb.	575	19,997	9,987	9,255	7,226	14,402		61,442
Mar.	0	19,997	10,115	9,636	6,495	14,471		60,714
Apr.	550	19,997	10,175	9,859	6,069	14,392		61,042
May	1,100	19,996	10,066	9,906	6,552	14,087		61,707
June	1,100	22,934	9,797	9,738	7,965	13,725		65,259
July	1,100	24,996	10,042	9,659	9,630	13,384		68,811
Aug	1,100	24,996	10,030	9,635	10,574	13,379		69,714
Sept.	1,100	24,996	10,244	9,315	10,662	13,503		69,820
Oct.	1,100	24,996	10,221	9,838	10,290	13,466		69,911
Nov.	1,100	25,241	10,161	10,259	10,176	13,608		70,545
Dec.	800	31,105	10,123	10,512	13,763	13,496		79,799
				1942				
Jan.	700	27,234	9,515	10,407	14,045	13,626		75,527
Feb.	600	31,319	9,188	10,261	13,963	13,336		78,667
Mar.	0	31,163	9,824	10,112	13,917	13,678		78,694
Apr.	1,050	31,078	9,600	9,538	13,960	13,617		78,843
May	1,100	31,297	9,939	9,763	14,078	13,420		79,597
June	1,100	31,209	9,982	9,085	12,476	13,538		77,390
July	1,100	30,993	10,607	9,158	10,527	13,214		75,599
Aug.	1,100	31,513	10,666	9,652	11,507	13,216		77,654
Sept.	1,100	31,459	10,304	10,494	13,150	13,623		80,130
Oct.	1,100	31,438	10.502	10,791	13,381	13,942		81,154
Nov.	1,100	31,418	10,310	10,711	13,391	14,163		81,093
Dec.	850	31.647	10.415	10,627	13,469	14,341		81,349
				1943				
Jan.	600	31,612	9,917	9,727	12,495	14,305		78,656
Feb.	575	31,777	10,353	10,230	12,530	14,808		80,273
Mar.	50	31,648	10,352	9 ,875	11,636	14,973		78,534
Apr.	975	31,830	9,926	10,320	11,158	14,891		79,100
May	1,100	31,268	10,560	10,291	10,803	14,777		78,799
June	1,100	31,100	10,631	8,877	10,723	14,136		76,567
July	1,100	31,401	10,643	9,182	10,666	14,364		77,356
Aug.	1,100	31,562	10,654	10,046	10,002	14,332		77,696
Sept.	1,100	31,727	10,674	10,066	8,434	14,818		76,819
Oct.	1,100	31,699	10,678	10,830	6,339	14,937		75,583
Nov.	1,100	31,844	10,358	10,757	8,028	14,830		76,917
Dec.	850	31.961	10.568	10,289	10,191	14,519		78.378
				1944				
Jan.	700	31,967	10.445	10,225	11,409	14,675		79,421
Feb.	500	32.070	10,292	10,120	12,112	14,730		79,824
Mar.	100	32,019	10,413	10,417	11,714	14,851		79,514
Apr.	700	31,633	10,222	10,182	10,964	14,707		78,408
May	1,100	31,725	10,563	9,264	11,684	14,348		78,684
June	1,100	31.683	10,639	9,239	12,631	14,317		79,609
July	1,100	31,227	10,671	8,764	11,277	14.395		77,434
Aug.	1,100	31,189	10,649	9,307	11.661	14,788		78,694
Sept.	1,100	31,101	10,574	9,109	12,127	14,949		78,960
Oct.	1,100	31,395	10,490	10,245	13,089	15,055		81,374
Nov.	1,100	32,066	10,405	10,804	13,818	14,931		83,124
Dec.	700	31,880	10,615	10,797	14,674	14,778		83,444

TABLE A-10

SUMMARY OF DISCHARGE DATA—NIAGARA RIVER MONTHLY MEANS IN C.F.S. 1927-1951 (Cont'd.)

Month	Actual flow over Falls	Additions for diversions: Above head of Niagara River (From Table 8)	Additions for diversions: Below head of Niagara River (From Table 9)	Flow which would have occurred had there been no diversions	Month	Actual flow over Falls	Additions for diversions: Above head of Niagara River (From Table 8)	Additions for diversions: Below head of Niagara River (From Table 9)	Flow which would have occurred had there been no diversions
				1939					
Jan.	121,400	9,700	51,400	182,500	July	143,200	9,200	52,000	204,400
Feb.	116,700	9,500	52,400	178,600	Aug.	141,600	9,200	53,800	204,600
Mar.	129,300	9,300	50,300	188,900	Sept.	132,000	9,100	55,700	196,800
Apr.	135,800	9,300	50,200	195,300	Oct.	129,600	9,000	56,500	195,100
May	145.200	9,200	52,800	207,200	Nov.	123,800	9,000	56,700	189,500
June	146,900	9,100	53,300	209,300	Dec.	127,400	9,000	56,300	192,700
				1940					
Jan.	109,200	8,800	55,700	173,700	July	139,200	8,400	56,600	204,200
Feb.	105,700	8,700	56,400	170,800	Aug.	130,700	8,400	57,000	196,100
Mar.	113,100	8,500	55,800	177,400	Sept.	133,200	8,400	56,900	198,500
Apr.	130.500	8,500	55,700	194,700	Oct.	126,400	8,400	57,000	191,800
May	134.200	8,500	56,700	199,400	Nov.	126.200	8,300	61,300	195,800
June	143,000	8,400	56,900	208,300	Dec.	127.200	8,300	61,000	196,500
				1941					
Jan.	125,600	8,200	61,200	195,000	July	112,300	7,800	68,800	188,900
Feb.	121,100	8,000	61,400	190,500	Aug.	108,800	7,800	69,700	186,300
Mar.	116,900	7,800	60,700	185,400	Sept.	105,900	7,600	69 800	183,300
Apr.	119,700	7,800	61,000	188,500	Oct.	102,900	7,600	69,900	180,400
May	121,500	7,800	61,700	191,000	Nov.	108,100	7,600	70,500	186,200
June	117,300	7,800	65,300	190,400	Dec.	93,000	7,600	79,800	180,400
				1942					
Jan.	87,900	7,500	75,500	170,900	July	123,300	7,000	75,600	205,900
Feb.	84,300	7,300	78,700	170,300	Aug.	121,800	7,000	77,700	206,500
Mar.	96,900	7 100	78,700	182,700	Sept.	117,200	7,000	80,100	204,300
Apr.	110,700	7,200	78,800	196,700	Oct.	112,600	6,900	81,200	200,700
May	118,900	7.100	79,600	205,600	Nov.	117,200	6,800	81,100	205,100
June	123,500	7,100	77,400	208,000	Dec.	117.700	6,700	81,300	205,700
				1943					
Jan.	107,500	6,600	78.700	192,800	July	152,600	6,100	77,400	236,100
Feb.	112,400	6,400	80,300	199,100	Aug.	149,300	6,100	77,700	233,100
Mar.	116,700	6,300	78,500	201,500	Sept.	142,900	6,100	76,800	225,800
Apr.	118,600	6,200	79,100	203,900	Oct.	134,200	6,200	75,600	216,000
May	141,800	6,200	78,800	226,800	Nov.	135,100	6,400	76,900	218,400
June	158,400	6,100	76,600	241,100	Dec.	129,600	6,700	78,400	214,700
				1944					
Jan.	112,100	6,600	79,400	198,100	July	135,600	6,800	77,400	219,800
Feb.	108,600	6,700	79,800	195,100	Aug.	127,800	6,800	78,700	213,300
Mar.	112,400	6,700	79,500	198,600	Sept.	124,200	6,900	79,000	209,900
Apr.	126.400	6,800	78,400	211,600	Oct.	116,200	6,700	81,400	204,300
May	138,900	6,800	78,700	224,400	Nov.	109,600	6,700	83,100	199,400
June	140,400	6,800	79,600	226,800	Dec.	112,300	6,600	83,400	202,300
				1945					
Jan.	116,700	6,600	80,900	204,200	July	136,800	6,300	80,400	223,500
Feb.	99,600	6,500	82,000	188,100	Aug.	135,700	6,400	80,800	222,900
Mar.	116,800	6,400	81,800	205,000	Sept.	129,600	6,300	82,000	217,900
Apr.	125,300	6,400	82,900	214,600	Oct.	141,000	6,100	82,000	229,100
May	135,400	6,300	81,900	223,600	Nov.	134,000	6,000	81,400	221,400
June	136,500	6,400	82,300	225,200	Dec.	131,200	5,900	82,300	219,400

TABLE A-9

MONTHLY MEAN DIVERSIONS FROM NIAGARA RIVER BETWEEN ITS HEAD AND NIAGARA FALLS, IN C.F.S. 1927 - 1951 (Cont'd.)

Month	New York State Barge Canal	Niagara Mohawk Power Corp.	Canadian Niagara Power Co.	Hydro-Electric Power Commission of Ontario			International Railway Co.	Total
				Ontario Plant	Toronto Plant	Sir Adam Beck Plant No. 1		
				1949				
Jan.	325	28,498	10,587	10,991	14,970	14,475		79,846
Feb.	700	31,895	10,541	10,779	14,821	14,432		83,168
Mar.	100	30,216	10,540	10,873	14,749	14,593		81,071
Apr.	700	30,736	9,675	10,595	13,864	14,734		80,304
May	1,100	31,991	10,222	10,589	14,224	14,420		82,546
June	1,100	30,562	10,604	10,307	14,042	13,834		80,449
July	1,100	31,113	10,421	10,224	14,112	13,489		80,459
Aug.	1,100	31,952	10,350	10,455	14,236	13,364		81,457
Sept.	1,100	32,028	10,552	10,956	14,828	13,601		83,065
Oct.	1,100	31,829	10,528	10,974	14,801	13,603		82,835
Nov.	1,100	32,212	10,608	10,922	14,842	13,764		83,448
Dec.	700	32,367	10,508	10,920	14.805	13,985		83,285
				1950				
Jan.	700	32,136	10,603	10,917	14,849	14,359		83,564
Feb.	700	32,057	10,611	10,820	14,804	14,342		83,334
Mar.	350	32,018	10,278	10,701	14,745	14,385		82,447
Apr.	300	31,821	10,428	10,378	14,129	14,716		81,772
May	1,100	32,002	10,608	10,302	14,490	14,719		83,221
June	1,100	32,243	10,122	10,861	14,921	14,270		83,517
July	1,100	31,743	10,248	10,515	14,322	13,850		81,778
Aug.	1,100	32,324	10,649	10,494	14,282	13,542		82,391
Sept.	1,100	32,348	10,629	10,782	14.528	13,584		82,971
Oct.	1,100	32,110	10,632	10,977	15,028	13,656		83,503
Nov.	1,100	32,092	10,662	10,911	15,129	13,779		83,673
Dec.	800	32.161	10,628	10,838	15,043	14,050		83.520
				1951				
Jan.	0	31,970	10,454	10,743	14,843	14,252		82,262
Feb.	575	32,174	10,521	10,652	14,743	14,340		83,005
Mar.	700	32,015	10,399	10,659	14,330	14,634		82,737
Apr.	950	31,679	10,137	9,865	13,240	14,805		80,676
May	1,100	31,952	9,582	10,775	14,218	14,730		82,357
June	1,100	31,395	10,228	11,024	13,932	14,204		81,883
July	1,100	31,887	10,627	10,782	13,728	13,845		81,969
Aug.	1,100	32,131	10,651	11,014	14.985	13,979		83,860
Sept.	1,100	31,938	10,659	11,079	14,777	14,058		83,611
Oct.	1,100	31,931	10,657	11,119	15,015	13,887		83,709
Nov.	1,100	31,900	10,520	11,107	14,999	14,048		83,674
Dec.	700	32.050	10.658	11.068	15.047	14.086		83.609

21. Niagara River flow had there been no diversions. — The previous discussion and tabulation of diversions from the Great Lakes and their effect on the flow of the Niagara River is preparatory to a determination of the flow which would have occurred at Niagara Falls if no diversions from or into the Great Lakes had been in effect. To determine this flow, it is necessary first of all to find the flow that actually occurred at Niagara Falls. Then the necessary corrections can be applied to give the flow if there had been no diversions. For the period 1860 through 1926, the data for the actual flow over the Falls and the flow which would have occurred had there been no diversions were taken as listed in Table 3, Appendix F of the 1928 report where the

November through March. These basic duration curves were then used to derive duration curves for the flow over Niagara Falls under conditions just prior to the 1950 Treaty and for certain conditions of power development under the terms of the 1950 Treaty, as discussed in paragraph 23. The data for the duration curves of flow over the Falls are given in Table A-11 and shown graphically on Plate A-4.

23. Duration curves — Flow over Falls.

(a) *Prior to 1950 Treaty.* — The duration curves for flow over the Falls under conditions of diversion existing just prior to the effective date of the 1950 Treaty were obtained by reducing the ordinates of the duration curves for flow of the Niagara River had there been no diversions by the total of the power and other diversions then in effect, which amounted to approximately 89,000 cfs. There follows a tabulation of the normal diversions from the Hudson Bay to Great Lakes drainage basins, the normal diversion through the DeCew plant, and the 1950 average for all other diversions:

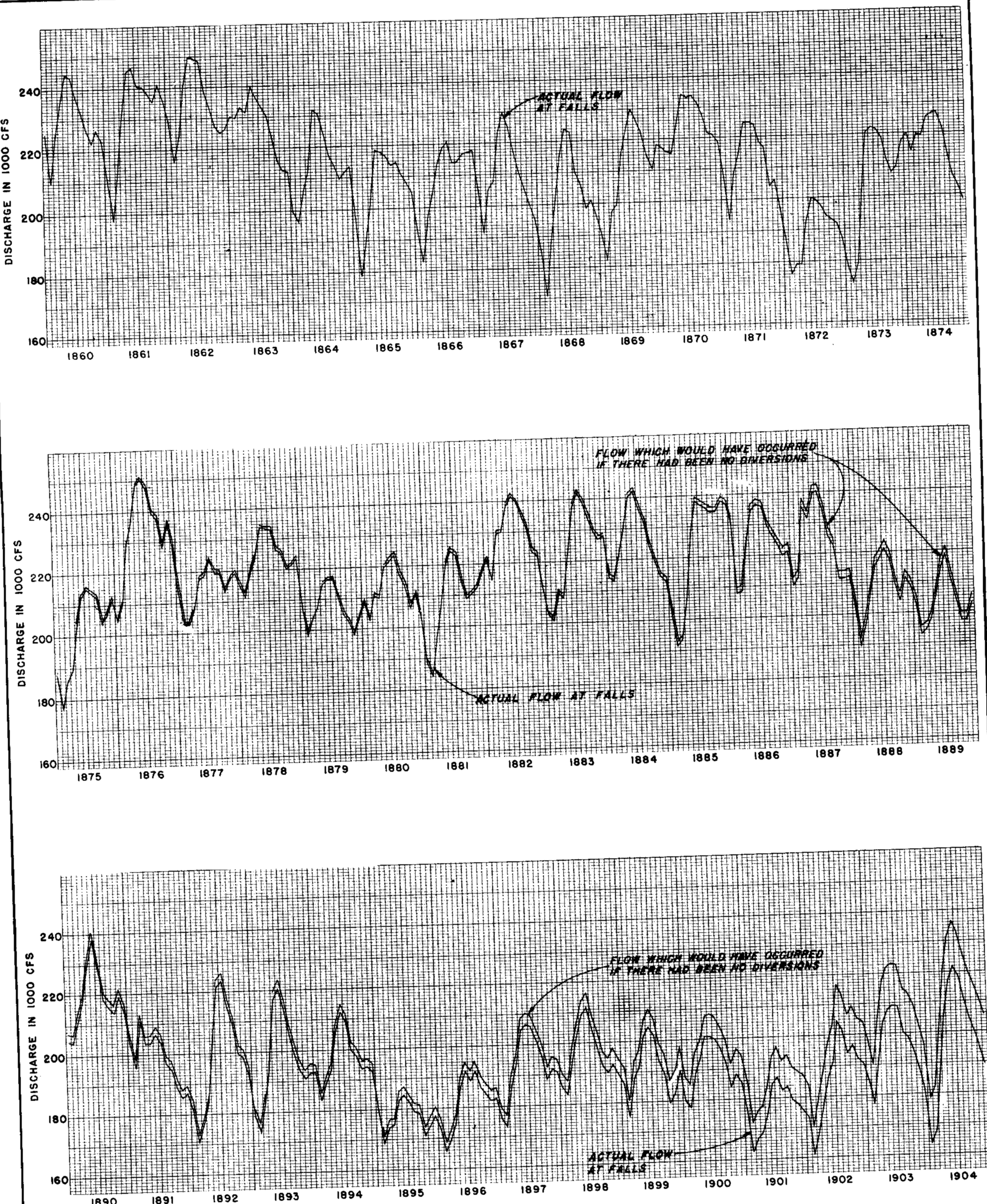
United States power diversions:	
Schoellkopf and Adams plants	32,100 c.f.s.
Canadian power diversions:	
Toronto Power plant	14,700 c.f.s.
Canadian Niagara Power plant	10,500 c.f.s.
Ontario Power plant	10,700 c.f.s.
Sir Adam Beck No. 1 plant	14,100 c.f.s.
DeCew plant	6,400 c.f.s.
Long Lake-Ogoki Basin	–5,000 c.f.s.
Total power diversions	83,500 c.f.s.
Diversions other than power:	
Sanitary District of Chicago	3,100 c.f.s.
New York State Barge Canal	900 c.f.s.
Welland Canal	1,100 c.f.s.
Total diversions other than power	5,100 c.f.s.
Total diversions above Niagara Falls, rounded	89,000 c.f.s.

(b) *Intermediate period.* — For the purpose of this report the intermediate period is defined as the period between the completion of the current construction of the Sir Adam Beck Niagara Generating Station No. 2 scheduled for 1955 and the completion of the proposed development at Lewiston not yet authorized. Maximum diversions through the power plants depend to some degree on the levels at the river intakes. Capacity diversions through the Sir Adam Beck plants will range from about 59,000 to 64,000 cfs with the present range of levels in the Chippawa-Grass Island Pool. Diversions through the United States plants and the plants whose intakes are in the Cascades vary but little within the present range of levels at the intakes. With additional diversions, the levels in the Chippawa-Grass Island Pool will drop and diversions through plants whose intakes are in the Pool will be reduced. Remedial works proposed and recommended elsewhere in this report would maintain present levels in the Chippawa-Grass Island Pool. On the basis of present levels, maximum diversions through the Cascades plants would be about 36,000 cfs and through existing United States plants, 32,500 cfs. Maximum total diversions would take place whenever the river discharge exceeds 231,000 cfs during the tourist season days and 179,000 cfs during the tourist season nights and non-tourist season. These discharges will be exceeded eight

TABLE A-10

SUMMARY OF DISCHARGE DATA—NIAGARA RIVER MONTHLY MEANS IN C.F.S. 1927-1951 (Cont'd.)

Month	Actual flow over Falls	Additions for diversions		Flow which would have occurred had there been no diversions	Month	Actual flow over Falls	Additions for diversions		Flow which would have occurred had there been no diversions
		Above head of Niagara River (From Table 8)	Below head of Niagara River (From Table 9)				Above head of Niagara River (From Table 8)	Below head of Niagara River (From Table 9)	
				1932					
Jan.	152,000	10,600	38,400	201,000	July	155,100	10,600	32,900	198,600
Feb.	154,900	10,500	38,800	204,200	Aug.	146,700	10,600	34,500	191,800
Mar.	145,300	10,500	39,600	195,400	Sept.	137,300	10,700	37,400	185,400
Apr.	149,500	10,500	36,900	196,900	Oct.	134,800	10,700	36,600	182,100
May	158,000	10,600	33,200	201,800	Nov.	133,500	10,700	35,300	179,500
June	156,700	10,600	33,700	201,000	Dec.	137,300	10,700	34,600	182,600
				1933					
Jan.	143,100	10,600	32,800	186,500	July	140,800	10,500	43,500	194,800
Feb.	131,300	10,500	34,800	176,600	Aug.	134,800	10,600	42,500	187,900
Mar.	130,200	10,300	33,300	173,800	Sept.	127,400	10,700	44,900	183,000
Apr.	140,200	10,400	32,800	183,400	Oct.	123,200	10,700	45,400	179,300
May	159,700	10,400	35,500	205,600	Nov.	116,800	10,600	48,500	175,900
June	155,600	10,400	38,900	204,900	Dec.	112,600	10,600	48,600	171,800
				1934					
Jan.	109,800	10,500	48,500	168,800	July	107,100	10,500	49,300	166,900
Feb.	93,000	10,500	51,300	154,800	Aug.	110,100	10,600	47,000	167,700
Mar.	95,700	10,400	52,200	158,300	Sept.	109,400	10,600	46,600	166,600
Apr.	115,900	10,400	44,400	170,700	Oct.	108.800	10,600	46,300	165,700
May	113,000	10,500	49,300	172,800	Nov.	104,200	10,500	46,600	161,300
June	109,600	10,500	50,800	170,900	Dec.	105,900	10,500	47,700	164,100
				1935					
Jan.	103,800	10,400	48,900	163,100	July	120,800	10,400	46,000	177,200
Feb.	96,700	10,300	49,700	156,700	Aug.	121,400	10,400	48,400	180,200
Mar.	105,300	10,200	47,000	162,500	Sept.	114,200	10,400	50,100	174,700
Apr.	111,100	10,300	46,000	167,400	Oct.	107,200	10,500	53,300	171,000
May	118,900	10,300	47,000	176,200	Nov.	102,600	10,500	55,700	168,800
June	122,000	10,300	47,100	179,400	Dec.	103,100	10,600	55,100	168,800
				1936					
Jan.	91,100	10,500	53,100	154,700	July	117,300	10,300	54,500	182,100
Feb.	68,200	10,300	51,000	129,500	Aug.	110,900	10,300	55,600	176,800
Mar.	105,500	10,200	53,100	168,800	Sept.	107,200	10,300	56,000	173,500
Apr.	120,300	10,300	53,200	183,800	Oct.	110,600	10,300	56,400	177,300
May	120,800	10,200	53,600	184,600	Nov.	113,600	10,300	56,300	180,200
June	122,500	10,300	54,900	187,700	Dec.	105,100	10,400	56,000	171,500
				1937					
Jan.	122,700	10,200	55,200	188,100	July	150,400	10,100	56,100	216,600
Feb.	130,300	10,100	55,600	196,000	Aug.	142,800	10,100	56,300	209,200
Mar.	123,700	9,900	55,400	189,000	Sept.	133,600	10,100	56,500	200,200
Apr.	132,000	9,900	56,100	198,000	Oct.	126,000	10,100	56,700	192,800
May	144,400	10,000	55,400	209,800	Nov.	125,100	10,000	55,800	190,900
June	144,600	10,000	56,500	211,100	Dec.	120,800	10,100	54,400	185,300
				1938					
Jan.	109,100	10,000	51,300	170,400	July	142,000	9,800	51,700	203,500
Feb.	111,100	9,900	52,800	173,800	Aug.	147,700	9,800	49,600	207,100
Mar.	127,100	9,600	52,100	188,800	Sept.	137,300	9,800	51,900	199,000
Apr.	141,200	9,700	52,100	203,000	Oct.	131,700	9,800	52,300	193,800
May	143,700	9,700	53,200	206,600	Nov.	132,700	9,900	52,600	195,200
June	142,000	9,800	53,300	205,100	Dec.	132,700	9,800	51,700	194,200



NIAGARA RIVER MEAN MONTHLY FLOWS
1860 TO 1904

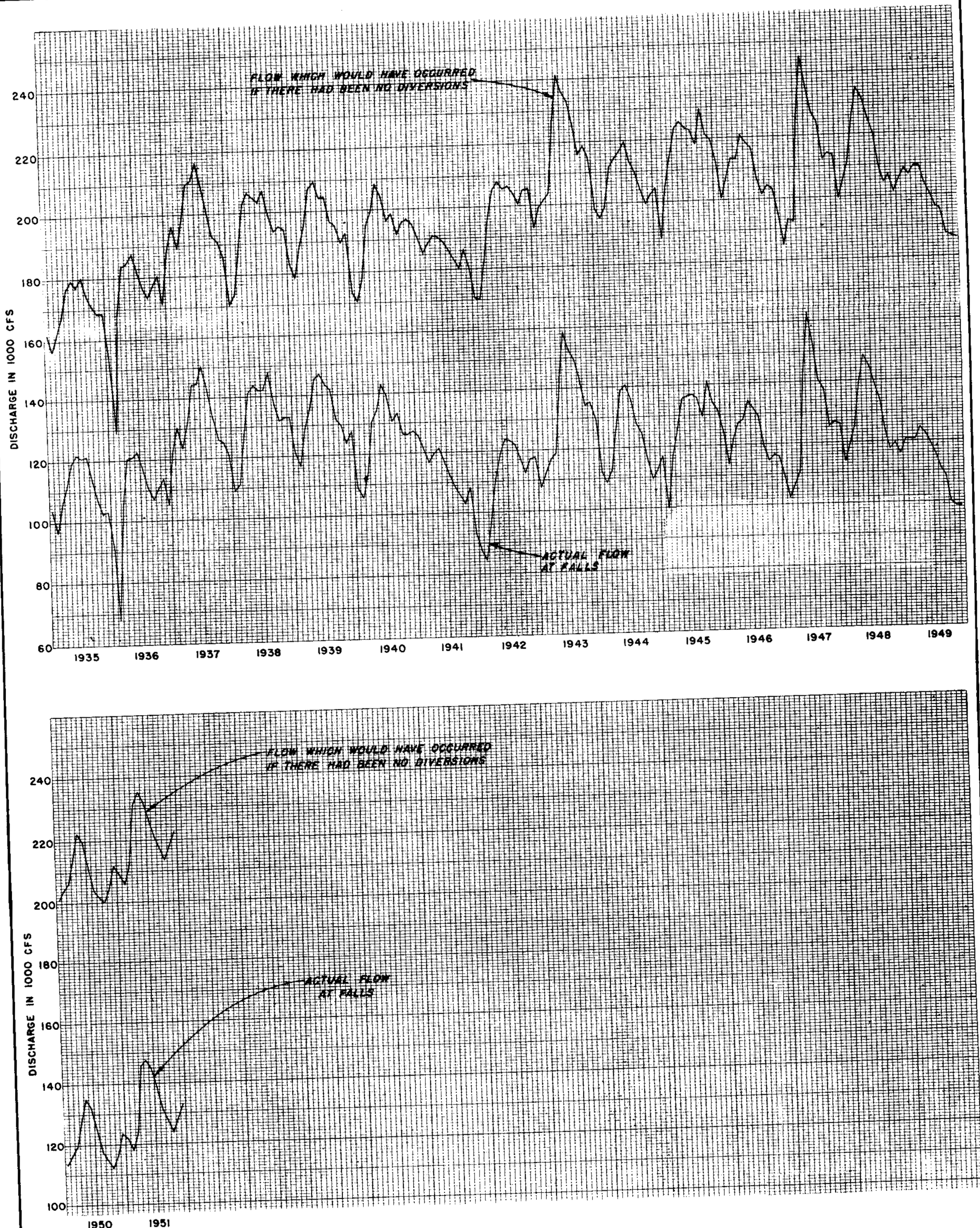
PLATE A-1

TABLE A-10

SUMMARY OF DISCHARGE DATA—NIAGARA RIVER MONTHLY MEANS IN C.F.S. 1927-1951 (Cont'd.)

Month	Actual flow over Falls	Additions for diversions: Above head of Niagara River (From Table 8)	Additions for diversions: Below head of Niagara River (From Table 9)	Flow which would have occurred had there been no diversions	Month	Actual flow over Falls	Additions for diversions: Above head of Niagara River (From Table 8)	Additions for diversions: Below head of Niagara River (From Table 9)	Flow which would have occurred had there been no diversions
				1946					
Jan.	124,300	5,600	82,500	212,400	July	131,700	5,100	81,300	218,100
Feb.	113,600	5,300	81,900	200,800	Aug.	129,400	5,100	81,900	216,400
Mar.	122,100	5,100	79,900	207,100	Sept.	119,700	5,000	82,100	206,800
Apr.	127,000	5,200	81,200	213,400	Oct.	114,600	5,000	82,200	201,800
May	128,000	5,200	80,400	213,600	Nov.	116,400	5,100	83,000	204,500
June	134,500	5,100	81,300	220,900	Dec.	115,600	5,100	82,400	203,100
				1947					
Jan.	109,200	4,900	81,000	195,100	July	153,100	4,600	78,200	235,900
Feb.	102,500	4,900	77,600	185,000	Aug.	140,500	4,500	82,200	227,200
Mar.	106,900	4,800	81,400	193,100	Sept.	137,400	4,400	82,700	224,500
Apr.	110,400	4,700	77,400	192,500	Oct.	125,400	4,500	82,800	212,700
May	143,400	4,700	77,400	225,500	Nov.	126,800	4,400	83,000	214,200
June	162,800	4,700	77,600	245,100	Dec.	126,200	4,500	82,800	213,500
				1948					
Jan.	113,900	4,600	81,400	199,900	July	138,800	4,400	82,000	225,200
Feb.	119,300	4,700	81,900	205,900	Aug.	134,000	4,400	81,800	220,200
Mar.	125,300	4,800	81,100	211,200	Sept.	123,600	4,200	82,600	210,400
Apr.	139,300	4,700	82,000	226,000	Oct.	117,700	4,300	82,600	204,600
May	148,200	4,600	82,100	234,900	Nov.	119,600	4,300	82,500	206,500
June	144,700	4,500	82,100	231,300	Dec.	116,000	4,300	81,200	201,500
				1949					
Jan.	121,000	4,500	79,800	205,300	July	115,800	4,400	80,500	200,700
Feb.	120,700	4,700	83,200	208,600	Aug.	110,800	4,300	81,500	196,600
Mar.	120,700	4,900	81,100	206,700	Sept.	108,300	4,100	83,100	195,500
Apr.	124,300	4,800	80,300	209,400	Oct.	100,400	4,200	82,800	187,400
May	122,300	4,500	82,500	209,300	Nov.	98,700	4,200	83,400	186,300
June	119,200	4,400	80,400	204,000	Dec..	98,600	4,200	83,300	186,100
				1950					
Jan.	113,600	4,400	83,600	201,600	July	125,100	4,300	81,800	211,200
Feb.	116,900	4,600	83,300	204,800	Aug.	117,700	4,200	82,400	204,300
Mar.	119,700	4,700	82,400	206,800	Sept.	115,000	4,100	83,000	202,100
Apr.	128,200	4,600	81,800	214,600	Oct.	112,500	4,400	83,500	200,400
May	135,100	4,500	83,200	222,800	Nov.	116,700	4,600	83,700	205,000
June	132,000	4,400	83,500	219,900	Dec.	123,700	4,800	83,500	212,000
				1951					
Jan.	122,200	4,800	82,300	209,300	July	138,800	5,500	82,000	226,300
Feb.	118,200	4,800	83,000	206,000	Aug.	131,200	5,600	83,900	220,700
Mar.	124,300	4,800	82,700	211,800	Sept.	127,900	5,700	83,600	217,200
Apr.	145,500	4,900	80,700	231,100	Oct.	124,000	5,800	83,700	213,500
May	147,700	5,100	82,400	235,200	Nov.	128,400	5,900	83,700	218,000
June	144,800	5,400	81,900	232,100	Dec.	132,900	5,900	83,600	222,400

22. Duration curves of flow in Niagara River. — The duration curves for the flow of Niagara River at Niagara Falls were computed, based on the record of monthly mean flows from 1860 to 1951, as they would have occurred had no diversions been in effect. Separate duration curves were constructed for the tourist season, April through October and the non-tourist season



NIAGARA RIVER MEAN MONTHLY FLOWS
1935 TO 1951

PLATE A-3

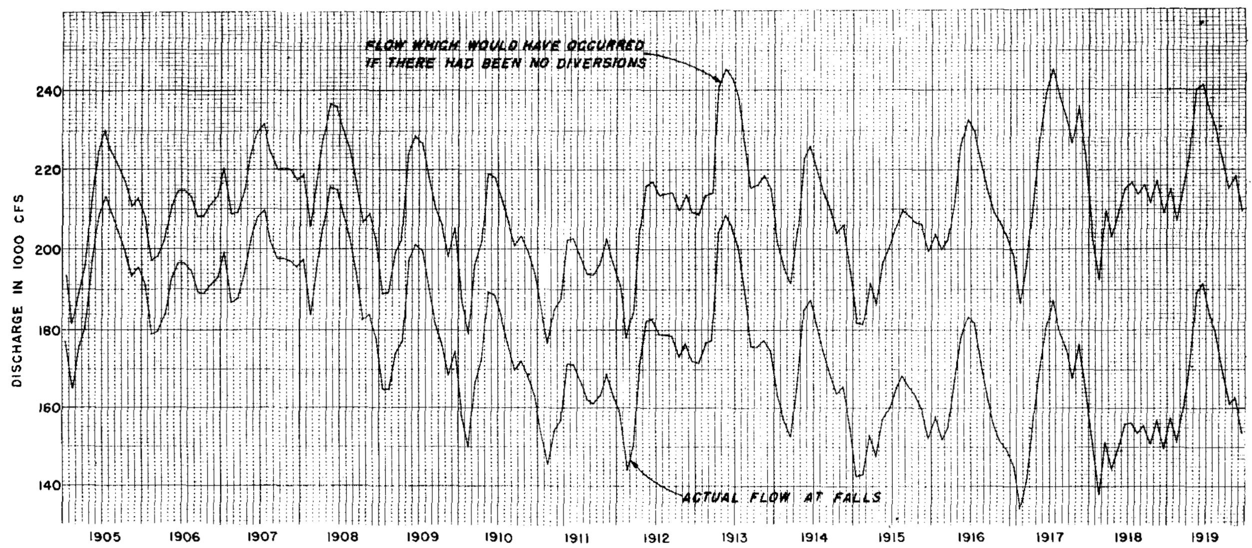
percent and 84 percent of the time during the respective periods. Accordingly, the flow over the Falls during the intermediate period will be 100,000 cfs for 92 percent of the tourist season days and somewhat higher for the remaining eight percent of the time, and during the tourist season nights and non-tourist season the flow over the Falls will be 50,000 cfs for 16 percent of the time and above 50,000 cfs for 84 percent of the time.

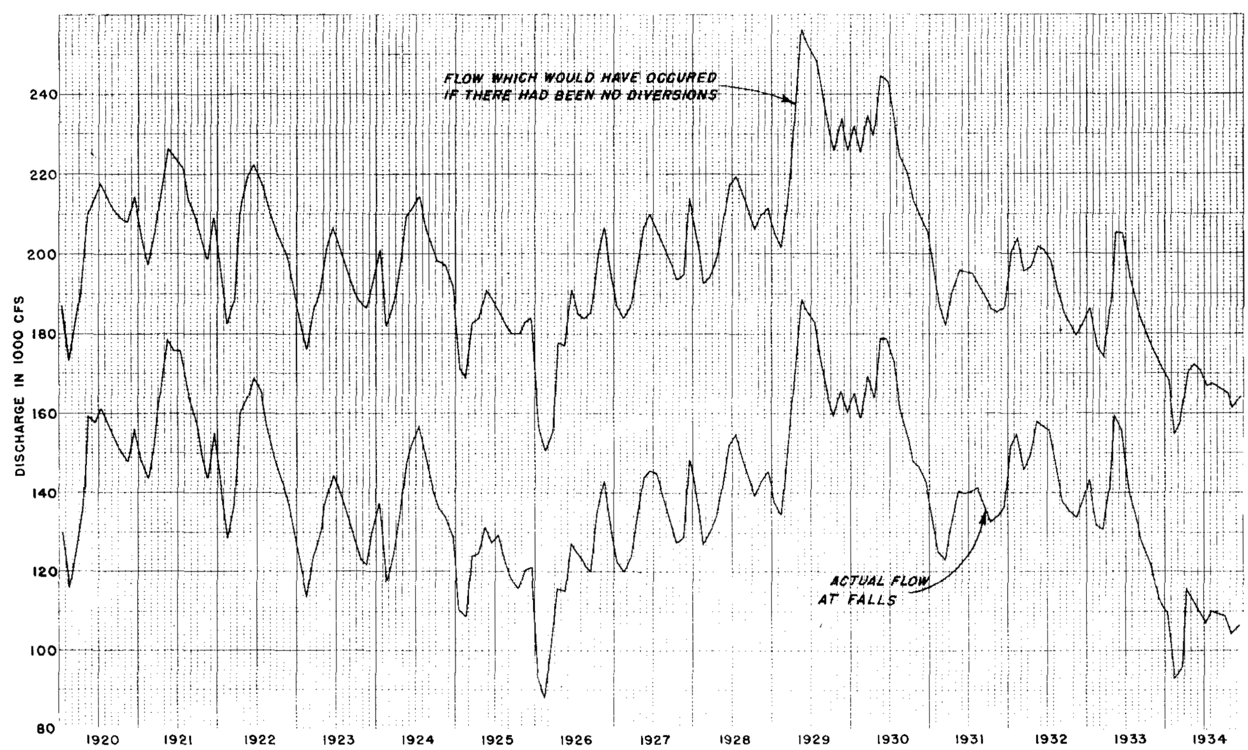
(c) *Future period.* – The future period for the purposes of this report is defined as the period after the completion of the proposed Conners Island-Lewiston development. Capacity diversions through United States plants, all from the Chippawa-Grass Island Pool, would then be about 100,000 cubic feet per second consisting of 32,500 through the existing United States plants and 67,500 through the proposed Conners Island-Lewiston development. Capacity diversions through Canadian plants would be the same as for the intermediate period, a maximum of about 100,000 cfs. Accordingly, the future maximum total power diversion will be about 200,000 cfs. Since the highest monthly mean flow of the Niagara River as it would have been had there been no diversions was 255,800 cfs, and in view of diversions of about 5,100 cfs for purposes other than power, it is anticipated that, in general, there will be sufficient hydro-electric installed capacity to utilize all Niagara River flow in excess of that required for the Falls as specified by the 1950 Treaty. The duration curves for the flow over the Falls under these conditions for the tourist season days and for the tourist season nights and non-tourist season are therefore straight lines with ordinates of 100,000 cfs and 50,000 cfs, respectively. These data, as for the intermediate period, are based on present capacity diversions through the Cascades plants.

TABLE A-11

DURATION OF FLOW OVER FALLS

Niagara River discharge with no diversions, cfs.	Corresponding flow over Falls, cfs					Duration in percent of time	
	Prior to 1950 Treaty	Under 1950 Treaty and intermediate development		Under 1950 Treaty and future development			
		Tourist season days	Tourist season nights and non-tourist season	Tourist season days	Tourist season nights and non-tourist season	Tourist season	Non tourist season
130,000	41,000	100,000	50,000	100,000	50,000	100.0	100.0
135,000	46,000	100,000	50,000	100,000	50,000	100.0	99.9
140,000	51,000	100,000	50,000	100,000	50,000	100.0	99.9
145,000	56,000	100,000	50,000	100,000	50,000	100.0	99.9
150,000	61,000	100,000	50,000	100,000	50,000	100.0	99.8
155,000	66,000	100,000	50,000	100,000	50,000	100.0	99.2
160,000	71,000	100,000	50,000	100,000	50,000	100.0	98.5
165,000	76,000	100,000	50,000	100,000	50,000	100.0	97.4
170,000	81,000	100,000	50,000	100,000	50,000	99.4	96.1
180,000	91,000	100,000	50,000	100,000	50,000	96.3	87.6
190,000	101,000	100,000	55,000	100,000	50,000	89.8	70.0
200,000	111,000	100,000	64,000	100,000	50,000	77.3	48.0
210,000	121,000	100,000	74,000	100,000	50,000	56.2	26.7
220,000	131,000	100,000	83,000	100,000	50,000	35.6	10.2
230,000	141,000	100,000	92,000	100,000	50,000	17.5	3.7
235,000	146,000	100,000	97,000	100,000	50,000	11.2	1.5
240,000	151,000	102,000	102,000	100,000	50,000	5.9	0.2
245,000	156,000	107,000	107,000	100,000	50,000	2.3	0
250,000	161,000	111,000	111,000	100,000	50,000	0.8	0
255,000	166,000	116,000	116,000	100,000	50,000	0.1	0





NIAGARA RIVER MEAN MONTHLY FLOWS
1905 TO 1934

PLATE A-2

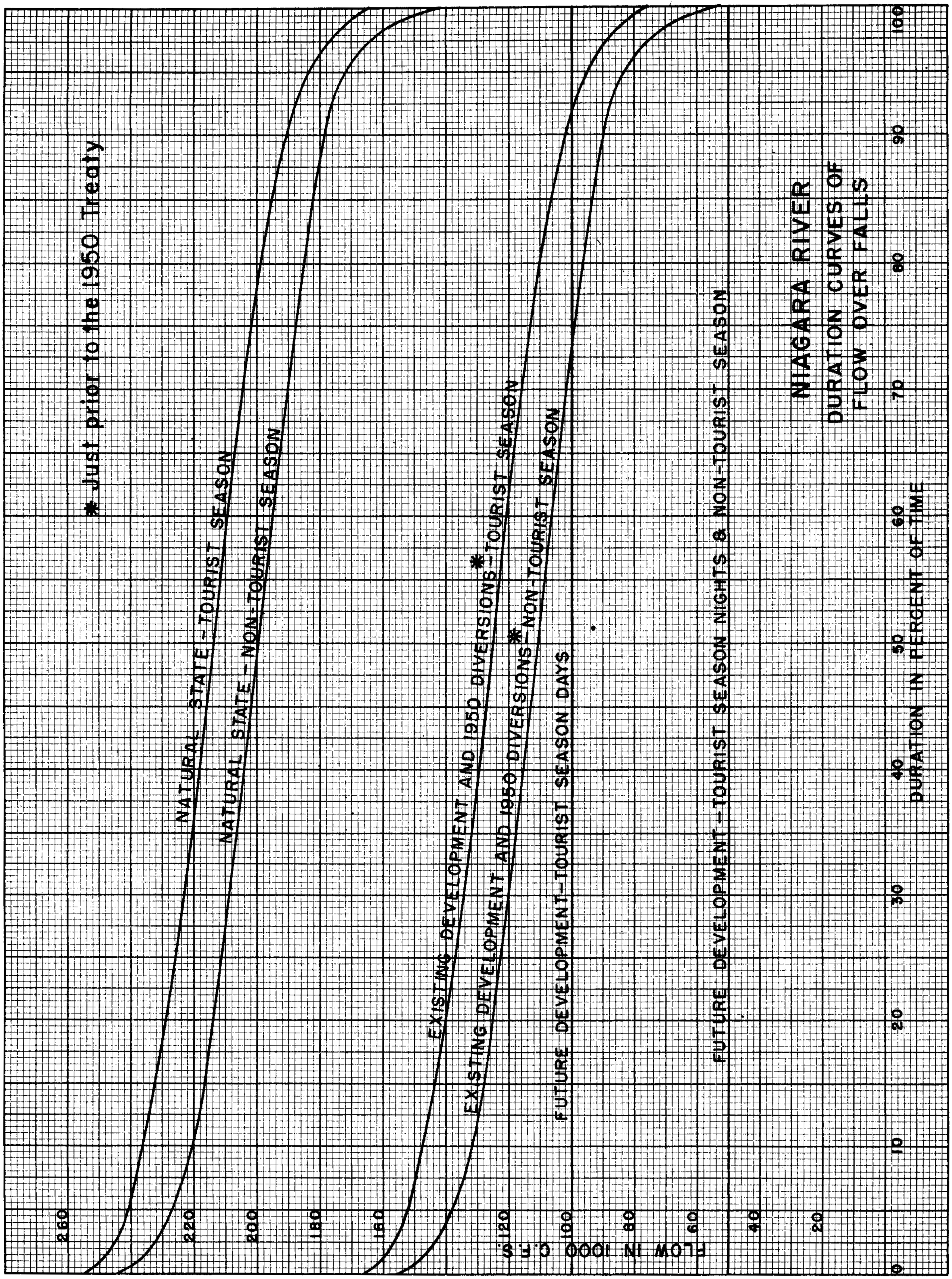

* Just prior to the 1950 Treaty
NATURAL STATE - TOURIST SEASON
NATURAL STATE - NON-TOURIST SEASON
EXISTING DEVELOPMENT AND 1950 DIVERSIONS*-TOURIST SEASON
EXISTING DEVELOPMENT AND 1950 DIVERSIONS*-NON-TOURIST SEASON
FUTURE DEVELOPMENT-TOURIST SEASON DAYS
FUTURE DEVELOPMENT-TOURIST SEASON NIGHTS & NON-TOURIST SEASON
NIAGARA RIVER
DURATION CURVES OF
FLOW OVER FALLS
FLOW IN 1000 C.F.S
260
220
200
180
160
120
100
80
60
40
20
DURATION IN PERCENT OF TIME
0
10
20
30
40
50
60
70
80
90
100

PLATE A-4

APPENDIX B

SURVEYS

(a) Complete detailed topography along the river banks from water's edge to the top of the bank was obtained by stadia and included the elevations over the banks and the locations and elevations of all structures near the water's edge.

(b) Sounding of sections approximately 300 feet apart from the water's edge to the eight-foot depth contour was done with a sounding pole used in a portable rubber boat which could be handled easily in shallow depths and weeded areas near shore.

(c) Soundings of check sections at one-half mile intervals across the entire width of the river for comparison with the information shown on the U.S. Lake Survey chart were obtained by using a sonic depth recorder mounted on a 16-foot inboard motorboat. The continuous section obtained could readily be compared with depth contours shown on the U.S. Lake Survey chart and additional sections taken if considered necessary. Portable radios provided an excellent means of communication between boat and shore stations where visual signaling across the wide expanses of the river would have been very difficult.

7. The control surveys, both horizontal and vertical, the inshore soundings, the sounding of check sections, and the shoreline topographic survey along approximately 80 miles of shoreline were completed between October 1, 1950, and December 31, 1950, by four field parties from the Buffalo District, Corps of Engineers, and two field parties from the U.S. Lake Survey which were loaned to the Buffalo District for approximately six weeks. The topography along the river banks is shown on a series of 26 maps on file in the Buffalo District Office of the Corps of Engineers. These maps are identified as Niagara River Shore Topography, file PH 131.

8. Survey of Chippawa-Grass Island Pool. — The bed of that section of the Niagara River known as Chippawa-Grass Island Pool extending from the downstream end of Buckhorn Island to Tower Island, a distance of approximately three miles, was surveyed by field parties of The Hydro-Electric Power Commission of Ontario (hereinafter referred to as "H.E.P.C." for brevity). The upper two miles of this reach, which averages one and one-quarter miles in width, was surveyed by echo sounder along transverse lines spaced roughly 1,000 feet apart. The sounding instrument was mounted in a 30-foot "pointer" type river boat, driven by an outboard motor, the boat running free. The same boat and instrument was used to sound the lower portion of the Pool below the H.E.P.C. Chippawa intake but here, due to swifter and more dangerous water, the boat was allowed to drift downstream at the end of a cable attached to a tug which was anchored at intervals of approximately 1,000 feet across the river. The boat was in communication at all times with shore transit parties by two-way radio and simultaneous stadia recordings were made at intervals controlled by the operator of the echo sounder. All echo sounding was accomplished during the periods September 18 to 22, 1950, and October 4 to 20, 1950, and bed elevations obtained are incorporated in H.E.P.C. drawing No. 210-e-567. This drawing and the other H.E.P.C. drawings referred to in the following paragraphs are on file in the Toronto office of the H.E.P.C.

9. Between June 27 and July 7, 1950, an area 400 feet in width, immediately offshore and extending from the downstream end of the Chippawa intake to a point 400 feet upstream from the submerged remedial weir was extensively sounded by weighted line. The resulting bed elevations are shown on H.E.P.C. drawing No. 210-e-446.

10. During construction of the Chippawa intake, a large quantity of rock fill was dumped opposite the intake and extending downstream for about half a mile. During 1922 and 1923, this area was extensively sounded, the results being recorded on H.E.P.C. drawing No. 210-e-446. The outer and inner edges of this disposal area were checked by echo sounder during October 1950 and no changes were found to have occurred.

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

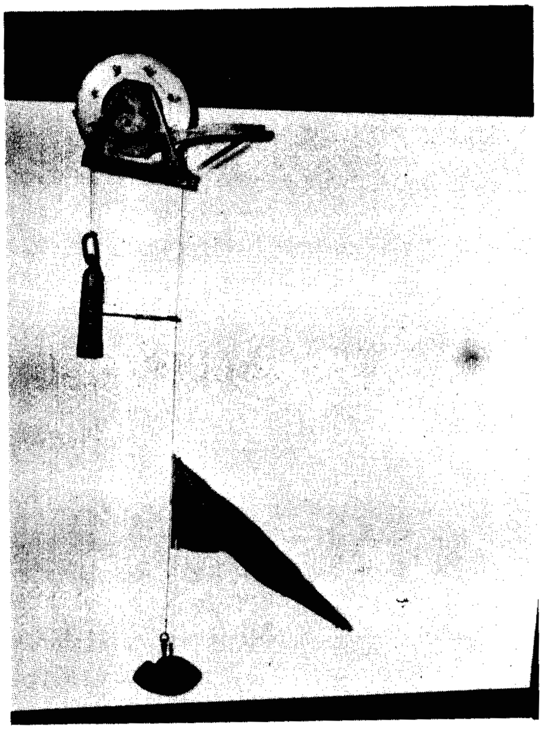
APPENDIX B

SURVEYS

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF PLATES



Sounding apparatus consists of 1,500 ft. of 0.026-in. steel music wire wound on aluminum reel, 8-lb. counterweight, and 12-lb. discus-shaped lead sounding weight.

Figure 1

Helicopter sounding apparatus attached on right side near front, within easy reach of co-pilot.

Figure 2

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX B

SURVEYS

1. SCOPE. — The accumulation of complete survey data over the entire water area and banks of Niagara River from Lake Erie to the crest of Niagara Falls was a prerequisite to the construction of a scale model and studies in the planning and design of remedial works for the preservation and enhancement of the scenic beauty of Niagara Falls. It was decided that the following survey information would be required and that all of the data should be accurate and referenced to a common horizontal plane and origin in a geographic grid system: shoreline topography along the banks of the river, river bed elevation, distribution of flow, aerial photography and water surface elevations, with particular emphasis on the Cascades area immediately upstream of the crest. This appendix describes the survey methods used and presents the data obtained. Plate B-1 indicates the areas covered by the survey.

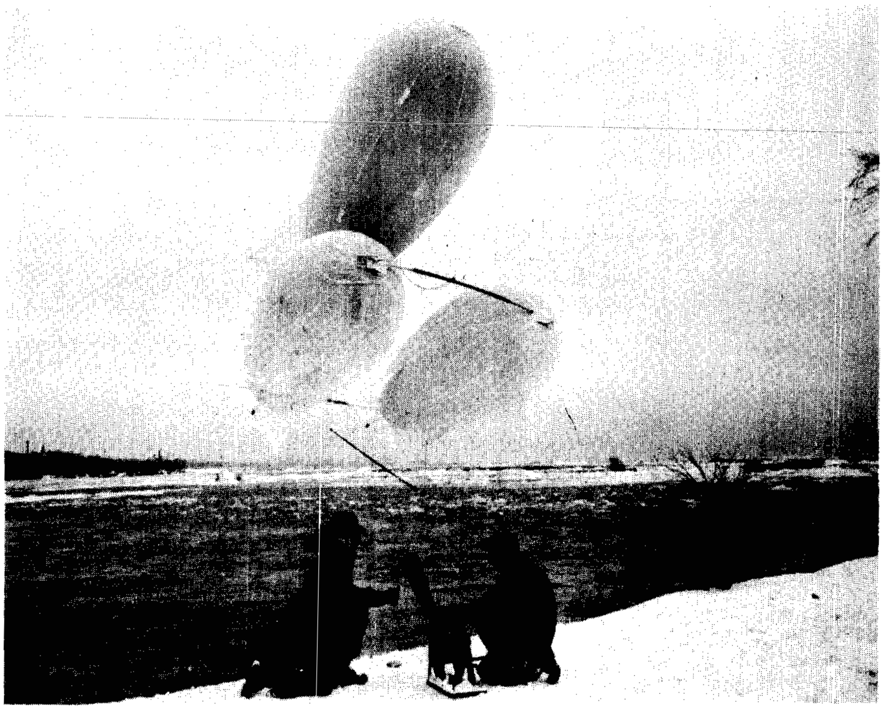
2. AVAILABLE DATA. — Considerable information was available from previous surveys by the Buffalo District, Corps of Engineers; the U.S. Lake Survey; the International Boundary Commission; The Hydro-Electric Power Commission of Ontario; and the Niagara Mohawk Power Corporation. These included detailed topography and depths in the Black Rock Canal, accurate horizontal control along both banks of Niagara River with well monumented stations established at about one-mile intervals; permanent bench marks at about five-mile intervals; navigation charts showing general depths, and detailed records of discharge measurements.

3. PRIMARY AND SECONDARY CONTROL. — The International Boundary Commission had established and monumented triangulation stations along the Canadian shore and part of the United States shore of the Niagara River in 1913 and the United States Lake Survey had established and monumented numerous triangulation stations along the remainder of the United States shore. The descriptions of these stations are contained in Publication No. 766 dated 1941 by the International Boundary Commission. The geographic positions of these control points are referred to the North American Datum of 1927.

4. The control points which could be occupied advantageously were located at about one-mile intervals. To meet the requirements of this survey, it was necessary only to establish a stadia traverse between the primary stations. Intermediate hubs were established at about 600-foot intervals and the geographic positions computed. The traverse was run along asphalt surfaced highways adjacent to the river banks where practical, and the points marked by a "PK" nail and a one and one-quarter inch aluminum washer with the number of the point stamped thereon. In addition, the points were marked by a guard stake with a red top for ease in finding the points. All primary triangulation control points were temporarily marked by a two-inch by two-inch pole eight-feet long with signal cloth attached to the upper end. This made it possible to select a long back sight from any hub occupied and a definite colour pattern made it easy to identify the point back sighted.

5. Permanent bench marks had been established by the U.S. Lake Survey at intervals of approximately five miles. Approximately 80 miles of levels were run between these bench marks and temporary bench marks marked by a "PK" nail driven into the pavement and circled in yellow paint were set at about 500-foot intervals.

6. SHORELINE SURVEY AND CHECK SECTIONS. — The U.S. Lake Survey charts furnished considerable information on river bottom elevations and shoreline topography. However, due to changes in the river banks, shoaling in certain reaches and a lack of detail between the shoreline and the eight-foot depth contour, the following surveys were made:



One 80 cubic foot "kytoon" and two 40 cubic foot "kytoons" grouped to lift six-pound weight. Target (wind sock) and weight are shown below "kytoon".

Figure 4.

Sounding in American Channel with three "kytoons" bridled together.

Figure 5

11. The boundaries of the four areas described above and the location of the lines of echo soundings are shown on H.E.P.C. drawing No. G.S.D. 85.

12. Survey of Cascades. — That section of the Niagara River extending from the crest of the Falls upstream for a distance of about 4,000 feet presented a very difficult problem in the overall survey. In this reach there was very little available data which could be used and the area was entirely inaccessible because of the strong currents and turbulence in the Cascades. This particular section was of paramount importance in a model study. Many schemes for obtaining bottom elevations were considered but most proved impracticable or prohibitive in cost. It appeared that the survey might be done by using a helicopter or "kytoons". After much experimentation, a definite plan was developed involving the use of both the helicopter and "kytoons" and equipment designed and constructed.

13. Helicopter survey of Cascades. — A helicopter with pilot and co-pilot was rented from the Bell Aircraft Corporation and the operation proceeded as follows: Fifteen hundred feet of 0.026-inch steel music wire was wound on a nearly frictionless aluminum reel having an outside diameter of seven inches. To the free end of the wire was attached a discus-shaped lead weight weighing approximately 12 pounds. (See Figure 1). This apparatus was then bolted to a bracket and mounted on the right side of the helicopter at a location within easy reach of the co-pilot. (See Figure 2). The helicopter was then flown to a predetermined position over the Cascades where it was made to hover at a height of about 2,000 feet, whereupon the co-pilot began lowering the sounding weight by releasing a hand brake affixed to the reel. At a point in the wire exactly 50 feet from the bottom of the 12-pound weight, a target resembling a wind sock about one foot in diameter and two feet long and constructed of orange signal cloth was attached to a ring which had previously been attached to the wire. After unreeling the entire 1,500 feet of wire, an eight-pound counterweight was attached to the end and the wire suspended over the reel in a 0.040-inch groove which had been machined in the circumference of the reel so that the reel could also serve as a pulley. The helicopter was then lowered until the 12-pound weight touched the bottom and the counterweight began to descend. (See Figure 3). A wire guide attached rigidly to the counterweight and circling the sounding wire kept the counterweight from swinging like a pendulum. At the instant the sounding weight touched the river bottom, the co-pilot signaled each of four transitmen over an air to ground and ground to ground radio network.

14. The transit positions were established so that good intersections could be obtained. The target was maintained in position for about 15 seconds to allow the instrumentmen to read both horizontal and vertical angles. The helicopter was then elevated until the sounding weight was clear of the water, after which it was moved approximately 300 feet horizontally and the procedure repeated. After each run, which was limited to about one-half hour by extreme cold since the door was removed from the helicopter, or when the sounding weight snagged on the bottom, the wire was cut and allowed to drop into the river along with the weight. This was found to be more economical than attempting to reel in the line because it cut down hazardous flying time. A second reel was always ready with new wire and weights for another run. A height of operations at 1,500 feet above the river was fixed by reasons of safety since it was necessary to be able to glide to a landing area in an emergency.

15. A recorder was assigned to each instrumentman to operate the radio and record the readings. The horizontal angles were plotted for each sounding and location fixed by the point of intersection of the four angles. Then with the scaled distance from each transit station and the vertical angle, the elevation of the target was computed. The bottom elevation in each case was 50 feet less than the target elevation. It was generally found that at least three of the vertical angles of the four turned to each target position resulted in computed elevations which checked

angles of the sightings, the elevations of the water surface were computed. The method was checked in an area where the water surface elevation was known and the results found to be accurate within 0.10 foot. In all, approximately 6,000 elevations were obtained in two nights, November 29 to December 1, 1951, working from dusk to daylight. The water surface contours determined from data obtained in this survey are shown on Plate B-3.

20. Velocity measurement in Chippawa-Grass Island Pool. — During the period December 4 to 9, 1950, the U.S. Lake Survey, assisted by Buffalo District personnel, measured velocities in the Chippawa-Grass Island Pool downstream from Navy Island. The work was accomplished by releasing partially submerged steel drums with flares and flag markers attached, and tracing their course and velocities by timed intersection angles from shore stations. The results of this survey are shown on Plate B-4.

21. For use in the Islington model, it was necessary to determine the proportion of flow carried by each of the three channels into which the river is divided by Navy and Grand Islands. Current meterings were made of the two smaller channels and the flow of the third channel was found by subtracting these from the known total flow of the river. The direction of flow at each of the metering points was found by using a float attached to a 250-foot line from the metering boat.

22. Velocity and direction determinations were made at 36 random positions in the area covered by the echo sounding operations of September 1950 which are mentioned in paragraph 8. These were obtained by current meter and trailing float, the position of the anchored boat being determined by instrumental intersection on the boat picket from shore survey stations. In addition, current velocity and direction measurements were made along the southern half of the river in the area between Navy Island and the uppermost cascades by means of free floats observed from shore instrument parties. All the work outlined in paragraphs 21 and 22 was done by field crews of the H.E.P.C. and are recorded on H.E.P.C. drawing No. NF28-e-2006.

23. River slope. — On April 25 and May 2, 1951, simultaneous staff gauge readings were taken at eight different points on the Niagara River from Lake Erie to Niagara Falls to determine the slope of the water surface for use in verification and adjustment of the model at Vicksburg. On May 10, 1951, the H.E.P.C. made observations of water surface elevations at 25 points located in the Cascades along the Canadian and Goat Island shorelines. The location of the points and the observed levels are given in Appendix F.

Sounding in Cascades just above Horseshoe Falls by helicopter which drops weighted line. Transitmen on shore take readings on target fixed 50 ft. above sounding weight. Line is run over reel and counterweighted since helicopter cannot be kept absolutely still. Counterweight hangs just below helicopter at right of sounding line.

Figure 3

within 0.2 foot. If any one of the four differed appreciably, it was not used and an average was taken of the elevations computed from the remaining vertical angles to obtain a final elevation. In all, 252 elevations were obtained in the Canadian channel between December 7 and December 27, 1950, in 21 hours of actual flying time. Check readings over an area previously covered by conventional survey methods proved that the results obtained by helicopter were correct within one-half foot.

16. "KYTOON" SURVEY OF CASCADES. — Elevations over the Cascades in the American Channel upstream from the crest could not be obtained by helicopter because of heavy tree growth along the banks, making an emergency landing impossible. Therefore, another method was employed using dirigible-shaped balloons called "kytoons" to replace the helicopter. "Kytoons" of both 40 cubic feet and 80 cubic feet capacity were used. They were constructed with a nylon cover and contained a rubber bladder which was inflated with helium. Numerous trials were made before an arrangement could be found which would lift a sounding weight. It was determined that two of the 40 cubic foot capacity "kytoons" fastened together side by side with an 80 cubic foot capacity "kytoon" bridled above the other two would lift a six pound lead weight in about a 10-mile wind. (See Figure 4). The specific fastenings were improvised and perfected only after many trials. The "kytoons" were flown in the same manner as a kite and, although the lifting force was small, the pull on the flying line was strong and increased with the wind velocity. It was found that a nylon cord such as is used on parachutes and which has a tensile strength of 100 pounds, would

serve as a satisfactory flying line when used double. This line, as finally used, was approximately 2,000 feet long and was wound on a sturdy hand reel. The same type line used singly was used to control the sounding lead. Music wire of 0.016 inch diameter was used in the 30 feet immediately above the sounding lead in order to keep the resistance to the strong current to a minimum. The sounding line was run over a small machined pulley which was fastened to the bridle line holding the three "kytoons" and then wound on a sturdy hand reel. As in the helicopter method, a target was fastened to the sounding line.

17. After the equipment was assembled, the "kytoons" were flown over the Cascades area and the sounding lead dropped to the bottom by paying out the sounding line. (See Figure 5). The nylon cord was quite elastic when several hundred feet had been unreeled and it was possible to keep the slack out of the line and also to be sure that the weight was on the bottom. The operation was carried on from either side of the river, depending on the wind direction and it was possible to obtain depths at distances of almost one-half mile. Transits were used, as in the helicopter method, with all operations synchronized by radio. From horizontal and vertical angles obtained and trigonometric computations, the elevation of approximately 500 points on the river bottom were obtained during January and February 1951. As the construction of the scale models progressed, it was decided that greater detail was required in certain sections of the Cascades in the Canadian channel and in November and December 1951, approximately 500 additional soundings were taken by the "kytoon" method. This method proved to be accurate within one-half foot. It was particularly adaptable for use in the specific area which was otherwise inaccessible. The subaqueous contours determined from data obtained by the helicopter and "kytoon" surveys are shown on Plate B-2.

18. Water surface elevations in Cascades. — Two independent aerial surveys were made to determine water surface elevations in the turbulent Cascades above the crest of the Falls. Both surveys were made in December 1950; one under contract with the H.E.P.C. and the other under contract with the Buffalo District of the Corps of Engineers. The water surface contour maps developed independently from each of the aerial surveys differed among themselves and also indicated elevations at specific points which were considered to be erroneous. It was concluded that both surveys produced results of doubtful accuracy, probably because the elevations of the surface of the swiftly moving water were determined from consecutive exposures not made at the same instant and therefore not true stereoscopic pairs. Rather than use a more elaborate and costly system of aerial survey which would produce true stereoscopic pairs, an entirely new and different method of obtaining water surface elevations was devised and used. This survey is described in the paragraph which follows.

19. Searchlight survey of Cascades. — Buffalo District personnel and H.E.P.C. personnel, working in two separate groups, made a detailed survey of the water surface of the Canadian Cascades using a new and unique method in November 1951. Two 800,000,000-candle power lights, one for each group, were set up at several carefully selected stations on the Canadian shore and on Goat Island. Then, with the beam directed approximately horizontally across the Cascades in a definite orientation, vertical angles were read to the line of beam reflection from three different transit stations with the transits also definitely oriented. The light beam was held in position until each transitman had read vertical angles to the beam reflection on the water at about five-degree horizontal increments along the light beam. For each reading both the horizontal and vertical angles were recorded. After all transitmen had completed an angular crossing along the light beam, the beam was moved horizontally two degrees and 30 minutes and another set of transit readings were made. This operation was continued until the entire area was completely covered, the light beam directions were plotted and each horizontal reading of the transits was plotted to intersect this line. With scaled distances from the transit station to these intersections and the vertical

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4. Data for gauge relation studies. — In order to be able to use Eq. (1) at any gauge, it is necessary to know the numerical values of the four unknowns: *K, a, b,* and *c*. The data available for this purpose consists of: the mean daily gauge heights as recorded at the automatic water stage recorders at Morrison Street and at the upper river gauge location; the mean daily power diversions as recorded at the various power plants. The gauge heights for each day must be the mean of 24 readings recorded automatically each hour during the day, not just single staff readings. Similarly the diversion records must consist of the mean of the 24 hourly readings for the day. Also there must be a considerable range of independent variation in river discharge and in each of the diversions during the period covered by the study. If the records used cover several different years, there will be sufficient variation in river flow for the accurate determination of the discharge coefficient. During the early years of the power diversions, there was considerable reduction in the diversions during Sundays and holidays, as is shown for 1925 by the bottom graph in Plate 19, Appendix F of the report on "The Preservation and Improvement of Niagara Falls and Rapids" published in Canada as "The Preservation of Niagara Falls" by the Special International Niagara Board (to be referred to as "the 1928 report" hereafter for brevity). This reduction still occurred in 1932, but by 1941 it had disappeared from the United States diversions because by that time the load had increased and the hydro-electric plants were kept loaded all week up to the limit allowed by law and international agreement, the fluctuations in load being carried by the steam plant. However, during 1941, there were two permanent increases in the allowable diversions, one in June and one in November. Thus, before the end of 1941, there was sufficient variation in the power diversions to make it possible to find accurate values of the diversion coefficients but since 1941, the variations have been too small.

5. Method of least squares. — The gauge relation problem is somewhat similar to an analysis of the tides, in which it is necessary to compute values for the effect of each of the various solar and lunar components. The mathematical process used in that case, the method of least squares, was used here also. Each day's record of gauge heights and diversions will give the data necessary for one observation equation of the general form of Eq. (1), in which the gauge heights and diversions are known and *K, a, b, c,* etc. are the unknowns. From the observation equations selected, usually several hundred, the normal equations are formed in the usual way. The solution of the normal equations as simultaneous algebraic equations will give the most probable set of values for the unknowns, the set that will make the sum of the residuals a minimum. In this case, the residuals are the differences between the gauge heights actually observed at the upper river gauge and those computed from Eq. (1), using the values found for *K, a, b, c,* etc.

6. Seasonal cycle. — Each summer there is a small rise in water level at all gauges in the Chippawa-Grass Island Pool which reaches a maximum during July or August and then gradually decreases to zero, or nearly zero, by December when the ice is starting to form. This rise and fall, which has been named the seasonal cycle, represents a change in the carrying capacity of the river which apparently is caused by the growth and decay of aquatic plants. The general trend of the cycle each year is fairly consistent though there are minor variations from year to year. In the Pool, the average maximum value originally was 0.2 foot but since the submerged weir was built, this maximum has increased to 0.5 foot. Below the crest of the Cascades, no seasonal cycle can be detected. To eliminate the effect of this cycle in solving the normal equations, each month or similar period must be allowed to have its own independent value of *K*; otherwise, incorrect values for the coefficients may result. In practice, only the values of *a, b, c,* etc. are computed in the solution of the normal equations, the particular value of *K* required for any purpose being determined by a different method, as explained in paragraph 11 below.

7. Effect of ice. — Frequently during the winter, the gauge relations are disturbed by ice. The effect of this can be avoided when making up the observation equations by using only days when there is no ice in the river.

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will be the change in stage at the gauge corresponding to a change of 10,000 cubic feet per second in river flow.

10. QUEENSTON DIVERSION. — The water diverted from the Pool at the Chippawa intake of the Queenston (Sir Adam Beck No. 1) plant is diverted around the Morrison Street gauge and is returned to the river farther downstream, so that the significance of the Queenston diversion coefficient *c* in Eq. (1) and Table C-1 differs from that of the United States coefficient *b* and requires some additional explanation. For any given upper river gauge, *c* represents the difference between the lowering due to the diversion of 10,000 cubic feet per second at the Chippawa intake and that due to an equal decrease in river flow. For gauges located between Chippawa and the crest of the Falls, no Queenston term is required in Eq. (1) because here the diversion has the same effect as a decrease in river flow and the value of *c* is zero. For gauges located above Chippawa, the diversion does not have exactly the same effect as a decrease in river flow, *c* is not zero and a *Qn* term is needed in Eq. (1). For example, at Material Dock gauge, which is located close to the intake at Chippawa, the local drawdown of the diversion is somewhat greater than the effect of a reduction in river flow so that the coefficient *c* is negative but is numerically small, as is shown in Table C-1. Farther upstream, as the drawdown decreases with the distance above the intake, the numerical value of *c* decreases, passes through a zero value and then becomes positive and begins to increase. At Slaters Point, *c* is positive but small; at Black Creek, its value is greater.

11. ELEVATION CONSTANT. — As stated in paragraph 3 above, the elevation constant, *K* in Eq. (1), is the elevation at any upper river gauge corresponding to 336.0 at Morrison Street gauge when the effect of the diversions has been eliminated. For any day when simultaneous mean daily gauge readings are available at an upper river gauge and at Morrison Street, the value of *K* for that gauge can be found by rearranging Eq. (1) and using the values of *a*, *b*, *c*, etc. given in Table C-1. Values of *K* found in this way will be independent of changes in river flow and power diversions but will show the effect of construction work, seasonal cycle and possibly ice. The values of *K* listed in Table C-2 are the means of those obtained for the first seven to 14 days in April, 1942, after the ice had gone and before work was started on the causeway for the submerged weir.

TABLE C-2

VALUE OF ELEVATION CONSTANT IN APRIL 1942 AND RISE DUE TO WEIR

Gauge	K — April 1942 (1)	Rise in K due to weir, April 1951
Black Creek	564.10	
Slaters Point	562.68	0.53
# 5 (Material Dock)	562.24	0.55
# 3	562.34	
#51	560.17	1.00
#45	558.52	
Ontario Intake B	558.22	
Toronto Forebay	532.82	
Canadian Niagara Forebay	517.71	
Conners Island	562.70	
Grass Island	561.33	0.85
Willow Island	560.05	

(1) Elevations are to U.S.L.S. 1935 Datum.

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1. Scope. — This appendix discusses the elevation of the water surface in the upper Niagara River from Black Rock to the Falls and particularly in that part of the upper river known as the Chippawa-Grass Island Pool. The water surface elevation in the upper river is subject to many effects, and it is necessary to know what they are and how they act. Between 1942 and 1947, as explained in paragraph 9 (i) of the main report, a submerged weir was built in the Pool for the purpose of restoring the water level so as to balance the effect of increases in the power diversions, and it was important to determine the amount of the resulting rise at each of the gauges above it. When the models were being made at Vicksburg and Islington, it was necessary to know what the gauge heights should be at the upper river gauge sites for various conditions of flow and diversions in the prototype; also what proportion of the flow would go over the American Falls for various water surface elevations in the Pool.

2. Gauge relations. — The elevation of the water surface at gauges in the lower river depends solely upon the flow of the river past the gauge, the water rising and falling as the flow increases and decreases. Gauges in the upper river are affected in the same way by changes in river flow, though the changes in stage are not as great for the same change in flow, but they are affected also by other things: by changes in the power diversions, by construction work that has been done in several parts of the river at various times, by the growth of aquatic plants in the river during the summer and by ice during the winter. By working out relations between lower river and upper river gauges, it is possible to determine the effect at upper river gauges of changes in river flow, of changes in the various power diversions and of the construction work that has been done between certain dates (see paragraph 9).

3. Form of gauge relation equations. — The Morrison Street gauge was used as the lower river gauge. In developing gauge relation equations between it and any gauge in the upper river, the factors involved are the fluctuations in the river flow, fluctuations in the various pertinent power diversions, and the seasonal cycle (paragraph 6). The fluctuations in river flow are shown by changes in the Morrison Street gauge height and the proportionate effect at the upper river gauge is shown by what is called the *discharge coefficient.* Similarly the values of the *diversion coefficients* show the effect of the various power diversions. The equations used are of the following form, additional terms being added for other diversions where necessary:

$$G.H. = K + a(M - 336) + b\,U.S. + c\,Qn \qquad (1)$$

where $G.H.$ = computed gauge height at given upper river gauge.

- K = elevation constant; the elevation at the given gauge corresponding to 336.0 at Morrison Street gauge when diversions are zero (see paragraph 11).
- a = dimensionless discharge coefficient, indicating the amount of change at the upper river gauge corresponding to a change of one foot at Morrison Street.
- M = mean daily gauge height at Morrison Street gauge.
- b = dimensional diversion coefficient for United States ($U.S.$) diversion, showing the amount of lowering at the upper river gauge for each 10,000 cubic feet per second of the diversion. The intakes for the Adams and Schoellkopf plants are so close that they may be treated as a single unit.
- c = diversion coefficient for Queenston (Qn) diversion (Sir Adam Beck plant No. 1) (see paragraph 10).

17. Numerical values were obtained for K_1 and a from November 1950 data and are listed in Table C-3. The values for a are the same as in Table C-1 except that values for the three new gauges mentioned above have been added. The month of November 1950, was selected for computing the value of K_1, November being the latest period when the value of the seasonal cycle was at or close to its minimum value. Knowing the value of a, the value of K_1 can be computed as before by rearranging Eq. (2). These values of K_1 of course apply only to the conditions of discharge, power diversions, and seasonal cycle that obtained in November 1950, the mean values for the diversions from the Pool for that month being as shown in the note at the foot of Table C-3.

TABLE C-3

ELEVATION CONSTANTS AND DISCHARGE COEFFICIENTS FOR NOVEMBER 1950 (1)

Gauge	K_1 (2)	a
Slaters Point	562.84	0.221
# 5 (Material Dock)	562.11	0.222
#51	560.64	0.220
Black Rock	566.04	0.303
Huntley	565.24	0.281
Tonawanda	564.63	0.270
Conners Island	562.87	0.237
Grass Island	561.35	0.217
Willow Island	559.74	0.182

(1) In equation $G.H. = K_1 + a\ (M - 336)$ when power diversions in cfs are: United States, 32,100; Queenston, 13,800, and river discharge is approximately 200,000 cfs.

(2) Elevations are to U.S.L.S. 1935 datum.

18. The use of the elevation constants listed in Table C-3 for computing elevations for discharges differing from 200,000 cfs, gives somewhat erroneous results because there is some evidence that subsequent to the construction of the submerged weir, the constant varies somewhat with the discharge. However, the error so introduced is relatively small. Thus it was possible to compute consistent sets of water surface elevations for these November 1950 conditions, including all the gauges listed in Table C-3, for any required river flow by using the general method described in paragraph 14 above, except that here the discharge coefficients and elevation constants listed in Table C-3 were used in Eq. (2) without any terms for the diversions. The profiles given by these elevations were used for verifying the Vicksburg model.

19. Verification of Islington model. — Before the weir was placed in the Islington model, it was verified by using profiles computed by the process explained in paragraph 14. To verify the model after the weir was added, a new set of profiles was derived, using gauge records for the month of May in the years 1948 and 1949. May was used to minimize the effect of the seasonal cycle. The general procedure was to produce gauge relation graphs between the Morrison Street gauge and the Slaters Point and Conners Island gauges; then between each of the upper gauges and the next one downstream. As the records did not cover the full range of stage required, it was necessary to extend the graphs beyond the range of the data used. The profiles thus obtained, which were used for verifying the model after the addition of the weir, are as shown in Table C-4.

8. NUMERICAL VALUES OF COEFFICIENTS. — Table C-1 shows the numerical values obtained for the various discharge and diversion coefficients for each of the upper river gauges listed. These represent months of tedious work. The discharge coefficient *a* shows the change in decimals of a foot, corresponding to a change of one foot at Morrison Street gauge. The diversion coefficients *b, c, d, e,* and *f* show the change in water level at each gauge due to each of the pertinent diversions, all the diversions being expressed in units of 10,000 cubic feet per second. Except for the Queenston coefficients at a few of the gauges, as explained in paragraph 10 below, all diversion coefficients are negative, as is to be expected because an increase in the diversion causes a drop in water level. Since the range of stage in the Pool is relatively small, it is safe to allow the values of all the coefficients in Table C-1 to remain constant for all river stages.

TABLE C-1

DISCHARGE AND DIVERSION COEFFICIENTS IN GAUGE RELATION EQUATIONS (1)

Gauge	a	b	c	d	e	f
Black Creek	0.264	—0.079	+0.142			
Slaters Point	0.221	—0.156	+0.045			
# 5 (Material Dock)	0.222	—0.201	—0.052			
# 3 (Hog Island)	0.235	—0.273				
#51	0.220	—0.240				
#45	0.161	—0.184		—0.291		
Ontario Intake B	0.165	—0.184		—0.840		
Toronto Forebay	0.114	—0.150		—0.222	—0.942	
Canadian Niagara Forebay	0.144	—0.210		—0.226	—0.410	—1.270
Conners Island	0.237	—0.111	+0.044			
Grass Island	0.217	—0.310				
Willow Island	0.182	—0.385				

(1) $G.H. = K + a\ (M - 336) + b\ U.S. + c\ Qn + d\ O.P. + e\ T.P. + f\ C.N.$ where

$G.H.$ = Computed gauge height
M = Morrison Street gauge height
$U.S.$ = United States Diversion
Qn = Queenston diversion (Sir Adam Beck No. 1)
$O.P.$ = Ontario Power diversion
$T.P.$ = Toronto Power diversion
$C.N.$ = Canadian Niagara diversion (Rankine plant)
and all diversions are expressed in units of 10,000 cubic feet per second.

9. From the method by which they were derived, it is evident that the numerical values of the coefficients listed in Table C-1 depend solely upon the stability of the gauges and the consistency of the gauge and diversion records and do not depend upon the accuracy of the discharge formula for the Morrison Street gauge, Eq. (2) in Appendix A. However, by using this discharge formula in combination with the coefficients listed in Table C-1, additional information can be obtained. For example, it can be found from Eq. (2) in Appendix A that at mean river stage a change of 10,000 cubic feet per second in river flow means a change of 1.4 feet at Morrison Street gauge. Since any of the values of *a* listed in Table C-1 shows the amount of change in river stage at an upper river gauge corresponding to a change of one foot at Morrison Street, the product 1.4 x *a*

TABLE C-5
DATA FOR RATING UPPER CASCADES

1 Date	2 Wing Dam Gauge Feet	3 Discharge Morrison St. c.f.s.	4 U.S. diversion c.f.s.	5 Flow over Upper Cascades Col. 3-Col. 4 c.f.s.
1947				
Nov. 5	558.38	195,600	31,900	163,700
Nov. 7	558.10	191,400	32,000	159,400
Nov. 10	558.08	194,100	31,700	162,400
Nov. 12	558.28	196,100	31,700	164,400
Nov. 14	558.20	190,400	31,800	158,600
Nov. 20	558.10	185,100	32,100	153,000
Nov. 21	557.95	184,100	32,200	151,900
Nov. 26	558.46	204,000	31,800	172,200
1948				
May 12	558.58	214,400	31,500	182,900
May 18	558.63	219,400	31,500	187,900
May 19	558.63	217,900	31,700	186,200
May 21	558.58	221,900	31,600	190,300
May 26	558.53	214,900	31,100	183,800
May 28	558.53	214,600	31,600	183,000
June 2	558.58	213,100	31,400	181,700
June 4	558.68	213,600	31,300	182,300
June 9	558.73	215,600	31,300	184,300
June 11	558.78	214,200	31,200	183,000
Nov. 3	557.78	176,500	31,700	144,800
Nov. 5	557.68	179,300	31,700	147,600
Nov. 12	557.88	184,600	31,500	153,100
Nov. 19	557.63	172,500	30,600	141,900
Nov. 24	557.83	180,900	31,800	149,100
Nov. 26	557.88	183,300	32,200	151,100
1949				
May 6	558.18	191,500	31,800	159,700
May 13	557.88	187,200	31,900	155,300

22. Rating curve for American Channel. — The rating curve for the channel leading to the American Falls, plotted against Wing Dam gauge, is shown in Plate C-2 and is based on the 1946 and 1947 meterings. These meterings locate the upper part of the graph. To get a reasonable location for the lower part, the meterings were plotted on logarithmic paper and a straight line was drawn through them. When changed to Cartesian coordinates, this became the following exponential equation, which was used to locate the graph in Plate C-2:

$$Q = 1{,}068.8 \text{ (Wing Dam} - 554)^{1.729} \qquad (3)$$

23. Rating curve for Upper Cascades. — By the same process, the data listed in Table C-5 was used to locate the graph in Plate C-3 which shows the total discharge over the Upper Cascades plotted against the Wing Dam gauge, the equation for the graph being as follows:

$$Q = 6{,}745.3 \text{ (Wing Dam} - 552)^{1.749} \qquad (4)$$

24. Flow in American Channel as percentage of flow over Upper Cascades. — For various selected elevations at Wing Dam gauge, a number of sets of corresponding American Channel and

12. Rise due to submerged weir. — From 1947 after the submerged weir was finished until the summer of 1952 when work was started on the intakes for the new Sir Adam Beck plant, no other important construction work was being done in the Chippawa-Grass Island Pool. For any day during that period, it is possible to compute the effect of the weir plus the seasonal cycle for any gauge in the Pool by means of the figures listed in Tables C-1 and C-2, assuming, of course, that it is at a time of year when there is no ice in the river. The necessary gauge heights and pertinent diversions for the given day being available from the records, it is possible to compute the corresponding gauge height at the upper river gauge under the conditions that existed in April 1942, before the weir was started, by using the value of K listed in Table C-2. Subtracting this from the gauge height actually observed for that day, the difference will show the rise due to the weir plus the seasonal cycle.

13. Plate C-1 is a diagram for gauge No. 51 showing the computed effect of the weir plus the seasonal cycle, storms and ice for each day during the year 1951. At times during the winter and spring, the relationship is affected by ice. From the middle of April to the middle of May, there is little change, the mean value being 1.0 foot. Similar diagrams for each gauge show the true effect of the weir with the seasonal cycle at a minimum. It is these values that are entered in the last column of Table C-2. After May 15, the effect of the seasonal cycle begins to show on Plate C-1, it reaches a maximum of 0.5 foot by the end of June and drops off to 0.2 foot by the middle of December. After that, the relationship is disturbed by storms and by ice. The next spring, in a similar diagram for 1952, the weir effect was back to slightly less than 1.0 foot.

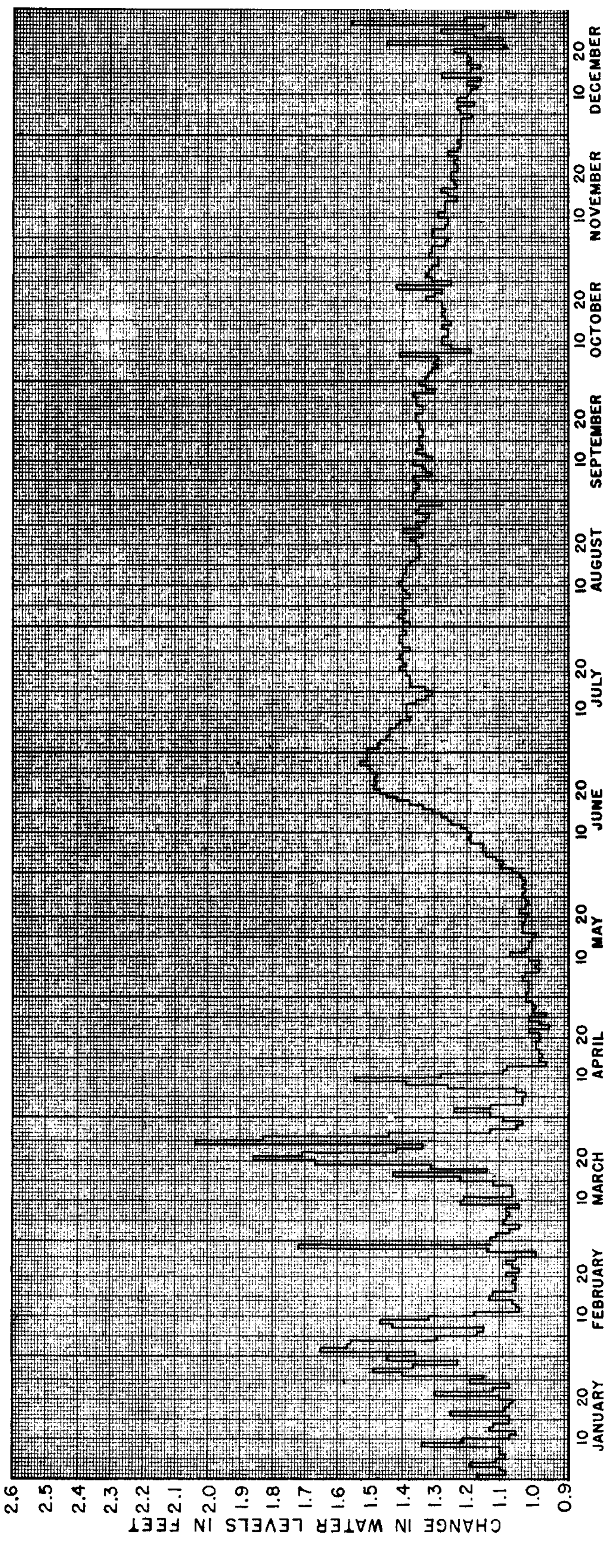
14. Verification of models without weir. — Part of the work of verifying the models above the Cascades was done before placing the submerged weir in the model. For this purpose, consistent sets of water surface elevations for the gauges in the Pool that are included in Tables C-1 and C-2 were computed for various river flows and for various combinations of diversions. For each required total flow, the amount of the required Queenston diversion was subtracted to give the flow past the Morrison Street gauge. From the rating table which has been prepared from the discharge formula, Eq. (2) in Appendix A, the corresponding Morrison Street gauge height was found. Then for the required diversions, the corresponding set of water surface elevations was computed from Eq. (1) using the coefficients listed in Table C-1 and the elevation constants in Table C-2.

15. Verification of Vicksburg model with submerged weir in place. — It was necessary also to verify parts of the models after the submerged weir was set in place, particularly the upper part of the Vicksburg model. On April 25, 1951, water surface elevations were observed at many points by the field survey parties. This gave a complete profile of the upper river for the flow and power diversions that actually occurred on the prototype during that day. Additional profiles for other flows and diversions were computed from the gauge relation equations.

16. The Black Rock, Huntley and Tonawanda gauges are so far upstream that it was difficult to compute accurate values for the diversion coefficients for them, particularly since the records at Huntley and Tonawanda gauges do not extend back much before 1941. Accordingly, in order to include them in the river profiles, an equation was used which did not include the terms for the diversions, as follows:

$$G.H. = K_1 + a\ (M - 336) \qquad (2)$$

where all the symbols have the same significance as in paragraph 3 above except K_1 takes the place of K and will have a different numerical value because it includes the effect of the submerged weir and the power diversions. By proper management, it is possible to omit the diversion terms in this way because in recent years the diversions do not change much from day to day.



Computed G.H. = 560.17 + 0.220 (M-336) - 0.240 U.S. Diversion

NIAGARA RIVER

MEAN DAILY

CHANGE IN WATER LEVELS

RESULTING FROM WEIR CONSTRUCTION AND SEASONAL CYCLE

Observed Stage minus Computed Stage

GAUGE NO. 51

1951

TABLE C-4

WATER SURFACE ELEVATIONS AFTER CONSTRUCTION OF SUBMERGED WEIR (1)

Gauge	Total river flow — cubic feet per second					
	140,000	160,000	180,000	200,000	225,000	250,000
Slaters Point	561.41	562.13	562.83	563.50	564.31	565.11
# 5 (Material Dock)	560.71	561.43	562.13	562.82	563.64	564.43
# 3	560.02	560.75	561.47	562.18	563.01	563.82
#51	559.33	560.00	560.65	561.29	562.05	562.79
#45	556.48	556.97	557.46	557.93	558.49	559.03
Ontario Intake B	555.53	556.09	556.63	557.17	557.79	558.40
Toronto Forebay	529.61	530.06	530.48	530.91	531.40	531.87
Conners Island	561.62	562.35	563.05	563.73	564.53	565.33
Grass Island	560.11	560.77	561.41	562.02	562.76	563.48
Willow Island	558.58	559.16	559.78	560.34	561.02	561.68

(1) From gauge relation curves plotted from daily readings in May 1948 and 1949, with power diversions as follows: Queenston — 14,700, U.S. — 31,450, O.P. — 10,450, T.P. — 14,900. Elevations are to U.S.L.S. 1935 datum.

20. Division of flow around Goat Island. — It is important to know how the flow of the river is divided around Goat Island at present. In verifying the models, this was used as one indication as to whether they agreed with the prototype. Also in designing works to control the level in the Chippawa-Grass Island Pool, it is necessary to know what the flow over the American Falls will be at various river stages so as to ensure that it will be sufficient to provide a satisfactory scenic spectacle. Consequently, a study was made of existing data with the result that the graph in Plate C-4 was drawn to show the flow over the American Falls as a percentage of the total flow over the Upper Cascades. The method of preparing this graph is explained in paragraphs 21 to 24 below.

21. Data available. — Measurements of the flow in the American Channel were made by current meter in 1927 and 1928 at a section just below the Wing Dam gauge near the head of Goat Island. On the basis of these meterings, the flow over the American Falls was expressed in the 1928 report as 4.7 percent of the total flow over the Upper Cascades. In connection with the building of the submerged weir, additional meterings were made at the same location in 1943, 1944, 1946 and 1947, and were referred to a re-established Wing Dam gauge. These new meterings are listed on pages 24 and 25 of the Final Report on the Niagara River Submerged Weir, dated September 1, 1948, and are plotted with the meterings of 1927 and 1928 on Plate 9 of the same report. The 1943 measurements appear to lie along the extension of the rating curve based on the 1927 and 1928 measurements, but the measurements of 1944, 1946 and 1947 indicate greater flow than earlier measurements for the same stages. The measurements made in 1946 and 1947, being more recent, are considered more representative of present conditions. In addition, there are available staff readings taken at Wing Dam gauge at infrequent intervals during 1947, 1948 and 1949. To minimize the effect of the seasonal cycle, only the readings in May, early June and November have been used. These readings, together with the pertinent river discharge and diversion data taken from the records, are listed in Table C-5.

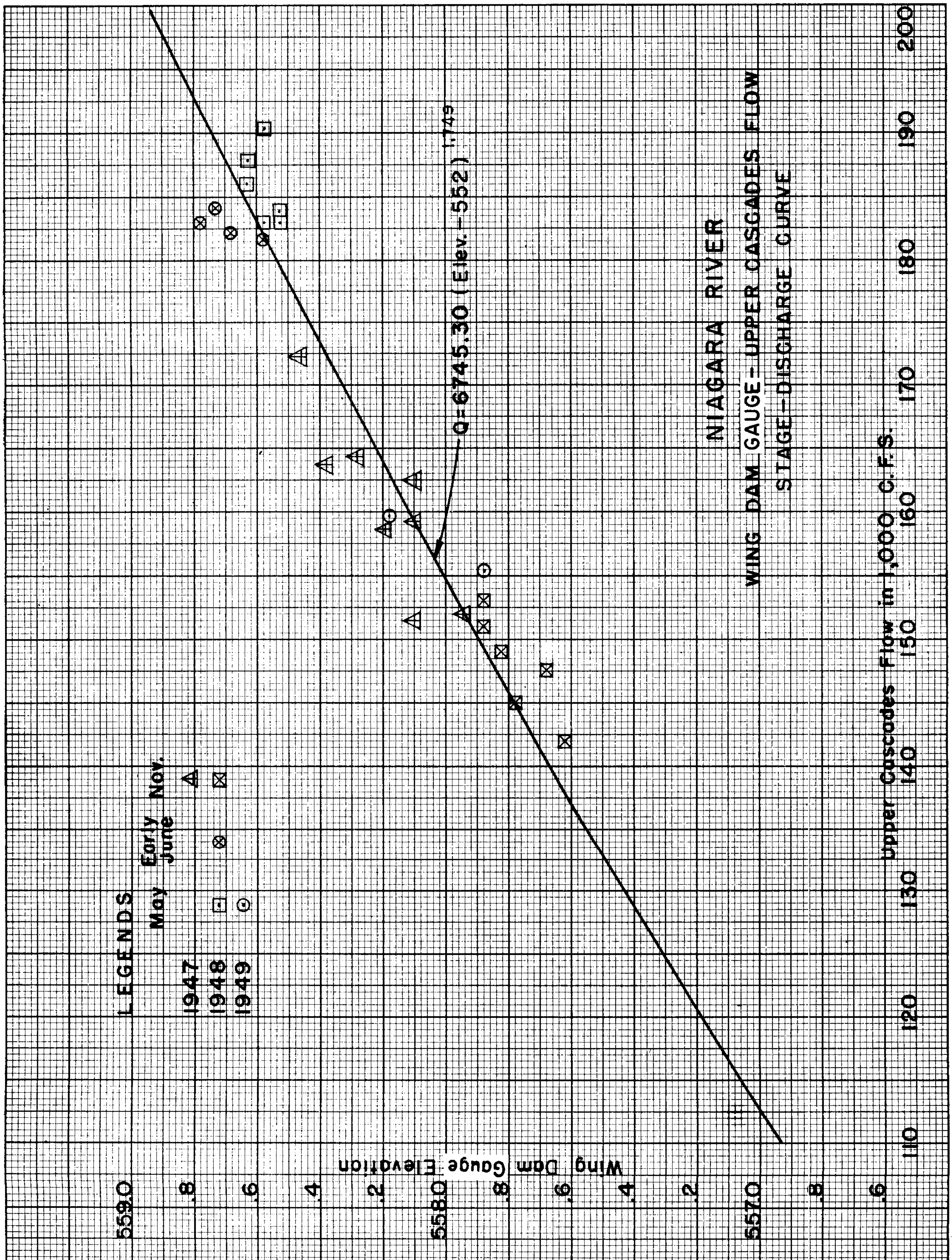

NIAGARA RIVER
WING DAM GAUGE – UPPER CASCADES FLOW
STAGE – DISCHARGE CURVE
Q=6745.30 (Elev.–552) 1.749
LEGENDS
May
Early June
Nov.
1947
1948
1949
Wing Dam Gauge Elevation
559.0
.8
.6
.4
.2
558.0
.8
.6
.4
.2
557.0
.8
.6
Upper Cascades Flow in 1,000 C.F.S.
110
120
130
140
150
160
170
180
190
200

PLATE C-3

TABLE C-4

WATER SURFACE ELEVATIONS AFTER CONSTRUCTION OF SUBMERGED WEIR (1)

Gauge	Total river flow — cubic feet per second 140,000	160,000	180,000	200,000	225,000	250,000
Slaters Point	561.41	562.13	562.83	563.50	564.31	565.11
# 5 (Material Dock)	560.71	561.43	562.13	562.82	563.64	564.43
# 3	560.02	560.75	561.47	562.18	563.01	563.82
#51	559.33	560.00	560.65	561.29	562.05	562.79
#45	556.48	556.97	557.46	557.93	558.49	559.03
Ontario Intake B	555.53	556.09	556.63	557.17	557.79	558.40
Toronto Forebay	529.61	530.06	530.48	530.91	531.40	531.87
Conners Island	561.62	562.35	563.05	563.73	564.53	565.33
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Willow Island	558.58	559.16	559.78	560.34	561.02	561.68

(1) From gauge relation curves plotted from daily readings in May 1948 and 1949, with power diversions as follows: Queenston — 14,700, U.S. — 31,450, O.P. — 10,450, T.P. — 14,900. Elevations are to U.S.L.S. 1935 datum.

20. Division of flow around Goat Island. — It is important to know how the flow of the river is divided around Goat Island at present. In verifying the models, this was used as one indication as to whether they agreed with the prototype. Also in designing works to control the level in the Chippawa-Grass Island Pool, it is necessary to know what the flow over the American Falls will be at various river stages so as to ensure that it will be sufficient to provide a satisfactory scenic spectacle. Consequently, a study was made of existing data with the result that the graph in Plate C-4 was drawn to show the flow over the American Falls as a percentage of the total flow over the Upper Cascades. The method of preparing this graph is explained in paragraphs 21 to 24 below.

21. Data available. — Measurements of the flow in the American Channel were made by current meter in 1927 and 1928 at a section just below the Wing Dam gauge near the head of Goat Island. On the basis of these meterings, the flow over the American Falls was expressed in the 1928 report as 4.7 percent of the total flow over the Upper Cascades. In connection with the building of the submerged weir, additional meterings were made at the same location in 1943, 1944, 1946 and 1947, and were referred to a re-established Wing Dam gauge. These new meterings are listed on pages 24 and 25 of the Final Report on the Niagara River Submerged Weir, dated September 1, 1948, and are plotted with the meterings of 1927 and 1928 on Plate 9 of the same report. The 1943 measurements appear to lie along the extension of the rating curve based on the 1927 and 1928 measurements, but the measurements of 1944, 1946 and 1947 indicate greater flow than earlier measurements for the same stages. The measurements made in 1946 and 1947, being more recent, are considered more representative of present conditions. In addition, there are available staff readings taken at Wing Dam gauge at infrequent intervals during 1947, 1948 and 1949. To minimize the effect of the seasonal cycle, only the readings in May, early June and November have been used. These readings, together with the pertinent river discharge and diversion data taken from the records, are listed in Table C-5.

Upper Cascades discharges were scaled from Plates C-2 and C-3 or computed from Eqs. (3) and (4). For each set, the flow in the American Channel was reduced to a percentage of the total flow over the Upper Cascades and these were plotted against the flow in the Upper Cascades to give the graph in Plate C-4. Each model, when adjusted to agree with the upper part of this graph which is well located, gave results that agreed reasonably well with the lower end of the graph.

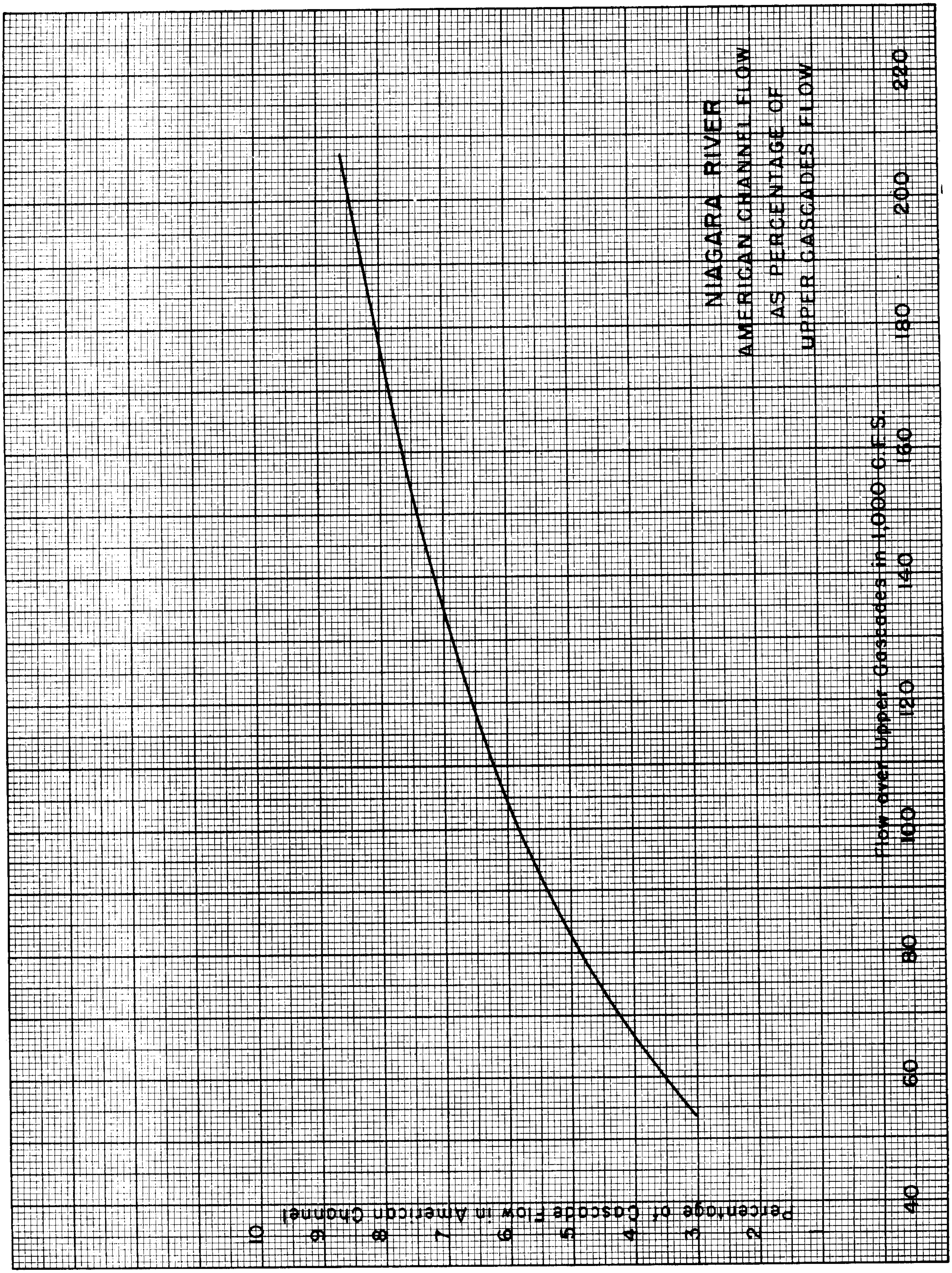

NIAGARA RIVER
AMERICAN CHANNEL FLOW
AS PERCENTAGE OF
UPPER CASCADES FLOW
Flow over Upper Cascades in 1,000 C.F.S.
40
60
80
100
120
140
160
180
200
220
Percentage of Cascade Flow in American Channel
1
2
3
4
5
6
7
8
9
10

PLATE C-4

LIST OF PLATES

APPENDIX D

VICKSBURG MODEL

DESCRIPTION, VERIFICATION AND PRELIMINARY TESTS

ditions could be readily changed to represent any of the proposed improvement plans. Surveys used in the model to define river bed elevations and shoreline topography are described in detail in Appendix B. The new and proposed power intakes along the river were precisely located in the model and were constructed of wood. Flow into each intake was controlled by a standard gate valve and was measured by a Van Leer weir. Provision was also made for measurement of the flow in the channels around Grand Island and the flow over the American and Horseshoe Falls. Water surface elevations were observed at the 18 manometer-type gauges shown on Plate D-1. Water surface elevations in special problem areas were measured by means of portable point gauges. During the course of the tests, it was found desirable to measure the flow over the Horseshoe Falls in 100-foot increments along the crest. This was accomplished by a specially constructed scoop which diverted the flow through one of the Van Leer weirs for measurement.

VERIFICATION OF THE MODEL

5. The verification of this type of hydraulic model is accomplished by careful adjustment of channel roughness until an accurate and detailed reproduction of all observed hydraulic phenomena of the prototype river is obtained. The results obtained at the culmination of this hydraulic adjustment phase demonstrated the degree of accuracy and reliability which could be expected from tests of proposed plans of improvement. Verification of the Niagara River and Falls model falls naturally into two separate operations: first, verification of the relatively low-velocity channel upstream from the Cascades, including verification of the distribution of flow around Grand and Goat Islands and second, verification of the relatively high-velocity Cascades and Falls section. A description of the verification of the reach upstream of the Cascades is presented in the following paragraphs; a description of the verification of the Cascades and Falls area is contained in Appendix F.

6. The first step in the verification of the Niagara model above the Cascades was to adjust the water surface elevations at the 18 gauges shown on Plate D-1 to agree with simultaneous readings made in the prototype at these gauge locations on 25 April 1951. The prototype observations were made at a time when there was very little fluctuation in river levels and discharge (223,500 cfs) and during the season of the year when the river was not yet affected by the seasonal weed cycle. To insure that the model was adjusted for the entire range of discharges which would be used later in the testing program, the water surface elevations at all standard gauges were checked against elevations computed by gauge-relation formulae as described in Appendix C for flows ranging from 150,000 cfs to 240,000 cfs.

7. Results of the verification tests are presented in Plate D-2. Examination of this plate shows that the model water surface elevations with a few exceptions check both the observed and computed prototype elevations at all gauges within about 0.1 foot to 0.2 foot. Such agreement is considered to be satisfactory in models of this type.

8. At the conclusion of the verification, observations were made to determine the division of flow between the American and Canadian Channels around Goat Island. Plate D-3 presents the results of these observations compared with the prototype division of flow as computed by the method described in Appendix C. Examination of Plate D-3 indicates a reasonable agreement between the model and prototype values.

TESTS AND RESULTS

9. PURPOSE OF TESTS. — Following the verification of the model, a series of tests was conducted and model data were collected to supplement known data and to extend the present knowledge of the hydraulics of the Niagara River over a wider range of flow conditions. These tests

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX D

VICKSBURG MODEL

DESCRIPTION, VERIFICATION AND PRELIMINARY TESTS

CONTENTS

LIST OF TABLES

test conditions was established. The 16 test conditions in the revised program are numbered 101 to 116 and the flows and diversions for each are presented in Table D-2.

15. A description of the information obtained in these tests follows:

(a) Water surface elevations at all gauges in river and Cascades.

(b) Flow distribution around Goat Island.

(c) Photographs: (1) American Falls from Canadian bank, (2) Horseshoe Falls from Canadian bank, (3) Vertical of Cascades area, and (4) Vertical of Cascades area showing streamlines by floating material.

(d) Discharge over 100-foot section along crest of Horseshoe Falls.

(e) Depth of flow and water surface elevation at center of each 100-foot section along crest of Horseshoe Falls.

16. The results of the 16 base tests are presented in Tables D-2 through D-8 and Plates D-8 through D-10. Although a complete set of photographs was obtained for each tests condition, only a few showing typical conditions are presented.

17. Analysis of the test results indicated that the additional authorized diversions, without remedial works, would reduce the flows over the American and Horseshoe Falls below that considered necessary to maintain the existing spectacle. For an average river flow of 200,000 cfs and existing diversions, the flows over the American and Horseshoe Falls were about 11,500 and 105,500 cfs, respectively. With the same river flow and future maximum diversions, the flows over the American and Horseshoe Falls would be reduced to about 5,000 and 95,000 cfs, respectively, during the tourist season days, and about 2,600 and 47,400 cfs, respectively, at all other times. Photographs of the model's Horseshoe Falls (Plate D-8 and D-9) and data in Tables D-5 and D-8 show that for a total Falls flow of 50,000 cfs the two flanks would be dry and for the 100,000 cfs flow the Goat Island flank would be partly dry and the Canadian flank would carry an appreciable but not impressive flow. It was also noted that under maximum diversions, relatively large areas of the Chippawa-Grass Island Pool and Upper Cascades bed would be exposed by the lower water levels.

CONCLUSIONS

18. Conclusions drawn from the study are summarized below:

(a) Without remedial works, the future maximum diversions would result in lower Chippawa-Grass Island Pool elevations. This reduction would be of such magnitude as to extend upstream and result in lowering Lake Erie levels.

(b) Without remedial works, the time required to change the Falls flow from 50,000 cfs to 100,000 cfs and vice versa would be of such length that only a small part of the extra diversion authorized at night during the tourist season could be utilized.

(c) In view of (a) and (b) above, consideration should be given to the construction of some type of remedial works at the head of the Cascades which would compensate for the added diversions and enable the existing range of levels in the Chippawa-Grass Island Pool to be maintained.

(d) The 50,000 cfs and 100,000 cfs flows over the Falls without remedial works would not be sufficient to maintain the existing spectacle.

(e) The tests clearly indicated the need for remedial works which would properly redistribute the flow over the Horseshoe Falls.

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX D

VICKSBURG MODEL, DESCRIPTION, VERIFICATION AND PRELIMINARY TESTS

INTRODUCTION

1. Two models of Niagara Falls and Cascades and portions of the river were constructed to assist in the design of remedial works: one by the Corps of Engineers, United States Army, at the Waterways Experiment Station, Vicksburg, Mississippi, and the other by The Hydro-Electric Power Commission of Ontario at Islington, Ontario. The purpose of the model study was to aid in the determination of the nature and design of remedial works required to preserve and enhance the scenic beauty of Niagara Falls and bearing in mind the provision for the diversion of the waters of Niagara River and the apportionment thereof which have been agreed upon by the two Governments by the Treaty of 1950 respecting the uses of the waters of the Niagara River. This appendix presents a description of the construction and verification of the Vicksburg model, together with results of preliminary tests to determine the effects on existing river conditions of the additional authorized diversions. Other reports on the Vicksburg model are contained in appendices F and G. Corresponding reports on the model study conducted at Islington may be found in appendices E, F, and H.

THE MODEL

2. Area reproduced. — The prototype area reproduced in the model is shown on Plate D-1 and a general view of the model is shown in Figure 1 following paragraph 51 of the main report. The model reproduces about 26 miles of the Niagara River extending from approximately 11,500 feet above the Peace Bridge to Rainbow Bridge about 5,000 feet below the Falls. The upper limits of the model extend far enough into Lake Erie to provide accurate reproduction of flow entering the Niagara River from the lake, and the lower limits of the model include the gorge below the Falls for pictorial purposes only. Between these extremities are reproduced the Falls and Cascades, the existing and proposed power intakes, Goat Island and Grand Island, and other important topographical features.

3. Scale ratios. — The Niagara River and Falls model was constructed to linear scale ratios, model-to-protoype, of 1:360 horizontally and 1:60 vertically, with a geometrically resultant slope scale of 6:1. The selection of these scale ratios was based upon the following considerations: (a) previous experience with similar problems indicated that such a model would furnish satisfactory solutions of the problems presented, and would be considerably more economical to construct than an undistorted model; and (b) known physical and hydraulic characteristics of the Niagara River indicated that such a model would accurately reproduce (to the proper Froudian scale relationships) the proper roughness factors and hydraulic characteristics of the prototype without appreciable alteration of the model channels. Scale ratios, model to prototype, in accordance with Froudian relationships are presented in the following tabulation:

Dimension	Relationship
Horizontal	1:360
Vertical	1:60
Velocity	1:7.74
Discharge	1:167,328
Time	1:46.48

4. Construction and appurtenances. — The model is of the fixed-bed type, with all channel and overbank areas being moulded in concrete. The concrete forms a thin shell about two inches thick and, in certain areas, removable concrete blocks were used so that the existing channel con-

TABLE D-2

TEST CONDITIONS

Tests 101 to 116 — Without Remedial Works

	Discharge in cfs							
	Test 101	Test 102	Test 103	Test 104	Test 105	Test 106	Test 107	Test 108
Inflow								
Buffalo	200,000	200,000	200,000	200,000	180,000	200,000	200,000	200,000
U. S. Diversions								
Conners Island	30,000	30,000	30,000	30,000	55,000	65,000	55,000	40,000
Adams Sta.	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Schoellkopf	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Canadian Diversions								
Sir Adam Beck #1	25,000	20,000	15,000	15,000	28,000	28,000	28,000	28,000
Sir Adam Beck #2	25,000	20,000	15,000		27,000	27,000	27,000	27,000
Toronto				15,000				15,000
Ontario		10,000	10,000	10,000		10,000	10,000	10,000
Canadian Niagara			10,000	10,000			10,000	10,000
Outflow								
Total flow at head of Cascades	100,000	110,000	120,000	135,000	50,000	60,000	70,000	85,000
American Falls Flow	4,900	5,400	6,800	8,600	1,100	1,700	2,600	3,500
Total Falls flow	100,000	100,000	100,000	100,000	50,000	50,000	50,000	50,000
Horseshoe Falls Flow								
Computed	95,100	94,600	93,200	91,400	48,900	48,300	47,400	46,500
Measured	95,500	94,500	93,500	91,400	48,600	48,600	47,700	46,800

	Test 109	Test 110	Test 111	Test 112	Test 113	Test 114	Test 115	Test 116
Inflow								
Buffalo	200,000	200,000	250,000	250,000	200,000	200,000	200,000	200,000
U. S. Diversions								
Conners Island	5,000	5,000	30,000	30,000	55,000	45,000	45,000	45,000
Adams Sta.	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Schoellkopf	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Canadian Diversions								
Sir Adam Beck #1	15,000	15,000	15,000	15,000	28,000	28,000	23,000	15,000
Sir Adam Beck #2	10,000		15,000		27,000	27,000	22,000	15,000
Toronto				15,000				15,000
Ontario		10,000	10,000	10,000		10,000	10,000	10,000
Canadian Niagara			10,000	10,000			10,000	10,000
Outflow								
Total flow at head of Cascades	150,000	160,000	170,000	185,000	70,000	80,000	90,000	105,000
American Falls Flow	10,250	11,810	13,050	15,250	2,460	3,160	3,990	5,020
Total Falls flow	150,000	150,000	150,000	150,000	70,000	70,000	70,000	70,000
Horseshoe Falls Flow								
Computed	139,750	138,190	136,950	134,750	67,540	66,840	66,010	64,980
Measured	139,500	138,000	137,000	134,600	67,600	67,000	66,100	65,000

were all conducted with existing river conditions (i.e. remedial works not installed) for river flows ranging from 140,000 cfs to 240,000 cfs. The tests were especially designed to provide much-needed information about the effect future power diversions would have on Niagara River stages and discharges without remedial works.

10. Effect of diversions on river flow. — A series of 20 tests was run to determine the effects on the Niagara River discharge of changes in diversions from the Chippawa-Grass Island Pool. These tests involved four basic river flows: 140,000 cfs, 180,000 cfs, 200,000 cfs, and 240,000 cfs. For each basic discharge, the river stage at Buffalo was held constant by regulation of the river inflow while the diversion from the Chippawa-Grass Island Pool was varied from 0 to 149,000 cfs. These tests were based on the premise that under existing river conditions an increase in diversions would lower the elevation of Chippawa-Grass Island Pool. This lowering of the Pool would result in a steeper water surface slope between Chippawa-Grass Island Pool and Lake Erie which in turn would cause an increase in discharge from the lake.

11. The results of the tests are presented in tabular form in Table D-1 and in graphic form on Plate D-4. As shown by the example on Plate D-4, these results indicate that for a total river flow of 140,000 cfs, the diversions from Chippawa-Grass Island Pool must be increased by 51,500 cfs to effect a reduction in flow at the head of the Cascades from 100,000 cfs to 50,000 cfs. Further examination of these data will show that, for a river flow of 236,000 cfs with zero diversion from the Pool, an increase of 149,000 cfs in the diversion from the Pool will result in a total river flow of 241,000 cfs. These figures indicate an increase of 5,000 cfs in discharge from Lake Erie resulting from a withdrawal of 149,000 cfs from Chippawa-Grass Island Pool.

12. Time-scale tests. — Four tests were conducted to determine the time required to change the total Falls flow from 100,000 cfs to 50,000 cfs and from 50,000 cfs to 100,000 cfs under specific diversion conditions for river discharges of 140,000 cfs and 200,000 cfs. At the beginning of each test the model was stabilized to one of the selected operating conditions. The diversion from Chippawa-Grass Island Pool as determined from information obtained in previous tests (see paragraph 11 and Plate D-4) was then rapidly changed to produce the ultimate desired Falls flow. The Buffalo gauge was held constant by regulation of the river inflow and continuous measurements at short time intervals were made on the river inflow, river stages, and Falls flow until a new stable condition obtained in the model.

13. The results of two of these tests are shown on Plates D-5, D-6, and D-7. The test results reveal that about 12 to 14 hours (prototype) would be required, under present river conditions, to change the Falls flow from 50,000 cfs to 100,000 cfs or vice versa. These data also indicate that about 90 per cent of the change could be effected in a period of about six hours. During the change-over in either direction, the Chippawa-Grass Island Pool elevation at the Material Dock gauge changed by about 1.4 foot, as shown on Plate D-6.

14. Base tests. — An initial test program consisting of 53 test runs was established during the early stages of the Niagara model study for the purpose of obtaining basic data under existing conditions of the river and Falls which could be used as a reference for measuring the effectiveness of various plans of remedial works. This series of tests covered all possible combinations of the following conditions: river flows of 140,000, 180,000, 200,000 and 240,000 cfs; discharges over the Falls of 50,000, 100,000, and 150,000 cfs; and various probable stages of power development. Preliminary tests of some of these conditions indicated that, for all practical purposes, the distribution of flow around the crest of the Horseshoe Falls is governed by the volume of flow at the head of the Cascades and the diversions by the Canadian Cascades plants. In view of these findings, a revised program consisting of only 16 base

TABLE D-4

WATER SURFACE ELEVATIONS — CASCADES GAUGES

Tests 101 to 116 — Without Remedial Works

Cascades Gauges *	Water Surface Elevations in ft USLSD							
	Test 101	Test 102	Test 103	Test 104	Test 105	Test 106	Test 107	Test 108
a	532.1	532.2	532.5	532.0	530.4	530.3	530.9	529.3
b	515.0	515.2	514.6	514.4	512.2	512.2	510.7	509.0
c	507.6	507.9	507.8	507.8	506.0	506.1	506.1	dry
d	554.3	554.7	554.7	555.4	552.3	552.5	553.1	553.7
e	517.6	518.1	518.0	517.2	514.3	514.2	514.4	513.0
f	514.5	514.7	514.8	514.0	512.0	511.7	510.3	509.6
g	508.7	508.7	508.5	508.1	504.6	505.1	504.5	504.7
h	519.5	519.3	519.9	520.4	516.9	517.3	517.6	518.2
j	551.5	551.8	552.5	553.0	548.5	548.8	549.7	550.3
k	520.3	520.3	521.0	521.3	517.5	518.3	518.6	520.0
l	517.2	517.3	517.8	518.0	514.2	514.8	515.5	516.2
m	508.7	508.5	508.8	508.7	507.6	506.5	507.6	508.0
n	529.2	529.7	529.7	530.2	525.9	526.4	527.1	528.2
o	512.8	512.8	513.1	513.0	511.5	511.2	511.7	512.2
p	537.5	537.2	537.8	536.9	535.4	535.3	535.6	536.3

Cascades Gauges *	Test 109	Test 110	Test 111	Test 112	Test 113	Test 114	Test 115	Test 116
a	534.0	534.0	534.0	533.7	530.5	530.8	531.4	530.5
b	517.2	517.2	516.3	516.0	513.8	514.1	512.5	512.3
c	509.3	509.0	509.1	508.9	506.4	506.5	506.3	506.1
d	556.0	556.2	556.1	556.4	553.7	553.4	554.0	554.2
e	520.9	520.7	520.7	520.3	515.7	515.7	516.1	514.5
f	516.9	516.9	515.9	515.7	513.3	513.5	512.7	511.8
g	511.2	511.8	511.4	510.8	506.4	507.1	506.1	505.8
h	521.5	521.4	521.7	521.6	518.2	518.3	518.5	519.0
j	553.2	553.8	554.2	554.2	549.6	550.4	551.0	551.0
k	522.4	522.1	522.2	522.3	519.2	519.5	520.1	520.3
l	519.1	519.1	519.5	519.3	515.9	516.2	516.5	516.8
m	511.0	511.3	511.8	511.8	507.9	508.5	508.7	508.8
n	530.5	530.5	530.7	530.6	527.7	528.2	528.5	528.8
o	513.9	514.1	514.0	514.0	511.7	512.1	512.0	512.2
p	539.5	539.3	539.7	540.3	536.2	536.3	536.5	537.0

* For location of gauges see Plate F-18

TABLE D-1

SUMMARY OF POWER DIVERSION — RIVER DISCHARGE TESTS

Without Remedial Works

	Test Number									
	54A	55A	56A	57A	58A	59B	60B	61B	62B	63B
	Flow and Diversions in 1,000 cfs									
River Inflow	138.5	140.0	142.5	141.6	141.0	177.5	179.0	180.0	181.5	181.5
Conners Island Intake			20.0	30.0	63.6			20.0	30.0	53.0
Schoellkopf Intake		20.0	20.0	30.0	24.3		20.0	20.0	30.0	40.0
Sir Adam Beck #1			20.0	30.0	30.2			20.0	30.0	30.0
Sir Adam Beck #2		20.0	20.0	26.0	24.3		20.0	20.0	26.0	26.0
Falls Outflow	139.0	99.6	61.9	27.4	00.0	177.4	138.4	100.6	66.5	32.9
Gauges	Water Surface Elevations in feet USLSD *									
Buffalo	569.8	569.8	569.8	569.8	569.8	571.6	571.6	571.6	571.6	571.6
Peace Bridge	566.8	566.7	566.6	566.4	566.3	568.4	568.3	568.1	568.2	568.2
Black Rock	565.2	564.8	564.4	564.1	563.7	566.6	566.4	565.9	565.8	565.5
Huntley	564.7	564.2	563.7	563.4	563.0	566.0	565.7	565.2	564.9	564.7
Hickory	564.5	564.0	563.5	563.2	562.8	565.7	565.4	564.9	564.7	564.4
Tonawanda Isle	564.4	563.9	563.4	563.1	562.7	565.6	565.2	564.8	564.5	564.2
Edgewater	564.0	563.5	562.9	562.6	562.1	565.1	564.8	564.2	563.9	563.6
Upper Cayuga	563.2	562.4	561.2	560.4	559.2	564.3	563.7	562.8	562.0	561.1
Lower Cayuga	563.1	562.2	560.9	560.2	558.8	564.2	563.6	562.6	561.8	560.7
Conners Isle	563.0	562.1	560.6	559.7	556.7	564.0	563.3	562.2	561.2	559.7
Grass Isle	562.1	560.7	558.9	557.0		563.1	562.1	560.7	559.2	556.5
Willow Isle	560.4	559.4	558.2	556.2		561.3	560.3	559.3	558.3	
Millers Creek	564.5	564.1	563.5	563.1	562.7	565.9	565.6	564.9	564.8	564.4
Black Creek	564.1	563.6	562.8	562.4	561.8	565.4	565.0	564.3	564.1	563.6
Little Six Creek	563.4	562.7	561.6	560.9	560.0	564.6	564.0	563.1	562.5	561.7
Slaters Point	562.8	561.9	560.4	559.5	557.9	564.0	563.2	562.1	561.2	559.9
Material Dock	562.5	561.5	559.7	558.3	553.3	563.6	562.7	561.3	560.1	558.5
Gauge 51	561.3	560.0	558.4	556.5		562.3	561.4	560.0	558.8	556.3

	Test Number									
	64C	65C	66C	67C	68C	69D	70D	71D	72D	73D
	Flows and Diversions in 1,000 cfs									
River Inflow	197.0	197.5	200.5	200.0	200.5	236.0	237.0	239.0	240.0	241.0
Conners Island Intake			20.0	35.0	46.5			25.0	35.0	46.5
Schoellkopf Intake		25.0	30.0	35.0	46.5		25.0	25.0	35.0	46.5
Sir Adam Beck #1			20.0	26.0	26.0			25.0	26.0	26.0
Sir Adam Beck #2		25.0	30.0	30.0	30.0		25.0	25.0	30.0	30.0
Falls Outflow	196.5	146.0	100.0	73.0	52.5	236.0	188.0	140.0	114.4	92.1
Gauges	Water Surface Elevations in ft USLSD*									
Buffalo	572.4	572.4	572.4	572.4	572.4	574.1	574.1	574.1	574.1	574.1
Peace Bridge	569.0	569.0	568.9	568.8	568.8	570.8	570.6	570.5	570.5	570.5
Black Rock	567.2	566.9	566.6	566.3	566.3	568.7	568.4	568.0	567.8	567.7
Huntley	566.6	566.1	565.8	565.5	565.4	568.0	567.6	567.1	566.9	566.7
Hickory	566.2	565.8	565.4	565.0	564.9	567.6	567.2	566.6	566.4	566.3
Tonawanda Isle	566.1	565.7	565.3	564.9	564.8	567.3	567.0	566.4	566.2	566.0
Edgewater	565.6	565.1	564.6	564.2	564.1	566.9	566.4	565.7	565.5	565.3
Upper Cayuga	564.8	564.0	563.1	562.4	561.9	566.0	565.3	564.3	563.7	563.3
Lower Cayuga	564.7	563.9	562.9	562.1	561.7	566.0	565.1	564.0	563.6	563.1
Conners Isle	564.4	563.6	562.5	561.5	561.0	565.6	564.9	563.6	563.0	562.4
Grass Isle	563.5	562.2	560.8	559.4	558.4	564.6	563.4	562.1	561.2	560.3
Willow Isle	561.6	560.4	559.2	558.3	557.2	562.5	561.5	560.4	559.6	558.8
Millers Creek	566.4	566.0	565.6	565.2	565.0	567.8	567.4	566.9	566.6	566.4
Black Creek	565.9	565.4	564.9	564.4	564.3	567.2	566.8	566.1	565.8	565.7
Little Six Creek	565.0	564.3	563.5	562.8	562.5	566.3	565.5	564.6	564.2	563.9
Slaters Point	564.3	563.5	562.4	561.5	561.0	565.5	564.7	563.5	562.9	562.4
Material Dock	564.0	563.0	561.5	560.4	559.7	565.1	564 2	562.7	562.0	561.3
Gauge 51	562.6	561.5	560.2	559.0	558.0	563.7	562.7	561.5	560.7	559.9

* United States Lake Survey Datum

TABLE D-6

CUMULATIVE FLOW — CREST OF FALLS

Tests 101 to 116 — Without Remedial Works

Station *	Cumulative Discharge in cfs measured in 100-ft. stations							
	Test 101	Test 102	Test 103	Test 104	Test 105	Test 106	Test 107	Test 108
1	620	730	560	470	30	30		
2	1,180	1,350	1,070	880	60	70		
3	2,180	2,400	1,990	1,740	180	237	30	
4	2,980	3,200	2,720	2,300	347	404	70	
5	6,250	6,360	5,670	4,860	817	874	237	
6	13,000	13,290	12,600	11,470	3,667	3,624	2,147	1,200
7	23,600	23,890	23,420	21,520	8,547	8,644	6,767	4,700
8	33,830	34,120	33,070	30,650	14,707	14,204	12,187	9,430
9	42,960	43,250	41,830	39,240	19,177	18,934	16,807	14,310
10	51,910	52,200	50,590	47,830	24,197	24,084	21,827	18,660
11	58,990	59,280	57,340	54,580	27,357	27,134	24,577	21,020
12	66,560	66,850	64,760	61,810	31,467	31,244	29,047	25,750
13	74,620	74,910	71,990	68,890	36,617	36,394	34,197	31,750
14	88,720	89,010	86,090	82,990	46,487	46,444	45,017	43,340
15	91,570	91,960	89,040	85,940	47,907	47,944	46,517	45,070
16	93,140	93,460	90,770	87,760	48,217	48,354	47,077	45,990
17	94,870	95,120	92,340	89,490	48,727	49,023	47,807	46,790
18	95,380	95,590	92,810	90,000	48,757	49,113	47,927	47,050
19	95,590	95,850	93,070	90,310			47,957	47,217
20	95,710	95,950	93,160	90,477				47,307
21	95,800	96,050	93,250	90,567				
22	95,850	96,100	93,300	90,642				
23	95,900	96,150	93,350	90,692				
24	95,950	96,200	93,400	90,742				
25	96,000	96,250	93,450	90,817				

Station *	Test 109	Test 110	Test 111	Test 112	Test 113	Test 114	Test 115	Test 116
1	1,570	1,570	1,500	1,570	120	120	90	30
2	3,140	3,140	3,070	3,140	287	240	120	60
3	5,600	5,500	5,250	5,715	597	500	330	180
4	8,870	8,770	8,300	8,465	1,067	970	740	347
5	13,600	13,390	12,770	13,195	2,567	2,390	1,740	1,207
6	23,250	22,520	22,640	23,245	7,037	6,500	5,590	4,707
7	37,570	36,620	36,300	37,135	14,267	13,730	12,520	10,867
8	51,230	50,510	50,400	51,235	21,837	21,480	20,090	18,097
9	63,850	62,930	62,400	62,235	28,447	28,230	26,400	24,257
10	75.040	73,930	73,220	72,085	35,197	34,980	32,850	30,567
11	84.910	83,230	82,350	81,565	40 217	40,000	37,580	34,817
12	96,300	94,230	93,350	92,385	45,637	45,420	43,140	40,817
13	108,500	105,620	104,740	103,575	51,057	50,980	49,140	46,817
14	126,670	124,320	122,910	122,025	63,257	63,180	61,760	59,867
15	131,690	129,470	127,530	126,755	65,077	65,000	63,670	62,227
16	135,800	133,460	131,640	130,745	65,937	66,000	64,720	63,567
17	139,070	136,410	134,490	133,495	66,857	66,860	65,640	64,907
18	139.800	137,079	135,220	134,495	67,067	67,170	66,000	65,377
19	140.469	137,699	135,889	135,055	67,157	67,260	66,120	65,587
20	140,779	137,959	136,299	135,222			66,150	65,754
21	141,089	138,219	136,609	135,389				65,754
22	141 256	138,339	136,819	135.479				65,784
23	141 423	138.429	136,909	135,529				65,814
24	141.513	138.504	136,984	135,579				65,814
25	141.603	138,594	137,074	135,679				65,844

* For location of 100-ft. stations see Plate D-11

TABLE D-3

WATER SURFACE ELEVATIONS — RIVER GAUGES

Tests 101 to 116 — Without Remedial Works

	Water Surface Elevations in ft USLSD							
River Gauges *	Test 101	Test 102	Test 103	Test 104	Test 105	Test 106	Test 107	Test 108
Buffalo	572.38	572.38	572.38	572.38	571.48	572.32	572.38	572.38
Peace Bridge	568.96	569.02	568.96	569.02	568.24	568.90	568.90	569.08
Black Rock	566.50	565.62	565.62	566.68	565.60	566.20	566.26	566.50
Huntley	565.72	565.84	565.84	565.90	564.76	565.30	565.36	565.66
Hickory	565.24	565.42	565.36	565.48	564.34	564.82	564.94	565.18
Tonawanda	565.06	565.24	565.24	564.30	564.22	564.70	564.76	565.00
Edgewater	564.28	564.52	564.46	564.58	563.44	563.80	563.92	564.22
Upper Cayuga	562.96	563.20	563.26	563.44	561.58	561.94	562.12	562.72
Lower Cayuga	562.66	562.96	562.96	563.26	561.22	561.52	561.76	562.42
Conners Island	562.24	562.54	562.66	562.90	560.50	560.74	561.10	561.82
Grass Island	560.62	561.04	561.22	561.70	558.58	559.00	559.36	560.20
Willow Island	559.12	559.48	559.72	560.14	557.56	557.86	558.22	558.82
Gauge 51	560.02	560.38	560.56	560.92	557.98	558.46	558.82	559.60
Material Dock	561.22	561.64	561.88	562.24	559.60	559.72	560.08	560.80
Slaters Point	562.18	562.48	562.54	562.84	560.62	560.92	561.10	561.88
Little Six Creek	563.38	563.62	563.68	563.86	562.18	562.54	562.72	563.20
Black Creek	564.76	564.94	564.94	565.12	563.74	564.28	564.34	564.64
Millers Creek	565.42	565.60	565.60	565.72	564.46	565.00	565.12	565.36

River Gauges *	Test 109	Test 110	Test 111	Test 112	Test 113	Test 114	Test 115	Test 116
Buffalo	572.38	572.38	574.36	574.42	572.26	572.32	572.32	572.32
Peace Bridge	569.20	569.08	570.82	571.00	569.02	569.02	568.90	569.02
Black Rock	566.98	566.92	568.30	568.42	566.32	566.44	566.38	566.50
Huntley	566.26	566.20	567.40	567.58	565.48	565.60	565.54	565.66
Hickory	565.78	565.78	566.80	566.92	565.00	565.12	565.06	565.18
Tonawanda	565.66	565.60	566.62	566.74	564.82	564.94	564.94	565.06
Edgewater	565.00	565.00	565.84	566.02	563.98	564.16	564.10	564.28
Upper Cayuga	564.04	564.10	564.70	564.94	562.30	562.54	562.60	562.90
Lower Cayuga	563.86	563.86	564.46	564.64	561.94	562.24	562.30	562.60
Conners Island	563.56	563.62	564.10	564.22	561.28	561.69	561.76	562.12
Glass Island	562.12	562.30	562.66	562.96	559.54	559.96	560.20	560.74
Willow Island	560.53	560.68	560.98	561.40	558.34	558.70	553.88	559.30
Gauge 51	561.40	561.52	561.88	562.12	559.00	559.42	559.60	560.14
Material Dock	562.78	562.84	563.38	563.53	560.20	560.62	560.80	561.46
Slaters Point	563.44	563.44	564.04	564.22	561.34	561.64	561.70	562.18
Little Six Creek	564.40	564.34	565.18	565.30	562.84	563.02	563.02	563.38
Black Creek	565.48	565.42	566.50	566.62	564.40	564.58	564.52	564.76
Millers Creek	566.02	565.90	567.22	567.34	565.12	565.30	565.24	565.48

* For location of gauges see Plate D-1

TABLE D-8

DEPTH OF FLOW — CREST OF FALLS

Tests 101 to 116 — Without Remedial Works

Station*	Depth of flow in ft.**							
	Test 101	Test 102	Test 103	Test 104	Test 105	Test 106	Test 107	Test 108
1	0.8	1.1	1.1	1.1	0.4	0.8	0.3	
2	0.7	1.2	1.4	0.8	0.4	0.7	0.4	
3	1.9	1.5	1.9	1.6	0.7	0.7	0.4	
4	0.8	1.1	0.6	0.7	0.6	0.6	0.5	
5	3.0	2.6	2.9	2.5	0.5	0.7	0.3	
6	3.7	3.8	3.9	3.1	1.8	2.1	1.9	1.1
7	6.7	6.7	6.9	6.5	4.4	4.5	4.1	3.1
8	8.0	8.2	8.5	8.6	6.0	5.8	5.3	5.5
9	5.7	6.5	6.7	6.0	4.3	4.9	4.6	4.0
10	7.2	8.1	8.1	7.8	6.0	6.1	6.4	6.4
11	5.3	5.8	5.8	5.7	5.5	3.2	2.6	1.9
12	5.5	5.9	5.9	6.1	4.0	4.3	4.8	5.3
13	4.4	4.9	4.9	4.7	3.6	3.9	3.8	4.1
14	14.1	13.6	14.3	14.3	12.1	12.5	12.7	12.9
15	3.7	3.5	3.6	4.0	2.1	2.4	2.5	2.6
16	3.7	3.3	3.9	4.0	1.2	1.3	2.0	2.3
17	1.0	0.5	0.8	0.5				
18	0.7	1.0	0.9	0.9	0.4	0.3	0.6	0.7
19	1.2	1.2	1.3	1.0		0.3	0.3	0.8
20	1.6	1.6	1.9	1.7				1.4
21	0.3	0.4	0.6	0.7				
22	0.6	0.4	0.4	0.5				
23	0.5	1.2	0.5	0.6				
24	0.4	0.2	0.4	0.4				
25	0.2	0.2	0.1	0.4				

Station*	Test 109	Test 110	Test 111	Test 112	Test 113	Test 114	Test 115	Test 116
1	1.6	1.8	1.9	1.6	0.8	0.8	0.5	0.6
2	2.3	2.1	2.0	2.0	0.8	0.8	0.5	0.6
3	2.6	2.8	2.9	2.6	1.2	1.1	0.5	0.9
4	1.9	2.2	2.2	1.9	0.7	0.4	0.5	0.9
5	3.8	4.0	4.1	4.2	1.5	1.3	1.3	1.0
6	5.6	5.5	5.6	5.4	2.9	2.7	2.7	2.4
7	7.9	7.5	7.5	7.8	5.7	5.2	5.2	4.8
8	9.5	9.0	10.2	10.1	7.8	8.0	8.0	7.5
9	7.6	7.5	7.5	7.4	5.7	5.0	5.5	5.1
10	8.0	7.8	7.9	8.0	6.4	6.2	7.0	6.7
11	6.9	6.4	7.0	7.0	4.8	4.5	4.4	4.3
12	7.8	7.5	7.2	7.1	5.3	4.9	5.2	5.7
13	5.7	5.8	5.4	5.6	4.4	4.1	4.0	4.1
14	15.4	15.3	15.8	15.4	13.1	13.1	13.1	13.4
15	5.0	4.8	5.0	4.9	2.7	2.8	2.6	3.0
16	5.4	5.6	5.5	4.5	2.2	2.2	2.4	3.2
17	1.0	1.3	1.2	0.7				
18	1.1	0.7	1.0	1.8	0.6	0.4	0.4	0.9
19	1.6	1.5	1.6	1.8	0.5	0.7	0.6	1.1
20	2.1	2.0	2.4	1.7	0.9	1.0	1.1	1.5
21	1.1	0.9	1.0	1.2				
22	0.6	0.4	0.4	0.5				0.4
23	0.8	0.7	1.0	0.9				0.5
24	0.9	0.8	0.9	0.6				
25	1.4	1.3	1.5	0.7				0.7

* For location of 100-ft. stations see Plate D-11

** Depth of flow measured 50 ft. upstream of crest at center of 100-ft. station.

TABLE D-5

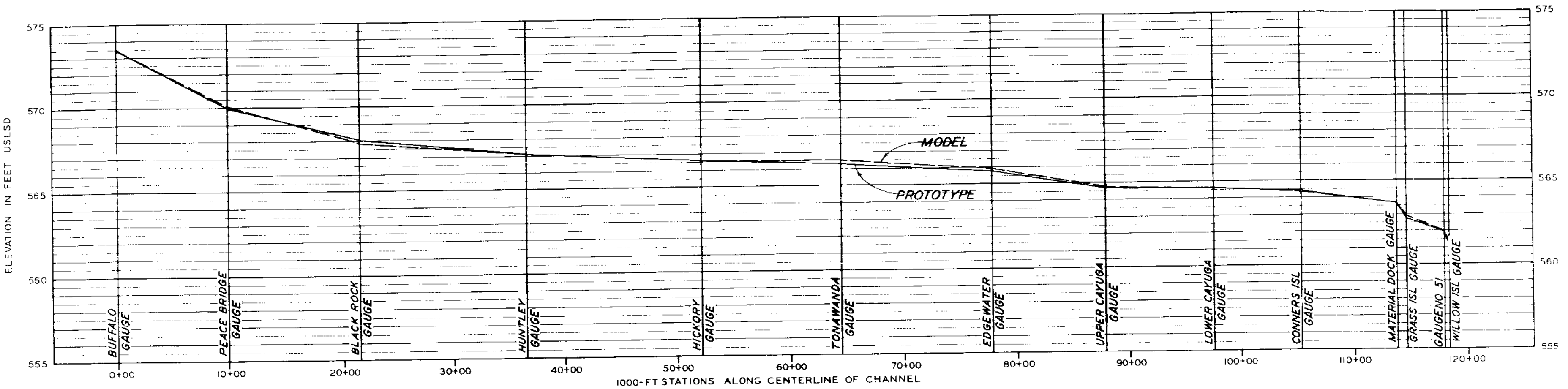
FLOW DISTRIBUTION — CREST OF FALLS

Tests 101 to 116 — Without Remedial Works

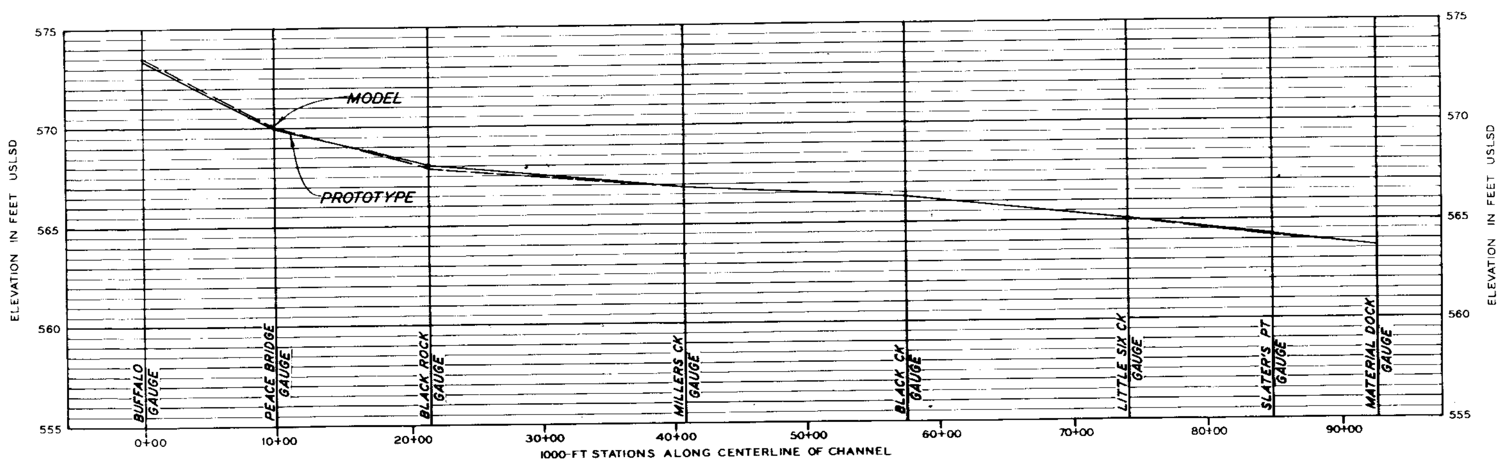
	Discharge in cfs per 100-ft. stations							
Stations *	Test 101	Test 102	Test 103	Test 104	Test 105	Test 106	Test 107	Test 108
1	620	730	560	470	30	30		
2	560	620	510	410	30	40		
3	1,000	1,050	920	860	120	167	30	
4	800	800	730	560	167	167	40	
5	3,270	3,160	2,950	2,560	470	470	167	
6	6,750	6,930	6,930	6,610	2,850	2,750	1,910	1,200
7	10,600	10,600	10,820	10,050	4,880	5,020	4,620	3,500
8	10,230	10,230	9,650	9,130	6,160	5,560	5,420	4,730
9	9,130	9,130	8,760	8,590	4,470	4,730	4,620	4,880
10	8,950	8,950	8,760	8,590	5,020	5,150	5,020	4,350
11	7,080	7,080	6,750	6,750	3,160	3,050	2,750	2,360
12	7,570	7,570	7,420	7,230	4,110	4,110	4,470	4,730
13	8,060	8,060	7,230	7,080	5,150	5,150	5,150	6,000
14	14,100	14,100	14,100	14,100	9,870	10,050	10,820	11,590
15	2,850	2,950	2,950	2,950	1,420	1,500	1,500	1,730
16	1,570	1,500	1,730	1,820	310	410	560	920
17	1,730	1,660	1,570	1,730	510	669	730	800
18	510	470	470	510	30	90	120	260
19	210	260	260	310			30	167
20	120	100	90	167				90
21	90	100	90	90				
22	50	50	50	75				
23	50	50	50	50				
24	50	50	50	50				
25	50	50	50	75				
TOTAL	96,000	96,250	93,450	90,817	48,757	49,113	47,957	47,307

Stations *	Test 109	Test 110	Test 111	Test 112	Test 113	Test 114	Test 115	Test 116
1	1,570	1,570	1,500	1,570	120	120	90	30
2	1,570	1,570	1,570	1,570	167	120	30	30
3	2,460	2,360	2,180	2,575	310	260	210	120
4	3,270	3,270	3,050	2,750	470	470	410	167
5	4,730	4,620	4,470	4,730	1,500	1,420	1,000	860
6	9,650	9,130	9,870	10,050	4,470	4,110	3,850	3,500
7	14,320	14,100	13,660	13,890	7,230	7,230	6,930	6,160
8	13,660	13,890	14,100	14,100	7,570	7,750	7,570	7,230
9	12,620	12,420	12,000	11,000	6,610	6,750	6,310	6,160
10	11,190	11,000	10,820	9,850	6,750	6,750	6,450	6,310
11	9,870	9,300	9,130	9,480	5,020	5,020	4,730	4,250
12	11,390	11,000	11,000	10,820	5,420	5,420	5,560	6,000
13	12,200	11,390	11,390	11,190	5,420	5,560	6,000	6,000
14	18,170	18,700	18,170	18,450	12.200	12,200	12,620	13,050
15	5,020	5,150	4,620	4,730	1,820	1,820	1,910	2,360
16	4,110	3,990	4,110	3,990	860	1,000	1,050	1,340
17	3,270	2,950	2,850	2,750	920	860	920	1,340
18	730	669	730	1,000	210	310	360	470
19	669	620	669	560	90	90	120	210
20	310	260	410	167			30	167
21	310	260	310	167				
22	167	120	210	90				30
23	167	90	90	50				30
24	90	75	75	50				
25	90	90	90	100				30
TOTAL	141,603	138,594	137,074	135,679	67.157	67,260	66,150	65,844

* For location of 100-ft. stations see Plate D-11



AMERICAN CHANNEL



CANADIAN CHANNEL

TEST CONDITIONS

INFLOW

NIAGARA RIVER	223,488 CFS

DIVERSIONS

SCHOELLKOPF	23,351 CFS
ADAMS STREET	8,610 CFS
QUEENSTON	15,258 CFS
TORONTO	13,915 CFS
CANADIAN NIAGARA	9,728 CFS
ONTARIO	10,093 CFS

OUTFLOW

FALLS	142,553 CFS

MODEL VERIFICATION - VARIOUS FLOWS*

CONDITION			WATER SURFACE ELEVATION IN FEET USLSD																			
TOTAL RIVER DISCHARGE IN 1000 CFS	QUEENSTON DIVERSION IN 1000 CFS	U.S. DIVERSION IN 1000 CFS	BUFFALO		BLACK ROCK		HUNTLEY		TONAWANDA		CONNERS ISLAND		GRASS ISLAND		WILLOW ISLAND		SLATERS POINT		MATERIAL DOCK		GAUGE NO. 51	
			PROTOTYPE	MODEL	PROTOTYPE	MODEL	PROTOTYPE	MODEL	PROTOTYPE	MODEL	PROTOTYPE	MODEL	PROTOTYPE	MODEL	PROTOTYPE	MODEL	PROTOTYPE	MODEL	PROTOTYPE	MODEL	PROTOTYPE	MODEL
150	13.8	32.1	569.9	570.3	565.0	565.2	564.3	564.5	563.7	564.2	562.1	562.3	560.6	560.9	559.1	559.5	562.1	562.1	561.4	561.6	559.9	560.0
180	13.8	32.1	571.5	571.7	566.4	566.3	565.6	565.6	564.9	565.1	563.1	563.2	561.6	561.8	559.9	560.0	563.1	563.1	562.4	562.4	560.9	561.0
210	13.8	32.1	572.9	573.0	567.7	567.7	566.8	566.7	566.1	566.1	564.1	564.0	562.5	562.7	560.7	560.8	564.0	563.9	563.3	563.4	561.8	561.9
240	13.8	32.1	574.3	574.2	568.9	568.5	567.9	567.7	567.2	567.0	565.1	564.9	563.4	563.4	561.4	561.5	564.9	564.8	564.2	564.2	562.7	562.7

* PROTOTYPE ELEVATIONS COMPUTED FROM GAUGE RELATION FORMULA.

WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF
NIAGARA RIVER AND FALLS

WATER SURFACE PROFILES

VERIFICATION TEST

TABLE D-7

WATER SURFACE ELEVATIONS — CREST OF FALLS

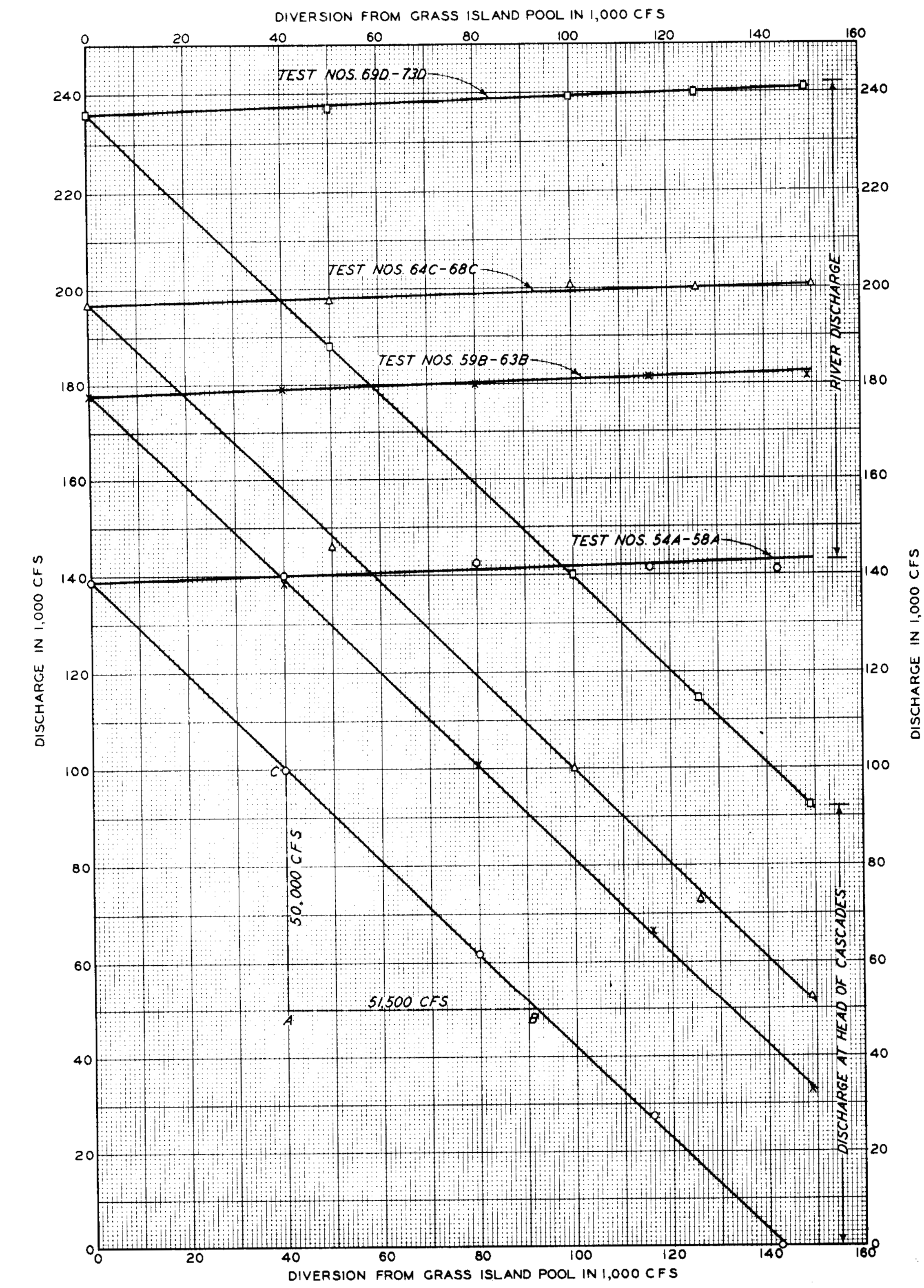
Tests 101 to 116 — Without Remedial Works

	Water surface elevations in ft. USLSD**							
Station*	Test 101	Test 102	Test 103	Test 104	Test 105	Test 106	Test 107	Test 108
1	503.4	503.7	503.7	503.7	503.0	503.4	502.9	
2	503.3	503.8	504.0	503.4	503.0	503.3	503.0	
3	504.0	503.6	504.0	503.7	502.8	502.8	502.5	
4	502.5	502.8	502.3	502.4	502.3	502.3	502.2	
5	505.1	504.7	505.0	504.6	502.6	502.8	502.4	
6	505.0	505.1	505.2	504.4	503.1	503.4	503.2	502.4
7	506.0	506.0	506.2	505.8	503.7	503.8	503.4	502.4
8	504.5	504.7	505.0	505.1	502.5	502.3	501.8	502.0
9	504.2	505.0	505.2	504.5	502.8	503.4	503.1	502.5
10	503.1	504.0	504.0	503.7	501.9	502.0	502.3	502.3
11	506.0	506.5	506.5	506.4	504.2	503.9	503.2	502.6
12	506.7	507.1	507.1	507.3	505.2	505.5	506.0	506.5
13	505.5	506.0	506.0	505.8	504.7	505.0	504.9	505.2
14	508.0	507.5	508.2	508.2	506.0	506.4	506.6	506.8
15	508.2	508.0	508.1	508.5	506.6	506.9	507.0	507.1
16	505.5	505.1	505.7	505.8	503.0	503.1	503.8	504.1
17	504.5	504.0	504.3	504.0				
18	502.8	503.1	503.0	503.0	502.5	502.4	502.7	502.8
19	503.7	503.7	503.8	503.5		502.8	502.8	503.3
20	504.2	504.2	504.5	504.3				504.0
21	505.4	505.5	505.7	505.8				
22	505.7	505.5	505.5	505.6				
23	504.3	505.0	504.3	504.4				
24	504.5	504.3	504.5	504.5				
25	504.8	504.8	504.7	505.0				

Station*	Test 109	Test 110	Test 111	Test 112	Test 113	Test 114	Test 115	Test 116
1	504.2	504.4	504.5	504.2	503.4	503.4	503.1	503.2
2	504.9	504.7	504.6	504.6	503.4	503.4	503.1	503.2
3	504.7	504.9	505.0	504.7	503.3	503.2	502.6	503.0
4	503.6	503.9	503.9	503.6	502.4	502.1	502.2	502.6
5	505.9	506.1	506.2	506.3	503.6	503.4	503.4	503.1
6	506.9	506.8	506.9	506.7	504.2	504.0	504.0	503.7
7	507.2	506.8	506.8	507.1	505.0	504.5	504.5	504.1
8	506.0	505.5	506.7	506.6	504.3	504.5	504.5	504.0
9	506.1	506.0	506.0	505.9	502.3	502.1	502.9	502.6
10	503.9	503.7	503.8	503.9	504.2	503.5	504.0	503.6
11	507.6	507.1	507.7	507.7	505.5	505.2	505.1	505.0
12	509.0	508.7	508.4	508.3	506.5	506.1	506.4	506.9
13	506.8	506.9	506.5	506.7	505.5	505.2	505.1	505.2
14	509.3	509.2	509.7	509.3	507.3	507.0	507.0	507.3
15	509.5	509.3	509.5	509.4	507.2	507.3	507.1	507.5
16	507.2	507.4	507.3	506.3	504.0	504.0	504.2	505.0
17	504.5	504.8	504.7	504.2				
18	503.2	502.8	503.1	503.9	502.7	502.5	502.5	503.0
19	504.1	504.0	504.1	504.3	503.0	503.2	503.1	503.6
20	504.7	504.6	505.0	504.3	503.5	503.6	503.7	504.1
21	506.2	506.0	506.1	506.3				
22	505.7	505.5	505.5	505.6				505.5
23	504.6	504.5	504.8	504.7				504.3
24	505.0	504.9	505.0	504.7				
25	506.0	505.9	506.1	505.3				505.3

* For location of 100-ft. stations see Plate D-11

** Elevations measured 50 ft. upstream of crest at center of 100 ft. stations.

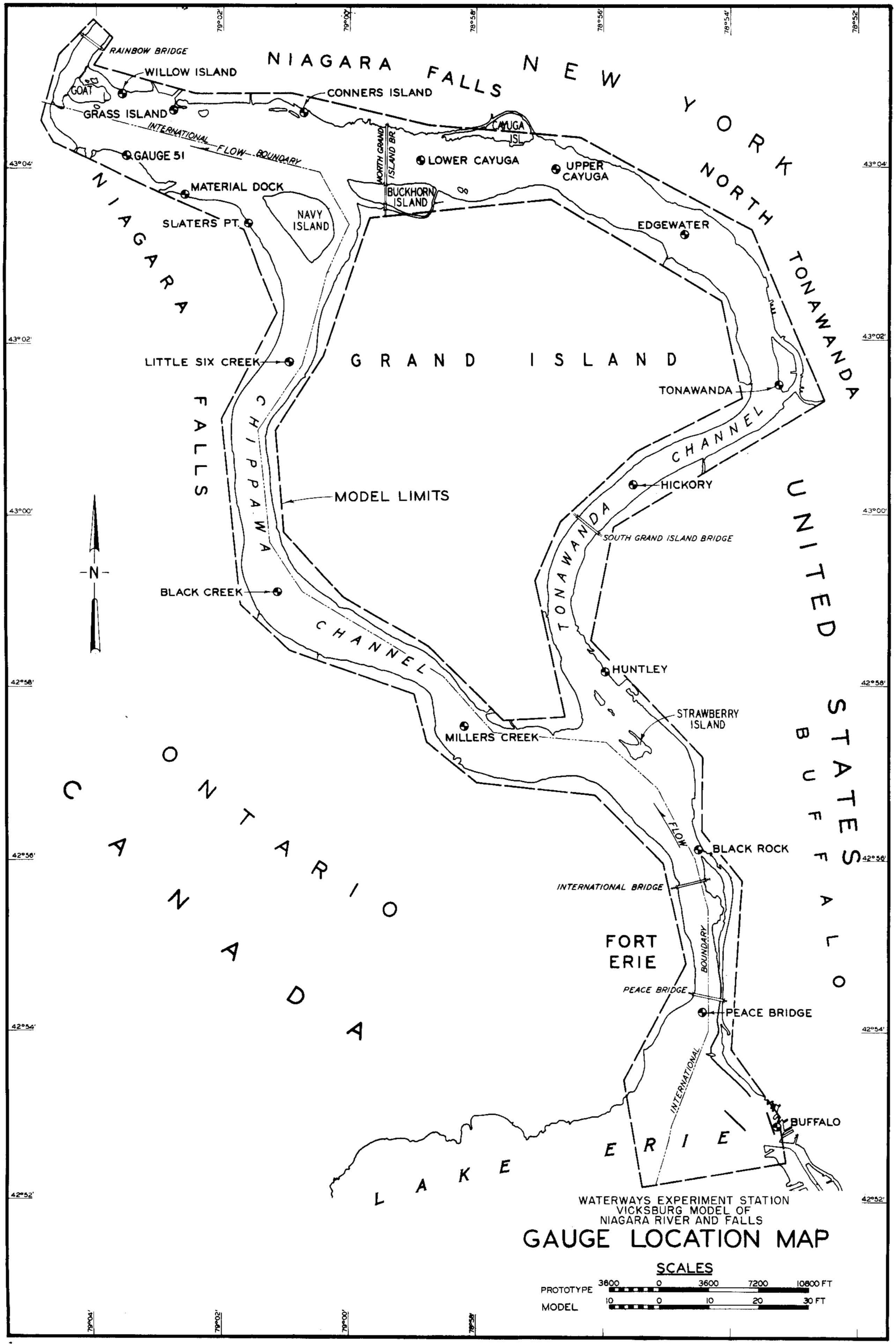


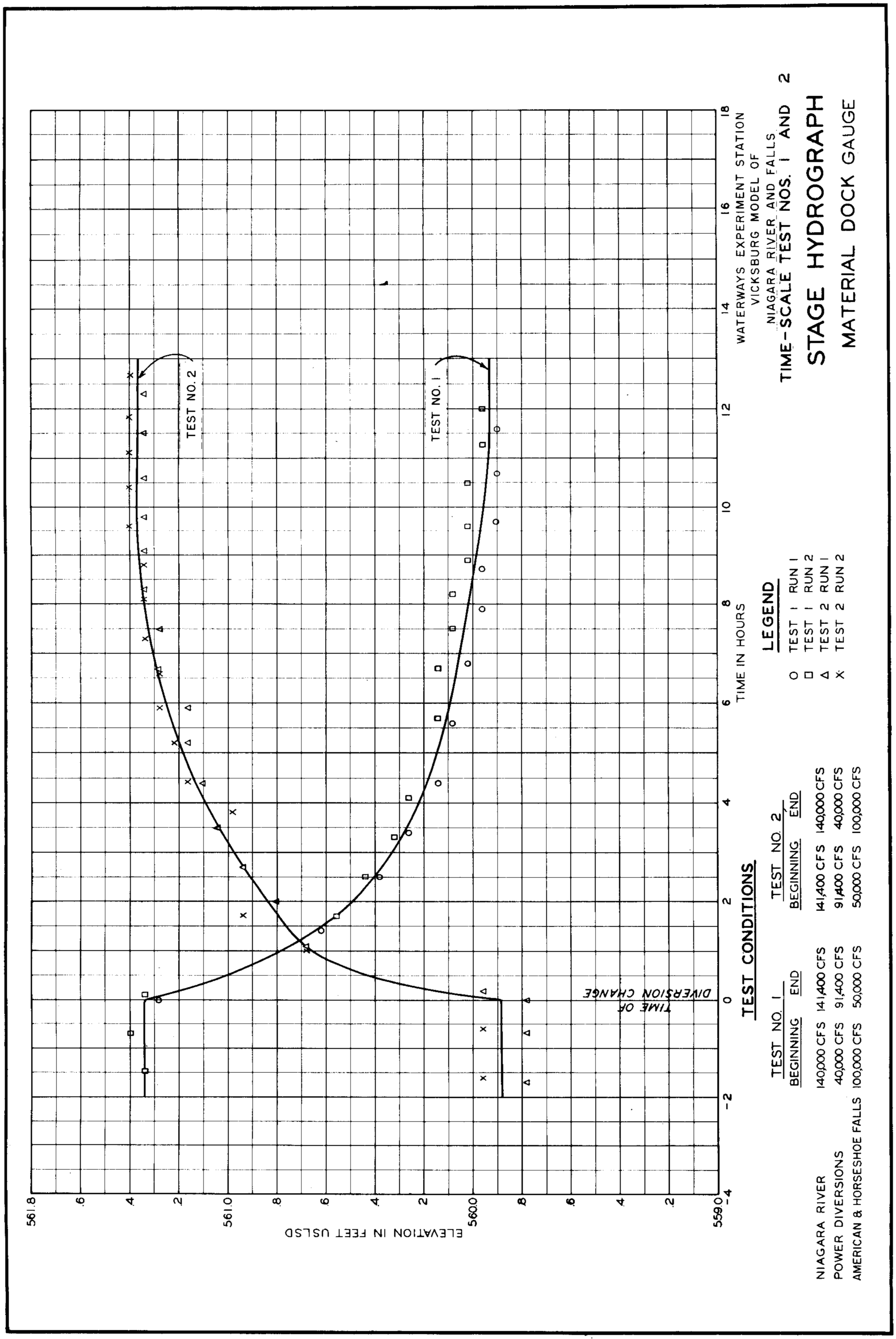
NOTE: ABSCISSA AB SHOWS THE INCREASE IN DIVERSION REQUIRED TO EFFECT A DECREASE IN FALLS DISCHARGE SHOWN BY THE ORDINATE CA. THE DIFFERENCE BETWEEN THE ABSCISSA AND THE ORDINATE IS EQUAL TO THE INCREASE IN TOTAL RIVER FLOW.

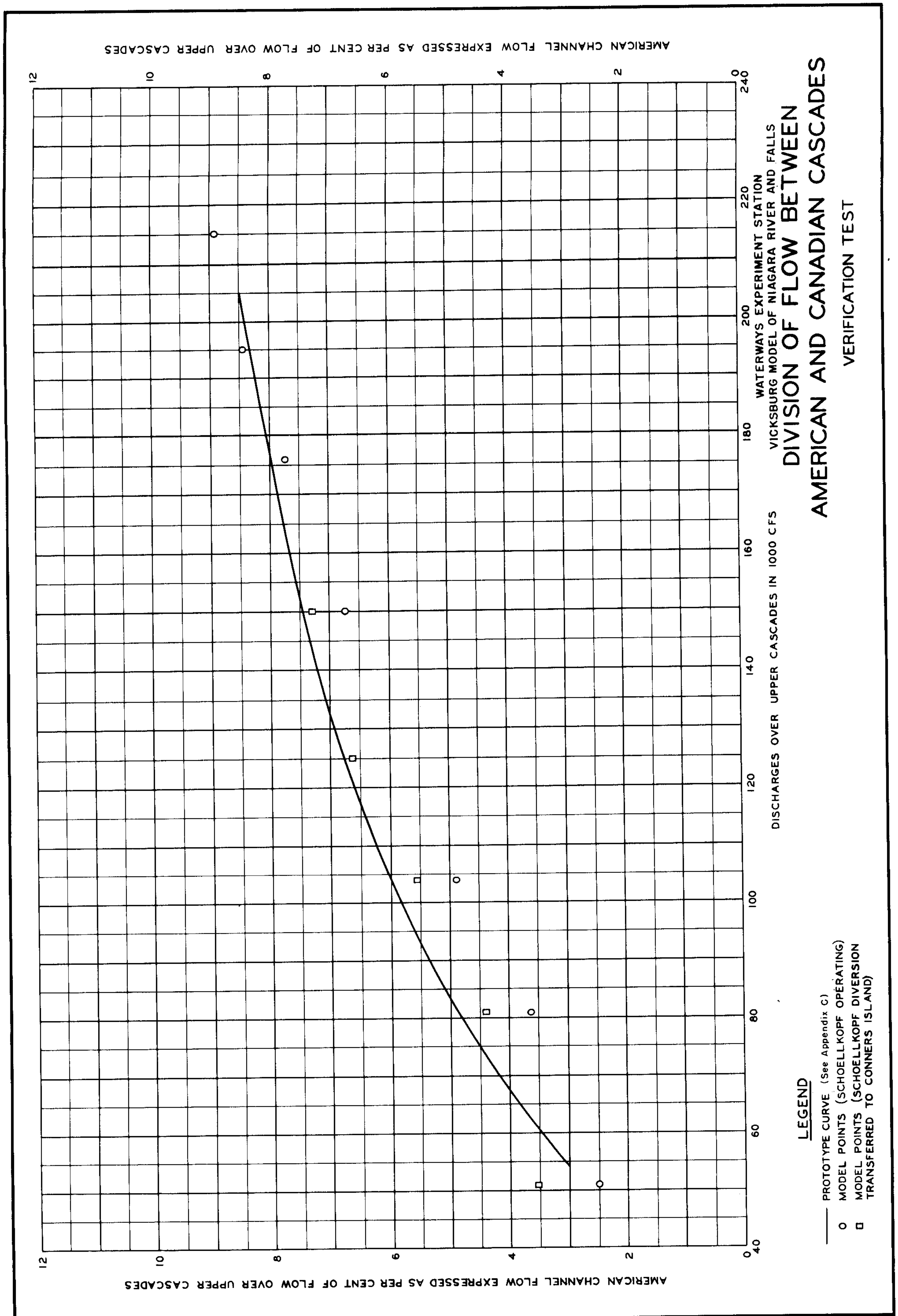
WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF
NIAGARA RIVER AND FALLS

GRASS ISLAND POOL DIVERSION

RIVER AND FALLS DISCHARGE RELATIONSHIP

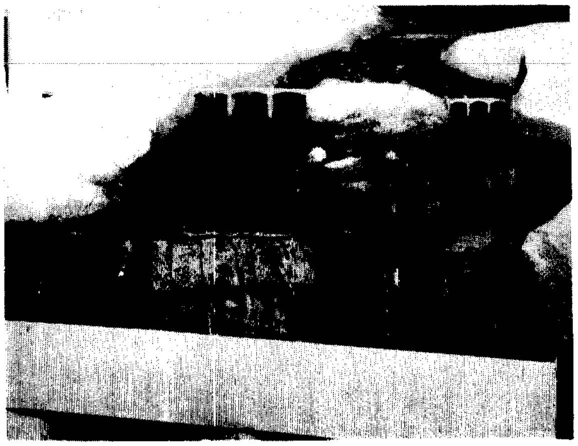

RAINBOW BRIDGE
WILLOW ISLAND
GOAT
GRASS ISLAND
CONNERS ISLAND
NIAGARA FALLS NEW YORK
INTERNATIONAL FLOW BOUNDARY
NORTH GRAND ISLAND BR.
CAYUGA ISL
GAUGE 51
LOWER CAYUGA
UPPER CAYUGA
MATERIAL DOCK
BUCKHORN ISLAND
NAVY ISLAND
SLATERS PT.
EDGEWATER
NORTH TONAWANDA
NIAGARA FALLS
LITTLE SIX CREEK
GRAND ISLAND
TONAWANDA
CHIPPAWA CHANNEL
TONAWANDA CHANNEL
HICKORY
MODEL LIMITS
SOUTH GRAND ISLAND BRIDGE
N
BLACK CREEK
UNITED STATES
HUNTLEY
STRAWBERRY ISLAND
MILLERS CREEK
BUFFALO
ONTARIO
CANADA
FLOW
BLACK ROCK
INTERNATIONAL BRIDGE
FORT ERIE
BOUNDARY
PEACE BRIDGE
PEACE BRIDGE
INTERNATIONAL
BUFFALO
LAKE ERIE
79°04'
79°02'
79°00'
78°58'
78°56'
78°54'
78°52'
43°04'
43°02'
43°00'
42°58'
42°56'
42°54'
42°52'
WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF
NIAGARA RIVER AND FALLS
GAUGE LOCATION MAP
SCALES
PROTOTYPE 3600 0 3600 7200 10800 FT
MODEL 10 0 10 20 30 FT


WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF
NIAGARA RIVER AND FALLS
TIME-SCALE TEST NOS. 1 AND 2
STAGE HYDROGRAPH
MATERIAL DOCK GAUGE
ELEVATION IN FEET USLSD
TIME IN HOURS
TEST NO. 1
TEST NO. 2
TIME OF DIVERSION CHANGE
LEGEND
O TEST 1 RUN 1
□ TEST 1 RUN 2
Δ TEST 2 RUN 1
X TEST 2 RUN 2
TEST CONDITIONS
TEST NO. 1 BEGINNING END
TEST NO. 2 BEGINNING END
NIAGARA RIVER 140,000 CFS 141,400 CFS 141,400 CFS 140,000 CFS
POWER DIVERSIONS 40,000 CFS 91,400 CFS 91,400 CFS 40,000 CFS
AMERICAN & HORSESHOE FALLS 100,000 CFS 50,000 CFS 50,000 CFS 100,000 CFS


WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
DIVISION OF FLOW BETWEEN
AMERICAN AND CANADIAN CASCADES
VERIFICATION TEST
DISCHARGES OVER UPPER CASCADES IN 1000 CFS
AMERICAN CHANNEL FLOW EXPRESSED AS PER CENT OF FLOW OVER UPPER CASCADES
LEGEND
PROTOTYPE CURVE (See Appendix C)
MODEL POINTS (SCHOELLKOPF OPERATING)
MODEL POINTS (SCHOELLKOPF DIVERSION TRANSFERRED TO CONNERS ISLAND)

AMERICAN FALLS

HORSESHOE FALLS



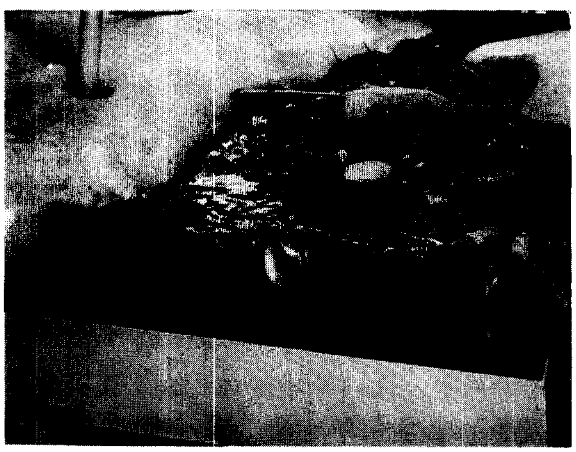
1,100 CFS

48,900 CFS

TEST CONDITION 105

Total River Flow 180,000 CFS

Total Falls Flow 50,000 CFS



2,500 CFS

67,500 CFS

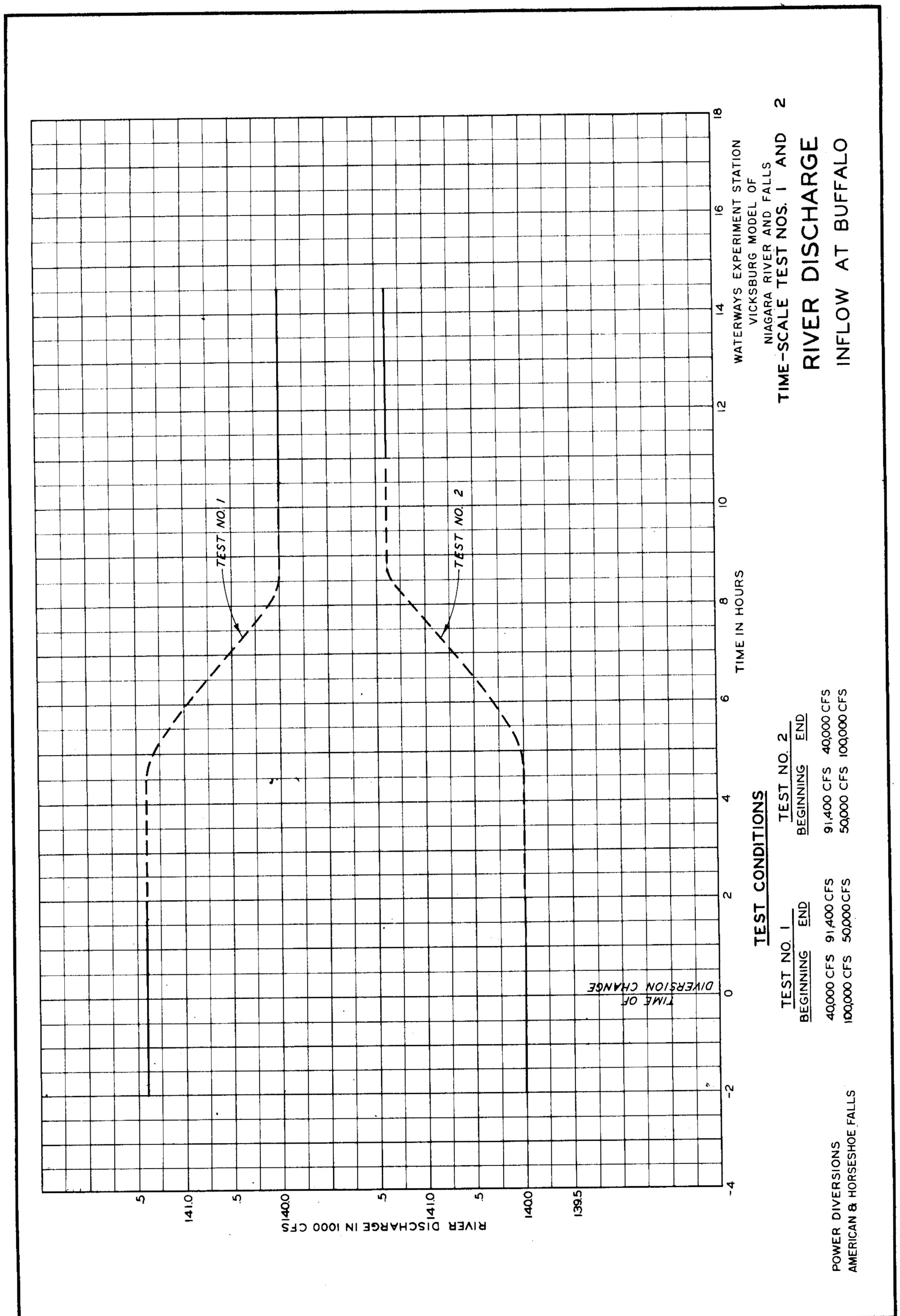
TEST CONDITION 113

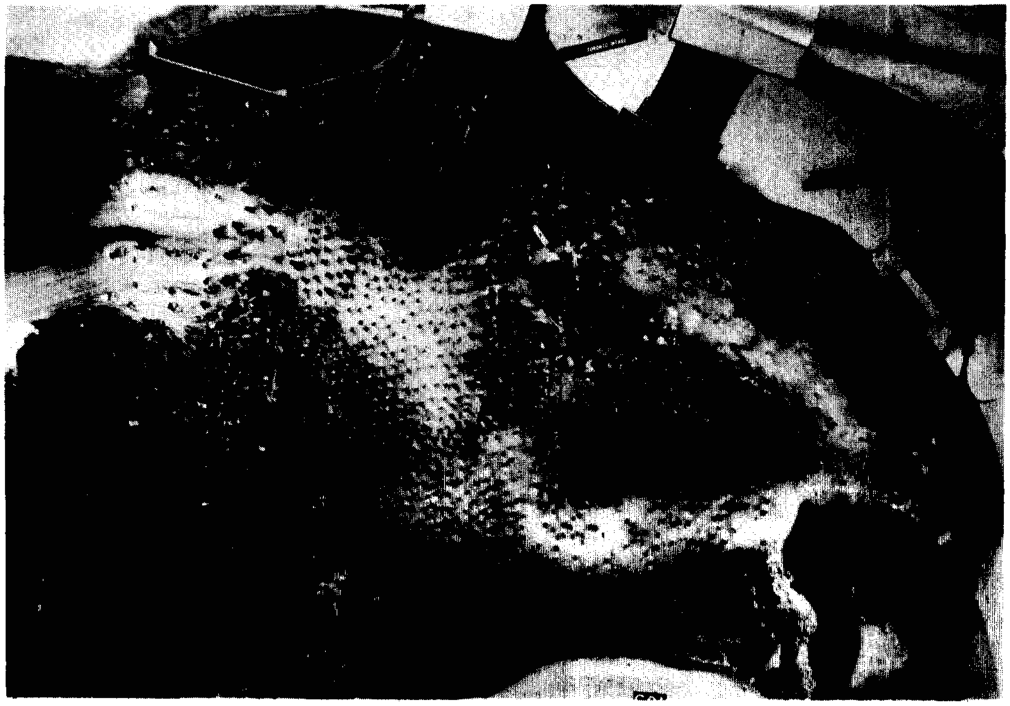
Total River Flow 200,000 CFS

Total Falls Flow 70,000 CFS

PHOTOGRAPHS OF MODEL FALLS WITHOUT REMEDIAL WORKS

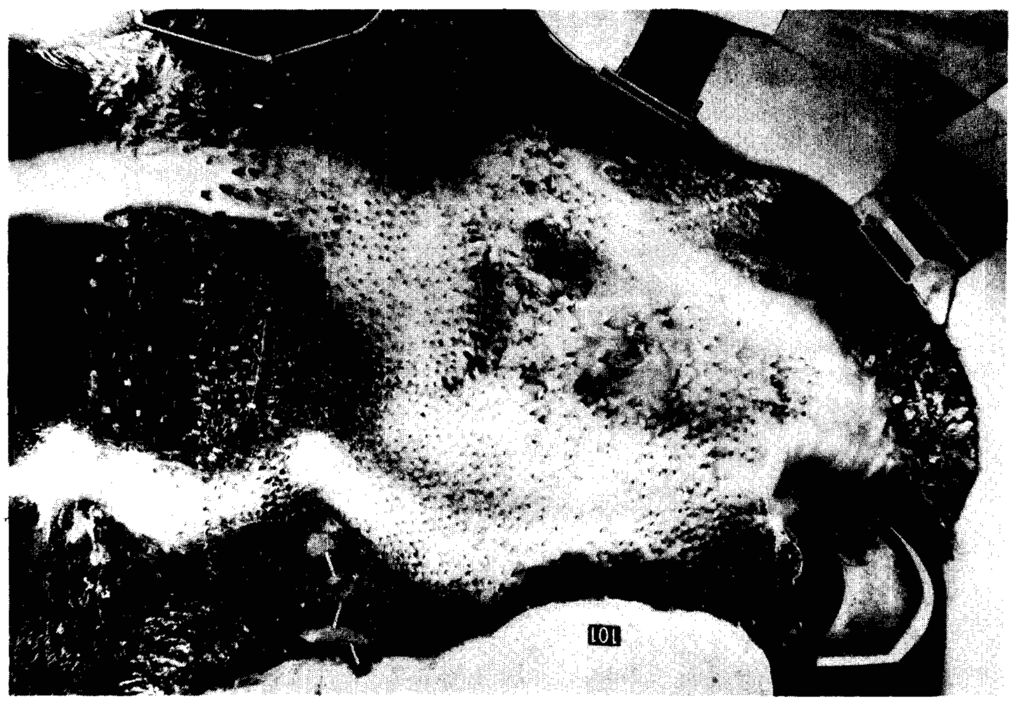
PLATE D-8


WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF
NIAGARA RIVER AND FALLS
TIME-SCALE TEST NOS. 1 AND 2
RIVER DISCHARGE
INFLOW AT BUFFALO
TEST CONDITIONS
TEST NO. 1
BEGINNING END
40,000 CFS 91,400 CFS
100,000 CFS 50,000 CFS
TEST NO. 2
BEGINNING END
91,400 CFS 40,000 CFS
50,000 CFS 100,000 CFS
POWER DIVERSIONS
AMERICAN & HORSESHOE FALLS
TEST NO. 1
TEST NO. 2
TIME OF
DIVERSION CHANGE
TIME IN HOURS
-4
-2
0
2
4
6
8
10
12
14
16
18
RIVER DISCHARGE IN 1000 CFS
.5
141.0
.5
140.0
.5
141.0
.5
140.0
139.5



TEST CONDITION 105

TOTAL RIVER FLOW 180,000 CFS TOTAL FALLS FLOW 50,000 CFS



TEST CONDITION 101

TOTAL RIVER FLOW 200,000 CFS TOTAL FALLS FLOW 100,000 CFS

STREAMLINES IN MODEL CASCADES WITHOUT REMEDIAL WORKS

AMERICAN FALLS

HORSESHOE FALLS

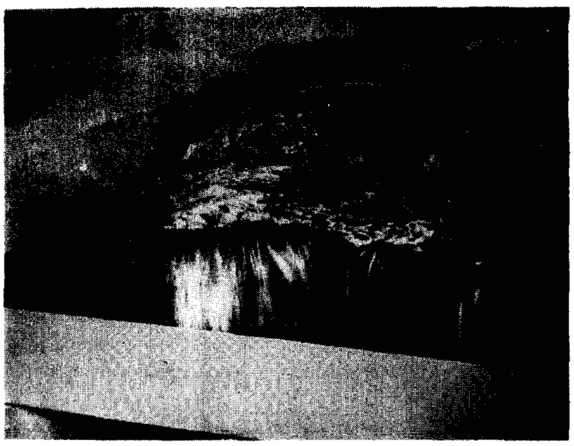
4,900 CFS

95,100 CFS

TEST CONDITION 101

Total River Flow 200,000 CFS

Total Falls Flow 100,000 CFS



10,200 CFS

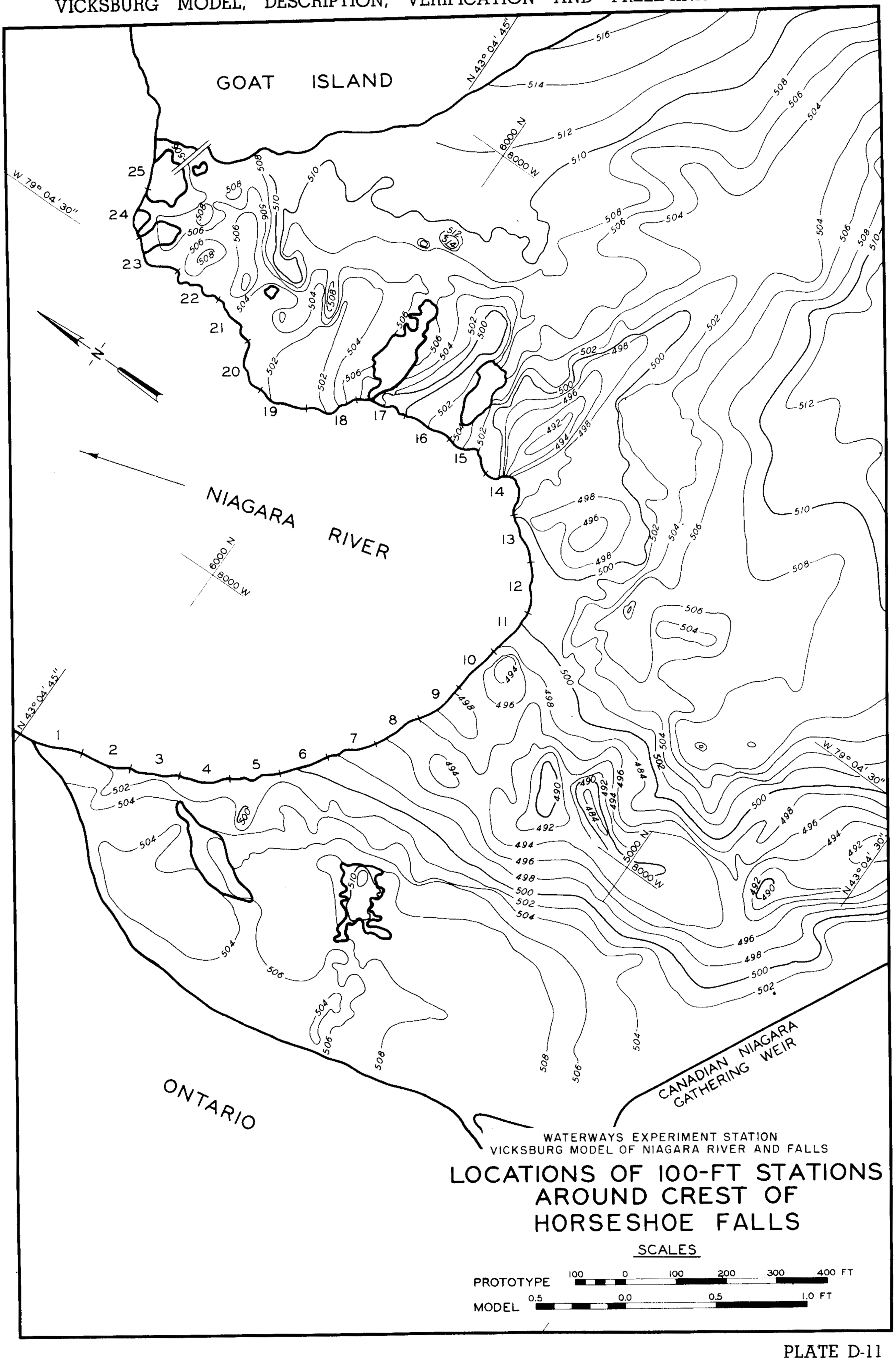
139,800 CFS

TEST CONDITION 109

Total River Flow 200,000 CFS

Total Falls Flow 150,000 CFS

PHOTOGRAPHS OF MODEL FALLS WITHOUT REMEDIAL WORKS



LOCATIONS OF 100-FT STATIONS AROUND CREST OF HORSESHOE FALLS

APPENDIX E

ISLINGTON MODEL

DESCRIPTION, VERIFICATION AND PRELIMINARY TESTS

LIST OF PLATES

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX E

ISLINGTON MODEL

DESCRIPTION, VERIFICATION AND PRELIMINARY TESTS

CONTENTS

LIST OF TABLES

measuring devices. As these three pipes supply respectively the three channels entering Chippawa-Grass Island Pool around Navy and Buckhorn Islands, the distribution of the total flow can be adjusted to that observed in the prototype. The various power plant intakes along the river were precisely located in the model and were generally constructed of plywood. The flow into these intakes is controlled by specially built valves and is measured before being discharged into the sump.

5. The general model topography was produced by erecting plywood templates across the model on two-foot centers with the top of each template accurately cut to match the survey information. A feature of this erection was that despite the size of the model and the large number of templates, a tolerance of one thirty-second of an inch was adhered to rigidly in their positioning. Between the templates, sand was placed to within a few inches of the top. Following this, concrete was added until its surface was flush with the top of the templates. In the Cascades area the templates were spaced more closely due to the more irregular topography. The construction of the Cascades and Falls was a special problem and is described in more detail in a later section. The determination of the roughness necessary for the model river bed was also a special problem, and is described in the sections dealing with the verification of the model.

6. Some statistics of the building and model are as follows:
Building: — 170 feet by 70 feet.
Model: — 96 feet by 37 feet.
Materials in Model: — Sand—550 tons; plywood—9,000 board-feet; concrete—25 cubic yards.
Water System: — Recirculating—30,000 Imperial gallons in sump.
Maximum model flow—about three and one-half cubic feet per second.

Construction of Falls and Gorge Area

7. The gorge area in the model extends from the Horseshoe Falls downstream to the Rainbow Bridge and reproduces both American and Horseshoe Falls. As the gorge is relatively deep, considerable water pressure was expected to act on the upstream side of the gorge wall. It was essential that leakage should not occur through this wall and that the wall should not be displaced by the pressure. This was accomplished by first building a brick wall three courses wide from the model floor to just below the top of the gorge wall. The height varied from seven to ten courses. Waterproofing was placed on the upstream face of this wall and in the joint between the wall and the model floor. The gorge wall, other than the sections immediately below the crest of the Falls, was constructed by fixing metal framework to the brick wall, shaped to the profile of the prototype. Metal lath was then wired to this frame, and plaster and concrete layers successively affixed to the lath. The sections of wall below the Falls crest were constructed similarly except that vertical steel rods were used to stiffen the framework. After the walls had hardened, details such as talus slopes, fallen rock, the Canadian Niagara tunnel outlet, and the Ontario Power Company plant were added. In order to bring the Cascades bed correctly to the Falls crest, a male plywood template was cut to reproduce accurately the Falls crestline in plan. To the edge of this template a sheet metal strip was fastened and cut to the profile of the crest in the vertical plane This assembly was then positioned at the correct elevation in the gorge to bring the crestline into its correct location. The concrete bed was then faired into this. In order to separate the Horseshoe Falls flow from the American Falls flow, a waterproofed brick wall was laid on the model floor from Goat Island to the weir tanks under the Rainbow Bridge.

Special Cascades Construction

8. Initially the Cascades area was constructed as described in paragraph 5. However, as the remedial works tests progressed it became desirable to be able to remove the original topography in certain areas and replace it by various remedial schemes involving excavation. It was also desirable to be able to replace any such scheme by the original topography or by some other

scheme, quickly, and at will. This was accomplished by replacing the original Cascades bed by a cellular type of construction in the areas in which the remedial schemes were found necessary. In two areas, above the Canadian flank and the Goat Island flank, a horizontal concrete "table" was built with its top at an elevation below the deepest excavation scheme, and carefully levelled. Rectangular sheet metal cells 6 x 12 inches were then placed on this table and their top edges cut to the topography level, thus becoming templates. These were then filled with concrete and the top surface of the concrete moulded in conformity with the topography. Any of these cells could then be removed and replaced by others incorporating remedial excavation schemes. Each cell was numbered and any of those incorporating excavation schemes were so labelled. Thus schemes could be filed for future reference and any scheme or the original topography could be replaced expeditiously. In Plate E-3 are shown views of this construction in progress on the Goat Island flank and the Canadian flank respectively.

Observing and Measuring Devices

9. General. Some special equipment was devised for observing the actions of the model and for measuring the water levels. An electrically driven gantry crane spanning the model and travelling the length of the building was designed and built to enable observers to work over the model at any point. For this purpose the gantry is equipped with special platforms which are adjustable in height. To enable materials to be brought into the model and heavy equipment to be moved, the gantry is equipped with a one-ton hoist. By this hoist, flow measuring weir tanks which hang in the sumps may be moved to any desired point. A general view of the crane may be seen in plate E-2.

10. Elevations. To measure water levels, a point gauge is used which runs on a truss especially designed for stiffness. The truss is supported by rails on the model walls and can travel the length of the model. This movable point gauge is also used for setting templates and for determining topography elevations. Piezometer openings were also built into the model bed at the river gauge locations, and rubber tubes connect these openings to manometers outside the model. This latter system of level measurement is used only for quick observation when setting up the model and not for accurate measurement.

11. Flow. The measurement of inflow into the model is accomplished by means of gravimetrically calibrated orifice meters in the three model supply pipes. The orifice differential head was read on direct reading water manometers calibrated to indicate directly in prototype flow units. The outflow from the power plant intakes is measured in most cases by six-inch calibrated Van Leer or pipe weirs. The Horseshoe and American Falls flows are measured separately in calibrated V-notch weir tanks. In the course of the tests it was found desirable to measure the flow over each 100-foot band of the Horseshoe Falls crest. This is accomplished by the use of a specially constructed scoop which intercepts the flow in a 100-foot band and directs it to one of the calibrated V-notch weir tanks for measurement.

Observed Division of Flow around Buckhorn and Navy Islands

12. Since the model at Islington begins at the confluence of the channels between the Canadian mainland and Navy Island, Navy Island and Buckhorn Island, and Buckhorn Island and the American mainland, the division of flow among these channels must be known accurately for correct operation of the model. In view of this, field measurements of the distribution of flow among these islands was required. Two such measurements were made shortly before the operation of the model and are tabulated in paragraph 13 below. These, in conjunction with earlier measurements, also shown in the tabulation, indicate that the percentage through each channel is relatively constant at all stages, and has varied little, if any, with time.

13. Results of Measurements

Observer	Canadian Mainland to Navy Is. Flow	%	Navy Island to Buckhorn Is. Flow	%	Buckhorn Is. to American Mainland Flow	%	Total Flow
	Flow in cfs and Percentage of Total						
E. Roberts H.E.P.C. of Ont. April 25, 1951	85,150	38.1	43,500	19.5	No measurement		223,400
E. Roberts H.E.P.C. of Ont. Oct. 16, 1950	72,850	38.0	———	——	No measurement		191,500
	———	——	36,700	19.0			
W.S. Richmond U.S. Asst. Eng. July 31 to Aug. 12, 1913	(Two channels combined) * 118,200 to 130,400			57.3	87,400 to 95,200	* 42.2	208,000 to 226,000

Notes — *Denotes average of 10 readings

14. Percentages Adopted for Model Tests. As a result of the above measurements, the following percentages of the total flow were adopted for the channels in the model:

(a) Canadian Mainland to Navy Island 38.0%

(b) Navy Island to Buckhorn Island 19.0%

(c) Buckhorn Island to American Mainland 43.0%

VERIFICATION OF ISLINGTON MODEL

Function of Verification and Procedure Followed

15. Before reliance can be placed on predictions of future conditions by a model, it is essential that the model faithfully reproduce known conditions of the past over as large a range as possible. In the case of the Niagara model, verification divides naturally into two separate operations. Firstly, the relatively low velocity river section upstream from the Cascades was verified, this section being required first for tests on the intake for the new Sir Adam Beck-Niagara Generating Station No. 2 development. Verification of this section included also the distribution of flow around Goat Island. Secondly, an initial verification of the high velocity Cascades and Falls section was attempted, using the limited prototype data available at that time. As this verification proceeded, it became evident that more reliable water level and bed level information was essential if the necessary similarity between model and prototype was to be achieved. A more accurate mapping of the Cascades area followed, resulting in a new bed contour map and a new comprehensive water surface contour map. Utilizing this new information, a final verification of the Cascades area was effected, which was considered to be satisfactory.

Verification of River Section above Cascades

16. Verification of this section of the model involved principally the correct reproduction by the model of known river gauge elevations for various total river flows and power diversions. Plates E-4 and E-5 show the location of the river gauges. Prior to construction of the model, a laboratory study had indicated that the required order of roughness would be reproduced if a

diamond-shaped pattern were rolled into the river bed concrete, and expanded metal screening laid on top of the bed. This finding was substantiated when the model was operated, and little further roughness adjustment in this section was found to be necessary. The first verification operation was to check the known water levels in the river without the submerged weir in place, computed as indicated in Appendix C, Table C-1. When the model was adjusted to give these levels correctly, the submerged weir was added, and the levels given in Table C-4, Appendix C were checked. In tabular form, the comparison of prototype and model river gauge levels for four total river flows is given in Table E-1. It is considered that this agreement is satisfactory.

Verification of Division of Flow around Goat Island

17. In Appendix C is described the method used in determining the prototype division of flow around Goat Island. The results of this study are plotted in Plate E-6, and points showing the corresponding model division of flow are also plotted. It is considered that this plotting indicates a satisfactory agreement between the model and prototype values.

Preliminary Verification of Cascades

18. The verification of the Cascades area posed many difficult problems. The 5:1 ratio between the vertical and horizontal model scales produced a steep slope in the Cascades, inducing high velocities in this region. To produce the correct model velocities and levels, it was found necessary to employ exaggerated roughness in the form of sheet metal strips one-half inch wide, embedded in the concrete bed, and extending to the water surface. Reliable records and observations of water levels, depths, velocities and flow distributions are very meagre and difficult to supplement, due primarily to the high velocities and violent wave action in the prototype, and the wide expanse and inaccessibility of the Cascades region. However, as certain information did exist, a preliminary verification was attempted. The information used was as follows:

(a) Water levels in Cascades power plant intakes.

(b) A shoreline water surface profile, Appendix F.

(c) Water surface contours produced by aerial photography.

(d) Flow patterns revealed by aerial photographs during ice runs.

(e) Bed contours developed by a previous float survey, 1928 report.

(f) Preliminary bed soundings obtained by helicopter survey.

This preliminary verification produced a model performance which appeared to be in general similar to the prototype, but quantitatively indeterminate due to lack of prototype data. A comparison with the Vicksburg model results revealed obvious dissimilarities in performance between the two models. An analysis of the differences indicated that they were largely due to different interpretations of the meagre data available. There appeared to be evidence also that the high velocity flow had an adverse effect on the method of obtaining water levels from aerial photography, and the levels in certain areas at least were known to be erroneous. In addition, many of the new bed soundings disagreed with those obtained in earlier surveys. It was concluded that more reliable prototype data were essential if a satisfactory verification was to be produced. By methods described in Appendix B comprehensive bed contour and water surface contour maps were produced which were considered to be adequate for a successful verification.

Final Cascades Verification

19. In Appendix F of this report is described the final verification of the Cascades area in both the Islington and Vicksburg models. Test data indicating their similarity with each other and with the prototype are given in detail.

PRELIMINARY TEST PROGRAMME

SCOPE OF PRELIMINARY TESTS

20. Following verification of the upper portion of the model and before commencing the remedial works investigation, tests were carried out to determine the best location for the intakes for the new Sir Adam Beck-Niagara Generating Station No. 2. These tests developed the best type of intake and the necessary river dredging. This determination was considered a necessary preliminary to the remedial works test, as the intake location and river dredging would alter the future flow distribution in the river. A location for the Lewiston-Conners Island intake on the United States shore was made by the Corps of Engineers, and both new intakes were located in the model.

21. An initial testing programme was next agreed upon which covered the full range of river flow and future power diversions. This programme was designed to provide full information as to river conditions under future power diversions with no remedial works constructed. While the Cascades area was not yet finally verified, this testing programme was carried out and the performance of the Chippawa-Grass Island Pool determined under future diversion conditions.

22. Following the final Cascades verification, a revised testing programme was adopted to provide similar information in the Cascades and Falls area. Upon completion of this series of tests, sufficient information existed on future river conditions without remedial works, and the remedial requirements could be assessed.

Tests to Determine the Location of the New Intakes for Sir Adam Beck-Niagara G.S. No. 2

23. Various locations for the intakes of the new Sir Adam Beck-Niagara Generating Station No. 2 were tested and that shown in Plate E-7, was finally selected as being the most suitable. Two submerged tubes, each 500 feet long, were decided upon, and the river excavation shown on the drawing was found to be adequate.

Grass Island Pool Tests

TEST PROGRAMME

24. An initial Testing Programme, flows 140,000 to 240,000 cfs and combinations of diversion, was approved on May 11th, 1951 with the provision that the 180,000 cubic feet per second series, tests 9 to 23 inclusive would be run first and the results reviewed before deciding whether the complete programme should be carried through. The flow and diversion details for these tests are given in Table E-2. On July 25 and 26, 1951, it was decided that tests 21 to 23 inclusive would be eliminated in the 180,000 cubic feet per second series of initial tests.

TEST DATA REQUIRED FROM INITIAL TESTS

25. The following test data were required for each of the test runs:

i. Gauge heights at all gauges.

ii. Flow distribution around Goat Island.

iii. Photographs to show streamlines from the foot of Grand Island to head of Cascades, with streamlines in Cascades to be determined where necessary.

iv. Photographs of the Falls and Cascades at established vantage points.

v. Water surface elevations at about 100-foot intervals along crest of Falls.

vi. Discharge through each 100-foot panel along crest of Falls.

Test Observations

26. While all the test data listed in (b) were obtained during these tests, only those relating to the Chippawa-Grass Island Pool area are given below, as the later final verification of the Cascades altered the performance in that region. The observations made were:

i. River gauge levels observed during the tests, Table E-3.

ii. The distribution of flow around Goat Island and the Horseshoe Falls flow, Table E-3.

iii. Photographs of streamlines from Grand Island to the head of Cascades. These were obtained by means of lighted candles placed on wooden floats which were equally spaced at the upstream end of the model, released simultaneously, and allowed to float through the model. Two pictures are shown on Plates E-16 and E-17 for Tests No. 9 and 15 only, one with the camera shutter open continuously and one with the shutter alternately open for fifteen seconds and closed for five seconds. The latter picture enables the relative velocity of the floats to be observed.

iv. In addition to the above, it was observed that under maximum diversions, relatively large areas of the Pool bed now normally covered appeared above the surface. These areas, visible in Plate E-16, were noted particularly upstream from Goat Island and in the region lying off the United States shoreline.

Test Results

27. From the river gauge readings taken during the tests, the Pool level at the various gauges is plotted in relation to discharge over the Upper Cascades and shown in Plates E-8 to E-15 inclusive. This plot indicates the Pool levels to be expected for the various diversions from the Pool. In Plate E-6, the flow in the American Channel around Goat Island is plotted in relation to the Upper Cascades flow for the various tests.

Analysis of Tests Results

28. A study of the plot of the gauge levels in relation to discharge over the Upper Cascades revealed three features. These are:

(1) The gauge levels depend primarily on the amount of the flow over the Upper Cascades, therefore, for any given river flow, on the amount of flow diversion from the Pool. The point of diversion is of secondary importance.

(2) Under the maximum diversions scheduled for the future, the Pool level will drop, at Gauge No. 5 for example, approximately four feet below the normal level now existing. The level at the upper gauges will drop somewhat less than this amount, and at the lower gauges somewhat more.

(3) Under maximum diversions, the flow over the American Falls would drop to between 1,000 cfs and 2,000 cfs.

Conclusions Drawn from Test Results

29. These findings suggested that in a future testing programme, the test runs might be condensed to cover only the varying amounts of flow diversion, and thus eliminate tests where only the points of diversion vary. Also the magnitude of the drop in Pool level suggests that consideration should be given to studying remedial works which would compensate for these added diversions and enable existing Pool levels to be maintained. Such works appeared desirable from a scenic standpoint in view of the large Pool bed areas exposed under maximum diversion conditions, and the low flow over the American Falls, which would produce a totally inadequate spectacle.

Cascades and Falls Tests

TEST PROGRAMME

30. At a meeting of the Working Committee on January 31, 1952, at Buffalo, it was decided that, in the light of the Chippawa-Grass Island Pool tests findings, a revised initial testing programme of 16 base tests would be sufficient to cover all conditions in the Cascades and Falls. The detailed flows and diversions in these 16 tests are given in Table E-4. The data to be collected in these tests are as follows:

(1) Depth and discharge for each 100-foot crest panel, the panels being located as shown on Plate E-21.

(2) Levels at all gauges in Cascades area.

(3) Four photographs as follows:

American Falls from Canadian bank

Horseshoe Falls from Canadian bank

Vertical of Cascades area

Vertical of Cascades area showing streamlines by floating material (50,000 cfs and 100,000 cfs over Falls only).

At a later meeting at Vicksburg, April 3, 1952, it was agreed that the photographic stations should be those designated PO, PN, and VPL, Plate E-4. Also following verification of the Cascades, new Cascades verification stations were chosen, their locations being shown on Plate F-18, Appendix F.

TEST RESULTS

31. The results of these tests are given in tabular form in Tables E-5 to E-10 inclusive. Levels observed were also plotted in relation to Cascades flow on Plates E-8 to E-15 inclusive. Although a complete set of photographs was obtained, only those showing the Falls for Tests Nos. 101, 105, 112 and 113, and the Cascades for Nos. 101 and 105, Plates E-18, E-19, and E-20, are included in this report.

ANALYSIS OF TEST RESULTS

32. A study of the test results indicated that for all tests with 50,000 cfs or 70,000 cfs over the Falls, the flow over each flank had either stopped completely or was entirely inadequate as a spectacle. With 100,000 cfs over the Falls, the Goat Island flank was largely dry, while the Canadian flank carried an appreciable though not impressive flow. Only in the tests with 150,000 cfs over the Falls, did the flow appear satisfactory from a scenic standpoint. Levels at upper river gauging stations agreed with previous points and produced well defined levels for these gauges under future flow conditions.

CONCLUSIONS FROM CASCADES AND FALLS TESTS

33. It was concluded from the results of these tests that Horseshoe Falls remedial works would be required which would give sufficient flank flows at 100,000 cfs over the Falls and adequate coverage at 50,000 cfs.

RESULTS AND CONCLUSIONS FROM PRELIMINARY TESTS

34. These two series of preliminary tests, incorporating the increased diversions permitted by the 1950 Treaty, indicated that the following conditions would occur if no remedial works were constructed:

(a) Under maximum future diversions, the Chippawa-Grass Island Pool level would drop by as much as four feet below its present normal level, thereby exposing considerable areas of the river bed presently covered, particularly upstream from the head of Goat Island and in the vicinity of the Three Sisters Islands.

(b) Because of the lowering of the Pool level, under maximum diversions the flow over the American Falls would drop to about 2,500 cfs with a total Falls flow of 50,000 cfs, and to slightly below 5,000 cfs with a total Falls flow of 100,000 cfs, under average river flows. Still lower flows over the American Falls would occur when the river flow would fall below the average.

(c) With a total Falls' flow of 50,000 cfs, both flanks of the Horseshoe Falls would be dry. With a total Falls' flow of 100,000 cfs, the Goat Island flank would still be dry, while the Canadian flank would be only inadequately supplied.

From these test results, it was concluded that in both the tourist and non-tourist seasons the American Falls flow would be below that necessary for a satisfactory spectacle, and the flanks of the Horseshoe Falls would either be dry or inadequately supplied. In the Chippawa-Grass Island Pool area, the reduced Pool level would impair the scenic spectacle, adversely affect power generation capacity, reduce the level of Lake Erie, and probably reduce the ability to pass ice during ice runs. It is considered, therefore, that these tests results give quantitative evidence of the need for remedial works if the terms of the 1950 Treaty are to be fulfilled. The tests and investigations carried out on the Islington model leading to the design of such remedial works are described in detail in Appendix H.

TABLE E-1

CHIPPAWA-GRASS ISLAND POOL VERIFICATION

Comparison of Model and Prototype Water Surface Elevations for Selected Flows

River Gauge (See Plate E-4)	Water Surface Elevations U.S.L.S. Datum — Total River Flow cfs 140,000		180,000		200,000		250,000	
	Model	Proto.	Model	Proto.	Model	Proto.	Model	Proto.
Slaters Pt.	561.35	561.41	562.70	562.83	563.45	563.50	564.70	565.11
#5 (Material Dock)	560.70	560.71	562.00	562.13	562.70	562.82	564.00	564.43
#3	560.10	560.02	561.50	561.47	562.00	562.18	563.55	563.82
#51	559.70	559.33	560.85	560.65	561.50	561.29	562.70	562.79
#45	556.50	556.48	557.60	557.46	558.10	557.93	559.30	559.03
Ontario Power "B"	555.35	555.53	556.65	556.63	557.20	557.17	558.35	558.40
Conners Island	561.55	561.62	562.90	563.05	563.60	563.73	564.85	565.33
Grass Island	560.25	560.11	561.45	561.41	562.20	562.02	563.45	563.48
Willow Island	558.70	558.58	559.90	559.78	560.50	560.34	561.35	561.68
Wing Dam	556.90	556.45	557.80	557.50	558.30	558.00	559.15	560.05

NOTE: 1. Prototype water levels based on Table C-4 (Appendix C).

2. Power Diversions used in Verification Tests.

United States	31,450 cfs
Sir Adam Beck No. 1	14,700 cfs
Ontario Power	10,450 cfs
Toronto Power	14,900 cfs
Canadian Niagara Power	10,000 cfs

TABLE E-2

INITIAL TESTING PROGRAMME (CONDENSED)

Test Conditions for Total River Flow of 180,000 cfs

Discharges in Thousands of cfs

Test No.	Total Falls	Upper Cascades	Schoell-kopf	Adams	Conners Island	Sir Adam Beck No. 1	Sir Adam Beck No. 2 #1 Intake	Sir Adam Beck No. 2 #2 Intake	Ontario Power	Toronto Power	Canadian Niagara Power
9	50	59	20	0	45	16	20	20	9	0	0
10	50	79	20	0	45	16	20	0	10	9	10
11	50	61	24	9	30	16	20	20	10	0	1
12	50	81	24	9	30	16	20	0	10	11	10
13	56	91	24	9	0	16	20	20	10	15	10
14	76	111	24	9	0	16	20	0	10	15	10
15	96	131	24	9	0	16	0	0	10	15	10
16	100	100	20	0	20	10	15	15	0	0	0
17	100	104	20	0	20	16	20	0	4	0	0
18	100	100	24	9	0	13	17	17	0	0	0
19	100	111	24	9	0	16	20	0	10	0	1
20	100	131	24	9	0	16	0	0	10	11	10
21	150	150	15	0	0	5	5	5	0	0	0
22	150	150	15	0	0	7	8	0	0	0	0
23	150	150	15	0	0	15	0	0	0	0	0

TABLE E-3

INITIAL TESTING PROGRAMME

OBSERVED WATER SURFACE ELEVATIONS AND FALLS FLOWS

Gauge	9	10	11	12	13	14	15	16	17	18	19	20
					Observed Water Surface Elevations							
Slaters Point	560.50	560.95	560.80	561.20	561.95	562.20	562.60	561.85	561.85	562.00	562.25	562.65
Gauge No. 5	559.40	560.05	559.60	560.25	560.80	561.30	561.85	561.00	561.00	561.10	561.40	561.95
Gauge No. 3	558.65	559.55	558.75	559.65	560.10	560.80	561.50	560.45	560.55	560.45	560.80	561.50
Gauge No. 51	558.35	559.05	558.50	559.10	559.70	560.10	560.85	560.00	560.00	560.00	560.10	560.80
Gauge No. 45	555.40	556.20	555.50	556.40	556.85	557.45	558.00	557.50	557.35	557.55	557.00	558.00
Ontario Power "B"	554.60	555.30	554.80	555.55	555.85	556.40	557.20	556.95	556.65	556.85	556.10	556.85
Conners Island	560.65	561.10	561.00	561.40	562.10	562.40	563.00	562.00	562.00	562.25	562.40	562.80
Grass Island	558.80	559.60	558.75	559.65	560.10	560.70	561.90	560.50	560.55	560.35	560.75	561.40
Willow Island	557.35	558.20	557.30	558.20	558.65	559.30	559.90	559.10	559.15	558.90	559.25	560.00
Wing Dam	556.35	556.90	556.25	556.90	557.00	557.35	557.90	557.35	557.40	557.25	557.50	558.00
Falls Flow					Observed Discharge cfs							
Horseshoe Falls	48,800	47,000	48,000	47,800	52,800	68,200	85,500	94,500	93,500	94,500	93,000	91,500
American Falls	1,800	3,400	1,600	3,400	4,400	6,600	9,000	5,800	5,800	5,400	6,700	9,000

TABLE E-4

REVISED INITIAL TESTING PROGRAMME — TEST CONDITIONS

Discharge in Thousands of Cubic Feet per Second

Test Number

Item	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
Total River Flow	200	200	200	200	180	200	200	200	200	200	250	250	200	200	200	200
Can. Falls (Measured)	96.5	94.5	93.0	91.8	49.8	48.0	47.6	48.1	138.5	140.8	136.3	135.2	68.8	66.9	65.0	64.3
Am. Falls (Measured)	5.0	5.7	6.6	8.0	1.2	1.8	2.6	3.5	10.1	11.1	12.3	13.8	2.6	3.3	4.0	5.2
Combined Falls Flow	101.5	100.2	99.6	99.8	51.0	49.8	50.2	51.6	148.6	151.9	148.6	149.0	71.4	70.2	69.0	69.5
Computed Cascades Flow	100	110	120	135	50	60	70	85	150	160	170	185	70	80	90	105
Schoel and Adams	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Conners	30	30	30	30	55	65	55	55	5	5	30	30	55	45	45	45
S.A.B. Nos. 1 and 2	50	40	30	15	55	55	55	40	25	15	30	15	55	55	45	30
Ontario Power	0	10	10	10	0	10	10	10	0	10	10	10	0	10	10	10
Canadian Niagara	0	0	10	10	0	0	10	10	0	0	10	10	0	0	10	10
Toronto Power	0	0	0	15	0	0	0	15	0	0	0	15	0	0	0	15

TABLE E-5

REVISED INITIAL TESTING PROGRAMME

OBSERVED WATER SURFACE ELEVATIONS — RIVER GAUGES

Test Number 101 to 108

Gauge	101	102	103	104	105	106	107	108
Slaters Point	561.9	562.1	562.3	562.5	560.1	560.5	561.0	561.2
Gauge No. 5	561.1	561.4	561.6	561.9	559.0	559.5	560.0	560.45
Gauge No. 3	560.45	560.9	561.2	561.6	558.3	558.8	559.25	559.85
Gauge No. 51	560.15	560.4	560.7	560.9	558.1	558.6	559.0	559.5
Gauge No. 45	557.25	557.2	557.4	557.7	554.6	554.7	555.5	556.1
Ont. Power "B"	556.6	555.85	556.2	555.5	554.2	553.5	554.1	554.85
Toronto Power	531.5	531.4	531.6	530.1	530.0	529.9	530.4	528.2
Can. Niagara	515.35	515.3	513.85	513.7	513.8	513.6	511.0	509.8
Conners Island	562.0	562.2	562.4	562.6	560.2	560.6	561.0	561.3
Grass Island	560.6	560.9	561.2	561.5	558.5	558.9	559.45	559.8
Willow Island	559.35	559.6	559.8	560.0	557.6	558.1	558.4	558.8

Test Number 109 to 116

Gauge	109	110	111	112	113	114	115	116
Slaters Point	563.1	563.25	563.8	564.0	560.9	561.25	561.4	561.7
Gauge No. 5	562.55	562.6	563.15	563.4	560.0	560.25	560.6	561.1
Gauge No. 3	562.1	562.3	562.7	563.0	559.3	559.75	560.0	560.[illegible]
Gauge No. 51	561.5	561.7	562.0	562.3	559.0	559.45	559.65	560.2
Gauge No. 45	558.8	558.4	559.0	559.5	555.85	555.8	556.0	556.9
Ont. Power "B"	558.0	557.3	557.6	558.0	555.35	554.5	554.7	555.5
Toronto Power	532.85	532.7	533.1	531.4	530.7	530.7	531.0	539.5
Can. Niagara	517.0	516.8	515.7	515.5	514.55	514.5	512.8	512.2
Conners Island	563.2	563.3	563.8	564.0	561.0	561.4	561.4	561.8
Grass Island	562.0	562.3	562.6	562.9	559.4	559.9	560.0	560.7
Willow Island	560.6	560.7	560.85	561.1	558.4	558.65	558.9	559.3

TABLE E-6

REVISED INITIAL TESTING PROGRAMME

OBSERVED WATER SURFACE ELEVATIONS — CASCADES GAUGES

Test Number

Gauge	101	102	103	104	105	106	107	108
a	531.7	531.5	531.5	531.2	530.2	530.0	530.4	529.2
b	515.3	515.4	515.0	514.5	514.2	513.8	512.2	511.0
c	507.5	507.2	507.2	506.8	505.5	505.7	505.0	504.8
d	555.4	555.0	555.4	555.9	552.7	552.5	553.2	554.1
e	518.5	518.2	519.0	517.7	515.5	515.4	515.3	514.1
f	514.8	514.7	514.7	513.9	512.7	512.3	511.3	510.2
g	509.0	508.8	508.5	508.5	505.8	505.1	505.1	504.8
h	518.8	518.9	519.2	519.3	517.2	517.2	517.5	518.0
j	551.1	551.0	551.5	551.8	548.9	548.9	549.4	549.9
k	521.3	521.1	521.4	522.1	517.9	517.7	518.5	519.2
l	516.2	516.2	516.5	517.0	513.2	513.1	514.0	514.8
m	510.2	509.8	509.8	510.0	507.1	507.1	507.7	508.2
n	526.5	526.4	527.2	528.0	dry	dry	526.0	526.2
o	511.7	511.5	511.8	511.9	510.5	510.4	510.7	511.2
p	538.3	537.2	537.5	538.0	536.0	535.9	536.3	536.5

Test Number

Gauge	109	110	111	112	113	114	115	116
a	532.8	532.9	533.0	532.3	531.0	530.8	530.8	530.2
b	517.0	517.1	516.8	516.6	514.4	514.5	513.8	513.1
c	509.5	509.5	509.3	509.3	506.1	506.0	505.6	505.4
d	556.5	556.5	506.7	557.1	554.0	553.5	554.0	554.6
e	522.0	522.0	522.0	520.9	516.8	516.5	516.3	515.5
f	516.4	516.3	516.3	516.1	513.4	513.0	512.9	512.3
g	511.4	511.3	511.8	511.4	506.8	507.1	506.2	505.9
h	520.0	520.1	520.4	521.0	518.0	517.6	517.9	518.2
j	552.5	552.6	552.8	553.3	550.0	549.8	549.4	550.7
k	523.7	523.8	524.1	524.2	519.3	519.2	519.8	520.6
l	517.8	517.8	517.5	518.7	514.5	514.6	515.0	515.7
m	511.9	511.5	511.6	511.7	508.5	508.4	508.5	509.0
n	528.9	528.9	529.4	529.9	526.2	526.2	526.3	526.4
o	512.5	512.7	512.5	512.7	511.2	511.0	511.3	511.4
p	538.5	538.3	537.4	538.9	536.1	536.1	536.2	536.4

TABLE E-7

REVISED INITIAL TESTING PROGRAMME

OBSERVED CREST PANEL DISCHARGE IN CFS PER FOOT OF CREST

Panel Number	Test Number 101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
Can. 1	1	1	2	1	0	W		W	8	8	11	8	W			
2	9	7	9	6	1	2		W	24	24	24	20	3	3	2	1
3	11	10	9	8	2	2		W	25	24	25	22	4	4	2	2
4	3	3	4		dry	0		dry	25	24	27	25	W			
5	20	17	16	14	2	2	1	W	46	44	49	45	6	4	4	3
6	65	64	62	59	26	26	22	19	104	99	105	97	43	43	36	32
7	118	118	113	108	72	68	64	48	171	167	159	162	93	93	83	80
8	138	134	116	126	80	78	71	65	179	179	177	181	105	104	95	88
9	89	86	82	82	46	44	43	40	120	123	123	126	60	59	55	54
10	62	61	63	60	34	34	34	35	87	88	83	82	45	43	44	43
11	81	78	74	69	45	42	38	36	103	101	102	100	59	57	54	48
12	81	78	76	73	36	35	33	34	103	105	101	99	52	51	48	46
13	81	80	78	75	35	34	39	47	95	102	99	99	55	53	54	57
14	159	150	157	161	102	100	110	119	176	181	182	181	125	123	132	137
15	33	34	33	35	14	12	18	18	48	49	49	48	21	22	20	22
16	24	23	27	30	6	4	9	14	38	39	40	39	14	13	16	20
17	9	8	11	8	W		3	5	14	11	11	10	4	4	5	6
18	1	1	4	3	W		2	W	4	5	4	4	W			1
19	5	3	5	5	W			3	4	5	7	6	2	2	3	2
20	3	1	3	2	W			W	4	3	3	2				
21	W							W	1	2	2	2				
22								W	2	3	3	4				
23								W	2	3	2	2				
24								dry	1	2	2	2				
G.I. 25								dry		2	2	2				
TOTALS	993	957	944	925	501	483	487	483	1384	1393	1392	1368	691	678	653	642

(W indicates trace of flow)

TABLE E-8

REVISED INITIAL TESTING PROGRAMME

OBSERVED CREST PANEL DISCHARGE

Cumulative Crest Panel Discharge to Panel Point in Hundreds of cfs

Panel Number	Test Number 101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
Can. 1	1	1	2	1	0	0	0	0	8	8	11	8	0	0	0	0
2	10	8	11	7	1	2	0	0	32	32	35	28	3	3	2	1
3	21	18	20	15	3	4	0	0	57	56	60	50	7	7	4	3
4	24	21	24	15	3	4	0	0	82	80	87	75	7	7	4	3
5	44	38	40	29	5	6	1	0	128	124	136	120	13	11	8	6
6	109	102	102	88	31	32	23	19	232	223	241	217	56	54	44	38
7	227	220	215	196	103	100	87	67	403	390	400	379	149	147	127	118
8	365	354	331	322	183	178	158	132	582	569	577	560	254	251	222	206
9	454	440	413	404	229	222	201	172	702	692	700	686	314	310	277	260
10	516	501	476	464	263	256	235	207	789	780	783	768	359	353	321	303
11	597	579	550	533	308	298	273	243	892	881	885	868	418	410	375	351
12	678	657	626	606	344	333	306	277	995	986	986	967	470	461	423	397
13	759	737	704	681	379	367	345	324	1090	1088	1085	1066	525	514	477	454
14	918	887	861	842	481	467	455	443	1266	1269	1267	1247	650	637	609	591
15	951	921	894	877	495	479	473	461	1314	1318	1316	1295	671	659	629	613
16	975	944	921	907	501	483	482	475	1352	1357	1356	1334	685	672	645	633
17	984	952	932	915	501	483	485	480	1366	1368	1367	1344	689	676	650	639
18	985	953	936	918	501	483	487	480	1370	1373	1371	1348	689	676	650	640
19	990	956	941	923	501	483	487	483	1374	1378	1378	1354	691	678	653	642
20	993	957	944	925	501	483	487	483	1378	1381	1381	1356	691	678	653	642
21	993	957	944	925	501	483	487	483	1379	1383	1383	1358	691	678	653	642
22	993	957	944	925	501	483	487	483	1381	1386	1386	1362	691	678	653	642
23	993	957	944	925	501	483	487	483	1383	1389	1388	1364	691	678	653	642
24	993	957	944	925	501	483	487	483	1384	1391	1390	1366	691	678	653	642
G.I. 25	993	957	944	925	501	483	487	483	1384	1393	1392	1368	691	678	653	642

TABLE E-9

REVISED INITIAL TESTING PROGRAMME

OBSERVED WATER SURFACE ELEVATIONS AT CREST OF HORSESHOE FALLS

Elevations Observed on Panel Centre Line 50 Feet Upstream from Crest

Panel Number	Test Number															
	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
Can. 1	503.7	503.6	503.6	503.6	dry	503.8	503.5	dry	504.4	503.7	504.6	504.8	503.2	dry	dry	503.8
2	503.1	502.6	503.1	503.1	502.7	502.6	502.5	502.5	505.0	504.0	504.6	505.7	503.0	502.7	503.2	502.6
3	504.7	504.7	504.4	504.0	503.5	503.4	503.1	502.8	505.8	505.6	506.0	506.0	503.4	503.7	503.4	503.3
4	503.1	503.1	503.4	503.0	dry	dry	dry	dry	503.6	503.5	503.8	503.6	dry	dry	dry	dry
5	503.1	502.8	502.7	502.6	wet	dry	dry	dry	505.0	504.3	505.3	504.8	502.2	503.5	dry	dry
6	504.8	504.8	504.3	504.5	503.1	502.8	502.4	502.1	505.5	505.1	506.0	505.6	503.2	504.1	503.2	503.2
7	506.2	505.8	505.6	505.3	503.4	503.5	503.2	501.7	506.7	506.4	507.0	507.1	504.3	503.7	503.5	503.4
8	505.7	505.9	505.0	504.7	503.2	503.0	503.0	502.1	507.2	506.9	507.0	507.1	504.0	504.2	503.5	503.4
9	507.8	507.0	506.7	506.7	504.1	504.1	503.7	502.9	508.4	508.0	508.6	508.3	504.9	504.0	504.0	503.7
10	507.0	506.0	506.2	505.5	503.9	502.7	504.1	504.2	509.6	509.6	509.6	509.6	505.9	505.2	505.4	504.6
11	506.3	506.1	505.8	506.7	504.6	504.5	504.4	504.1	508.8	507.9	508.4	508.0	505.3	505.2	505.3	505.0
12	508.7	507.8	507.4	507.3	505.6	504.0	505.4	506.2	509.5	509.1	509.5	509.8	505.8	506.5	506.9	505.2
13	507.4	507.2	506.9	506.8	505.6	505.4	505.6	505.8	508.5	508.0	508.2	508.1	506.3	506.3	505.9	506.3
14	508.7	508.7	508.3	503.5	506.2	505.7	506.3	507.0	510.1	509.4	510.0	509.7	507.2	507.0	507.4	507.3
15	507.8	507.8	507.6	507.6	505.7	505.6	505.9	506.2	508.7	508.3	508.5	508.6	506.5	506.7	506.6	506.8
16	505.4	505.4	505.5	505.6	503.3	503.3	503.8	504.4	506.0	505.9	506.3	506.2	504.4	503.9	504.3	504.7
17	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry	dry
18	503.2	503.0	502.9	503.1	502.5	502.7	502.7	503.1	503.4	503.3	503.5	503.4	502.9	503.0	503.0	503.0
19	503.5	503.3	503.3	503.3	502.6	502.6	502.7	503.2	503.4	503.5	503.3	503.4	502.9	503.0	503.0	503.3
20	503.4	503.5	503.4	503.6	dry	503.0	503.1	503.3	503.4	503.3	503.5	503.6	503.2	503.2	503.3	503.4
21	505.1	505.1	505.0	505.0	dry	dry	dry	dry	505.1	505.0	505.5	505.3	dry	504.5	504.6	504.6
22	504.6	dry	dry	504.8	dry	dry	dry	504.7	505.0	dry	505.0	505.3	dry	dry	dry	504.7
23	506.0	506.0	506.0	505.7	dry	dry	dry	dry	506.2	506.5	506.5	506.5	dry	dry	dry	dry
24	505.8	505.9	505.9	506.1	dry	dry	dry	dry	506.1	506.3	506.2	506.1	dry	dry	dry	505.2
G.I. 25	505.4	505.4	505.6	505.9	dry	dry	dry	dry	506.2	506.1	506.0	506.7	dry	dry	505.3	505.2

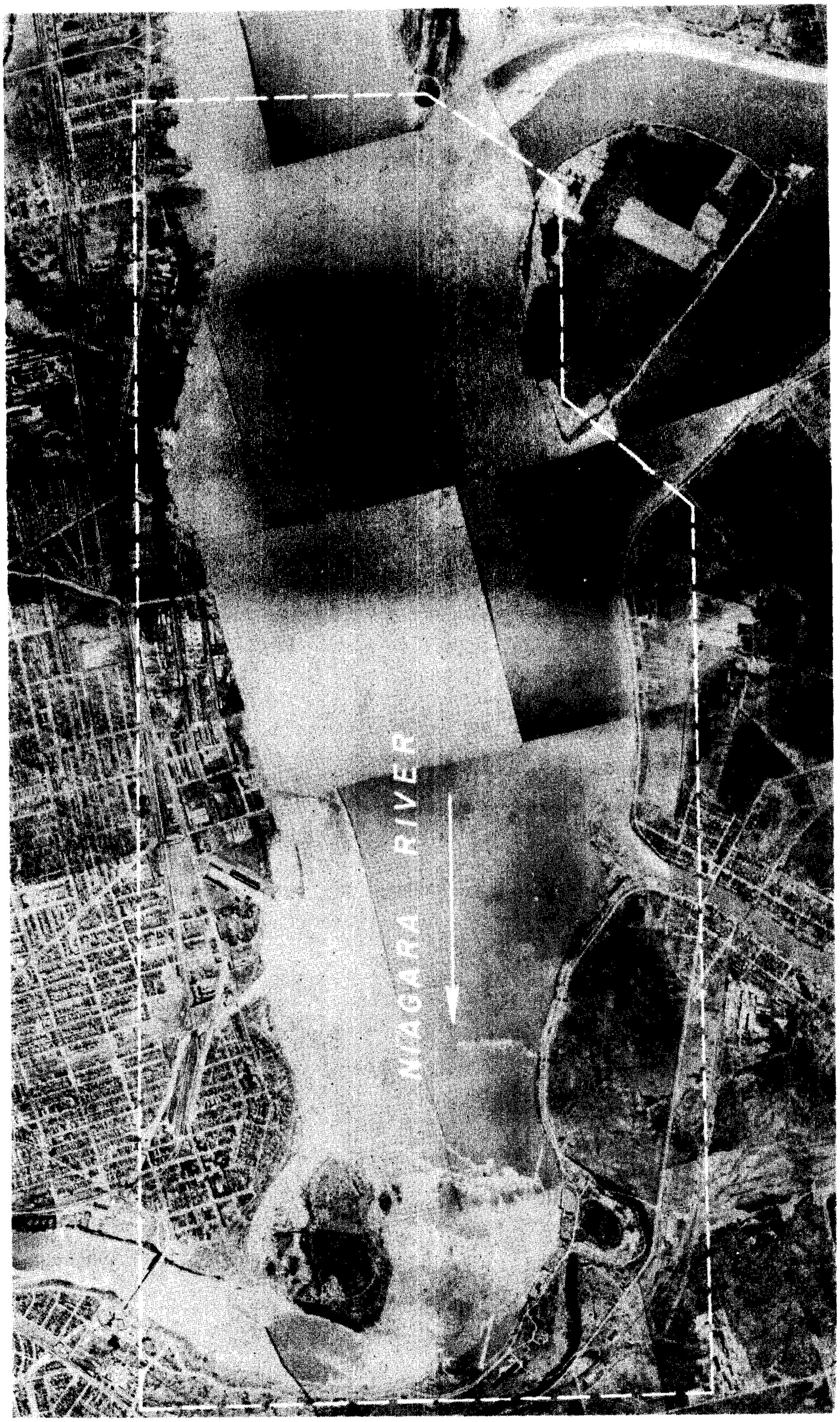
TABLE E-10

REVISED INITIAL TESTING PROGRAMME

OBSERVED DEPTH OF FLOW AT CREST OF HORSESHOE FALLS

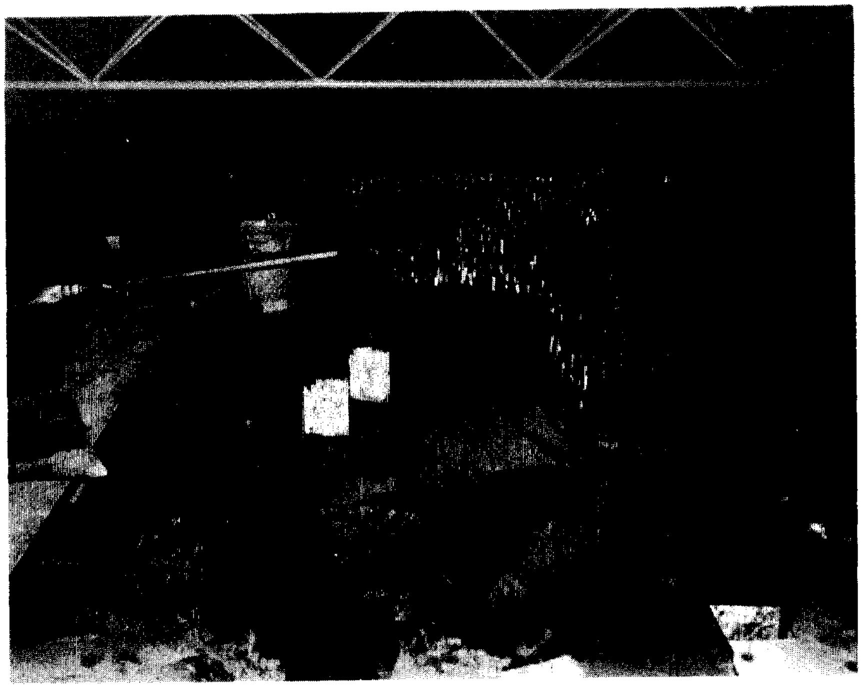
Depths Observed on Panel Centre Line 50 Feet Upstream from Crest

Panel Number	Test Number															
	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
Can. 1	0.7	0.6	0.6	0.6	0	0.8	0.5	0	1.4	0.7	1.6	1.8	0.2	0	0	0.8
2	0.8	0.3	0.8	0.8	0.4	0.3	0.2	0.2	2.7	1.7	2.3	3.4	0.7	0.4	0.9	0.3
3	2.1	2.1	1.8	1.4	0.9	0.8	0.5	0.2	3.2	3.0	3.4	3.4	0.8	1.1	0.8	0.7
4	0.4	0.4	0.7	0.3	0	0	0	0	0.9	0.8	1.1	0.9	0	0	0	0
5	1.1	0.8	0.7	0.6	0	0	0	0	3.0	2.3	3.3	2.8	0.2	1.5	0	0
6	4.0	4.0	3.5	3.7	2.3	2.0	1.6	1.3	4.7	4.3	5.2	4.8	2.4	3.3	2.4	2.4
7	9.4	9.0	8.8	8.5	6.6	6.7	6.4	4.9	9.9	9.6	10.2	10.3	7.5	6.9	6.7	6.6
8	9.6	9.8	8.9	8.6	7.1	6.9	6.9	6.0	11.1	10.8	10.9	11.0	7.9	8.1	7.4	7.3
9	10.3	9.5	9.2	9.2	6.6	6.6	6.2	5.4	10.9	10.5	11.1	10.8	7.4	6.5	6.5	6.2
10	7.4	6.4	6.6	5.9	4.3	3.1	4.5	4.6	10.0	10.0	10.0	10.0	6.3	5.6	5.8	5.0
11	6.4	6.2	5.9	6.8	4.7	4.6	4.5	4.2	8.9	8.0	8.5	8.1	5.4	5.3	5.4	5.1
12	8.1	7.2	6.8	6.7	5.0	3.4	4.8	5.6	8.9	8.5	8.9	9.2	5.2	5.9	6.3	4.6
13	6.7	6.5	6.2	6.1	4.9	4.7	4.9	5.1	7.8	7.3	7.5	7.4	5.6	5.6	5.2	5.6
14	15.0	15.0	14.6	9.8	12.5	12.0	12.6	13.3	16.4	15.7	16.3	16.0	13.5	13.3	13.7	13.6
15	3.4	3.4	3.2	3.2	1.3	1.2	1.5	1.3	4.3	3.9	4.1	4.2	2.1	2.3	2.2	2.4
16	4.2	4.2	4.3	4.4	2.1	2.1	2.6	3.2	4.8	4.7	5.1	5.0	3.2	2.7	3.1	3.5
17 Dry	(OnIsl)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	0.8	0.6	0.5	0.7	0.1	0.3	0.3	0.7	1.0	0.9	1.1	1.0	0.5	0.6	0.6	0.6
19	1.5	1.3	1.3	1.3	0.6	0.6	0.7	1.2	1.4	1.5	1.3	1.4	0.9	1.0	1.0	1.3
20	0.6	0.7	0.6	0.8	0	0.2	0.3	0.5	0.6	0.5	0.7	0.8	0.4	0.4	0.5	0.6
21	0.7	0.7	0.6	0.6	0	0	0	0	0.7	0.6	1.1	0.9	0	0.1	0.2	0.2
22	0.1	0	0	0.3	0	0	0	0.2	0.5	0	0.5	0.8	0	0	0	0.2
23	0.9	0.9	0.9	0.6	0	0	0	0	1.1	1.4	1.4	1.4	0	0	0	0
24	1.2	1.4	1.4	1.6	0	0	0	0	1.6	1.8	1.7	1.6	0	0	0	0.7
G.I. 25	0.4	0.4	0.6	0.9	0	0	0	0	1.2	1.1	1.0	1.7	0	0	0.3	0.2

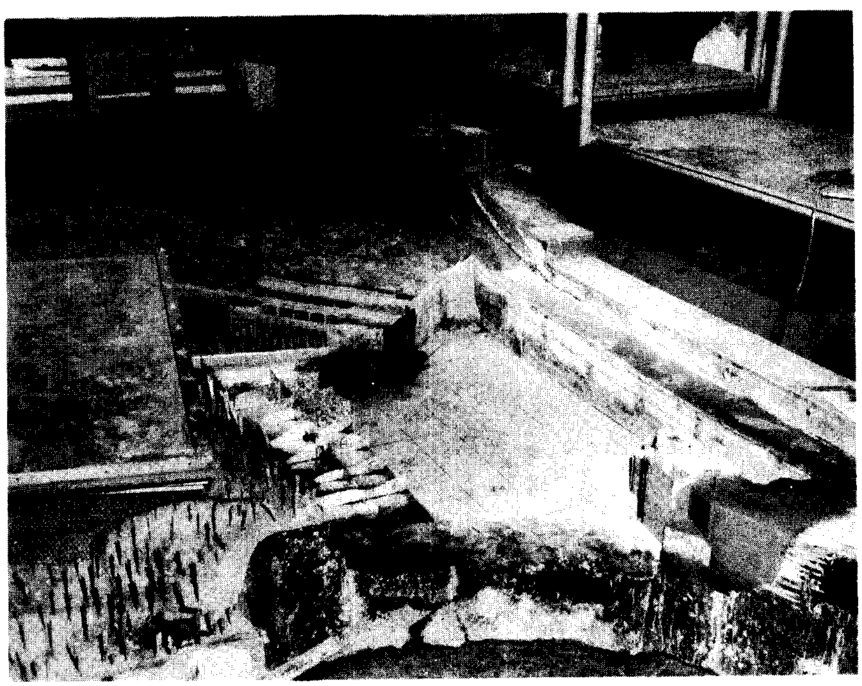


NIAGARA RIVER AND FALLS
SHOWING AREA REPRODUCED IN MODEL

PLATE E-1



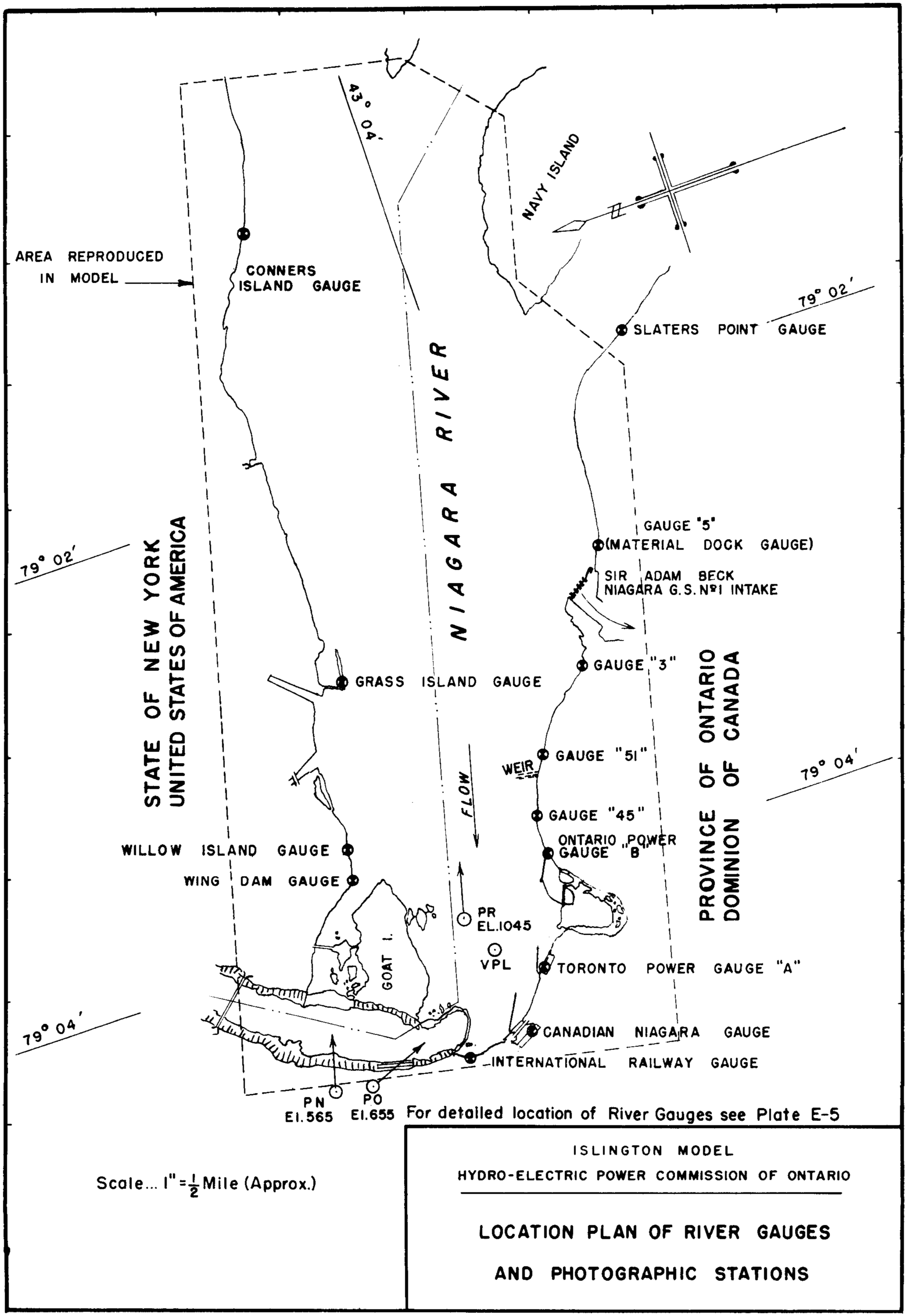
Goat Island Flank



Canadian Flank

ISLINGTON MODEL

CELLULAR CONSTRUCTION IN HORSESHOE FALLS CASCADES



NAVY ISLAND
43° 04′
AREA REPRODUCED IN MODEL
CONNERS ISLAND GAUGE
79° 02′
SLATERS POINT GAUGE
NIAGARA RIVER
GAUGE "5" (MATERIAL DOCK GAUGE)
SIR ADAM BECK NIAGARA G.S. Nº1 INTAKE
79° 02′
STATE OF NEW YORK
UNITED STATES OF AMERICA
GAUGE "3"
GRASS ISLAND GAUGE
PROVINCE OF ONTARIO
DOMINION OF CANADA
GAUGE "51"
WEIR
FLOW
79° 04′
GAUGE "45"
ONTARIO POWER GAUGE "B"
WILLOW ISLAND GAUGE
WING DAM GAUGE
PR EL.1045
GOAT I.
VPL
TORONTO POWER GAUGE "A"
79° 04′
CANADIAN NIAGARA GAUGE
INTERNATIONAL RAILWAY GAUGE
PN El.565
PO El.655
For detailed location of River Gauges see Plate E-5
Scale... 1" = 1/2 Mile (Approx.)
ISLINGTON MODEL
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
LOCATION PLAN OF RIVER GAUGES AND PHOTOGRAPHIC STATIONS

PLATE E-4

GAUGE REFER TO PLATE E-4	GEOGRAPHICAL CO-ORDINATES		H.E.P.C. (QUEENSTON CO-ORDINATES) T-1= ZERO	
	LATITUDE	LONGITUDE	LATITUDE	DEPARTURE
SLATERS POINT GAUGE	43°03' 21".845 N	79°01' 36".625 W	2,292·1 S	5,284·5 E
MATERIAL DOCK GAUGE	43°03' 40".581 N	79°02' 33".305 W	395·2 S	1,075·9 E
GAUGE Nº 3	43°03' 51".892 N	79°03' 04".847 W	750·0 N	1,265·7 W
GAUGE Nº 51	43°04' 05".759 N	79°03' 25".759 W	2,154·0 N	2,818·0 W
GAUGE Nº 45	43°04' 11".112 N	79°03' 42·222 W	2,696·0 N	4,040·0 W
GAUGE Nº B	43°04' 11".547 N	79°03' 53".819 W	2,740·0 N	4,866·0 W
TORONTO POWER GAUGE	43°04' 20".242 N	79°04' 26".870 W	3,620·3 N	7,354·0 W
CANADIAN NIAGARA · GAUGE	43°04' 27".076 N	79°04' 43".509 W	4,312·2 N	8,588·4 W
INTERNATIONAL RAILWAY GAUGE	43°04' 40".309 N	79°04' 44".760 W	5,711·9 N	8,693·2 W
WING DAM GAUGE	43°04' 52".112 N	79°03' 41".653 W	6,847·0 N	3,997·0 W
WILLOW ISLAND GAUGE	43°04' 51".035 N	79°03' 32".389 W	6,737·9 N	3,309·4 W
GRASS ISLAND GAUGE	43°04' 41".000 N	79°02' 44".189 W	5,721·9 N	267·8 E
CONNERS ISLAND GAUGE *	43°04' 33".380 N	79°00' 30".646 W	4,910·0 N	10,180·0 E
PHOTOGRAPHIC STATIONS				
PN – AMERICAN FALLS	43°05' 09".376 N	79°04' 40".279 W	8,595·0 N	8,347·5 W
PO – HORSESHOE FALLS	43°05' 02".463 N	79°04' 42".600 W	7,895·0 N	8,520·0 W
VPL – VERTICAL POINT	43°04' 28".664 N	79°04' 16".766 W	4,473·0 N	6,603·8 W
PR – OBLIQUE FLOAT PHOTO	43°04' 33".227 N	79°04' 03".811 W	4,935·0 N	5,642·0 W

* CO-ORDINATES SCALED

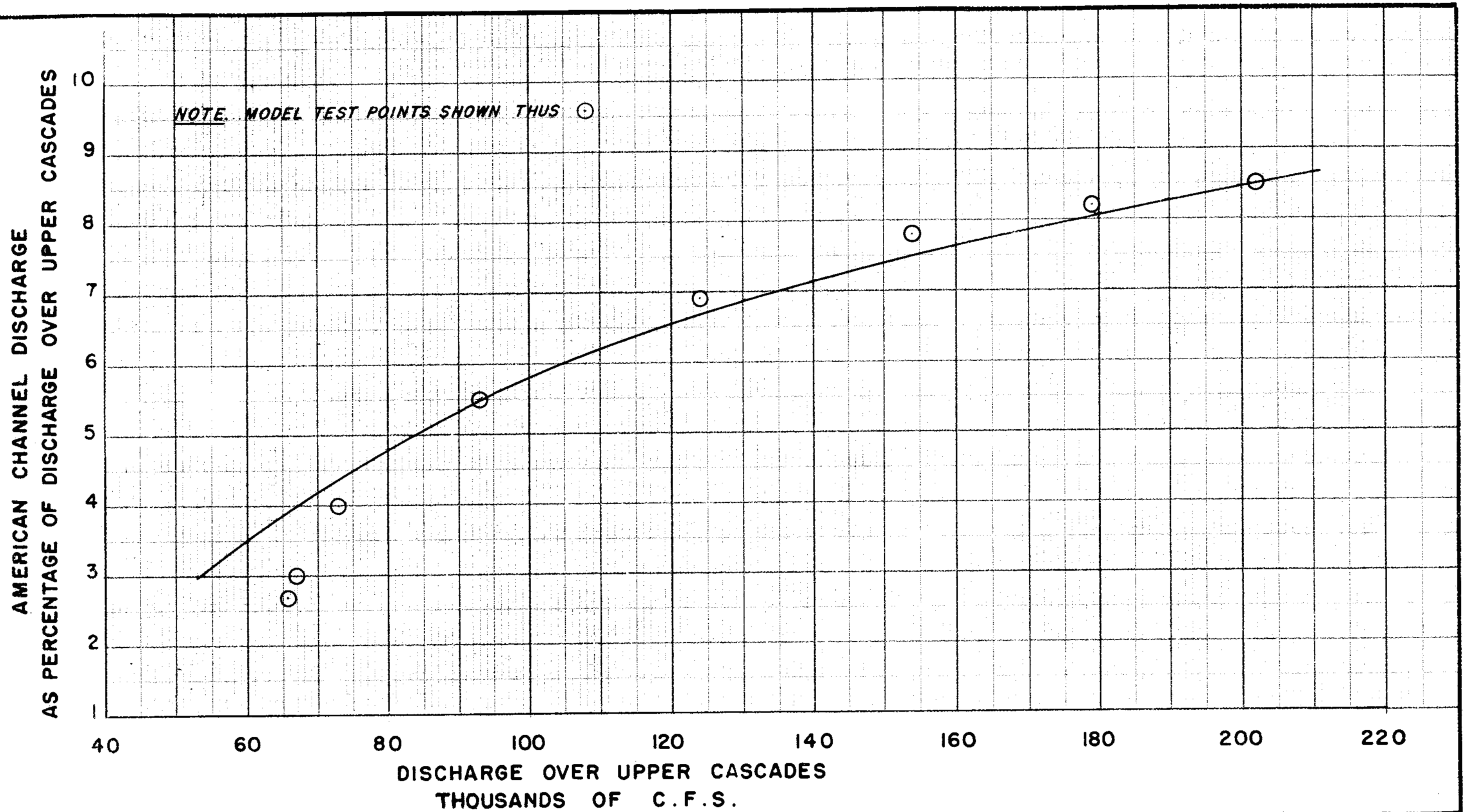
ISLINGTON MODEL

HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

DETAILED LOCATION OF RIVER GAUGES

AND PHOTOGRAPHIC STATIONS

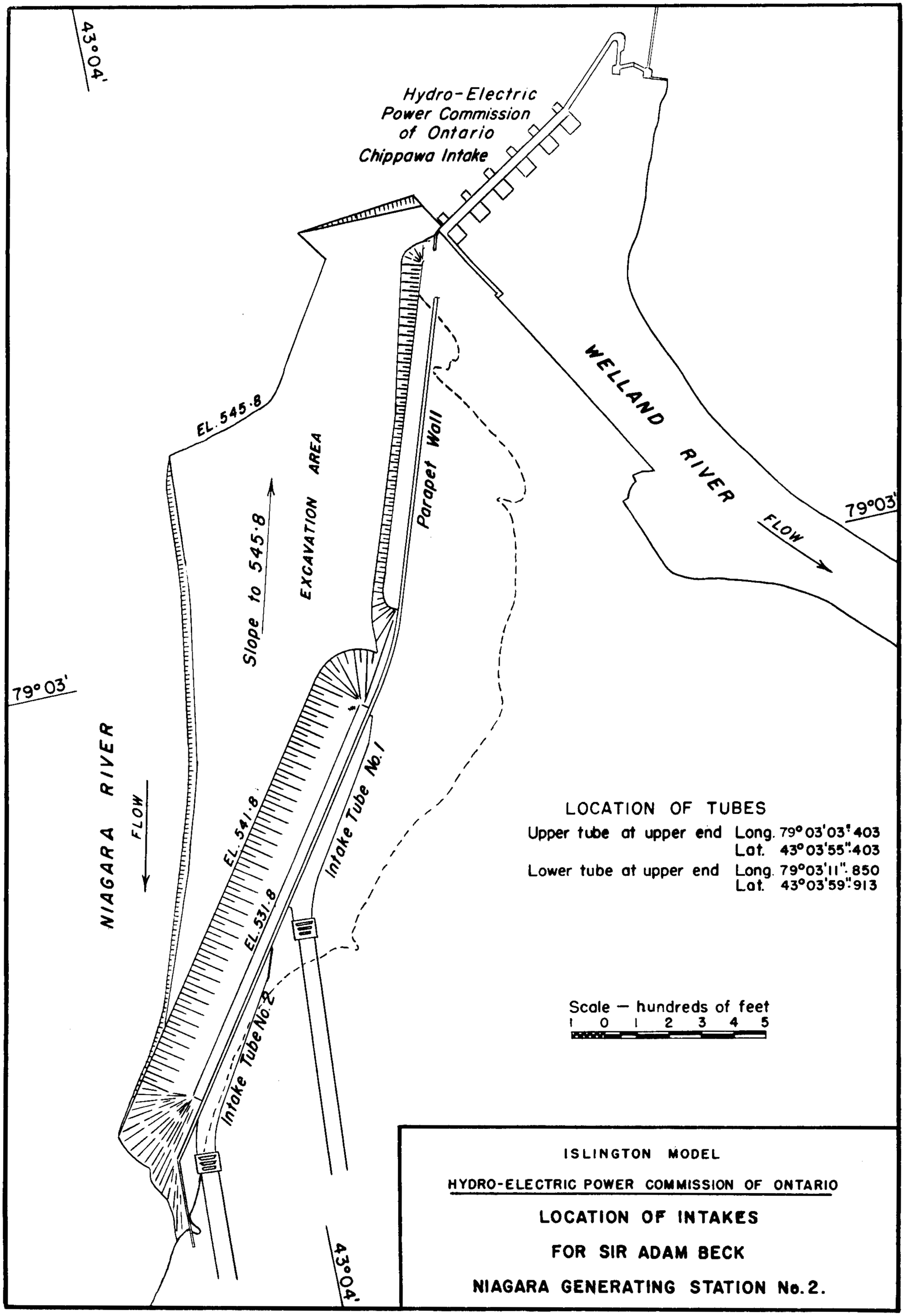
PLATE E-5

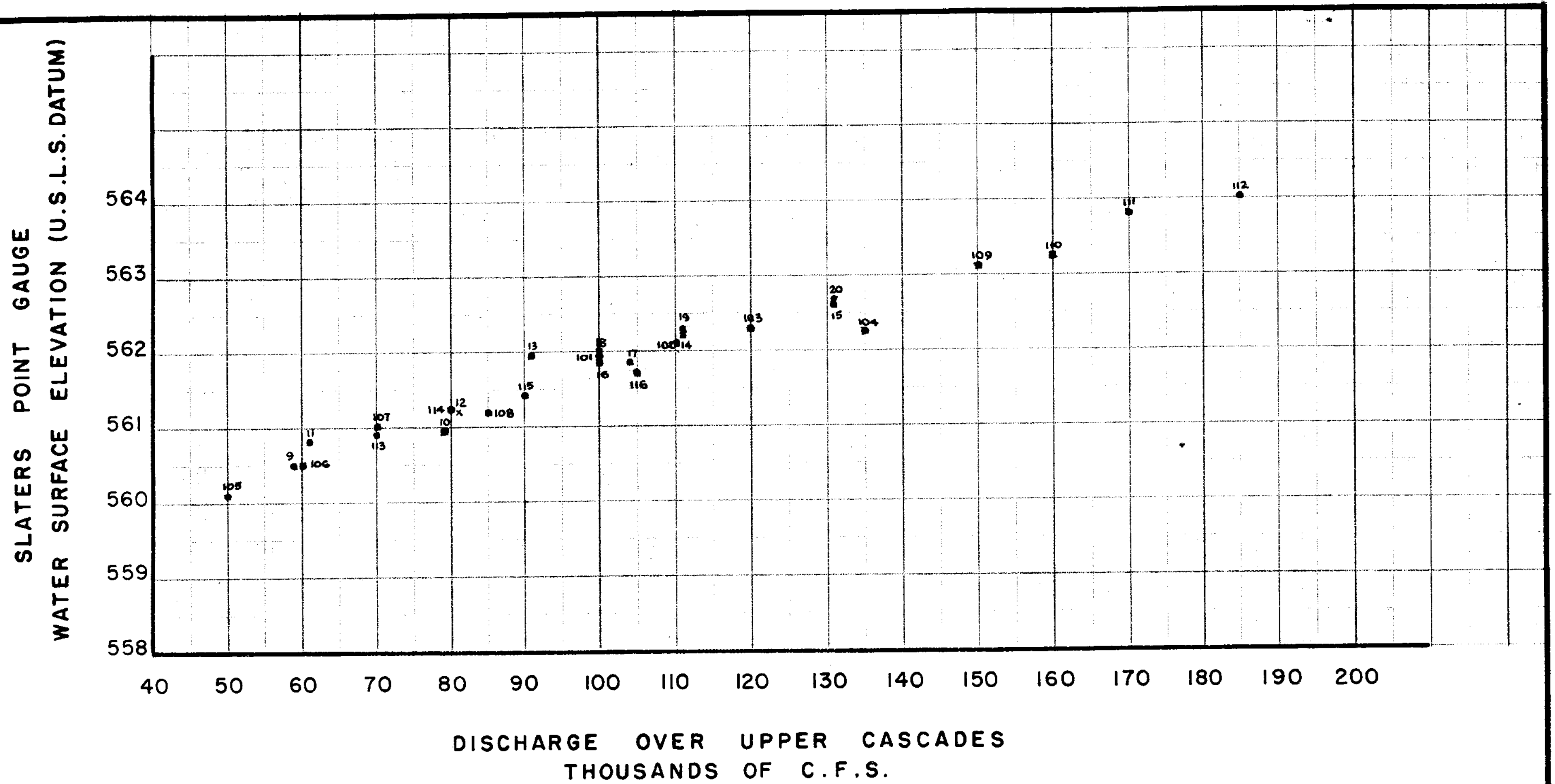


OBTAINED FROM WING DAM STAGE—
UPPER CASCADES FLOW RELATION
(SEE APPENDIX C)

ISLINGTON MODEL
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

AMERICAN CHANNEL DISCHARGE
AS PERCENTAGE OF UPPER CASCADES DISCHARGE
MODEL TO PROTOTYPE COMPARISON

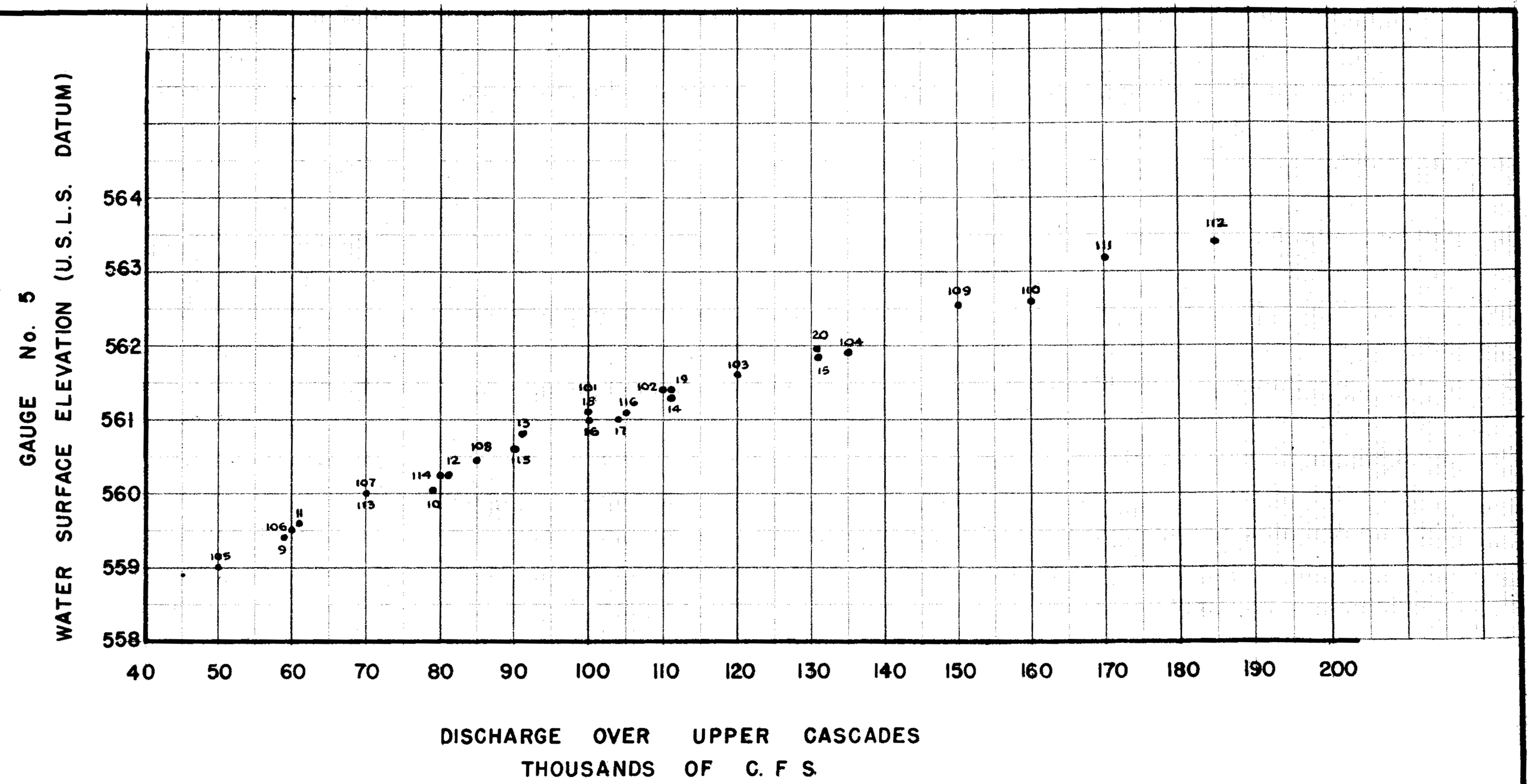

43°04'
Hydro-Electric
Power Commission
of Ontario
Chippawa Intake
WELLAND RIVER
FLOW
79°03'
EL. 545.8
EXCAVATION AREA
Slope to 545·8
Parapet Wall
79°03'
NIAGARA RIVER
FLOW
EL. 541.8
EL. 531.8
Intake Tube No. 1
Intake Tube No. 2
LOCATION OF TUBES
Upper tube at upper end Long. 79°03'03".403
Lat. 43°03'55".403
Lower tube at upper end Long. 79°03'11".850
Lat. 43°03'59".913
Scale — hundreds of feet
1 0 1 2 3 4 5
43°04'
ISLINGTON MODEL
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
LOCATION OF INTAKES
FOR SIR ADAM BECK
NIAGARA GENERATING STATION No. 2.



ISLINGTON MODEL

HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

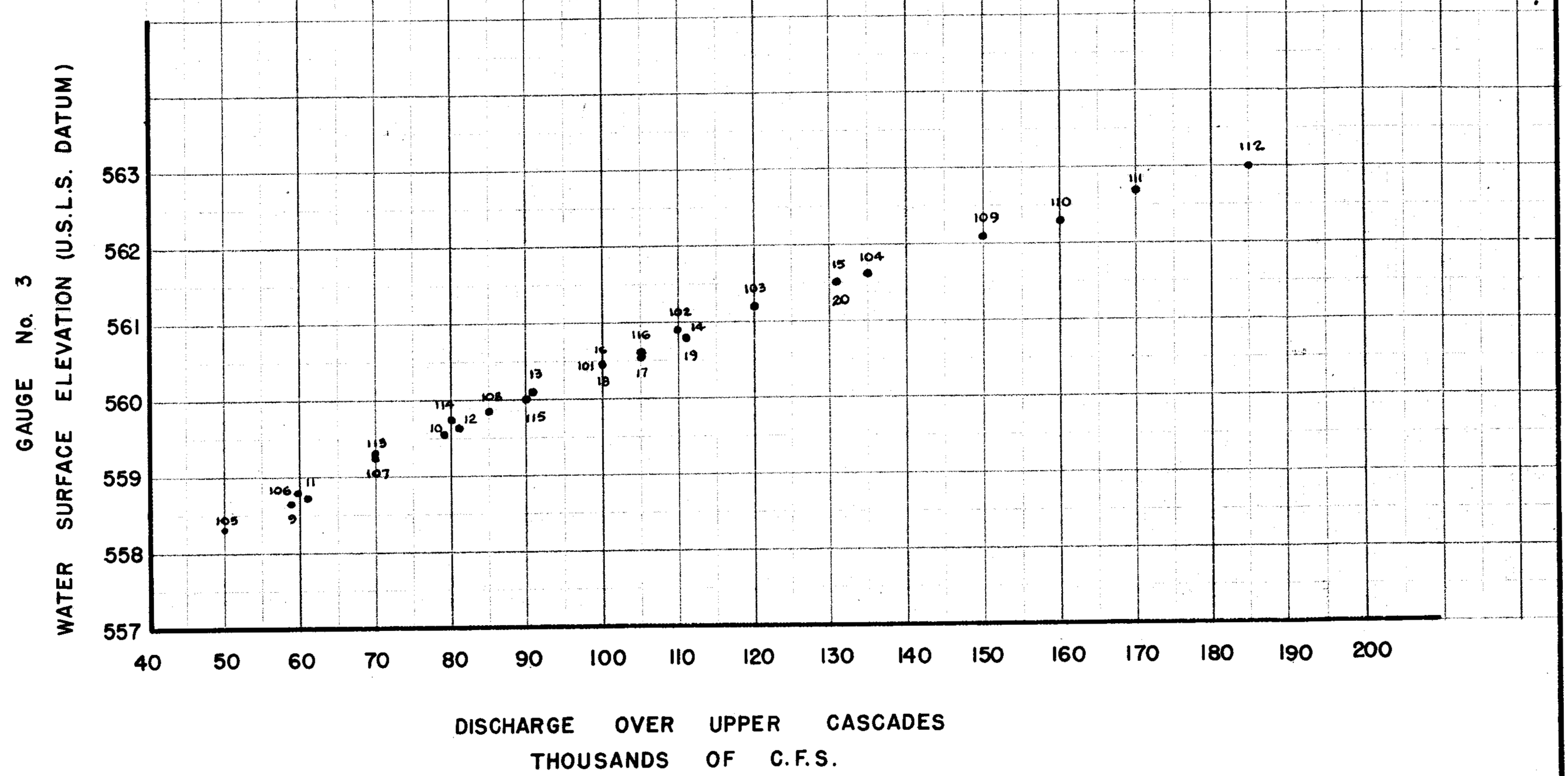
WATER SURFACE ELEVATION
SLATERS POINT GAUGE
IN RELATION TO
DISCHARGE OVER UPPER CASCADES



ISLINGTON MODEL

HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

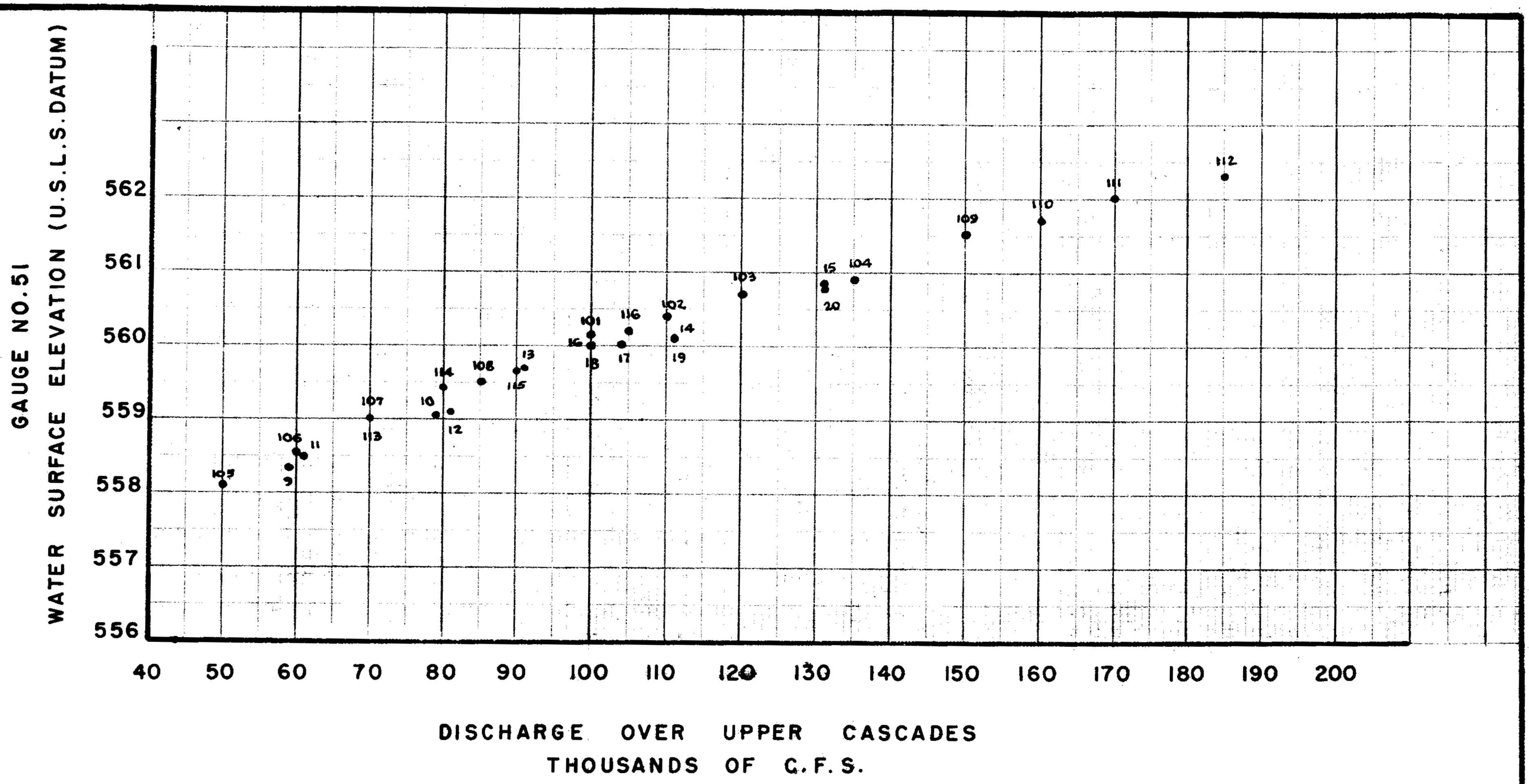
WATER SURFACE ELEVATION
GAUGE No. 5
IN RELATION TO
DISCHARGE OVER UPPER CASCADES



ISLINGTON MODEL

HYDRO - ELECTRIC POWER COMMISSION OF ONTARIO

WATER SURFACE ELEVATION
GAUGE No. 3
IN RELATION TO
DISCHARGE OVER UPPER CASCADES



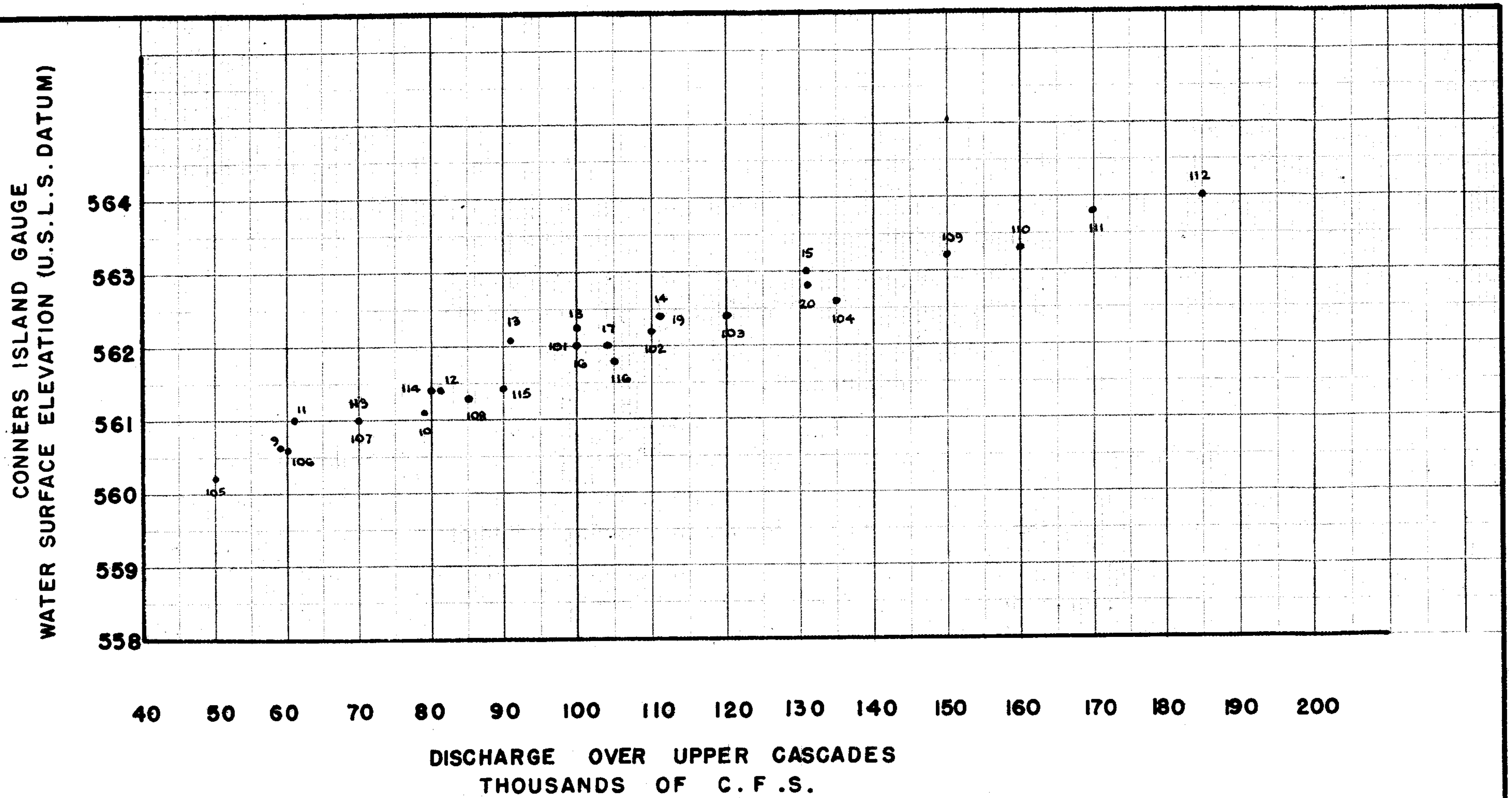
ISLINGTON MODEL

HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

WATER SURFACE ELEVATION
GAUGE NO. 51
IN RELATION TO
DISCHARGE OVER UPPER CASCADES

PLATE E-11

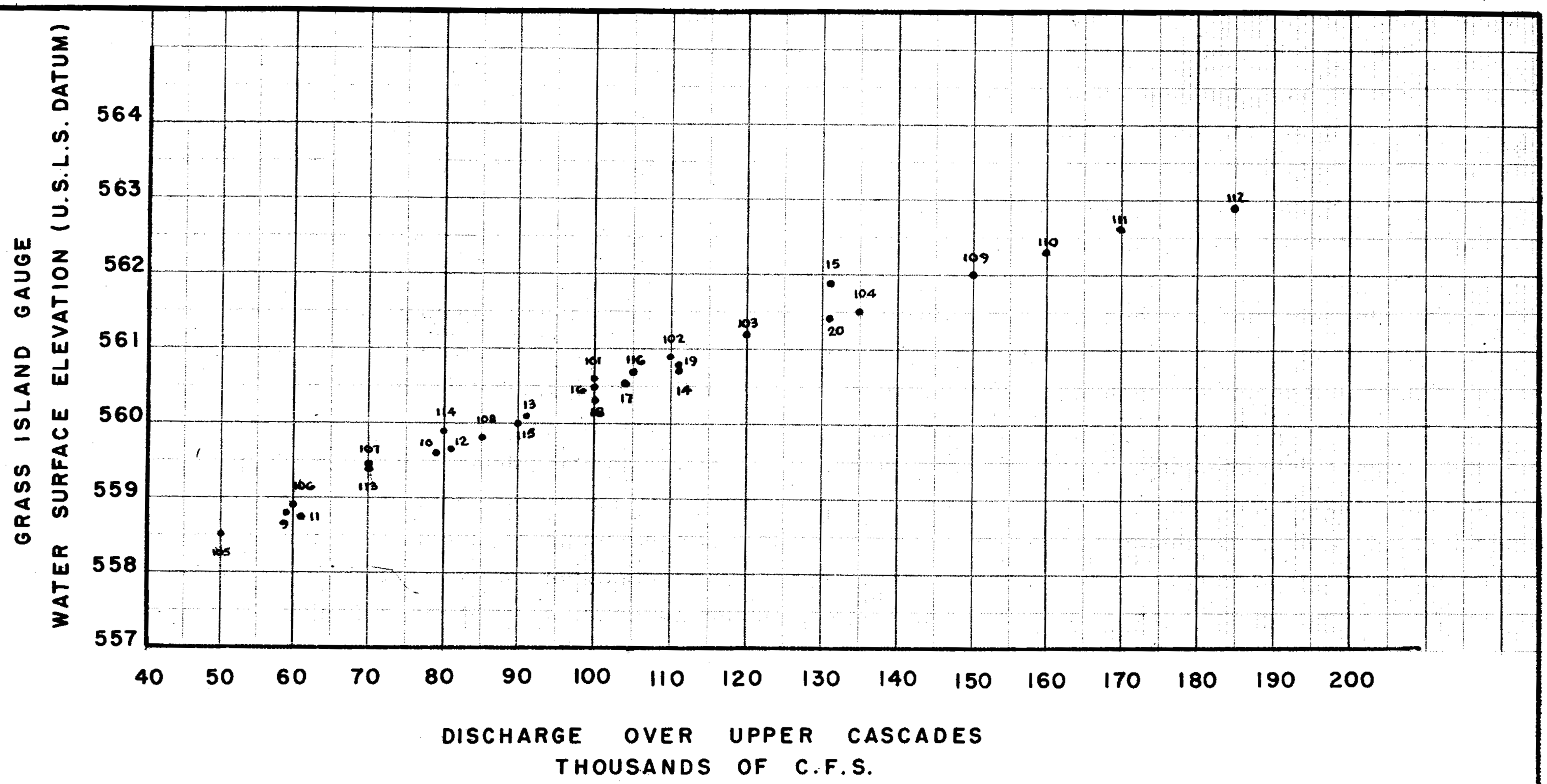
PLATE E-12



ISLINGTON MODEL

HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

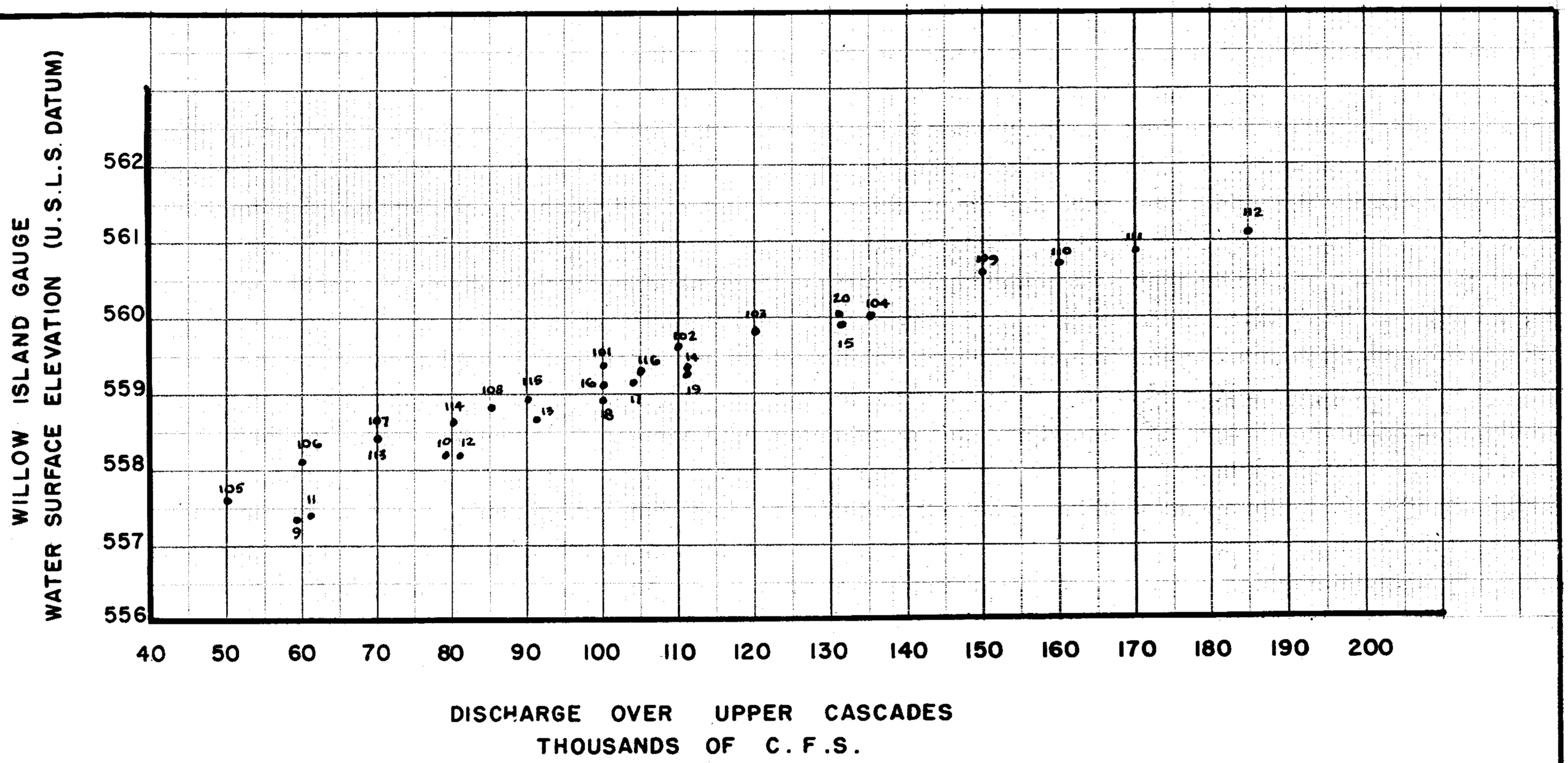
WATER SURFACE ELEVATION
CONNERS ISLAND GAUGE
IN RELATION TO
DISCHARGE OVER UPPER CASCADES



ISLINGTON MODEL

HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

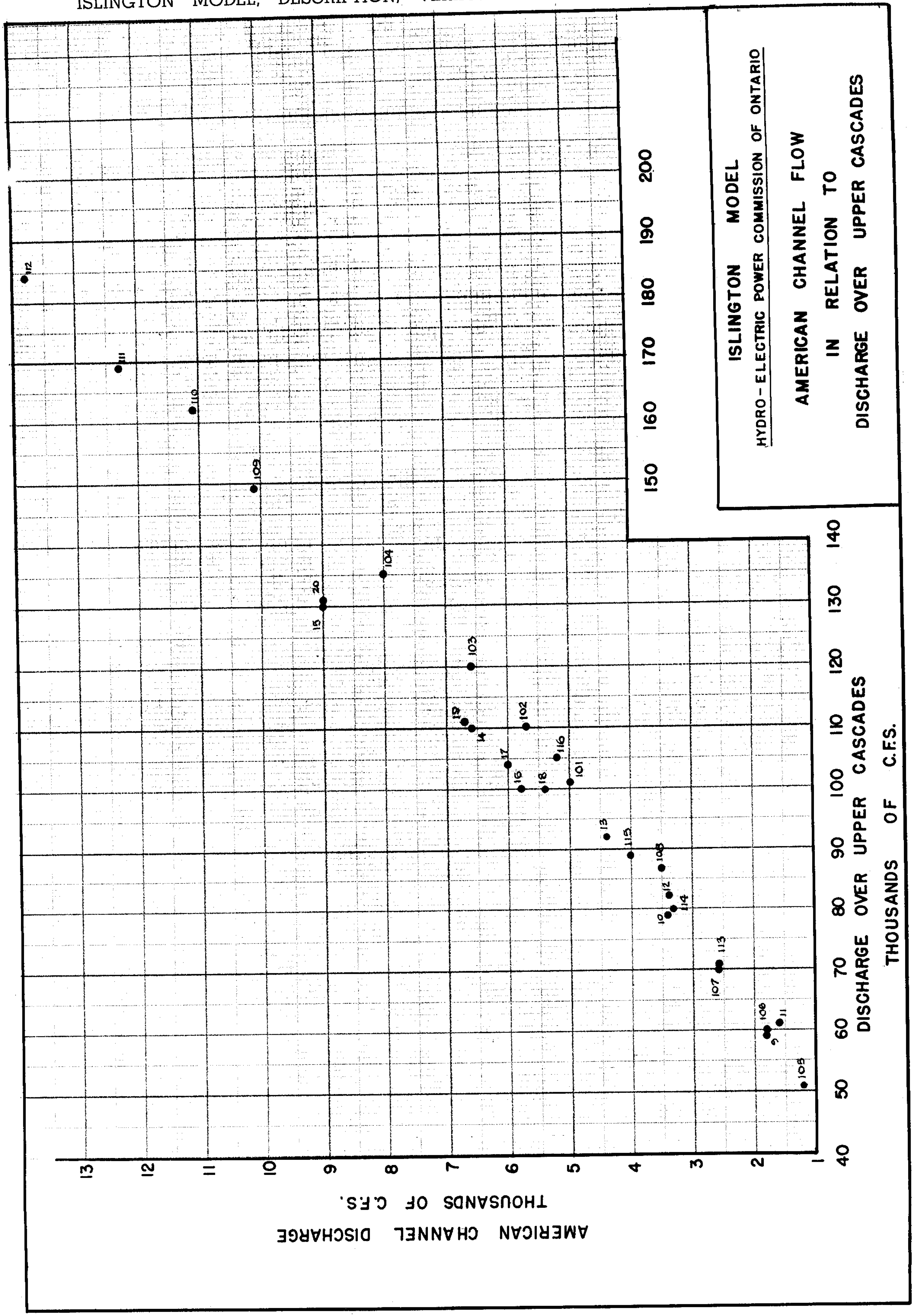
**WATER SURFACE ELEVATION
GRASS ISLAND GAUGE
IN RELATION TO
DISCHARGE OVER UPPER CASCADES**

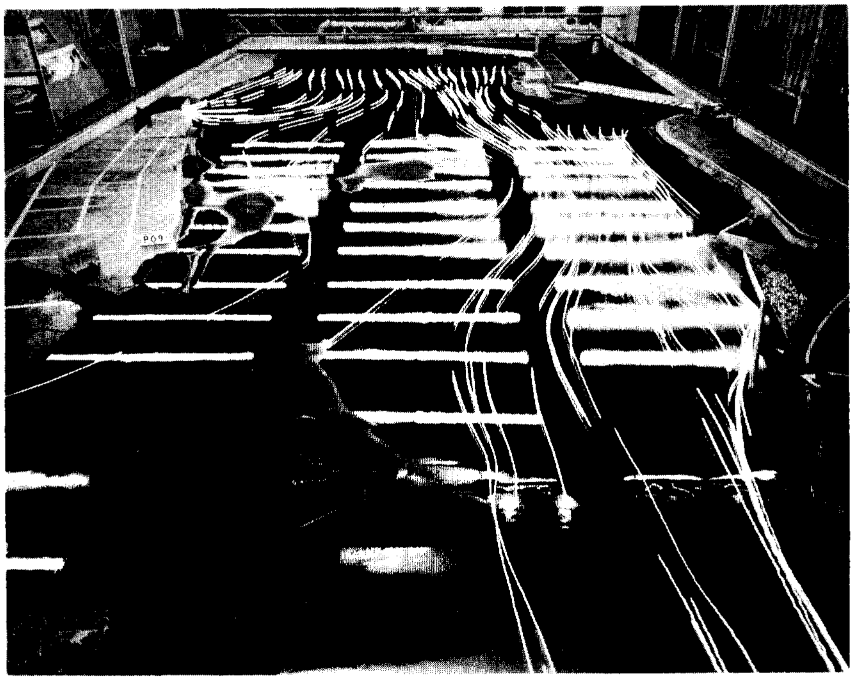


ISLINGTON MODEL

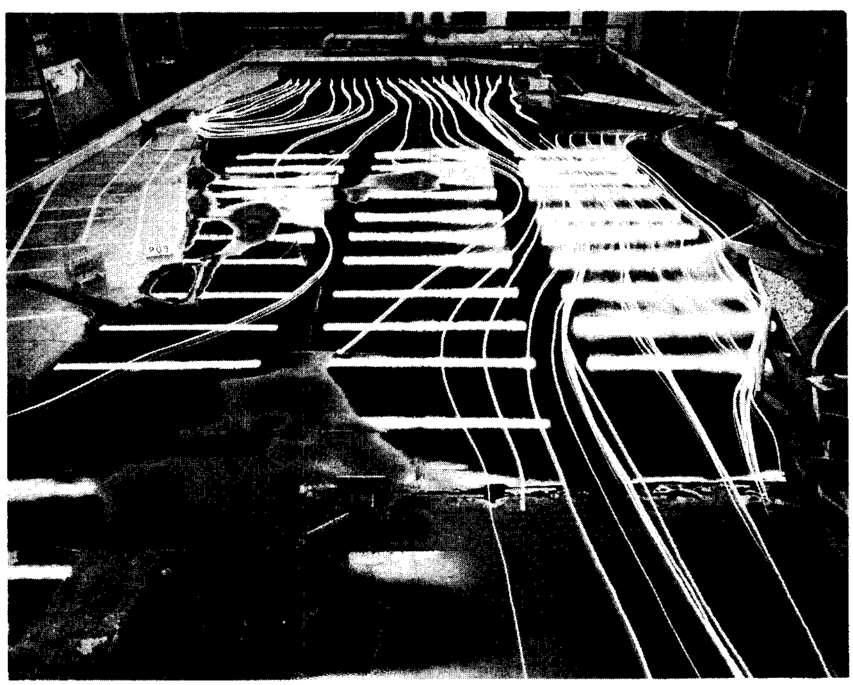
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

WATER SURFACE ELEVATION
WILLOW ISLAND GAUGE
IN RELATION TO
DISCHARGE OVER UPPER CASCADES


ISLINGTON MODEL
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
AMERICAN CHANNEL FLOW
IN RELATION TO
DISCHARGE OVER UPPER CASCADES
DISCHARGE OVER UPPER CASCADES
THOUSANDS OF C.F.S.
AMERICAN CHANNEL DISCHARGE
THOUSANDS OF C.F.S.



Shutter open 15 seconds; closed 5 seconds to indicate relative streamline velocities.



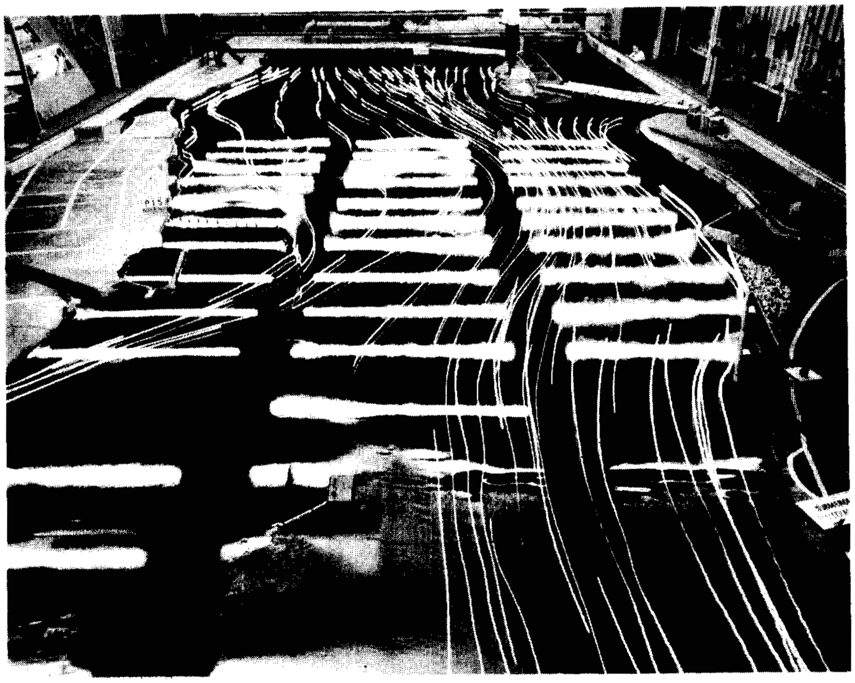
Shutter continuously open.

PHOTOGRAPHS SHOWING STREAMLINES, GRAND ISLAND TO CASCADES

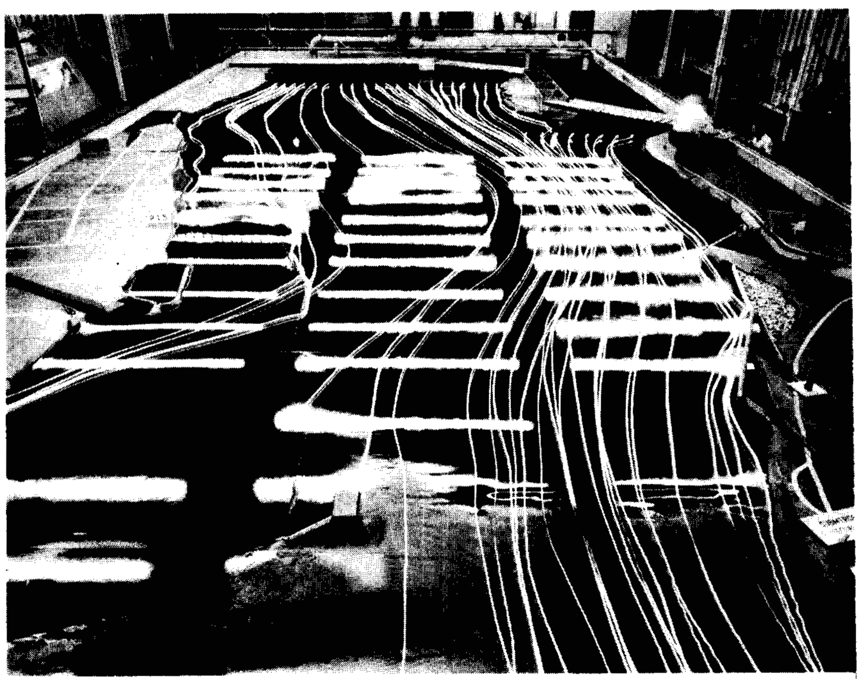
TEST 9 WITH TOTAL RIVER FLOW 180,000 C.F.S.

VANTAGE POINT PR

PLATE E-16



Shutter open 15 seconds; closed 5 seconds, to indicate relative streamline velocities.



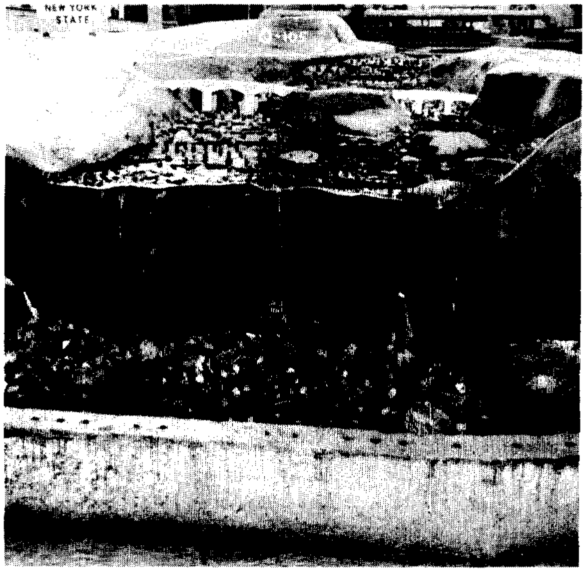
Shutter continuously open.

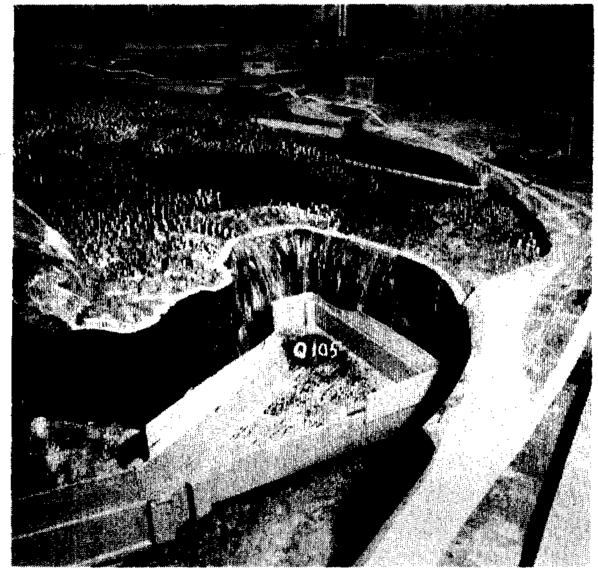
PHOTOGRAPHS SHOWING STREAMLINES, GRAND ISLAND TO CASCADES

TEST 15 WITH TOTAL RIVER FLOW 180,000 C.F.S.

VANTAGE POINT PR

AMERICAN FALLS | HORSESHOE FALLS





TEST No. 105
Falls Flow 50,000 c.f.s.
Total River Flow 180,000 c.f.s.

TEST No. 113
Falls Flow 70,000 c.f.s
Total River Flow 200,000 c.f.s.

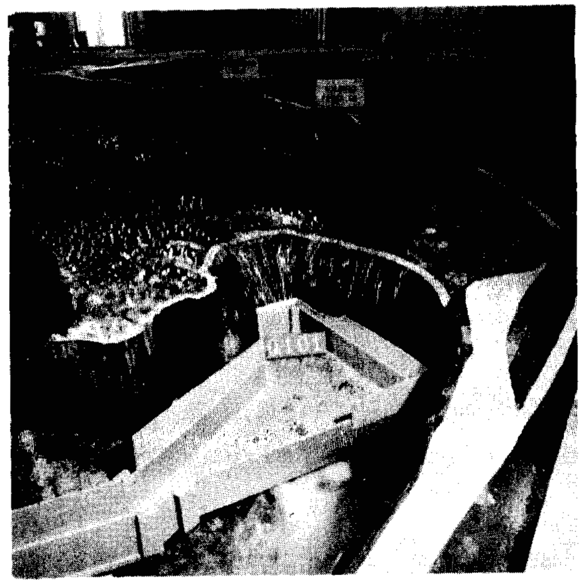
ISLINGTON MODEL

AMERICAN AND HORSESHOE FALLS WITHOUT REMEDIAL WORKS

PLATE E-18

AMERICAN FALLS

HORSESHOE FALLS



TEST No. 101

Falls Flow 100,000 c.f.s.

Total River Flow 200,000 c.f.s.

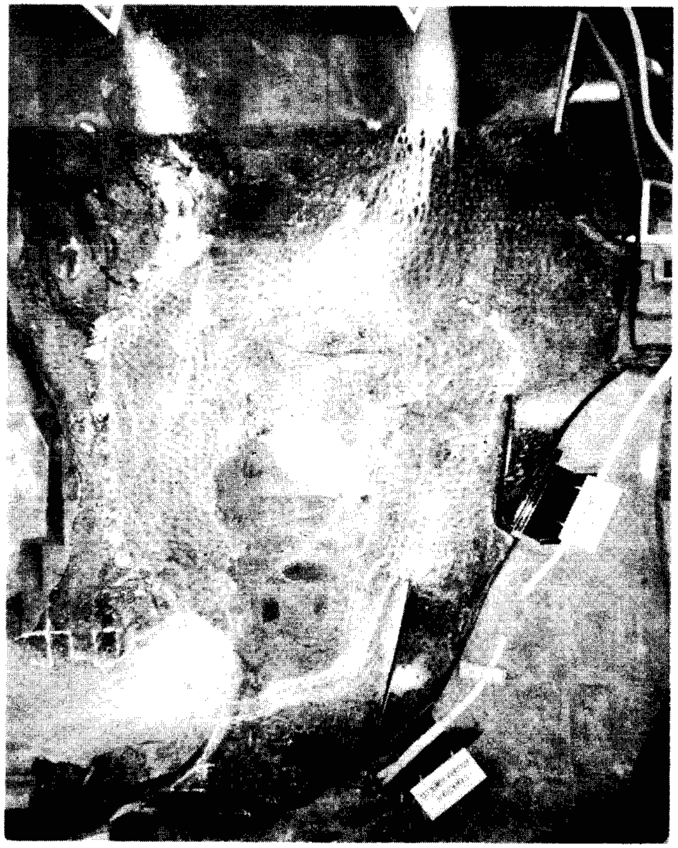
TEST No. 112

Falls Flow 150,000 c.f.s.

Total River Flow 250,000 c.f.s.

ISLINGTON MODEL

AMERICAN AND HORSESHOE FALLS WITHOUT REMEDIAL WORKS



TEST No. 105

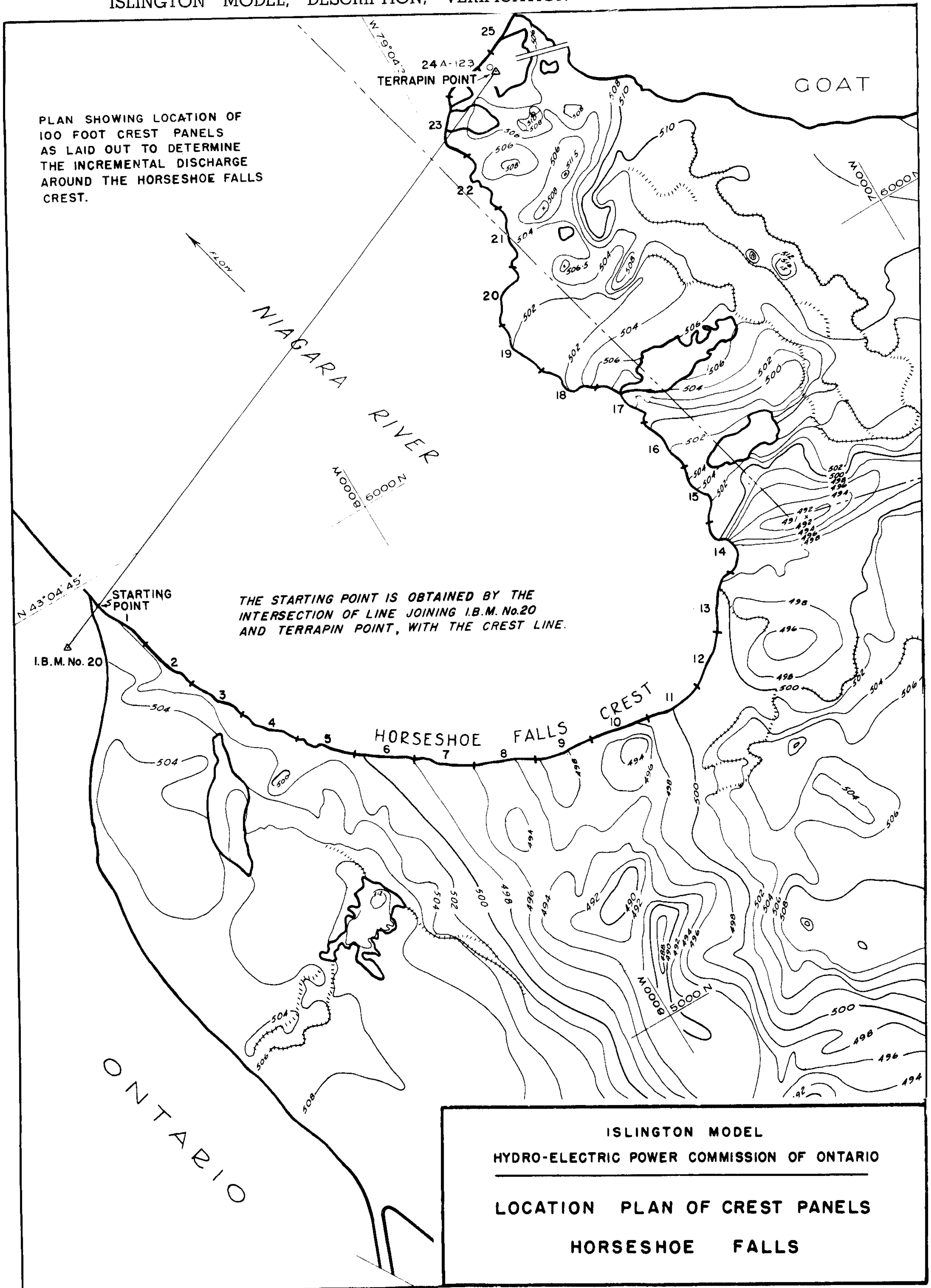
Falls Flow 50,000 c.f.s.

TEST No. 101

Falls Flow 100,000 c.f.s.

ISLINGTON MODEL

AERIAL PHOTOGRAPHS SHOWING STREAMLINES IN HORSESHOE FALLS CASCADES


PLAN SHOWING LOCATION OF 100 FOOT CREST PANELS AS LAID OUT TO DETERMINE THE INCREMENTAL DISCHARGE AROUND THE HORSESHOE FALLS CREST.
TERRAPIN POINT
24 A-123
GOAT
FLOW
NIAGARA RIVER
STARTING POINT
I.B.M. No. 20
N 43°04'45"
THE STARTING POINT IS OBTAINED BY THE INTERSECTION OF LINE JOINING I.B.M. No.20 AND TERRAPIN POINT, WITH THE CREST LINE.
HORSESHOE FALLS CREST
ONTARIO
6000 N
8000 M
5000 N
ISLINGTON MODEL
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
LOCATION PLAN OF CREST PANELS
HORSESHOE FALLS

APPENDIX F

VERIFICATION OF CASCADES SECTIONS OF MODELS

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX F

VERIFICATION OF CASCADES SECTIONS OF MODELS

CONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF PLATES (Cont'd.)

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX F

VERIFICATION OF CASCADES SECTIONS OF MODELS

INTRODUCTION

1. Two models of Niagara Falls, the Cascades, and portions of the upper river were constructed to assist in the design of remedial works, one by the Corps of Engineers, United States Army, at the Waterways Experiment Station, Vicksburg, Mississippi, and the other by The Hydro-Electric Power Commission of Ontario at Islington, Ontario.

2. This appendix presents the results of the final verification of the Cascades sections of the two models and includes discussions of the prototype data used in the original verification, revisions and additions to these data, methods used in verification of the two models and a presentation of the model data resulting from the final verification. Other reports on the models are contained in Appendices D, E, G, and H.

3. Initially, the Cascades section of each model was adjusted and verified independently of the other to agree with the data given by the surveys made in December 1950 and January and February 1951 described in paragraphs 13 through 18 of Appendix B. Comparisons made in October 1951 disclosed considerable dissimilarity between the Cascades sections of the two models, particularly in the flow conditions near and over the crest of the Horseshoe Falls. After a complete examination it was concluded that the dissimilarity was due largely to different interpretations placed on the limited prototype data available, and it was decided that both models should be brought into closer agreement with the prototype and with each other.

PROTOTYPE DATA

4. The data obtained for the hydrographic survey of the Canadian Cascades made during the winter of 1950-51 and used in the construction and initial verification of the Cascades section of the models were examined closely during October 1951 and it was concluded that the existing survey was inadequate for the desired purpose, that additional soundings were required near the crest of the Falls, and that a more detailed map of the problem area would be developed jointly by the Buffalo District of the Corps of Engineers (hereinafter referred to as "Buffalo District" for brevity) and The Hydro-Electric Power Commission of Ontario (hereinafter referred to as "H.E.P.C." for brevity) prior to effecting revisions in the models. Accordingly, additional bottom and water surface elevations were obtained in the Cascades during November and December 1951, as described in paragraphs 17 and 19 of Appendix B.

5. Another factor which produced conflicting information and resulted in differences in the hydraulic performance of the models was that the Buffalo District and the H.E.P.C. had each produced a water surface contour map developed independently by stereoscopic methods from different aerial photographs. As these maps differed and also indicated levels at specific points which were considered to be erroneous, it was concluded that this method, under such circumstances, produced results of doubtful accuracy, because of the difficulties mentioned in paragraph 18, Appendix B. Therefore, the H.E.P.C. and the Buffalo District agreed to develop jointly a new water surface contour map for use in the reverification of both models.

6. The final hydrographic and water surface contour maps of the Canadian Cascades prepared jointly by the H.E.P.C. and the Buffalo District are shown in Appendix B, Plates B-2 and B-3. The hydrographic map was developed from aerial and ground surveys as well as from soundings obtained by helicopter and "kytoons" during the winter of 1950-51 and November and December 1951. Improved data for the preparation of the water surface contour map were obtained by deter-

mining the location and elevation of the water contacts of a reflected high-powered light beam which was directed on the Cascades and moved in a pattern to ensure complete coverage thereof in a field operation during November 1951. This operation, known as the searchlight survey is described in detail in paragraph 19 of Appendix B.

7. On 10 May 1951, the H.E.P.C. made observations of water surface elevations at 25 points in the Cascades along the Canadian and Goat Island shorelines, as shown on Plate F-1, for a total river flow of 217,000 cfs at Buffalo. The water surface elevations observed at 23 of these were used in the verification of the models, but the data at two of them X and W, were eliminated because prototpye elevations were affected by local construction in the area.

8. Plates 5 and 6, Appendix B, Final Report of the Special International Niagara Board, dated 22 June 1928, depict flow distribution along the crest of the Horseshoe Falls based on a float survey made in 1927. In general, floats cannot be depended upon to give precise measurement of discharge but in this case the total flow was known and the floats were used merely to show the relative distribution. It is believed that the present flow pattern is similar to that shown by the 1927 survey in spite of the changes in the crestline due to the recession during the intervening 25 years, hence the 1927 survey was used as a guide in adjusting the distribution of flow along the crest in both models.

9. A vertical aerial photograph of the Canadian Cascades and Horseshoe Falls taken on December 29, 1950 during an extremely heavy ice flow depicts general prototype streamlines through the Cascades. This aerial picture, Plate F-2, was used as a guide in developing the streamlines in the models.

MODEL CONSTRUCTION AND VERIFICATION

10. Hydraulic verification of the models was accomplished by adjusting the roughness of the stream bed by trial until accurate reproduction of observed prototype data was obtained. The required roughness was provided by using sheets of expanded metal in the channels above the Cascades and small vertical strips of metal in the more turbulent Cascades reach.

11. Verification of the Cascades sections of both models was a time-consuming trial and error process. Adjustments were necessary until satisfactory agreement existed with the three main sources of data mentioned above, i.e., water levels as obtained by the searchlight survey, crest flow distribution set out in the 1927 survey report, and prototype streamlines revealed by photographs of the passage of ice. The river flow of the 10th of May 1951, at which time the shoreline elevations discussed in paragraph 7 were obtained, was then introduced in each model. The model water surface elevations at these locations were measured for comparison with the observed prototype elevations, and any necessary local adjustments were made.

12. Adjustment of each model to observed prototype data insures agreement between the models and prototype and between the models themselves for the adjustment flow. However, intra-model agreement for extremely high and low flows was also required. Therefore, tests No. 105 and No. 112 of the revised testing programme, giving total flows over the Falls of 50,000 cfs and 150,000 cfs, respectively, were made. The detailed flow conditions for these tests are presented in Table F-1.

VERIFICATION RESULTS

13. Water surface elevations in the Cascades observed in the two models for the searchlight flow are shown by numerals on Plates F-3 and F-4. The water surface elevations in each model generally agree within one foot with the prototype elevations shown by the contours. Flow dis-

tribution patterns around the crest of the Falls for the searchlight flow for both models are shown on Plate F-5 along with the flow pattern resulting from the 1927 float survey. Similarly, mass diagrams are shown on Plate F-6. Corresponding flow patterns and mass diagrams for tests No. 105 and No. 112 are shown on Plates F-7, F-8 and F-9. A study of these plates indicates that the general crest flow pattern determined from the 1927 float survey is closely followed in the models for the searchlight flow, Plate F-5, and test No. 112, Plate F-8. Equally important is the fact that the two models have similar flow patterns for the very low and very high crest flows. The data from which the graphs were plotted are listed in Table F-4.

14. A further check on the reliability of the two models to reproduce the prototype is shown on Table F-6 and Plates F-10 and F-11. Table F-6 presents a comparison of observed prototype water surface elevations along the Canadian and Goat Island shorelines with water surface elevations obtained in the models for the same river conditions. Locations of the shoreline points are shown on Plate F-1. Plates F-10 and F-11 show a model-prototype comparison of flow distribution over the Horseshoe Falls with a discharge of 107,000 cfs in that channel. Plate F-12 shows the general reproduction of streamlines in the model Cascades for comparison with ice flow of December 29, 1950, Plate F-2.

15. Compatibility of the two models is shown by a study of Plates F-13 to F-17, which show Cascades and Falls flow conditions for the searchlight flow and for tests No. 105 and No. 112. Table F-3 presents a comparison of water surface elevations in the two models at selected gauging stations throughout the Cascades. The locations of these gauging stations are shown on Plate F-18. In Table F-2 is shown a comparison between the Chippawa-Grass Island Pool gauge levels in both models, and the prototype where possible, for the three verification flows. In Table F-5 is shown a comparison of the depths observed in the two models at points 100 feet apart along a line 50 feet upstream from the crest of the Horseshoe Falls and extending for the length of the crest. While such depths are not considered as reliable as crest discharge measurements, due to the effect of the roughness, reasonably satisfactory agreement appears to exist.

CONCLUSIONS

16. Study of the prototype and model data presented in this report shows that the Cascades sections of the two models are in close agreement with all available prototype information, and that the two models are in reasonable agreement with each other for low and high discharges for which there are no prototype data. Therefore, it is believed that the models are in sufficient agreement with the prototype and with each other to give reliable information on remedial works required for the preservation of the scenic beauty of the Falls which are necessary as a result of the increased power diversions permitted under the Niagara Diversion Treaty of 1950.

TABLE F-1

VERIFICATION TEST CONDITIONS — DISCHARGE IN CFS

Item	1927 Survey	Searchlight Flow	Test 105	Test 112
Inflow at Buffalo	185,000	209,600	180,000	250,000
U. S. Diversions				
Conners Island			55,000	30,000
Adams Station	9,000	8,686	10,000	10,000
Schoellkopf	10,700	23,840	10,000	10,000
Canadian Diversions				
Sir Adam Beck Nos. 1 & 2	15,000	14,037	55,000	15,000
Toronto Power	3,000	15,112		15,000
Ontario Power	6,500	11,136		10,000
Canadian Niagara Power	10,200	10,676		10,000
Flow at head of Cascades		163,037	50,000	185,000
American Falls Flow, Measured				
Vicksburg Model		11,800	1,100	15,250
Islington Model		11,200	1,200	13,800
Horseshoe Falls Flow				
Computed	123,000			
(1) Vicksburg Model measured		115,000	48,600	134,600
(1) Islington Model measured		115,000	49,800	135,200

(1) Measured total Horseshoe Falls flow somewhat different than accumulation of flows in 100-foot panels shown in Table F-4 and on Plates F-6 and F-9 due to different methods of measurement.

TABLE F-2

MODELS — PROTOTYPE COMPARISON

GRASS ISLAND POOL GAUGES — ELEVATIONS IN FEET (1)

	Searchlight Flow			Test 105		Test 112	
Gauge	Prototype	Vicksburg Model	Islington Model	Vicksburg Model	Islington Model	Vicksburg Model	Islington Model
Conners Island	564.0	563.98	563.6	560.50	560.2	564.22	564.0
Grass Island	562.4	562.48	562.3	558.58	558.5	562.96	562.9
Willow Island	560.7	560.92	560.7	557.56	557.6	561.40	561.1
Gauge 51	561.7	561.70	561.75	557.98	558.1	562.12	562.3
Material Dock	563.2	563.14	562.9	559.60	559.0	563.56	563.4
Slaters Point	563.9	563.80	563.4	560.62	560.1	564.22	564.0

(1) U.S.L.S. 1935 Datum

TABLE F-3

MODELS — PROTOTYPE COMPARISON

CASCADES GAUGES — ELEVATIONS IN FEET (1

Gauge	Bed Elevation		Searchlight Flow			Test 105		Test 112	
	Vicksburg Model	Islington Model	Proto-type	Vicksburg Model	Islington Model	Vicksburg Model	Islington Model	Vicksburg Model	Islington Model
a	552.9	522.5	532—	533.0	531.8	530.4	530.2	533.7	532.3
b	507.0	501.0	515+	515.3	515.4	512.2	514.2	516.0	516.6
c	505.2	503.5	508.0	508.0	508.2	506.0	505.5	508.9	509.3
d	545.4	542.9	557+	556.4	556.5	552.3	552.7	556.4	557.1
e	506.5	507.5	520—	518.7	519.4	514.3	515.5	520.3	520.9
f	500.8	501.2	515—	515.2	515.4	512.0	512.7	515.7	516.1
g	495.0	494.3	510+	508.5	509.7	504.6	505.8	510.8	511.4
h	515.4	514.0	520+	520.9	519.8	516.9	517.2	521.6	521.0
j	547.5	543.9	553+	554.0	552.5	548.5	548.9	554.2	553.3
k	507.0	506.4	522±	522.0	523.8	517.5	517.9	522.3	524.2
l	503.2	503.7	519+	518.8	517.5	514.2	513.2	519.3	518.7
m	501.8	500.7	512—	511.2	510.8	507.6	507.1	511.8	511.7
n	526.0	525.7	530±	530.7	529.0	525.9	Dry	530.6	529.9
o	510.1	510.9	516—	513.3	512.5	511.5	510.5	514.0	512.7
p	530.5	534.4	540—	539.3	-	535.4	536.0	540.3	538.9

(1) U.S.L.S. 1935 Datum

TABLE F-4

COMPARISON OF VICKSBURG AND ISLINGTON MODELS

CREST FLOW DISTRIBUTION IN HUNDREDS OF CFS PER 100-FOOT CREST PANEL

Panel	1927 Survey		Searchlight Flow				Test 105				Test 112			
			Vicksburg Model		Islington Model		Vicksburg Model		Islington Model		Vicksburg Model		Islington Model	
	Delta Q	Acc Q	Delta Q	Acc Q	Delta Q	Acc Q	Delta Q	Acc Q	Delta Q	Acc Q	Delta Q	Acc Q	Delta Q	Acc Q
Can. 1	2	2	11	11	2	2					16	16	8	8
2	8	10	11	22	5	7			1	1	16	32	20	28
3	17	27	15	37	15	22	2	2	2	3	26	58	22	50
4	10	37	18	55	10	32	2	4	0	3	27	85	25	75
5	31	68	40	95	30	62	4	8	2	5	47	132	45	120
6	89	157	83	178	86	148	29	37	26	31	100	232	97	217
7	154	311	124	302	135	283	49	86	72	103	139	371	162	379
8	152	463	124	426	151	434	61	147	80	183	141	512	181	560
9	105	568	97	523	104	538	45	192	46	229	110	622	126	686
10	83	651	95	618	71	609	50	242	34	263	98	720	82	768
11	82	733	86	704	88	697	32	274	45	308	95	815	100	868
12	100	833	88	792	86	783	41	315	36	344	108	923	99	967
13	87	920	89	881	88	871	52	367	35	379	112	1035	99	1066
14	201	1121	167	1048	175	1046	99	466	102	481	184	1219	181	1247
15	66	1187	37	1085	42	1088	14	480	14	495	47	1266	48	1295
16	33	1220	30	1115	35	1123	3	483	6	501	40	1306	39	1334
17	2	1222	17	1132	11	1134	5	488			27	1333	10	1344
18	3	1225	8	1140	5	1139					10	1343	4	1348
19	2	1227	5	1145	6	1145					6	1349	6	1354
20	2	1229	2	1147	4	1149					2	1351	2	1356
21	2	1231	1	1148	3	1152					2	1353	2	1358
22	2	1233	1	1149	2	1154					1	1354	4	1362
23	2	1235	1	1150	2	1156					1	1355	2	1364
24			1	1151	2	1158					1	1356	2	1366
G.I. 25			1	1152	1	1159					1	1357	2	1368

TABLE F-5

COMPARISON OF VICKSBURG AND ISLINGTON MODELS -- DEPTH OF FLOW AT CREST OF FALLS IN FEET (1)

Crest Panel Number	Bed Elev.		Searchlight Flow				Test 105				Test 112			
	Vicksburg Model	Islington Model	Vicksburg WS Elev.	Model Depth	Islington WS Elev.	Model Depth	Vicksburg WS Elev.	Model Depth	Islington WS Elev.	Model Depth	Vicksburg WS Elev.	Model Depth	Islington WS Elev.	Model Depth
Can. 1	502.6	503.0	504.1	1.5	504.2	1.2	503.0	0.4	Dry	0	504.2	1.6	504.8	1.8
2	502.6	502.3	503.9	1.3	504.2	1.9	503.0	0.4	502.7	0.4	504.6	2.0	505.7	3.4
3	502.1	502.6	504.0	1.9	505.6	3.0	502.8	0.7	503.5	0.9	504.7	2.6	506.0	3.4
4	501.7	502.7	503.3	1.6	503.4	0.7	502.3	0.6	Dry	0	503.6	1.9	503.6	0.9
5	502.1	502.0	505.5	3.4	504.4	2.4	502.6	0.5	Wet	0	506.3	4.2	504.8	2.8
6	501.3	500.8	505.7	4.4	505.4	4.6	503.1	1.8	503.1	2.3	506.7	5.4	505.6	4.8
7	499.3	496.8	507.0	7.7	506.0	9.2	503.7	4.4	503.4	6.6	507.1	7.8	507.1	10.3
8	496.5	496.1	505.9	9.4	506.4	10.3	502.5	6.0	503.2	7.1	506.6	10.1	507.1	11.0
9	498.5	497.5	505.3	6.8	507.5	10.0	502.8	4.3	504.1	6.6	505.9	7.4	508.3	10.8
10	495.9	499.6	504.5	8.6	506.3	6.7	501.9	6.0	503.9	4.3	503.9	8.0	509.6	10.0
11	500.7	499.9	506.8	6.1	507.0	7.1	504.2	3.5	504.6	4.7	507.7	7.0	508.0	8.1
12	501.2	500.6	507.8	6.6	506.8	6.2	505.2	4.0	505.6	5.0	508.3	7.1	509.8	9.2
13	501.1	500.7	506.4	5.3	507.4	6.7	504.7	3.6	505.6	4.9	506.7	5.6	508.1	7.4
14	493.9	493.7	508.9	15.0	509.8	16.1	506.0	12.1	506.2	12.5	509.3	15.4	509.7	16.0
15	504.5	504.4	509.0	4.5	508.5	4.1	506.6	2.1	505.7	1.3	509.4	4.9	508.6	4.2
16	501.8	501.2	506.4	4.6	505.4	4.2	503.0	1.2	503.3	2.1	506.3	4.5	506.2	5.0
17	503.5	Island	503.9	0.4	Island	-	Dry	0	Dry	0	504.2	0.7	Dry	0
18	502.1	502.4	503.6	1.5	503.5	1.1	502.5	0.4	502.5	0.1	503.9	1.8	503.4	1.0
19	502.5	502.0	504.1	1.6	503.2	1.2			502.6	0.6	504.3	1.8	503.4	1.4
20	502.6	502.8	504.3	1.7	504.0	1.2			Dry	0	504.3	1.7	503.6	0.8
21	505.1	504.4	505.6	0.5	504.9	0.5					506.3	1.2	505.3	0.9
22	505.1	504.5	505.7	0.6	506.2	1.7					505.6	0.5	-	-
23	503.8	505.1	504.5	0.7	Dry	0					504.7	0.9	506.5	1.4
24	504.1	504.5	504.7	0.6	-						504.7	0.6	506.1	1.6
G.I. 25	504.6	505.0	505.4	0.8	-						505.3	0.7	506.7	1.7

(1) 50 ft. upstream

TABLE F-6

MODELS — PROTOTYPE COMPARISON

CANADIAN AND GOAT ISLAND SHORELINE PROFILES — MAY 10, 1951

TEST CONDITIONS

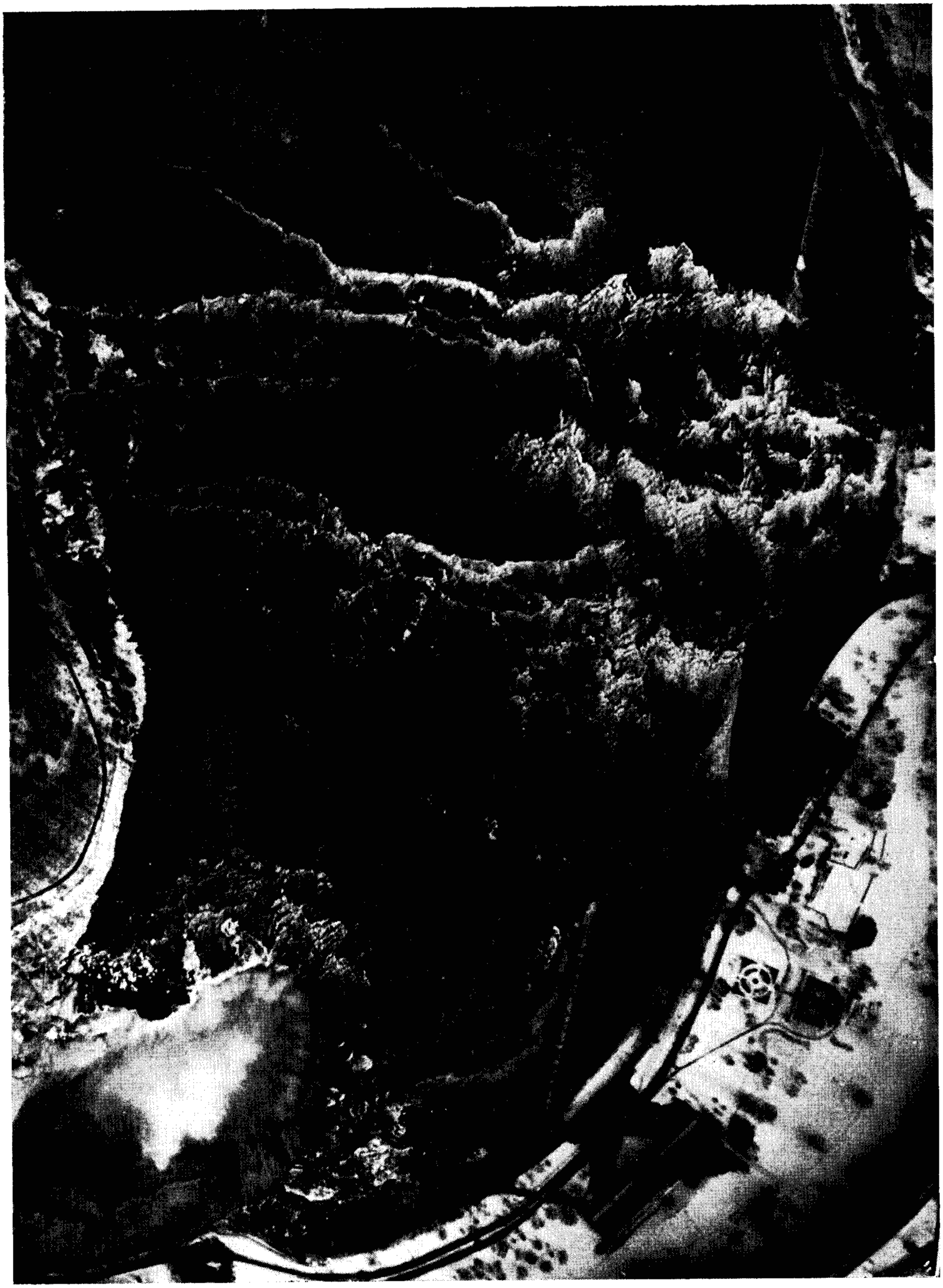
Discharge at Buffalo	217,200 cfs
Diversions	
Sir Adam Beck #1	14,900
Schoellkopf	23,500
Adams Station	8,600
Ontario	10,450
Toronto	14,000
Canadian Niagara	9,750
Total flow at head of Cascades	170,200
Total Falls flow	136,000
American Falls flow	13,400
Horseshoe Falls flow	122,600

WATER SURFACE ELEVATIONS IN FT. USLSD

Gauge (1)	Prototype	Vicksburg Model	Islington Model
A	552.13	551.8	551.0
B	538.28	537.6	539.0
C	534.24	534.6	534.1
D	531.78	533.9	532.5
E	531.98	534.5	533.1
F	516.73	519.0	517.5
G	516.02	515.7	516.3
H	515.95	516.2	515.8
J	516.09	516.3	515.9
K	512.86	513.8	513.7
L	513.08	511.7	512.7
M	510.25	511.5	510.9
N	508.81	510.0	508.8
O	507.21	508.1	508.7
P	505.70	505.5	505.3
Q	506.38	Dry	506.8
R	512.15	512.3	511.0
S	514.55	514.2	512.7
T	519.61	520.0	519.0
U	522.51	524.3	524.5
V	528.09	529.8	528.2
Y	559.69	559.8	559.8
Z	557.32	557.9	557.0

(1) For location see Plate F-1

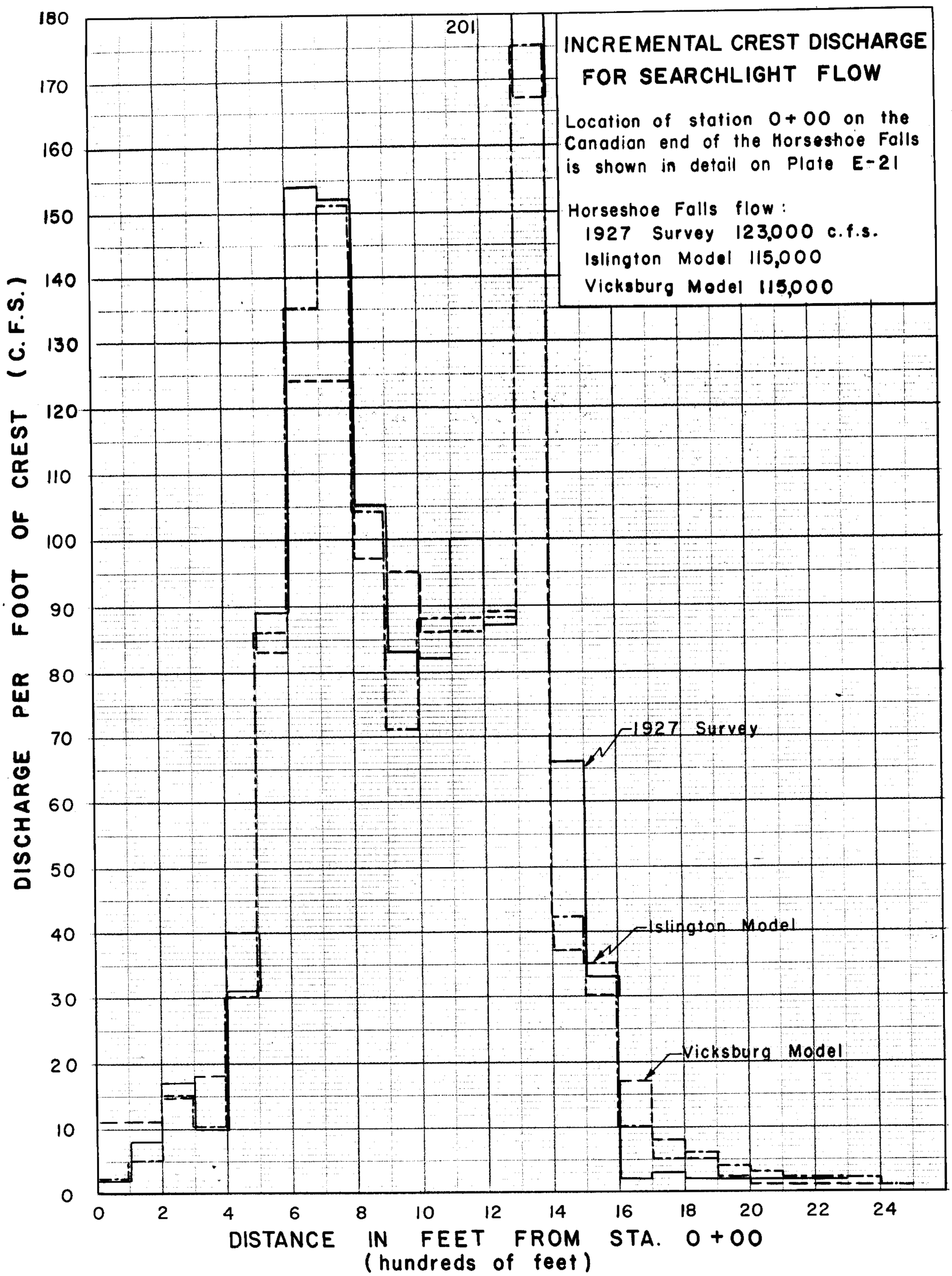
LOCATION PLAN OF SHORELINE GAUGES



AERIAL PHOTOGRAPH OF PROTOTYPE, DEC. 29, 1950

COMBINED FALLS DISCHARGE OF 113,000 c.f.s. SHOWING STREAMLINES

PLATE F-2



INCREMENTAL CREST DISCHARGE FOR SEARCHLIGHT FLOW
Location of station 0+00 on the Canadian end of the Horseshoe Falls is shown in detail on Plate E-21
Horseshoe Falls flow:
1927 Survey 123,000 c.f.s.
Islington Model 115,000
Vicksburg Model 115,000
201
1927 Survey
Islington Model
Vicksburg Model
DISCHARGE PER FOOT OF CREST (C.F.S.)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
0
2
4
6
8
10
12
14
16
18
20
22
24
DISTANCE IN FEET FROM STA. 0+00
(hundreds of feet)

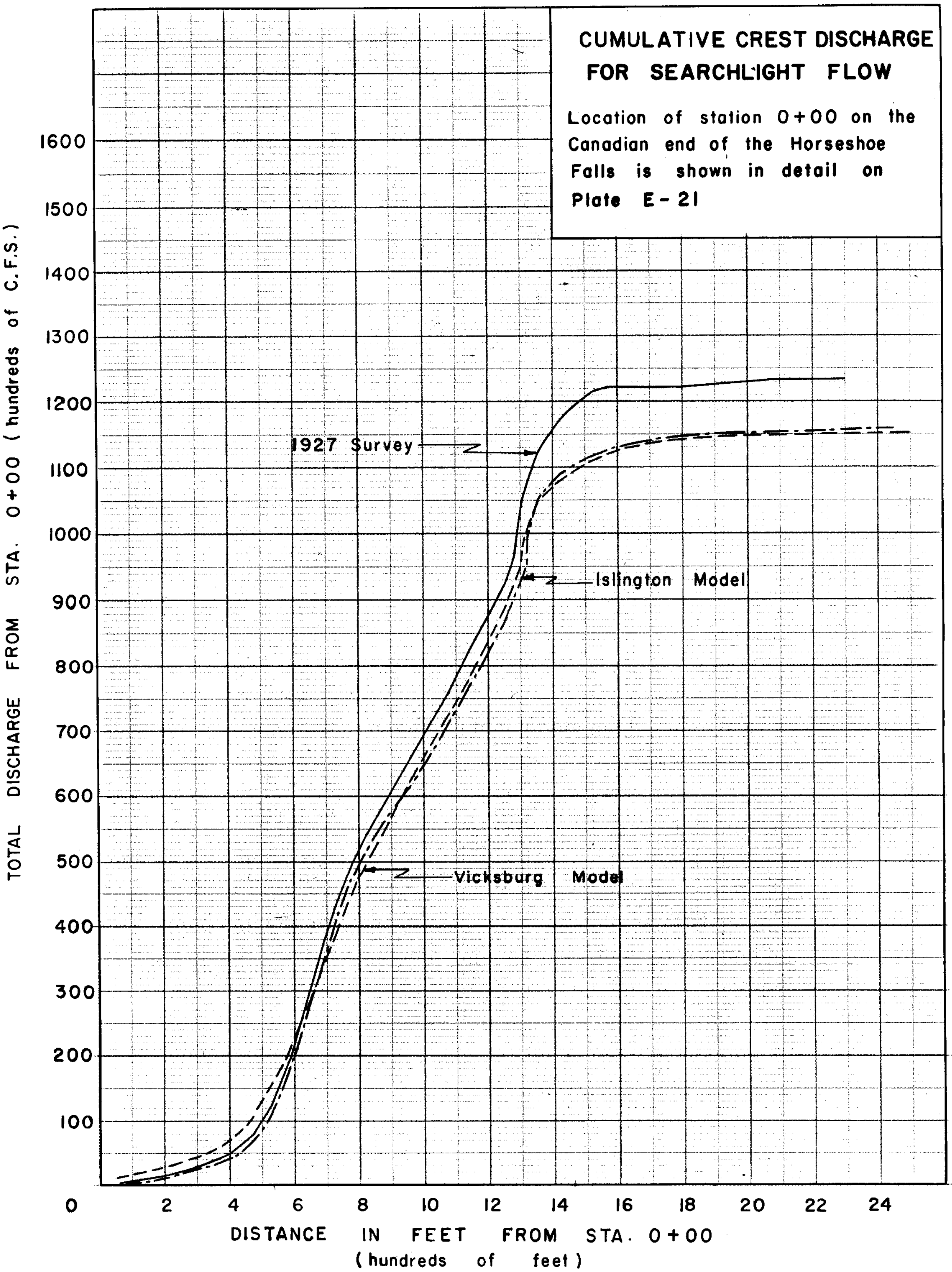
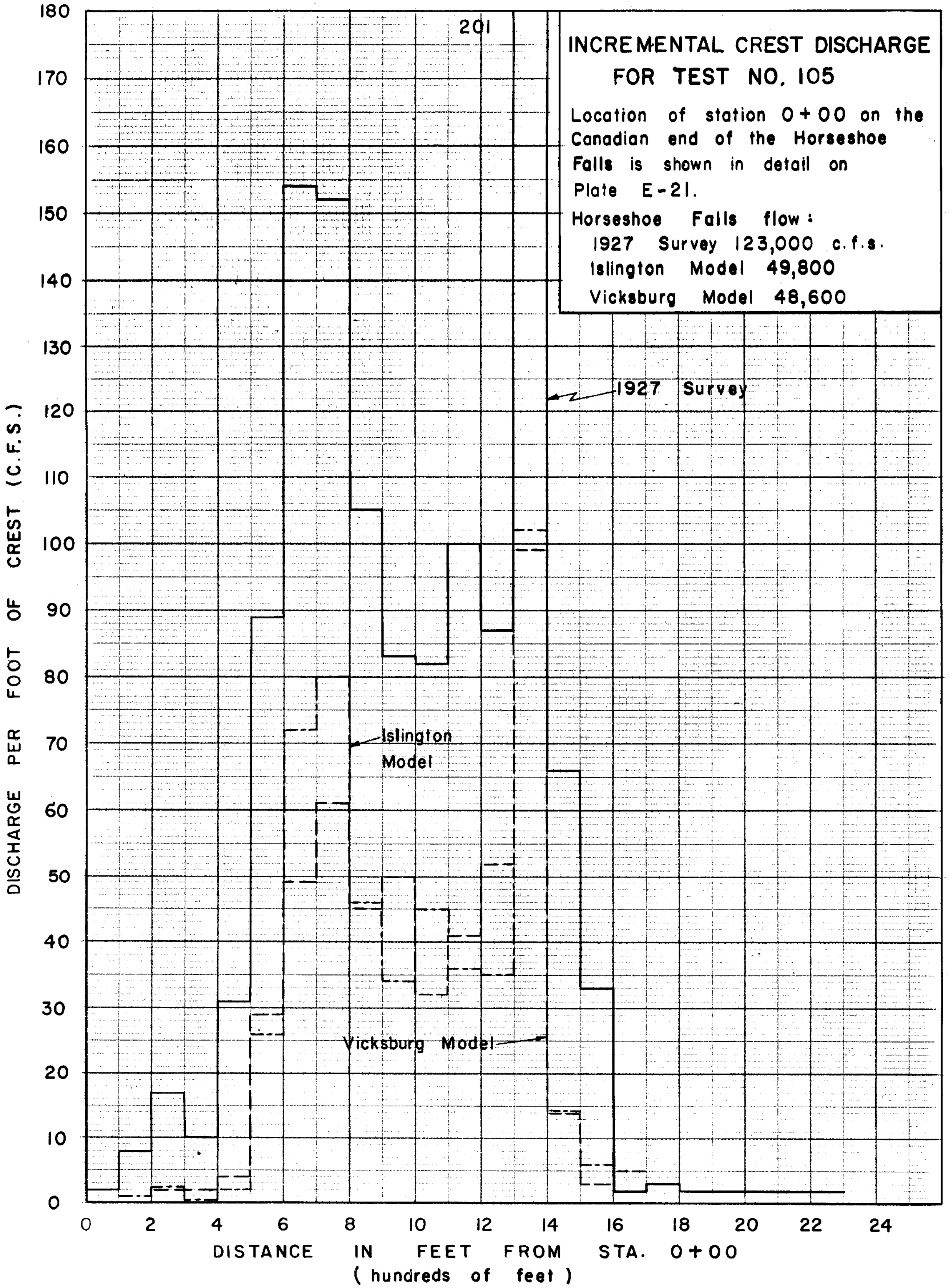

CUMULATIVE CREST DISCHARGE FOR SEARCHLIGHT FLOW
Location of station 0+00 on the Canadian end of the Horseshoe Falls is shown in detail on Plate E-21
1927 Survey
Islington Model
Vicksburg Model
TOTAL DISCHARGE FROM STA. 0+00 (hundreds of C.F.S.)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
2
4
6
8
10
12
14
16
18
20
22
24
DISTANCE IN FEET FROM STA. 0+00
(hundreds of feet)

PLATE F-6


INCREMENTAL CREST DISCHARGE
FOR TEST NO. 105
Location of station 0+00 on the Canadian end of the Horseshoe Falls is shown in detail on Plate E-21.
Horseshoe Falls flow:
1927 Survey 123,000 c.f.s.
Islington Model 49,800
Vicksburg Model 48,600
201
1927 Survey
Islington Model
Vicksburg Model
DISCHARGE PER FOOT OF CREST (C.F.S.)
DISTANCE IN FEET FROM STA. 0+00
(hundreds of feet)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
0
2
4
6
8
10
12
14
16
18
20
22
24

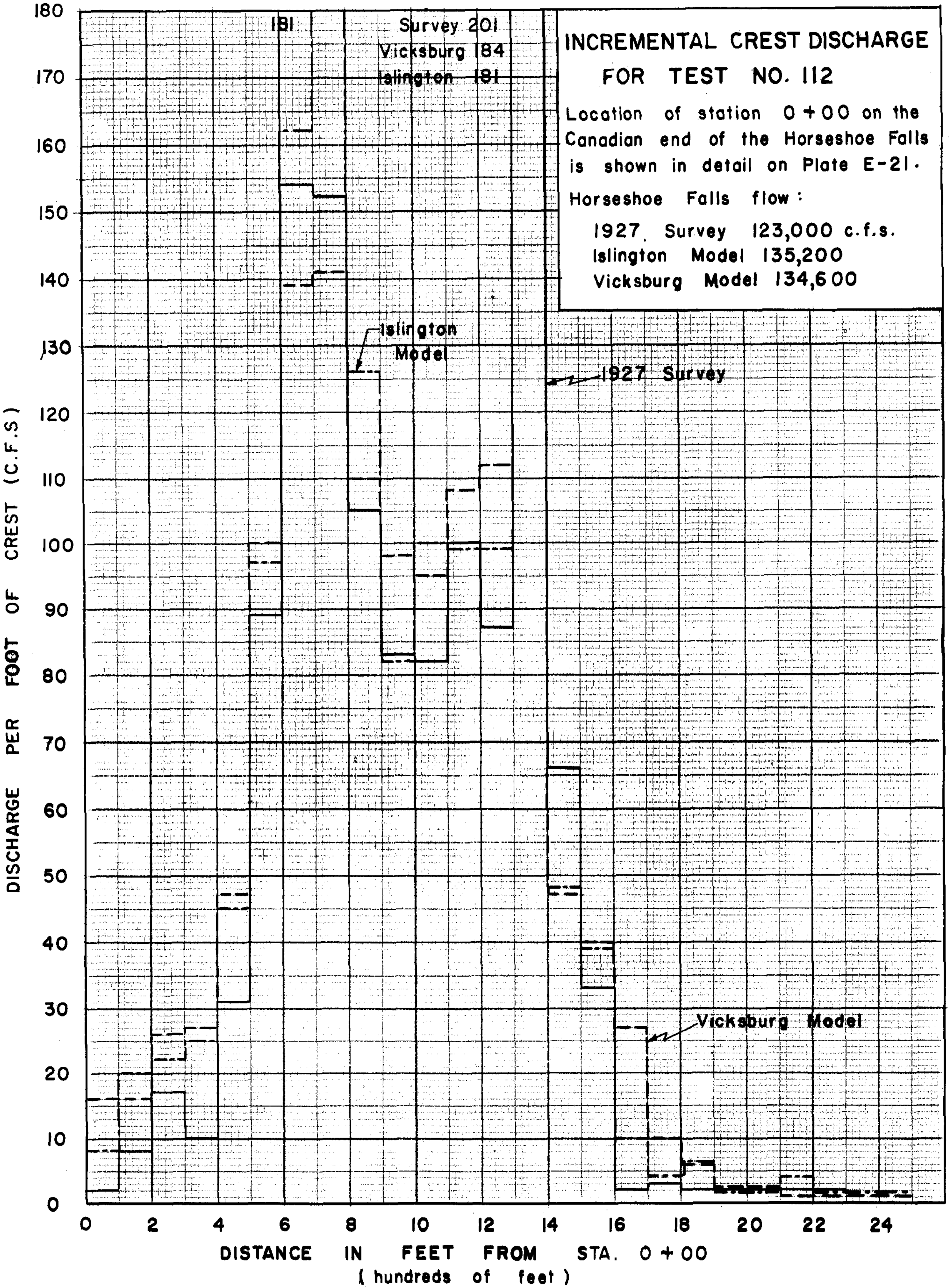
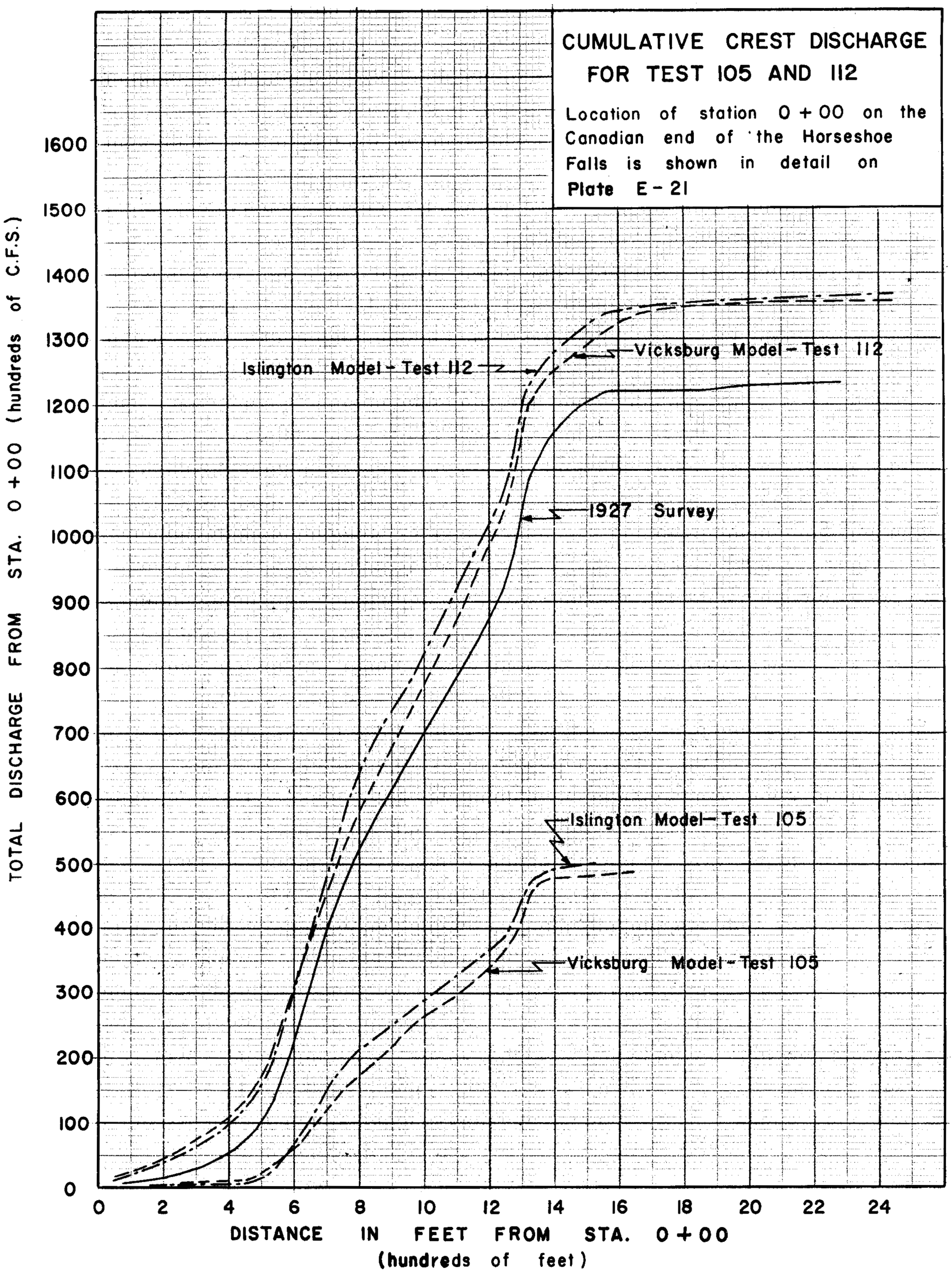
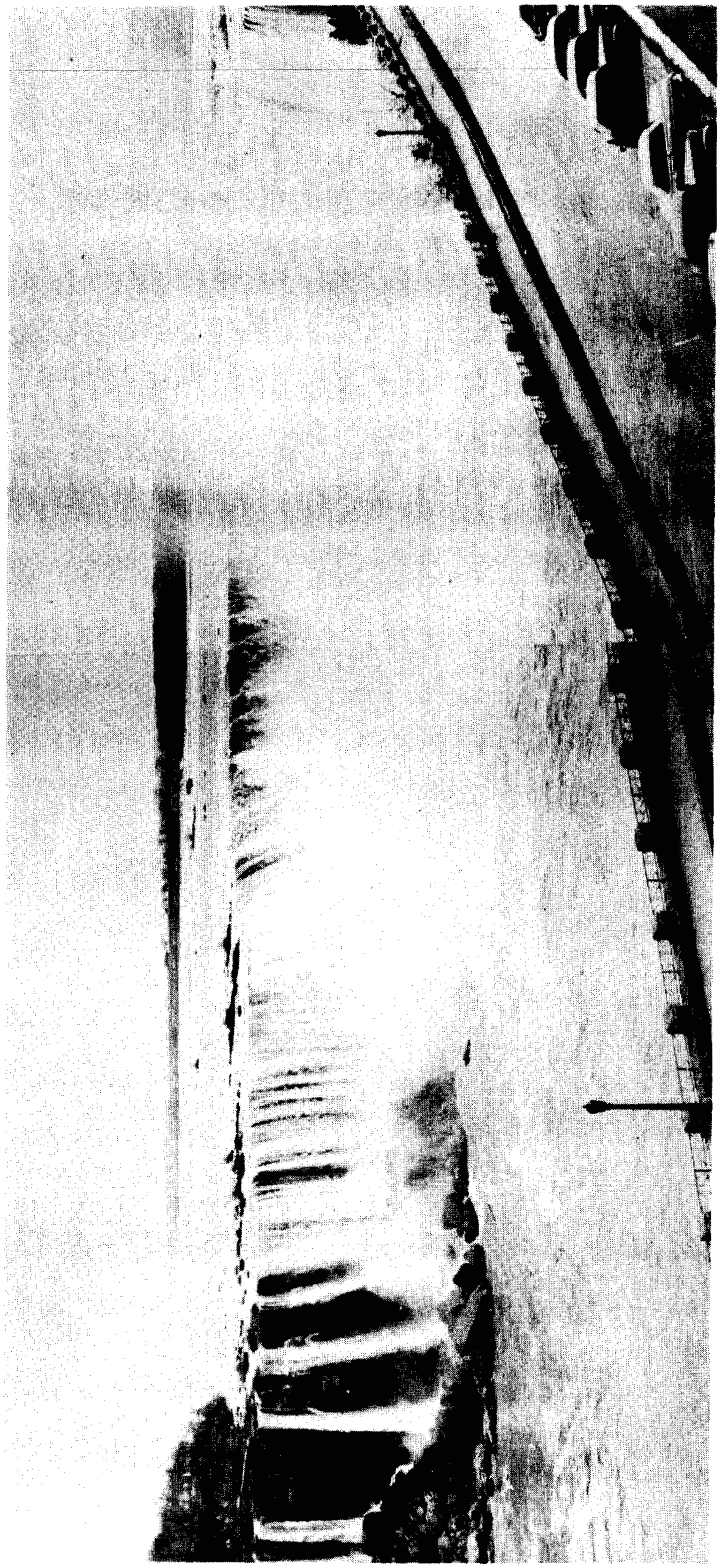

INCREMENTAL CREST DISCHARGE
FOR TEST NO. 112
Location of station 0 + 00 on the Canadian end of the Horseshoe Falls is shown in detail on Plate E-21.
Horseshoe Falls flow:
1927 Survey 123,000 c.f.s.
Islington Model 135,200
Vicksburg Model 134,600
181
Survey 201
Vicksburg 184
Islington 181
Islington Model
1927 Survey
Vicksburg Model
DISCHARGE PER FOOT OF CREST (C.F.S.)
DISTANCE IN FEET FROM STA. 0 + 00
(hundreds of feet)
0
2
4
6
8
10
12
14
16
18
20
22
24
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180

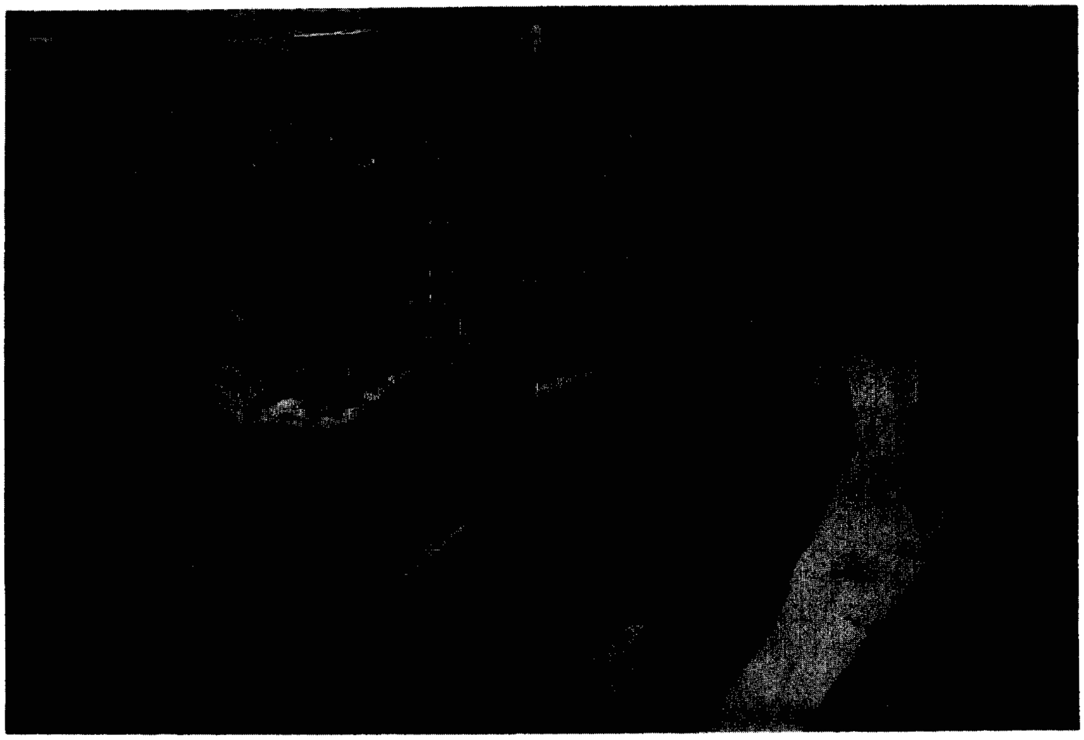
PLATE F-8


CUMULATIVE CREST DISCHARGE
FOR TEST 105 AND 112
Location of station 0 + 00 on the Canadian end of the Horseshoe Falls is shown in detail on Plate E-21
Islington Model - Test 112
Vicksburg Model - Test 112
1927 Survey
Islington Model - Test 105
Vicksburg Model - Test 105
TOTAL DISCHARGE FROM STA. 0 + 00 (hundreds of C.F.S.)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
0
2
4
6
8
10
12
14
16
18
20
22
24
DISTANCE IN FEET FROM STA. 0 + 00
(hundreds of feet)

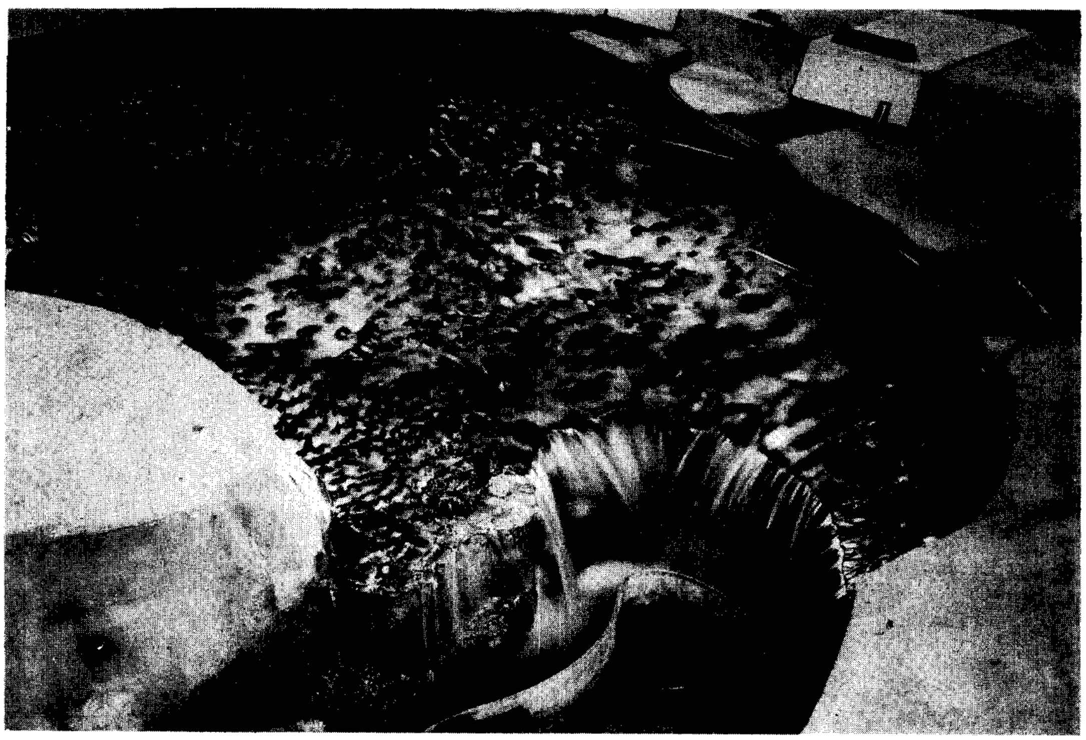


HORSESHOE FALLS ON DECEMBER 5, 1950.

FLOW OVER HORSESHOE FALLS 107,000 c.f.s.

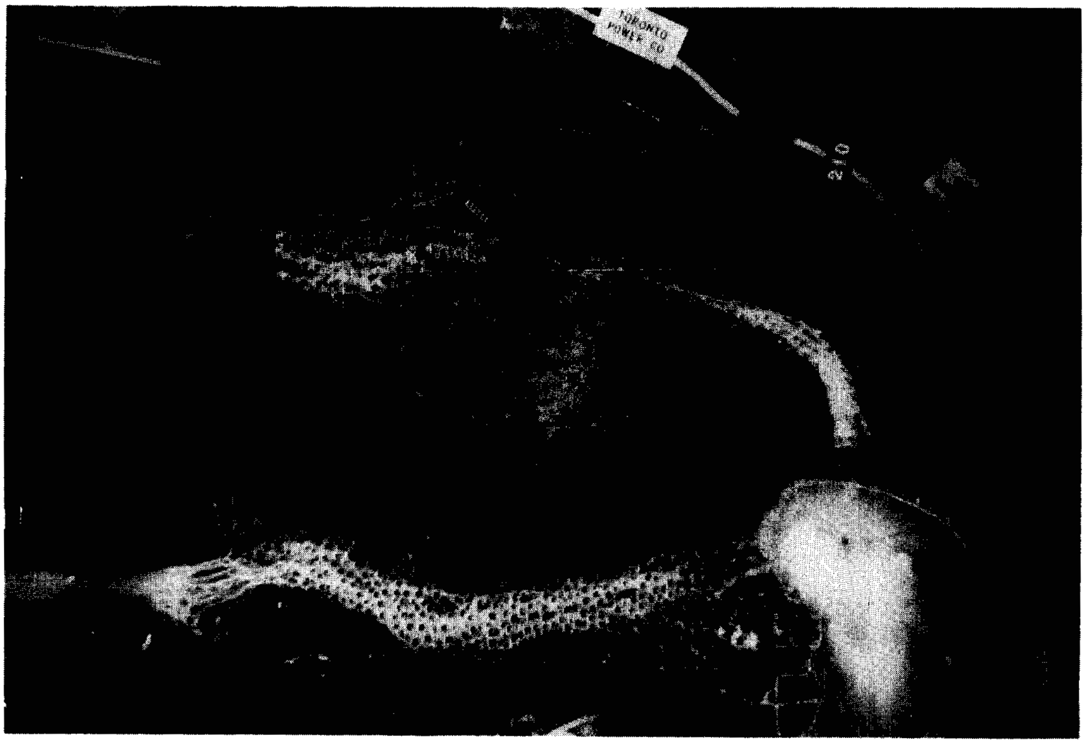


ISLINGTON MODEL WITH 107,000 C.F.S. FLOW

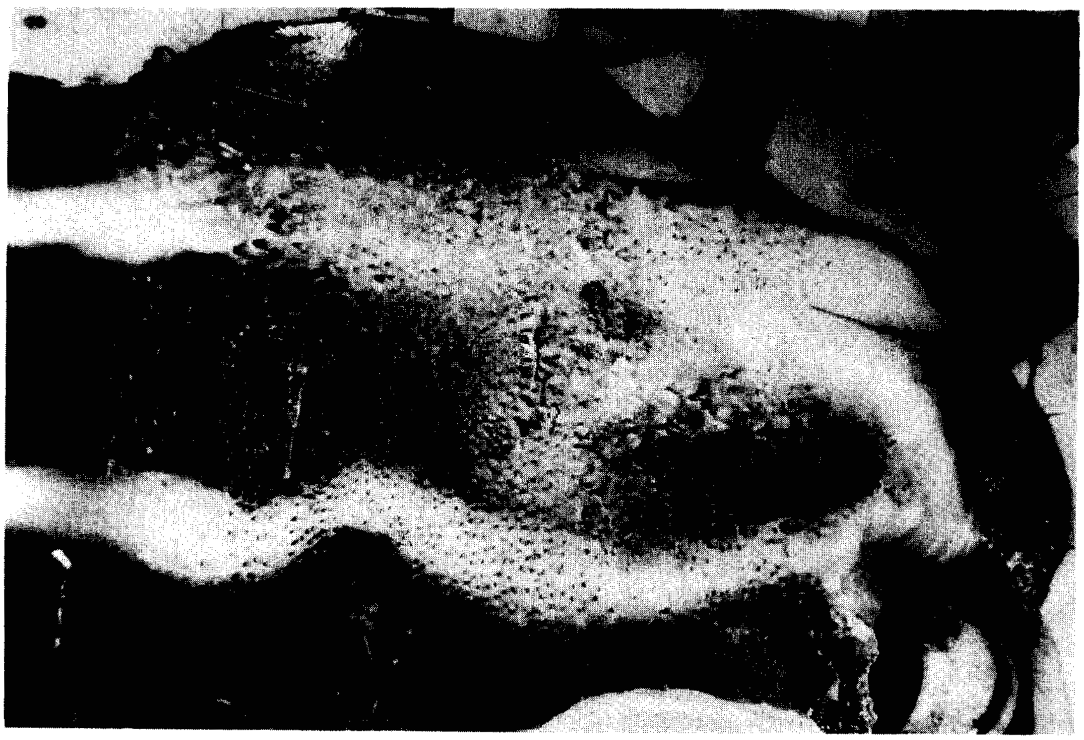


VICKSBURG MODEL WITH 107,000 C.F.S. FLOW

HORSESHOE FALLS WITH FLOW OF 107,000 C.F.S.



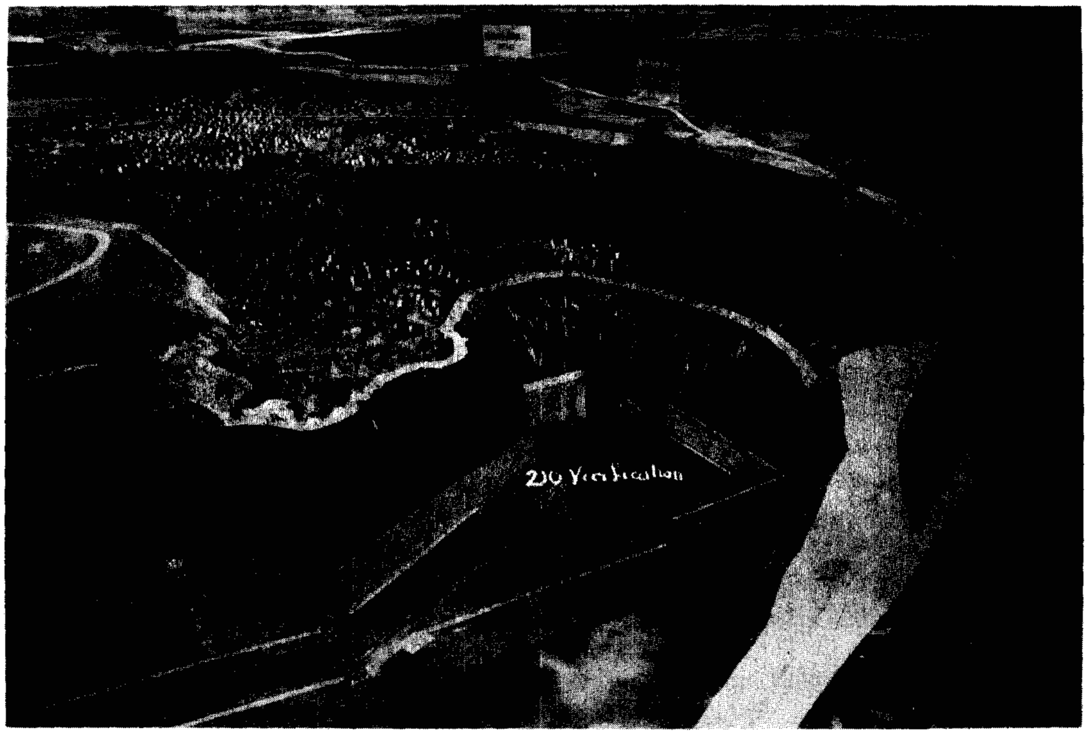
ISLINGTON MODEL WITH 115,000 C.F.S. FLOW



VICKSBURG MODEL WITH 114,300 C.F.S. FLOW

CANADIAN CASCADES WITH SEARCHLIGHT FLOW

PLATE F-12

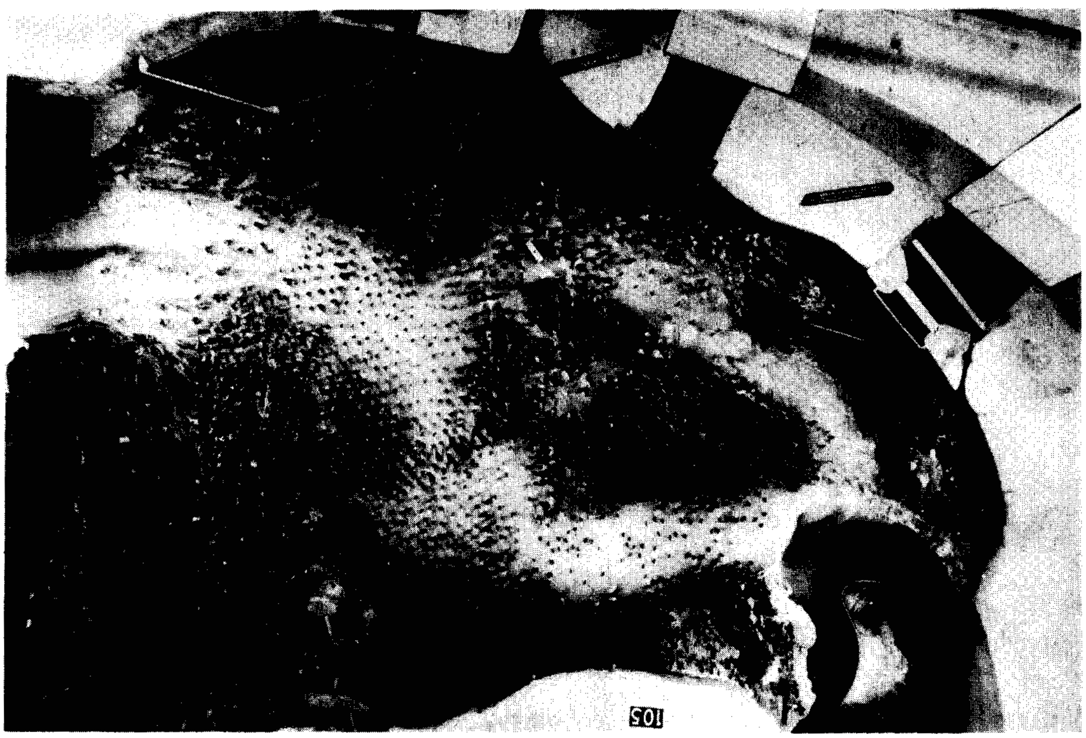


ISLINGTON MODEL WITH 115,000 C.F.S. FLOW

VICKSBURG MODEL WITH 114,300 C.F.S. FLOW

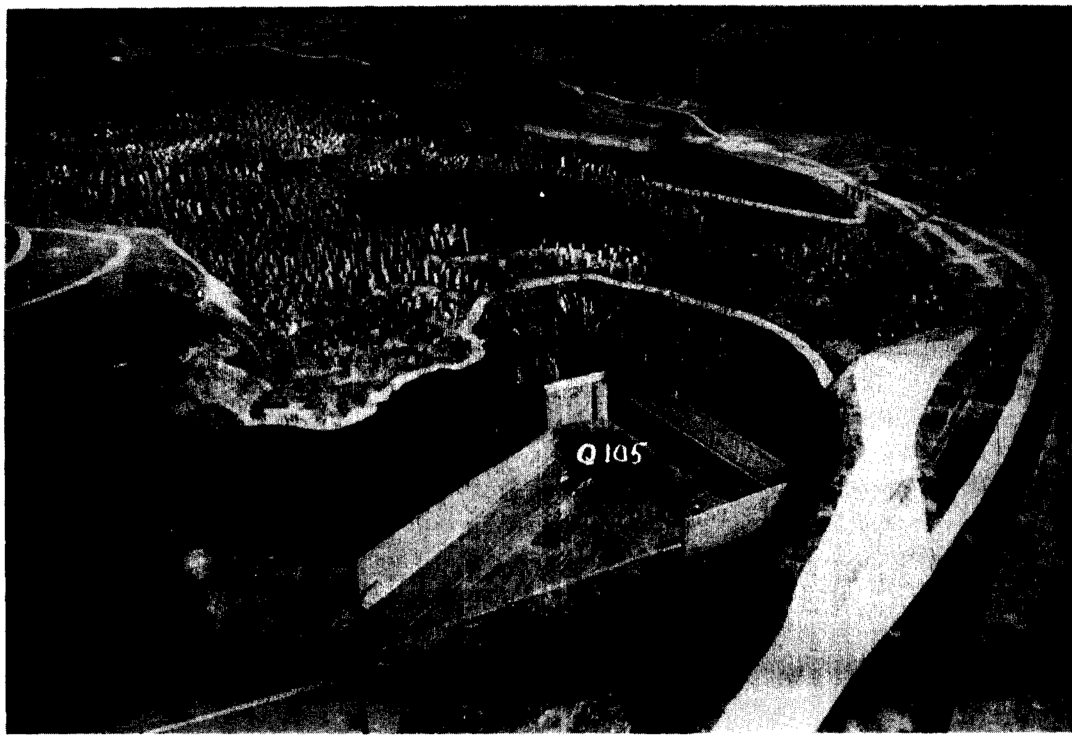
HORSESHOE FALLS WITH SEARCHLIGHT FLOW

ISLINGTON MODEL WITH 49,800 C.F.S. FLOW



VICKSBURG MODEL WITH 48,900 C.F.S. FLOW

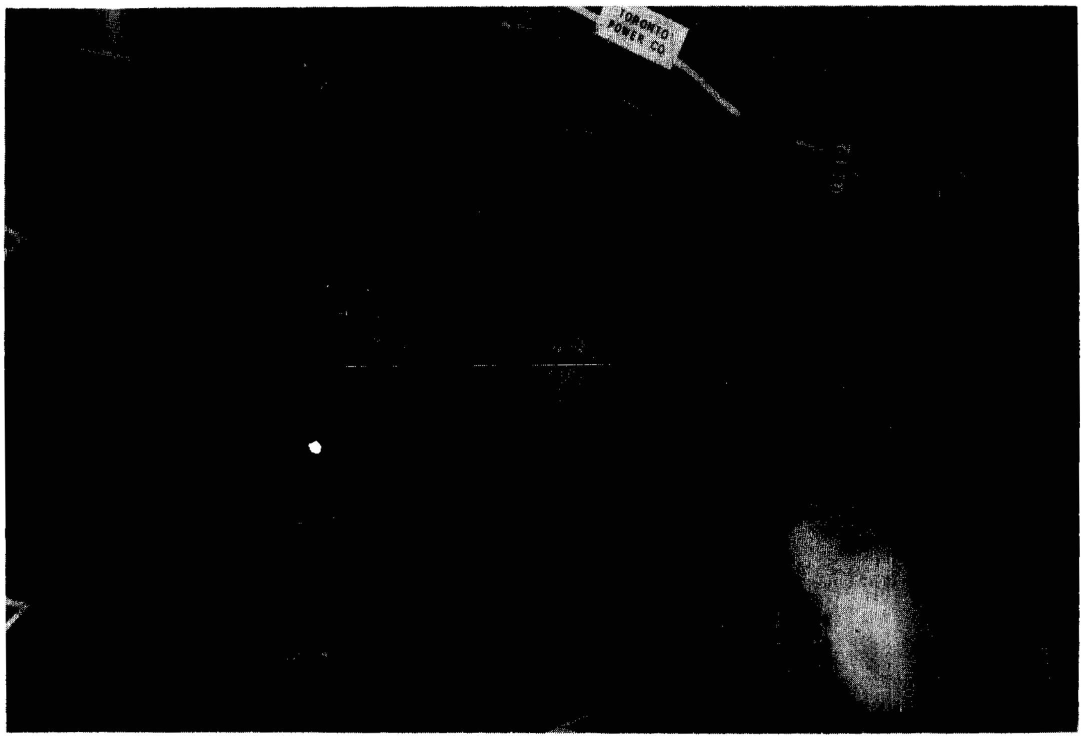
CANADIAN CASCADES WITH TEST 105 CONDITIONS



ISLINGTON MODEL WITH 49,800 C.F.S. FLOW

VICKSBURG MODEL WITH 48,900 C.F.S. FLOW

HORSESHOE FALLS WITH TEST 105 CONDITIONS



ISLINGTON MODEL WITH 134,200 C.F.S. FLOW

VICKSBURG MODEL WITH 134,750 C.F.S. FLOW

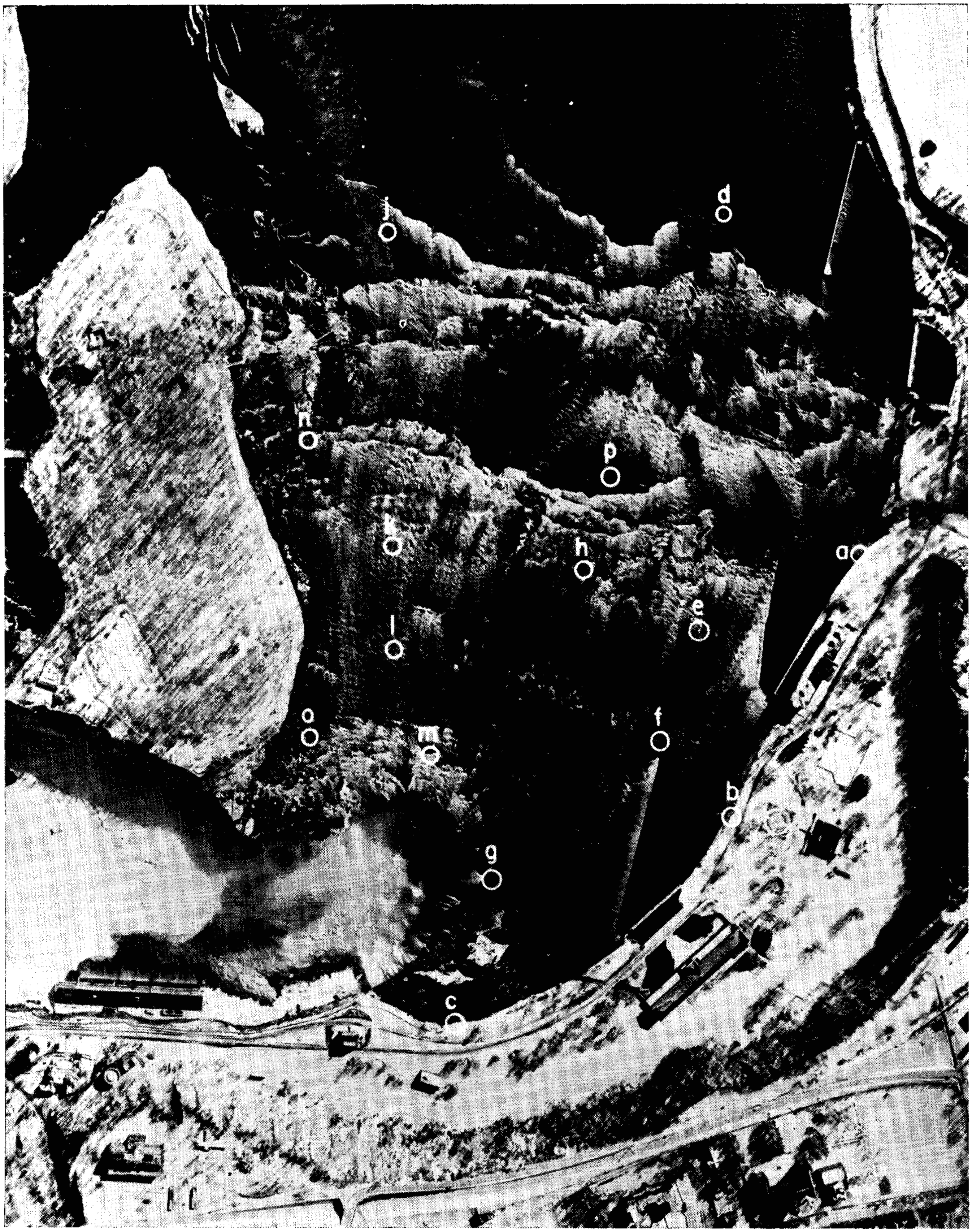
CANADIAN CASCADES WITH TEST 112 CONDITIONS

PLATE F-16

ISLINGTON MODEL WITH 134,200 C.F.S. FLOW

VICKSBURG MODEL WITH 134,750 C.F.S. FLOW

HORSESHOE FALLS WITH TEST 112 CONDITIONS



LOCATION PLAN OF MODEL CASCADES GAUGES

APPENDIX G

VICKSBURG MODEL STUDIES OF REMEDIAL WORKS

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX G

VICKSBURG MODEL, STUDIES OF REMEDIAL WORKS

CONTENTS

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF PLATES

LIST OF PLATES (Cont.)

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX G

VICKSBURG MODEL, STUDIES OF REMEDIAL WORKS

INTRODUCTION

1. Two models of Niagara Falls and Cascades and portions of the river were constructed to assist in the design of remedial works; one by the Corps of Engineers, United States Army, at the Waterways Experiment Station, Vicksburg, Mississippi, and the other by The Hydro-Electric Power Commission of Ontario at Islington, Ontario. The purposes of the model studies were to determine the effects of the additional authorized diversions and to determine the nature and extent of remedial works required to preserve and enhance the scenic beauty of the Falls. This appendix presents a description of the tests conducted at Vicksburg to develop the remedial works and the results obtained. A description of the construction and verification of the Vicksburg model and the tests to determine the effects of the additional authorized diversions are contained in Appendices D and F. Corresponding data on the Islington model may be found in Appendices E, F, and H.

NEED AND FUNCTION OF REMEDIAL WORKS

2. Results of tests of existing conditions presented in Appendix D indicated that the additional diversions atuhorized by the Treaty of 1950 would result in lower Chippawa-Grass Island Pool levels and that this lowering would expose considerable areas of river bed presently covered, particularly in the vicinity of the head of Goat Island, and would result in some lowering of levels of Lake Erie. The lowering of the Pool elevations also would reduce the flow over the American Falls to such an extent as to impair seriously the spectacle. The model test also indicated that the time required to change the Falls flow from 50,000 cfs to 100,000 cfs and vice versa would be of such length that only a small part of the extra diversion authorized at night during the tourist season could be utilized. It was obvious, therefore, that consideration had to be given to construction of some type of remedial works at the head of the Cascades which would compensate for the added diversions and enable the existing relation between river flow and Pool levels to be maintained. The model tests under existing conditions further indicated that for the 50,000 cfs and 100,000 cfs flows over the Falls, the flows at the flanks of the Horseshoe Falls would be even less than existing flows which are already inadequate for a satisfactory scenic spectacle. Therefore, consideration had to be given also to some type of remedial works that would properly redistribute the flow over the Horseshoe Falls.

TESTS OF CONTROL STRUCTURE AT HEAD OF CASCADES

3. Purpose of tests. — Tests under existing conditions indicated that some type of structure at the head of the Cascades would be necessary to maintain existing Pool levels with added diversions and to reduce the amount of time required to change the Falls flow from 50,000 to 100,000 cfs and vice versa. Tests to develop a structure or works to accomplish these objectives were undertaken after completion of the verification of the upstream reach of the model.

4. Hydraulic design criteria. — It was decided that a structure with openings as wide as possible would be desirable, such a structure to be located downstream from the existing submerged weir which would be left in place. In order to minimize interference with the free passage of ice, the sills of the proposed structure should not be placed at an elevation above the bed of the river except in the portion opposite the existing submerged weir where the sill elevations should not exceed the present weir crest. In all tests at Vicksburg, sluice openings 100 feet wide, separated by piers 10 feet wide, were used.

5. It was further agreed that the remedial works, when in place, should cause no higher water levels upstream therefrom, under a high river flow of 320,000 cfs and certain conditions of sluice openings and new power plant diversions, than under existing conditions with the same river flow. Two sets of operating conditions were specified as follows:

(a) All sluices fully open and new power plants using 25 percent of their combined discharge capacity.

(b) Three sluices closed and others fully open and new power plants using 50 percent of their combined discharge capacity.

6. Effects of control structure on river levels. — Preliminary tests of a control structure extending completely from the Canadian shore to the United States shore on a line located 250 feet downstream from the existing submerged weir, as shown on Plate G-1, were conducted to test conformity with the criteria stated in paragraph 5. Sluices were numbered 1 through 40 with sluice No. 1 located adjacent to the Canadian shore. Test conditions for the hydraulic design criteria and the resulting levels at upstream gauges are given in Table G-1. In these tests, the elevations of the sluice sills were at the maximum levels permitted under the criteria stated in paragraph 4.

7. Additional tests were conducted to determine the effect of the structure on river levels under normal river flows. Three conditions of river flow and diversion were selected and for each, river levels at upstream gauges were determined for (a) existing channel conditions, (b) control structure in place with sills flush with the river bottom, and (c) control structure in place but with sills at the maximum levels permitted under the criteria stated in paragraph 4. Tests conditions and results are given in Table G-2.

8. It is indicated by the test results that with the sills of the sluices flush with the channel bottom and all sluices fully open, no significant changes in river levels were recorded. Raising the sills to elevation 553.5 feet in the Canadian channel caused a rise in stage of about 0.3 to 0.5 foot in the Chippawa-Grass Island Pool, but operation of new power plants at 25 percent of their discharge capacity compensated for the channel restriction caused by the structure with all sluices fully open. Likewise, operation of new plants at 50 percent of their discharge capacity compensated for the channel restriction caused by the structure with three sluices closed.

9. Length of structure required to regulate Pool levels. — Tests were conducted to determine the number of sluices and sluice combinations required to be closed in order to maintain the Chippawa-Grass Island Pool at the same level under increased diversions as under present diversions. Tests were conducted also to determine the effect of opening or closing sluices near the Canadian shore on the distribution of flow over the Horseshoe Falls. Test conditions and results of the tests are shown in Table G-3. Results of these tests indicated that the opening or closing of gates near the shore had no measurable effect on the distribution of flow over the Horseshoe Falls and that normal Pool levels could be maintained by operating only the gates in the Canadian channel thus making a structure extending completely across the river unnecessary. Tests were then made to determine the number of gates necessary to maintain the desired Pool levels with only the gates in the Canadian channel in operation. Test conditions and results of these tests are presented in Table G-4. Tests of the partial structure indicated that 15½ sluices or 1,705 feet of structure would be required to maintain Pool levels. The Board, on September 23, 1952, decided that 1,550 feet of control structure would be used initially to regulate Pool levels and that after its construction this length could be increased if found necessary. A third series of tests was then conducted to determine Pool levels that would obtain with 1,550 feet of control structure in the Canadian channel. Test conditions and results shown in Table G-5 indicated that Pool

levels would be from 0.1 foot below the required level with a river flow of 200,000 cfs to 0.5 foot below for a river flow of 240,000 cfs.

TESTS OF HORSESHOE FALLS REMEDIAL WORKS

10. Purpose of tests. — The Treaty of 1950 specified that Canada and the United States recognize "their primary obligation to preserve and enhance the scenic beauty of the Niagara Falls and River". Since tests under existing conditions as reported in Appendix D indicated that the flows of 50,000 and 100,000 cfs over the Horseshoe Falls were not sufficient to maintain the existing spectacle, tests were undertaken to devise remedial works which would redistribute the available flow over the Falls.

11. Design criteria. — The design criteria which was used to determine the adequacy of the remedial works tested specified that the works should produce a flow of six to eight cfs per foot on the Goat Island flank and a flow of 10 to 12 cfs per foot on the Canadian flank with a total Falls flow of 100,000 cfs. The design criteria further specified that for a total Falls flow of 50,000 cfs the remedial works should provide complete coverage of both flanks and an unbroken crest-line flow at all times.

12. Types of works tested. — It was decided to test works consisting of excavations of the flanks, submerged weirs in the deep streams in the central portion of the Horseshoe, and shortening of the crest length by means of fills at the extreme ends of the Horseshoe. It was decided to test first, remedial works consisting of excavations alone and then to incorporate crest fills to determine the reduction in the volume of excavation which could be accomplished thereby. From an examination of the configuration of the shoreline, it appeared that a fill of 300 feet on the Goat Island flank and 100 feet on the Canadian flank would be desirable and fills of these dimensions were tested on the Vicksburg model. Upon completion of tests on plans including excavations, it was proposed to test works consisting of submerged weirs both alone and in combination with excavations. Based on the results of preliminary tests and on data from similar but more extensive tests on the Islington model, it was decided that although the desired distribution of flow could be accomplished with submerged weirs, they would be difficult and extremely hazardous to construct and maintain and would mar the natural appearance of the Falls. Construction costs would be as much as for the excavation plans. Accordingly, it was decided to make no further tests of plans including submerged weirs.

13. Tests on excavation plans. — In arriving at an adequate remedial plan of excavation on the flanks of the Horseshoe Falls, excavations were progressively increased in depth with increments of one to two feet and, by trial-and-error methods, the location and depth of dredging was varied until the criteria described in paragraph 11 were reached. Each plan was developed wih a river flow of 200,000 cfs and power diversions that resulted in total Falls flows of 50,000 cfs and 100,000 cfs. The plan requiring the minimum amount of excavation, as determined from these tests, and meeting the criteria set forth in paragraph 11 except for a break in the crest flow near an island about 900 feet from the Goat Island end of the Horseshoe is shown on Plate G-2 as Plan R-11. The plan of excavation including the crest fills referred to in paragraph 12 is shown on Plate G-3 as Plan R-12. This plan was developed by the same method as Plan R-11 and gave about the same results, including the break in crest flow. Comparable plots of the distribution of flow along the crest of the Falls for Plans R-11 and R-12 are shown on Plates G-4 and G-5. Examination of these plots shows that Plan R-12 including crest fills increased the flow over the Canadian flank and gave about the same results on the Goat Island flank as Plan R-11, with considerably less excavation.

14. To eliminate the break in the crest flow near the island referred to above and to further increase the flow over both flanks, Plan R-17, shown on Plate G-6, comprising excavation R-17 on the Goat Island flank, excavation CE on the Canadian flank, and the crest fills, was developed. This was accomplished by increasing the dredging on both flanks of the Horseshoe Falls and dredging in the vicinity of the Island. Plan R-17 gave the desired results for a complete range of river flows and diversions as shown by tests referred to in the next two paragraphs.

15. To document completely Plan R-17 and to ensure that it would give the desired results for a full range of river flows and power diversions it was tested with flow conditions of the 16 base tests described in Appendix D and six additional tests added to include data at low, average, and high river discharges. The six additional test conditions are numbered 117 through 122. Test conditions and results of the 16 base tests (101 through 116) without remedial works are given in Appendix D. Test conditions and results for the six additional tests without remedial works are given in Tables G-6 through G-10 of this appendix.

16. For each test with remedial works in place, the Pool was held to the elevation it would have under existing conditions by the closure of the required number of sluices in the control structure. Test conditions are shown in Table G-11. Test results are given in Tables G-12 through G-16. Comparative photographs of the model Falls for tests 117 through 122 without remedial works and with the proposed works in place are shown on Plates G-7 through G-12. Photographs of the model Falls for test conditions 101, 105, 109, and 113 with the proposed remedial works in place are shown on Plates G-13 and G-14 for comparison with similar photographs of the same test conditions without remedial works as shown on Plates D-8 and D-9 of Appendix D. Plots of the crest flow distributions for test conditions 117 through 122 both both with and without the proposed works are shown on Plates G-15 through G-20.

17. Examination of Plates G-15, G-17, and G-19, shows that the proposed remedial works, excavation R-17 on the Goat Island flank and excavation CE on the Canadian flank including crest fills, produced flows averaging from 23 to 29 cfs per foot of crest on the Canadian flank of the Horseshoe Falls and about 11 cfs per foot of crest on the Goat Island flank under the full range of conditions to be expected during the tourist season days. Photographs on Plates G-8, G-10, and G-12 show that the proposed works provided an unbroken curtain of water for the range of conditions to be expected during the non-tourist season and nights of the tourist season. The flows over the flanks during the tourist season days exceed the design criteria stated in paragraph 11 by substantial amounts. Lesser plans tested, such as R-12 as indicated on Plate G-3, produced flows closer to the design criteria for the tourist season days but failed to meet the criteria for the non-tourist season.

18. Cofferdam tests. — Eight tests were conducted to determine the location, length, and height of the cofferdam necessary to protect the remedial works excavation (during construction) on the Goat Island flank. The various plans were developed with the cofferdam on the Canadian flank (as developed on Islington model) installed in the model as shown on Plates G-21 through G-24 and with river flows of 320,000 cfs and 209,000 cfs and total Falls flows of 240,000 cfs and 126,000 cfs, respectively. Top elevations of the cofferdam were such that they were not overtopped by the Cascades flow. Two typical plans tested are shown on Plates G-21 through G-24. Results of the tests indicated that in order to protect completely the area to be excavated, the cofferdam would have to extend to the crest of the Falls. Plan 2, shown on Plates G-23 and G-24 would probably be the best plan since the cofferdam would be located in shallower water and would be shorter than for plan 1; however, either would be satisfactory.

19. Test of structure to control flow in Channel leading to American Falls. — Tests with a bascule-type structure located at the head of the channel leading to the American Falls were made to determine if it would limit the amount of water going over the American Falls to a maximum of 7,000 cfs during the non-tourist season and tourist season nights. This would increase the flow over the Horseshoe Falls thereby reducing the amount of excavation required to meet the design criteria for flow over the flanks. Twelve tests of a bascule-type structure of various lengths and locations, operating in conjunction with the main control structure, were conducted for the purpose of determining the location, length and height of structure necessary. The test results indicated that in order to meet the above criteria, the structure should be located as shown on Plate G-1, and should be 450 feet long and seven feet high. Plate G-25 shows the results of one test with the structure in operation plotted against the results of the same test without the structure in operation. Examination of Plate G-25 shows a slight increase on the amount of flow over the flanks of the Horseshoe Falls. The Board decided that the increase was insufficient to warrant further consideration of this structure.

CONCLUSIONS

20. It was concluded from the tests of control works that normal Pool elevations could be maintained with a structure located 250 feet downstream from the existing submerged weir with only sluices in the Canadian channel operating and that for adequate redistribution of flow over the crest of the Horseshoe Falls, Plan R-17 was the most effective. Model tests indicated that the combination of the above plans would meet all requirements set forth for the design of remedial works.

TABLE G-1

CONTROL STRUCTURE FROM U.S. SHORE TO CANADIAN SHORE
EFFECT ON RIVER LEVELS UNDER HIGH RIVER FLOWS

Item	Existing channel condition	Control structure with sluices 21 & 22 closed, others fully open	Control structure with sluices 5, 6, 7, 21 & 22 closed, others fully open
Inflow		Flow in cfs	
Buffalo	320,000	320,000	320,000
U. S. Diversions			
Conners Island	0	15,000	30,000
Adams Sta.	6,810	6,810	6,810
Schoellkopf	23,450	23,450	23,450
Canadian Diversions			
Sir Adam Beck No. 1	15,258	15,258	15,258
Sir Adam Beck No. 2	0	10,000	20,000
Toronto	13,915	13,915	13,915
Ontario	10,093	10,093	10,093
Canadian Niagara	9,728	9,728	9,728
Gauge		River levels in feet above U.S.L.S. 1935 Datum	
Buffalo	576.70	576.70	576.70
Peace Bridge	573.40	573.22	573.28
Black Rock	570.64	570.52	570.52
Huntley	569.62	569.56	569.56
Hickory	568.90	568.84	568.84
Tonawanda	568.72	568.60	568.60
Edgewater	567.88	567.70	567.76
Upper Cayuga	566.92	566.74	566.80
Lower Cayuga	566.74	566.56	566.56
Conners Island	566.38	566.14	566.14
Grass Island	564.82	564.70	564.94
Gauge 51	563.80	563.98	564.64
Material Dock	565.60	565.42	565.54
Slaters Point	566.26	566.02	566.14
Little Six Creek	567.28	567.10	567.10
Black Creek	568.66	568.54	568.54
Millers Creek	569.44	569.32	569.32

TABLE G-2

CONTROL STRUCTURE FROM U.S. SHORE TO CANADIAN SHORE

EFFECT ON RIVER LEVELS AND FALLS FLOW

Channel condition: (a) Existing condition — no control structure; (b) Control structure — sluice sills flush with river bed; (c) Control structure — sluice sills at maximum levels under criteria stated in paragraph 4

Item	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
Inflow									
Buffalo	209,600	209,600	209,600	200,000	200,000	200,000	200,000	200,000	200,000
U. S. Diversion									
Conners Island				65,000	65,000	65,000	5,000	5,000	5,000
Adams & Schoellkopf	32,526	32,526	32,526	20,000	20,000	20,000	20,000	20,000	20,000
Canadian Diversion									
Sir Adam Beck No. 1	14,037	14,037	14,037	28,000	28,000	28,000	15,000	15,000	15,000
Sir Adam Beck No. 2				27,000	27,000	27,000	10,000	10,000	10,000
Cascades plants	36,924	36,924	36,924	10,000	10,000	10,000			
Falls Flows									
American	12,000	12,000	12,000	1,660	1,660	2,450	10,250	10,250	11,810
Horseshoe	115,000	115,000	115,000	48,600	48,600	47,700	139,500	139,500	138,000
Gauge	River levels in feet above U.S.L.S. 1935 Datum								
Buffalo	572.80	572.80	572.80	572.32	572.32	572.26	572.38	572.38	572.32
Peace Bridge	569.62	569.44	569.50	568.90	568.96	568.84	569.20	569.08	569.08
Black Rock	567.40	567.22	567.34	566.20	566.14	566.08	566.98	566.80	566.86
Huntley	566.62	566.50	566.56	565.30	565.24	565.12	566.26	566.08	566.14
Hickory	566.14	566.02	566.14	564.82	564.76	564.70	565.78	565.66	565.72
Tonawanda	566.02	565.90	566.02	564.70	564.64	564.58	565.66	565.54	565.60
Edgewater	565.36	565.18	565.36	563.80	563.80	563.74	565.00	564.88	564.94
Upper Cayuga	564.40	564.28	564.58	561.94	561.94	561.94	564.04	563.92	564.04
Lower Cayuga	564.22	564.16	564.34	561.52	561.52	561.52	563.86	563.74	563.86
Conners Island	563.98	563.86	564.04	560.74	560.62	560.74	563.56	563.44	563.56
Grass Island	562.48	562.42	562.84	559.00	559.06	559.36	562.12	562.12	562.42
Gauge 51	561.70	561.70	562.24	558.46	558.52	559.06	561.40	561.40	561.82
Material Dock	563.14	563.08	563.44	559.72	559.72	559.90	562.78	562.72	562.96
Slaters Point	563.80	563.68	564.04	560.92	560.80	560.86	563.44	563.32	563.50
Little Six Creek	564.70	564.58	564.76	562.54	562.48	562.48	564.40	564.22	564.34
Black Creek	565.84	565.66	565.84	564.28	564.10	564.04	565.48	565.24	565.36
Millers Creek	566.38	566.26	566.44	565.00	564.88	564.82	566.02	565.84	565.90

TABLE G-3

CONTROL STRUCTURE FROM U.S. SHORE TO CANADIAN SHORE

SLUICE CLOSURE REQUIRED FOR POOL CONTROL

Test Number	Discharge in cfs: River at Buffalo	Diversions: Conners Island	Diversions: Adams & Schoellkopf	Diversions: Sir Adam Beck 1 & 2	Diversions: Cascades Plants	Falls	(1) Elevation of Pool at Material Dock Gauge	Sluices required to be closed for Pool elevation indicated in preceding column
1	140,000	-	33,000	36,000	21,000	50,000	561.04	3 thru 6
2	140,000	-	33,000	36,000	21,000	50,000	561.04	1 thru 4
3	140,000	25,000	20,000	45,000	-	50,000	561.04	3 thru 10
4	140,000	25,000	20,000	45,000	-	50,000	561.04	1 thru 9
5	200,000	55,000	20,000	55,000	20,000	50,000	563.08	3 thru 15
6	200,000	55,000	20,000	55,000	20,000	50,000	563.08	1 thru 13
7	200,000	55,000	20,000	64,000	11,000	50,000	563.08	3 thru 16½
8	200,000	55,000	20,000	64,000	11,000	50,000	563.08	1 thru 14½
9	233,000	60,000	33,000	55,000	31,750	53,250	563.98	3 thru 15½
10	233,000	60,000	33,000	55,000	30,800	54,200	563.98	1 thru 14
11	240,000	60,000	33,000	62,000	31.500	53,500	564.22	3 thru 16
12	240,000	60,000	33,000	62,000	31,850	53,150	564.22	1 thru 14½

(1) Elevation under present conditions for the river flow indicated, elevation in feet U.S.L.S. 1935 datum.

TABLE G-4

CONTROL STRUCTURE FROM CANADIAN SHORE TO TOWER ISLAND

SLUICE CLOSURE REQUIRED FOR POOL CONTROL

Test Number	Discharge in cfs								(1) Elevation of Pool at Material Dock Gauge	Number of sluices required to be closed for elev. indicated in preceeding column
	River at Buffalo	Diversions			Falls					
		U.S.	Sir Adam Beck 1 & 2	Cascades plants	American	Horseshoe	Total			
1	170,000	35,000	35,000	-	7,200	92,800	100,000		562.1	4
2	170,000	60,000	59,000	1,000	8,900	41,100	50,000		562.1	13½
3	200,000	50,000	50,000	-	12,000	88,000	100,000		563.0	9
4	200,000	75,000	61,000	14,000	12,800	37,200	50,000		563.0	14½
5	240,000	70,000	64,000	6,000	18,000	82,000	100,000		564.2	12½
6	240,000	95,000	64,000	23,800	18,500	38,700	57,200		564.2	15½

(1) Elevation of Pool under present conditions for indicated river flow, elevations in feet U.S.L.S. 1935 Datum.

TABLE G-5

1,550-FOOT LONG CONTROL STRUCTURE STAGE — DISCHARGE RELATIONSHIP

Test Number	Discharge in cfs							Elevation of Pool at Material Dock gauge	
	River at Buffalo	Diversions			Falls			Present Conditions (1)	With control structure in place and all sluices closed
		U.S.	Sir Adam Beck 1 & 2	Cascades plants	American	Horseshoe	Total		
1	170,000	60,000	59,000	1,000	9,000	41,000	50,000	562.1	562.2
2	200,000	75,000	61,000	14,000	12,100	37,900	50,000	563.0	562.9
3	220,000	85,000	62,000	23,000	13,600	36,400	50,000	563.6	563.3
4	230,000	90,000	63,000	27,000	14,600	35,400	50,000	563.9	563.5
5	240,000	95,000	64,000	26,800	15,500	38,700	54,200	564.2	563.7

(1) Elevation of Pool under present conditions for indicated river flow, elevations in feet U.S.L.S. 1935 Datum.

TABLE G-6

TEST CONDITIONS

Tests 117 through 122 (1) — Without Remedial Works

Item	Test 117	Test 118	Test 119	Test 120	Test 121	Test 122
Inflow						
Buffalo	170,000	170,000	200,000	200,000	240,000	240,000
U. S. Diversions						
Conners Island	15,000	40,000	30,000	55,000	50,000	62,500
Adams Sta.						12,500
Schoellkopf	20,000	20,000	20,000	20,000	20,000	20,000
Canadian Diversions						
Sir Adam Beck #1	9,550	16,100	13,600	15,000	17,500	17,500
Sir Adam Beck #2	25,450	42,900	36,400	40,000	46,500	46,500
Toronto				10,000		11,000
Ontario		1,000		10,000	6,000	10,000
Canadian Niagara						10,000
Outflow						
Total flow at head of Cascades	100,000	51,000	100,000	70,000	106,000	81,000
American Falls flow	5,500	2,000	5,500	3,500	6,000	4,000
Total Falls Flow	100,000	50,000	100,000	50,000	100,000	50,000
Horseshoe Falls Flow						
Computed	94,500	48,000	94,500	46,500	94,000	46,000
Measured	94,500	48,000	94,500	46,500	94,000	46,000

(1) Test conditions for tests 101 through 116 given in Table D-2, Appendix D.

TABLE G-7

WATER SURFACE ELEVATIONS — CASCADES GAUGES

Tests 117 through 122 (1) — Without Remedial Works

Cascades gauges (2)	Water surface elevations in feet, U.S.L.S. 1935 Datum					
	Test 117	Test 118	Test 119	Test 120	Test 121	Test 122
a	532.4	530.8	532.4	529.7	532.4	530.0
b	515.5	513.0	515.2	511.7	515.2	509.1
c	508.0	Dry	508.0	Dry	508.0	Dry
d	554.5	552.6	554.2	552.5	554.2	553.2
e	516.5	514.5	516.5	513.2	516.3	513.4
f	514.8	512.4	514.8	511.0	514.8	509.2
g	509.7	506.2	509.5	505.3	509.4	505.0
h	518.7	517.0	519.3	517.8	518.8	517.8
j	551.4	548.3	551.5	548.8	551.9	550.0
k	521.7	519.0	521.7	519.8	521.6	520.1
l	516.5	514.9	517.2	515.2	516.9	515.7
m	509.8	508.0	510.0	508.3	510.0	508.6
n	529.6	526.2	529.3	527.1	529.6	527.7
o	513.8	512.5	514.1	512.6	514.1	513.1
p	537.3	535.7	537.2	536.0	537.3	536.1

(1) Data for tests 101 through 116 given in Table D-4, Appendix D.

(2) For location of gauges see Plate F-18, Appendix F.

TABLE G-8

FLOW DISTRIBUTION — CREST OF FALLS

Tests 117 through 122 (1) — Without Remedial Works

	Discharge in cfs per 100 ft. station					
Station (2)	Test 117	Test 118	Test 119	Test 120	Test 121	Test 122
Can. 1	210	30	410	30	310	30
2	860	30	1,050	30	920	30
3	1,200	30	1,280	30	1,280	30
4	860	30	920	30	920	30
5	2,090	360	2,090	360	2,090	170
6	5,420	2,270	5,420	2,000	5,420	1,340
7	8,250	3,850	8,420	3,620	7,930	2,660
8	9,650	5,420	9,300	4,730	9,130	3,850
9	10,420	5,420	11,000	5,150	10,600	4,350
10	8,420	5,560	8,250	5,420	8,250	5,020
11	8,420	4,470	8,420	4,250	8,420	3,270
12	8,590	3,990	8,760	3,850	8,590	4,350
13	8,060	4,730	8,420	5,020	7,930	5,720
14	13,890	9,870	12,820	10,050	14,550	11,000
15	3,050	1,500	3,050	1,500	3,050	2,180
16	2,270	620	2,270	730	2,180	1,120
17	1,910	510	1,820	670	1,820	1,050
18	470	30	510	90	470	210
19	210	30	210	30	210	90
20	170	30	170		120	30
21	30		30		30	30
22	90		90		90	30
23	30		30		30	
24	0		30		30	
G.I. 25	30		30		30	
Total	94,600	48,780	94,800	47,590	94,400	46,590

(1) Data for tests 101 through 116 given in Table D-5, Appendix D.

(2) For location of 100-ft. stations see Plate D-11, Appendix D.

TABLE G-9

WATER SURFACE ELEVATIONS — CREST OF FALLS

Tests 117 through 122 (1) — Without Remedial Works

Station (2)	Water surface elevations in feet U.S.L.S. 1935 Datum (3)					
	Test 117	Test 118	Test 119	Test 120	Test 121	Test 122
Can. 1	504 3	Dry	504.6	Dry	504.3	Dry
2	504.4	Dry	504.4	Dry	504.2	Dry
3	504.9	503.2	505.0	Dry	504 5	Dry
4	503.5	Dry	504.5	Dry	504.3	Dry
5	503.5	Dry	503.5	Dry	503 2	Dry
6	503.5	501.4	504.2	501.4	504.1	501.4
7	505.0	503.0	505.6	502.6	505.8	502.2
8	504.6	501.9	505.6	501.8	505.4	502.0
9	502 8	502.2	505.1	501.7	503.5	501.2
10	504.1	502.5	500.7	502.1	503.7	502.1
11	506.5	504.2	506.5	504.5	506.4	503.3
12	506 9	505.6	507.3	505.4	507.2	505.8
13	505.2	503.0	505.7	503.3	505.5	503.0
14	505.6	505.5	506.5	506.0	506.5	505.6
15	507.4	506.0	507.3	506.4	507.7	506.4
16	506.2	504.4	506.1	504.7	506.2	505.1
17	504.5	503.9	505.4	504.2	505.1	504.0
18	502.7	502.8	503.8	502.8	503.4	503.2
19	504.5	502.9	504.3	503.5	504.2	503.7
20	504.3	503.5	504.3	504.1	504.3	504.0
21	505.5	Dry	505.7	505.3	505.5	505.6
22	505.3	Dry	506.4	505.2	506.4	505.5
23	505.5	Dry	506.0	Dry	506.0	Dry
24	506.0	Dry	506.3	Dry	506.2	Dry
G.I. 25	507.3	Dry	507.7	Dry	507.7	Dry

(1) Data for tests 101 through 116 given in Table D-7, Appendix D.

(2) For locations of 100-ft stations see Plate D-11, Appendix D.

(3) Elevations measured 50-ft upstream of crest at center of 100-ft stations.

TABLE G-10

DEPTH OF FLOW — CREST OF FALLS

Tests 117 through 122 (1) — Without Remedial Works

Station (2)	Depth of flow in feet (3)					
	Test 117	Test 118	Test 119	Test 120	Test 121	Test 122
Can. 1	1.7	0	2.0	0	1.7	0
2	1.8	0	1.8	0	1.6	0
3	2.8	1.1	2.9	0	2.4	0
4	1.8	0	2.8	0	2.6	0
5	1.4	0	1.4	0	1.1	0
6	2.2	0.1	2.9	0.1	2.8	0.1
7	5.7	3.7	6.3	3.3	6.5	2.9
8	8.1	5.4	9.1	5.3	8.9	5.5
9	4.3	3.7	6.6	3.2	5.0	2.7
10	8.2	6.6	4.8	6.2	7.8	6.2
11	5.8	3.5	5.8	3.8	5.7	2.6
12	5.7	4.4	6.1	4.2	6.0	4.6
13	4.1	1.9	4.6	2.2	4.4	1.9
14	11.7	11.6	12.6	12.1	12.6	11.7
15	2.9	1.5	2.8	1.9	3.2	1.9
16	4.4	2.6	4.3	2.9	4.4	3.3
17	1.0	0.4	1.9	0.7	1.6	0.5
18	0.6	0.7	1.7	0.7	1.3	1.1
19	2.0	0.4	1.8	1.0	1.7	1.2
20	1.7	0.9	1.7	1.5	1.7	1.4
21	0.4	0	0.6	0.2	0.4	0.5
22	0.2	0	1.3	0.1	1.3	0.4
23	1.7	0	2.2	0	2.2	0
24	1.9	0	2.2	0	2.1	0
G.I. 25	2.7	0	3.1	0	3.1	0

(1) Data for tests 101 through 116 given in Table D-8, Appendix D.

(2) For locations of 100-ft. stations see Plate D-11, Appendix D.

(3) Depth of flow measured 50-ft. upstream of crest at center of 100-ft. stations.

TABLE G-11

TEST CONDITIONS

Tests 101 through 122 with 1,550-foot Control Structure and Excavations R-17 and CE

	Discharge in cfs										
	Test 101R	Test 102R	Test 103R	Test 104R	Test 105R	Test 106R	Test 107R	Test 108R	Test 109R	Test 110R	Test 111R
Inflow											
Buffalo	200,000	200,000	200,000	200,000	180,000	200,000	200,000	200,000	200,000	200,000	250,000
U.S. Diversions											
Conners Island	30,000	30,000	30,000	30,000	55,000	65,000	55,000	40,000	5,000	5,000	30,000
Adams Sta.	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Schoellkopf	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Canadian Diversions											
Sir Adam Beck #1	25,000	20,000	15,000	15,000	28,000	28,000	28,000	28,000	15,000	15,000	15,000
Sir Adam Beck #2	25,000	20,000	15,000		27,000	27,000	27,000	27,000	10,000		15,000
Toronto				15,000				12,000			
Ontario		10,000	10,000	10,000		10,000	10,000	10,000		10,000	10,000
Canadian Niagara			10,000	10,000			7,600	6,600			10,000
Outflow											
Total flow at head of Cascades	100,000	110,000	120,000	135,000	50,000	60,000	70,000	85,000	150,000	160,000	170,000
American Falls flow	12,000	12,800	12,500	12,500	8,900	11,000	13,200	13,400	12,000	12,000	20,000
Horseshoe Falls flow	88,000	87,200	87,500	87,500	41,000	39,000	39,200	43,000	138,000	138,000	130,000
Total Falls flow	100,000	100,000	100,000	100,000	50,000	50,000	52,400	56,400	150,000	150,000	150,000

	Test 112R	Test 113R	Test 114R	Test 115R	Test 116R	Test 117R	Test 118R	Test 119R	Test 120R	Test 121R	Test 122R
Inflow											
Buffalo	250,000	200,000	200,000	200,000	200,000	170,000	170,000	200,000	200,000	240,000	240,000
U.S. Diversions											
Conners Island	30,000	55,000	45,000	45,000	45,000	15,000	40,000	30,000	55,000	50,000	62,500
Adams Sta.	10,000	10,000	10,000	10,000	10,000						12,500
Schoellkopf	10,000	10,000	10,000	10,000	10,000	20,000	20,000	20,000	20,000	20,000	20,000
Canadian Diversions											
Sir Adam Beck #1	15,000	28,000	28,000	23,000	15,000	9,550	16,100	13,600	15,000	17,500	17,500
Sir Adam Beck #2		27,000	27,000	22,000	15,000	25,450	42,900	36,400	40,000	46,500	46,500
Toronto	15,000				15,000				10,000		11,000
Ontario	10,000		10,000	10,000	10,000		1,000		10,000	6,000	10,000
Canadian Niagara	10,000			10,000	10,000						10,000
Outflow											
Total flow at head of Cascades	185,000	70,000	80,000	90,000	105,000	100,000	51,000	100,000	70,000	106,000	81,000
American Falls flow	20,000	12,500	13,500	13,000	13,000	7,200	8,900	12,000	12,200	18,000	15,800
Horseshoe Falls flow	130,000	57,500	56,500	57,000	57,000	92,800	41,100	88,000	37,800	82,000	40,000
Total Falls flow	150,000	70,000	70,000	70,000	70,000	100,000	50,000	100,000	50,000	100,000	55,800

TABLE G-12

WATER SURFACE ELEVATIONS — RIVER GAUGES

Tests 101 through 122 with 1,550-foot Control Structure and Excavations R-17 and CE

River Gauges	Water Surface elevations in ft. USLSD										
	Test 101R	Test 102R	Test 103R	Test 104R	Test 105R	Test 106R	Test 107R	Test 108R	Test 109R	Test 110R	Test 111R
Buffalo	572.50	572.50	572.50	572.50	571.72	572.50	572.50	572.50	572.50	572.56	574.60
Peace Bridge	569.08	569.08	569.08	569.08	568.36	569.08	569.08	569.08	569.08	569.14	571.06
Black Rock	566.74	566.80	566.80	566.80	565.90	566.68	566.74	566.86	566.86	566.92	568.60
Huntley	566.14	566.20	566.14	566.20	565.30	566.02	566.14	566.20	566.26	566.26	567.88
Hickory	565.78	565.78	565.84	565.84	564.94	565.60	565.72	565.84	565.90	565.96	567.40
Tonawanda	565.66	565.66	565.66	565.66	564.82	565.42	565.60	565.66	565.72	565.78	567.22
Edgewater	565.00	565.06	565.06	565.06	564.22	564.76	564.94	565.06	565.06	565.18	566.56
Upper Cayuga	564.10	564.10	564.10	564.10	563.08	563.62	563.98	564.16	564.28	564.34	565.66
Lower Cayuga	563.86	563.98	563.92	563.92	562.84	563.50	563.74	563.98	564.10	564.16	565.48
Conners Island	563.56	563.68	563.68	565.62	562.48	563.02	563.44	563.68	563.86	563.92	565.12
Grass Island	562.72	562.78	562.72	562.72	561.88	562.54	562.90	562.96	562.60	562.60	564.16
Willow Island	561.04	561.16	561.10	561.04	560.32	560.92	561.28	561.40	560.98	560.98	562.48
Gauge 51	562.72	562.72	562.66	562.48	562.00	562.60	562.96	563.02	562.06	562.00	564.10
Material Dock	563.02	563.02	563.02	563.02	562.06	562.66	563.02	563.02	563.02	563.08	564.52
Slaters Point	563.56	563.62	563.62	563.68	562.60	563.14	563.50	563.68	563.74	563.80	565.12
Little Six Creek	564.28	564.40	564.34	564.40	563.38	563.98	564.22	564.40	564.52	564.52	565.90
Black Creek	565.18	565.24	565.24	565.24	564.34	565.00	565.18	565.30	565.36	565.42	566.92
Millers Creek	565.78	565.84	565.84	565.84	564.94	565.60	565.78	565.90	565.96	566.02	567.52

River Gauges	Test 112R	Test 113R	Test 114R	Test 115R	Test 116R	Test 117R	Test 118R	Test 119R	Test 120R	Test 121R	Test 122R
Buffalo	574.60	572.50	572.50	572.50	572.50	571.24	571.24	572.50	572.50	574.12	574.12
Peace Bridge	571.00	569.14	569.14	569.14	569.14	568.00	567.94	569.14	569.08	570.58	570.58
Black Rock	568.60	566.80	566.80	566.80	566.80	565.72	565.72	566.86	566.68	568.12	567.88
Huntley	567.88	566.20	566.20	566.20	566.20	565.12	565.12	566.20	566.02	567.46	567.22
Hickory	567.34	565.78	565.78	565.78	565.78	564.82	564.76	565.84	565.66	566.98	566.74
Tonawanda	567.16	565.60	565.66	565.66	565.66	564.70	564.64	565.66	565.48	566.86	566.56
Edgewater	566.50	564.88	565.00	565.06	565.06	564.16	564.10	565.06	564.82	566.14	565.78
Upper Cayuga	565.66	563.98	564.10	564.04	564.04	563.20	563.14	564.16	563.86	565.30	564.76
Lower Cayuga	565.42	563.80	563.86	563.86	563.86	563.02	562.96	563.98	563.62	565.06	564.64
Conners Island	565.06	563.38	563.56	563.50	563.50	562.78	562.60	563.68	563.26	564.70	564.16
Grass Island	564.10	562.84	562.90	562.84	562.84	561.58	561.94	562.78	562.66	563.98	563.38
Willow Island	562.42	561.34	561.40	561.34	561.28	559.84	560.26	561.10	561.04	562.42	561.88
Gauge 51	563.92	562.96	563.02	562.96	562.84	561.28	562.00	562.72	562.72	564.10	563.56
Material Dock	564.52	563.02	563.02	563.02	563.02	562.12	562.12	563.02	562.90	564.22	563.68
Slaters Point	565.06	563.44	563.56	563.56	563.50	562.72	562.66	563.68	563.32	564.76	564.22
Little Six Creek	565.84	564.22	564.34	564.28	564.28	563.38	563.32	564.40	564.10	565.48	565.12
Black Creek	566.86	565.12	565.24	565.24	565.24	564.22	564.22	565.30	565.12	566.50	566.20
Millers Creek	567.46	565.78	565.78	565.78	565.78	564.76	564.76	565.84	565.66	567.10	566.80

TABLE G-13

WATER SURFACE ELEVATIONS — CASCADES GAUGES

Tests 101 through 122 with 1,550-foot Control Structure and Excavations R-17 and CE

Cascades Gauges *	Water Surface elevations in ft. USLSD										
	Test 101R	Test 102R	Test 103R	Test 104R	Test 105R	Test 106R	Test 107R	Test 108R	Test 109R	Test 110R	Test 111R
a	531.7	531.8	531.9	532.1	529.9	529.4	529.8	526.3	534.0	534.1	534.1
b	514.5	514.3	514.2	514.0	511.0	510.4	508.1	507.5	516.0	516.5	515.5
c	504.2	504.1	504.3	504.2	502.3	502.1	501.7	501.6	507.2	507.5	506.5
d	553.3	553.0	553.4	554.1	551.0	550.4	550.7	551.6	555.4	555.4	554.7
e	516.5	516.0	516.2	516.0	512.8	512.5	512.7	511.8	518.8	518.6	518.4
f	514.2	514.0	513.8	513.7	510.4	510.0	508.4	507.7	516.1	516.1	515.2
g	507.7	507.5	507.7	507.5	504.4	504.0	503.3	503.2	510.3	510.6	511.4
h	518.5	518.8	519.1	519.8	517.3	517.4	517.7	517.9	520.9	521.1	521.0
j	551.7	552.1	552.4	553.3	550.4	550.6	550.8	551.4	554.1	554.0	555.0
k	521.3	521.4	521.8	522.1	518.7	518.8	519.4	520.3	523.0	522.9	522.9
l	516.6	516.8	517.0	517.6	514.2	514.2	514.8	515.5	518.2	518.2	517.8
m	509.4	509.4	509.5	509.6	507.2	507.6	507.9	508.2	512.0	512.1	511.3
n	529.4	529.4	529.4	529.9	526.2	526.1	526.8	527.6	530.8	530.8	530.5
o	510.1	510.1	510.1	510.7	509.1	509.2	509.2	509.4	511.0	511.2	511.7
p	537.1	537.6	537.9	538.3	535.1	534.8	535.4	536.2	539.2	539.5	539.5

Cascades Gauges *	Test 112R	Test 113R	Test 114R	Test 115R	Test 116R	Test 117R	Test 118R	Test 119R	Test 120R	Test 121R	Test 122R
a	533.5	530.3	530.6	530.0	530.4	532.3	529.9	531.9	528.6	531.5	525.4
b	516.0	513.0	512.9	512.2	509.6	514.9	511.0	514.6	509.7	514.3	507.2
c	507.0	503.5	503.4	503.9	503.0	504.4	502.2	504.4	501.8	504.0	501.4
d	554.5	552.3	552.4	551.8	552.7	554.2	551.2	553.2	550.3	552.5	551.0
e	518.2	514.6	514.2	513.5	513.6	516.0	512.9	516.0	511.7	516.2	511.4
f	515.3	512.5	512.3	511.6	510.0	514.5	510.3	514.3	509.1	513.6	507.6
g	510.3	505.9	505.7	505.6	505.7	508.1	504.3	508.0	503.6	507.5	502.7
h	521.2	518.0	518.0	518.0	518.2	519.0	517.3	518.8	517.3	518.7	517.7
j	555.1	551.0	551.1	551.5	552.1	551.4	550.3	552.1	551.1	552.8	551.6
k	523.0	520.2	520.0	520.6	521.2	521.3	519.0	521.4	519.3	521.7	520.4
l	517.8	515.2	515.3	515.8	516.4	517.0	514.4	516.7	514.6	516.5	515.4
m	511.3	508.5	508.4	508.6	509.9	509.8	507.5	509.5	507.5	509.3	508.2
n	530.5	527.5	527.4	528.9	528.8	529.0	526.0	529.1	526.1	528.4	527.3
o	512.3	509.5	509.6	509.5	510.2	510.1	509.0	510.6	509.2	510.3	509.4
p	540.0	535.8	535.8	536.3	537.0	537.0	535.1	537.3	535.0	537.3	536.1

* For location of gauges see Plate F-18, Appendix F.

TABLE G-14

FLOW DISTRIBUTION — CREST OF FALLS

Tests 101 through 122 with 1,550-foot Control Structure and Excavations R-17 and CE

	Discharge in cfs per 100-ft. stations										
Stations *	Test 101R	Test 102R	Test 103R	Test 104R	Test 105R	Test 106R	Test 107R	Test 108R	Test 109R	Test 110R	Test 111R
Can. 1	....	....	....	....	....	....	....	....	....	....	....
2	2,360	2,270	2,270	2,270	560	410	360	310	5,020	4,880	4,620
3	2,750	2,660	2,660	2,750	620	470	170	170	5,150	5,280	5,150
4	3,160	3,160	3,270	3,050	1,050	920	670	620	7,230	7,080	6,930
5	2,560	2,360	2,460	2,270	560	410	170	210	5,720	5,720	5,020
6	4,880	4,880	4,730	4,730	1,120	1,120	800	860	9,130	9,650	8,250
7	9,480	8,950	8,760	8,760	3,270	2,950	2,270	2,270	12,200	12,000	11,190
8	9,480	9,300	9,300	9,300	4,470	4,470	3,850	3,850	13,660	13,450	12,420
9	5,280	5,420	5,420	5,420	2,360	2,270	2,090	2,180	9,130	9,130	8,590
10	6,930	6,750	6,930	6,750	3,850	3,500	3,400	3,270	9,300	9,130	8,950
11	6,610	6,610	6,610	6,930	2,660	2,180	1,730	2,000	10,050	10,230	9,840
12	6,930	6,750	6,610	6,610	3,750	3,750	4,350	4,730	10,420	10,820	9,650
13	5,720	5,660	5,720	5,280	3,750	3,270	3,850	4,250	9,650	9,480	8,250
14	12,000	12,000	12,200	12,000	8,420	8,590	8,950	10,420	14,320	14,100	14,320
15	2,360	2,360	2,360	2,660	1,200	1,120	1,420	1,820	4,470	4,470	4,250
16	1,050	1,120	1,120	1,120	260	260	510	730	2,090	2,180	2,000
17	1,340	1,340	1,280	1,570	620	560	730	1,050	2,460	2,460	2,180
18	1,500	1,420	1,340	1,660	860	860	1,050	1,200	2,360	2,460	2,270
19	1,050	1,000	1,000	1,050	470	410	620	670	1,340	1,420	1,500
20	1,200	1,120	1,200	1,280	560	560	670	920	1,500	1,500	1,500
21	1,120	1,120	1,120	1,280	620	510	730	1,050	1,660	1,660	1,500
22	1,120	1,200	1,200	1,340	560	470	620	860	1,810	1,810	1,910

Stations *	Test 112R	Test 113R	Test 114R	Test 115R	Test 116R	Test 117R	Test 118R	Test 119R	Test 120R	Test 121R	Test 122R
Can. 1	....	....	....	....	....	....	....	....	....	....	....
2	4,620	1,200	1,050	1,050	800	2,850	670	2,660	470	2,270	210
3	5,280	1,280	1,120	1,120	920	2,850	560	2,750	170	2,270	210
4	6,930	1,820	1,730	1,500	1,420	3,400	920	3,050	620	2,750	470
5	5,020	1,200	1,200	1,050	860	2,460	620	2,270	470	2,090	210
6	8,250	1,820	1,910	1,730	1,500	5,280	1,120	4,470	800	3,750	730
7	11,190	5,020	5,020	4,620	3,990	9,870	2,950	9,300	2,270	8,420	2,000
8	12,420	6,610	6,450	6,160	5,560	10,050	4,730	10,050	3,850	9,130	3,620
9	8,590	3,500	3,500	3,500	3,270	6,000	2,660	5,720	2,180	5,150	2,000
10	8,950	5,020	5,020	5,020	4,730	7,080	4,110	7,080	3,270	6,750	2,660
11	9,870	3,850	3,850	3,750	3,500	7,080	2,360	6,750	1,820	6,610	1,910
12	9,650	4,470	4,470	4,730	5,280	7,080	3,500	6,610	3,400	5,850	4,470
13	8,060	4,470	4,250	4,170	4,620	6,610	3,620	5,720	3,850	5,560	4,470
14	14,320	10,050	10,050	10,230	11,390	11,810	8,590	11,590	8,590	11,810	10,050
15	4,250	1,820	1,660	1,820	2,090	2,660	1,200	2,270	1,340	2,460	1,660
16	2,000	670	560	730	860	1,200	310	920	470	1,000	670
17	2,360	1,000	1,000	1,120	1,050	1,340	560	1,340	620	1,200	1,000
18	2,360	1,050	1,050	1,120	1,200	1,500	860	1,500	920	1,420	1,120
19	1,420	620	620	730	920	920	470	1,050	510	860	670
20	1,570	920	920	1,000	1,120	1,050	560	1,200	620	1,050	860
21	1,660	920	920	1,000	1,050	1,050	560	1,200	670	1,120	860
22	2,000	800	800	920	1,120	1,120	510	1,200	620	1,120	800

* For location of 100-ft. stations see Plate D-11, Appendix D

TABLE G-15

WATER SURFACE ELEVATIONS — CREST OF FALLS

Tests 101 through 122 with 1,550-foot Control Structure and Excavations R-17 and CE

Station *	Water Surface elevations in ft. USLSD **										
	Test 101R	Test 102R	Test 103R	Test 104R	Test 105R	Test 106R	Test 107R	Test 108R	Test 109R	Test 110R	Test 111R
Can. 1	....	....	....	....	....	....	....	....	....	....	....
2	502.8	502.7	502.9	502.5	501.1	501.1	500.9	500.8	504.9	504.8	504.1
3	503.2	503.0	503.0	503.2	501.5	501.4	501.2	501.1	505.1	505.1	504.3
4	502.2	502.1	502.4	502.1	501.4	501.1	501.0	500.9	504.5	504.4	503.8
5	502.7	502.0	502.1	502.0	501.2	501.0	500.8	500.8	505.3	505.3	504.3
6	502.8	502.6	503.0	502.1	501.0	501.0	500.9	501.0	505.7	506.0	504.9
7	505.3	505.1	505.5	505.0	501.6	501.5	501.4	501.4	506.1	506.1	505.8
8	502.8	502.4	503.0	502.9	501.4	501.1	501.0	500.8	505.0	505.0	503.7
9	502.1	502.2	502.2	502.4	500.1	500.1	500.1	500.1	504.8	504.7	503.7
10	503.1	502.9	502.8	502.3	501.7	501.6	501.5	501.6	506.5	505.0	505.0
11	505.5	505.3	505.3	506.0	503.3	502.4	502.1	502.4	507.5	506.8	507.4
12	506.4	506.4	506.3	506.3	504.8	504.6	504.6	505.4	508.2	508.4	507.2
13	503.8	503.9	504.0	503.4	502.8	502.8	502.8	502.8	506.2	506.3	505.8
14	506.4	506.8	506.7	506.7	505.4	505.2	505.4	506.4	507.8	507.9	506.3
15	506.6	506.6	506.6	506.9	506.0	506.0	506.1	506.4	508.3	508.6	507.5
16	503.6	504.0	504.1	504.6	502.8	502.9	503.1	502.7	505.4	505.4	505.1
17	503.0	502.8	502.7	503.0	502.5	502.5	502.6	503.0	503.8	503.6	503.8
18	503.2	503.1	503.2	503.1	502.9	503.3	503.7	503.0	504.0	504.2	503.9
19	503.4	503.4	503.6	503.5	503.3	503.4	503.5	503.4	503.8	503.8	503.7
20	504.9	505.0	505.1	505.0	504.3	504.5	504.6	504.7	505.4	505.4	505.3
21	505.0	505.1	505.2	505.3	505.0	505.1	505.2	505.7	505.5	505.6	505.2
22	506.0	505.6	506.0	506.2	505.6	505.8	506.1	505.1	506.4	506.3	506.6

Station *	Test 112R	Test 113R	Test 114R	Test 115R	Test 116R	Test 117R	Test 118R	Test 119R	Test 120R	Test 121R	Test 122R
Can. 1	....	....	....	....	....	....	....	....	....	....	....
2	504.5	501.9	502.1	501.6	501.6	503.0	501.1	503.0	500.9	502.4	500.6
3	505.3	502.2	502.5	502.1	502.1	503.3	501.3	503.2	501.3	503.0	500.8
4	504.1	501.6	502.3	501.6	501.7	502.4	501.4	502.4	501.3	502.1	500.8
5	505.3	501.7	502.3	501.8	501.5	502.6	501.1	502.2	500.9	501.8	500.6
6	505.7	501.4	501.5	501.5	501.3	503.4	501.0	503.2	501.1	502.8	500.8
7	506.3	503.0	503.0	502.3	502.1	505.6	501.6	505.5	501.6	505.2	501.2
8	505.2	501.7	501.9	501.8	501.8	502.0	501.1	503.3	501.0	502.7	501.0
9	503.3	501.0	501.3	501.1	501.0	501.8	500.4	502.2	500.5	502.1	500.6
10	506.5	502.5	502.5	502.4	502.6	503.5	501.6	503.4	501.6	503.0	501.6
11	507.5	504.4	504.7	504.4	504.0	505.5	503.3	505.5	501.8	505.4	502.3
12	507.4	505.0	505.3	505.1	505.4	506.4	504.8	506.4	505.1	506.2	505.2
13	505.5	504.5	504.6	504.9	503.1	504.7	502.7	504.2	502.6	503.6	502.8
14	506.6	506.1	506.3	505.9	505.9	506.1	505.2	506.8	505.8	506.7	506.0
15	508.0	506.3	506.3	506.0	506.1	507.2	505.8	506.8	506.1	506.6	506.4
16	505.2	504.0	504.1	503.9	503.4	504.0	503.2	503.5	502.7	503.9	503.0
17	503.9	503.1	503.1	502.7	502.5	502.9	502.5	503.0	502.6	503.1	502.9
18	504.0	503.1	503.3	503.2	503.0	503.1	503.2	503.2	503.2	503.1	503.4
19	504.3	503.5	503.6	503.5	503.4	503.4	503.4	503.5	503.4	503.5	503.4
20	505.5	504.7	504.7	505.0	505.1	505.1	504.3	505.1	504.5	505.0	504.6
21	505.5	505.4	505.6	505.1	505.2	505.3	505.0	505.3	505.0	505.3	505.0
22	507.0	506.1	506.0	505.3	505.6	506.0	505.4	506.1	505.7	506.0	505.5

* For location of 100-ft. stations see Plate D-11, Appendix D.

** Elevations measured 50-ft. upstream of crest at center of 100-ft. stations.

TABLE G-16

DEPTH OF FLOW — CREST OF FALLS

Tests 101 through 122 with 1,550-foot Control Structure and Excavations R-17 and CE

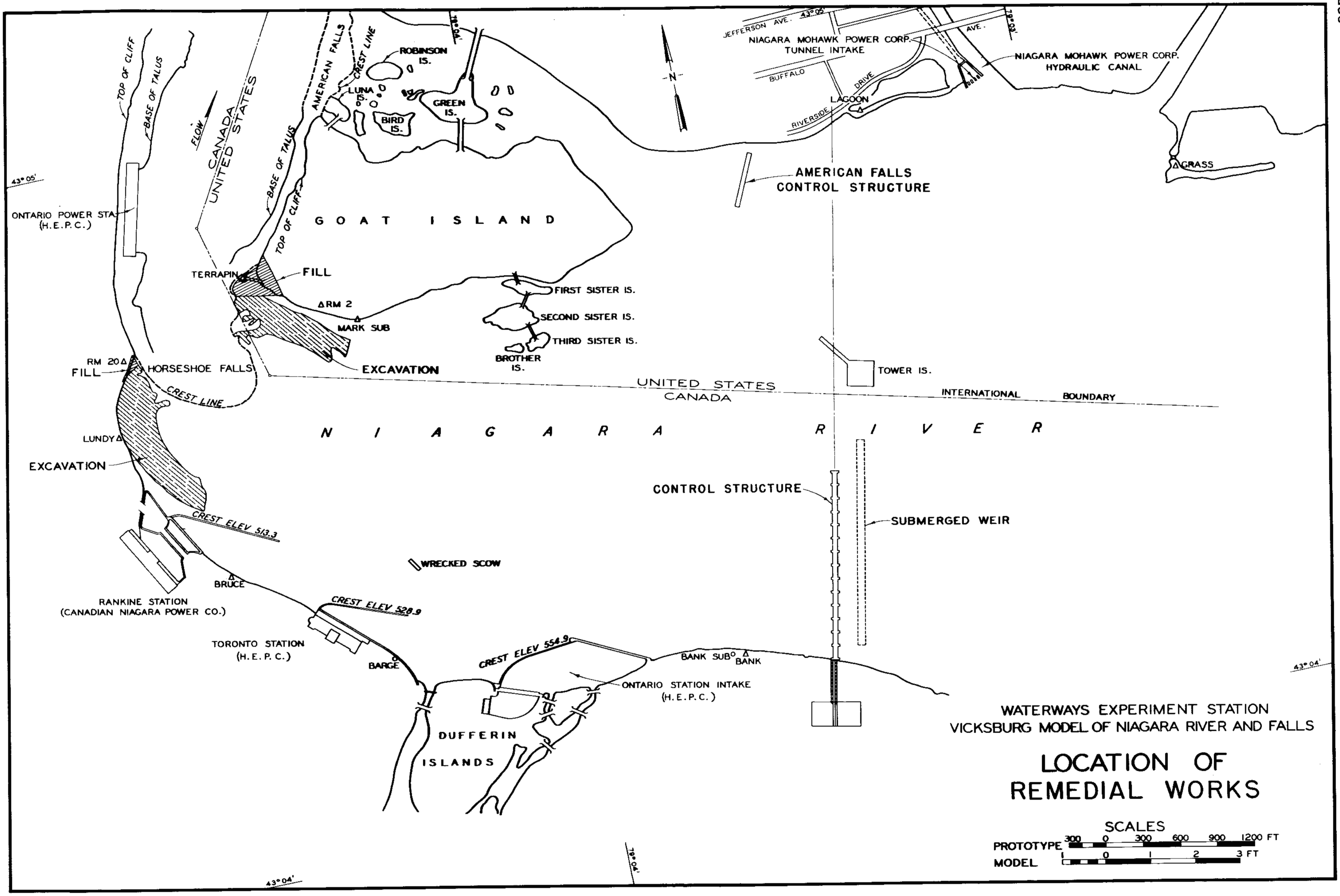
Station *	Depth of Flow in Ft. **										
	Test 101R	Test 102R	Test 103R	Test 104R	Test 105R	Test 106R	Test 107R	Test 108R	Test 109R	Test 110R	Test 111R
Can.. 1	....	....	....	....	....	....	....	....	....	....	....
2	2.8	2.7	2.9	2.5	1.1	1.1	0.9	0.8	4.9	4.8	4.1
3	3.2	3.0	3.0	3.2	1.5	1.4	1.2	1.1	5.1	5.1	4.3
4	2.2	2.1	2.4	2.1	1.4	1.1	1.0	0.9	4.5	4.4	3.8
5	2.7	2.0	2.1	2.0	1.2	1.0	0.8	0.8	5.3	5.3	4.8
6	2.8	2.6	3.0	2.1	1.0	1.0	0.9	1.0	5.7	6.0	4.9
7	6.0	5.8	6.2	4.7	2.3	2.2	2.1	2.1	6.8	6.8	6.5
8	6.3	5.9	6.5	6.4	4.9	4.6	4.5	4.3	8.5	8.5	7.2
9	3.6	3.7	3.7	3.9	1.6	1.6	1.6	1.6	6.3	6.2	5.2
10	7.2	7.0	6.8	6.4	5.8	5.7	5.6	5.7	10.6	9.1	9.1
11	4.8	4.6	4.6	5.3	2.6	1.7	1.4	1.7	6.8	6.1	6.7
12	5.2	5.2	5.1	5.1	3.6	3.4	3.4	4.2	7.0	7.2	6.0
13	2.7	2.8	2.9	2.3	1.7	1.7	1.7	1.7	5.1	5.2	4.7
14	12.5	12.9	12.8	12.8	11.5	11.3	11.5	12.5	13.9	14.0	12.4
15	2.1	2.1	2.1	2.4	1.5	1.5	1.6	1.9	3.8	4.1	3.0
16	1.8	2.2	2.3	2.8	1.0	1.1	1.3	0.9	3.6	3.6	3.3
17	1.5	1.3	1.2	1.5	1.0	1.0	1.1	1.5	2.3	2.1	2.3
18	1.1	1.0	1.1	1.0	0.8	1.2	1.6	0.9	1.9	2.1	1.8
19	0.9	0.9	1.1	1.0	0.8	0.9	1.0	0.9	1.3	1.3	1.2
20	2.3	2.4	2.5	2.4	1.7	1.9	2.0	2.1	2.8	2.8	2.7
21	1.1	1.2	1.3	1.4	1.1	1.2	1.3	1.8	1.6	1.7	1.3
22	1.7	1.3	1.7	1.9	1.3	1.5	1.8	0.8	2.1	2.0	2.3

Station *	Test 112R	Test 113R	Test 114R	Test 115R	Test 116R	Test 117R	Test 118R	Test 119R	Test 120R	Test 121R	Test 122R
Can.. 1	....	....	....	....	....	....	....	....	....	....	....
2	4.5	1.9	2.1	1.6	1.6	3.0	1.1	3.0	0.9	2.4	0.6
3	5.3	2.2	2.5	2.1	2.1	3.3	1.3	3.2	1.3	3.0	0.8
4	4.1	1.6	2.3	1.6	1.7	2.4	1.4	2.4	1.3	2.1	0.8
5	5.3	1.7	2.3	1.8	1.5	2.6	1.1	2.2	0.9	1.8	0.6
6	5.7	1.4	1.5	1.5	1.3	3.4	1.0	3.2	1.1	2.8	0.8
7	7.0	3.7	3.7	3.0	2.8	6.3	2.3	6.2	2.3	5.9	1.9
8	8.7	5.2	5.4	5.3	5.3	5.5	4.6	6.8	4.5	6.2	4.5
9	4.8	2.5	2.8	2.6	2.5	3.3	1.9	3.7	2.0	3.6	2.1
10	10.6	6.6	6.6	6.5	6.7	7.6	5.7	7.5	5.7	7.1	5.7
11	6.8	3.7	4.0	3.7	3.3	4.8	2.6	4.8	1.1	4.7	1.6
12	6.2	3.8	4.1	3.9	4.2	5.2	3.6	5.2	3.9	5.0	4.0
13	4.4	3.4	3.5	3.8	2.0	3.6	1.6	3.1	1.5	2.5	1.7
14	12.7	12.2	12.4	12.0	12.0	12.2	11.3	12.9	11.9	12.8	12.1
15	3.5	1.8	1.8	1.5	1.6	2.7	1.3	2.3	1.6	2.1	1.9
17	3.4	2.2	2.3	2.1	1.6	2.2	1.4	1.7	0.9	2.1	1.2
16	2.4	1.6	1.6	1.2	1.0	1.4	1.0	1.5	1.1	1.6	1.4
18	1.9	1.0	1.2	1.1	0.9	1.0	1.1	1.1	1.1	1.0	1.3
19	1.8	1.0	1.1	1.0	0.9	0.9	0.9	1.0	0.9	1.0	0.9
20	2.9	2.1	2.1	2.4	2.5	2.5	1.7	2.5	1.9	2.4	2.0
21	1.6	1.5	1.7	1.2	1.3	1.4	1.1	1.4	1.1	1.4	1.1
22	2.7	1.8	1.7	1.0	1.3	1.7	1.1	1.3	1.4	1.7	1.2

* For location of 100-ft. stations see Plate D-11, Appendix D.

** Depth of flow measured 50 feet upstream of crest at center of 100-ft. stations.

PLATE G-1



WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS

LOCATION OF REMEDIAL WORKS

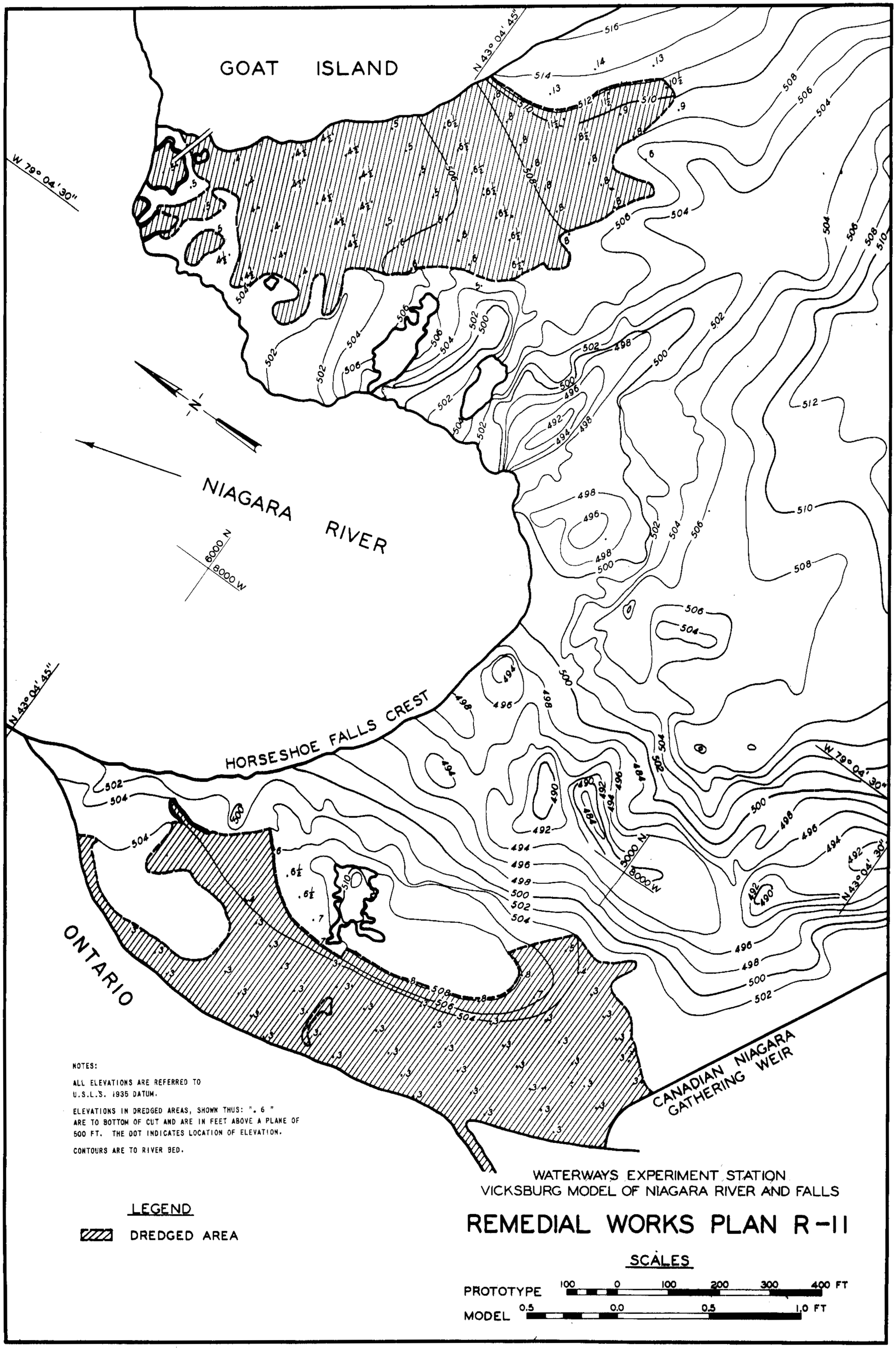

GOAT ISLAND
N 43° 04' 45"
W 79° 04' 30"
NIAGARA RIVER
N
6000 N
8000 W
HORSESHOE FALLS CREST
N 43° 04' 45"
W 79° 04' 30"
N 43° 04' 30"
5000 N
8000 W
ONTARIO
CANADIAN NIAGARA GATHERING WEIR
NOTES:
ALL ELEVATIONS ARE REFERRED TO U.S.L.S. 1935 DATUM.
ELEVATIONS IN DREDGED AREAS, SHOWN THUS: ". 6 " ARE TO BOTTOM OF CUT AND ARE IN FEET ABOVE A PLANE OF 500 FT. THE DOT INDICATES LOCATION OF ELEVATION.
CONTOURS ARE TO RIVER BED.
LEGEND
DREDGED AREA
WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
REMEDIAL WORKS PLAN R-11
SCALES
PROTOTYPE 100 0 100 200 300 400 FT
MODEL 0.5 0.0 0.5 1.0 FT

PLATE G-2

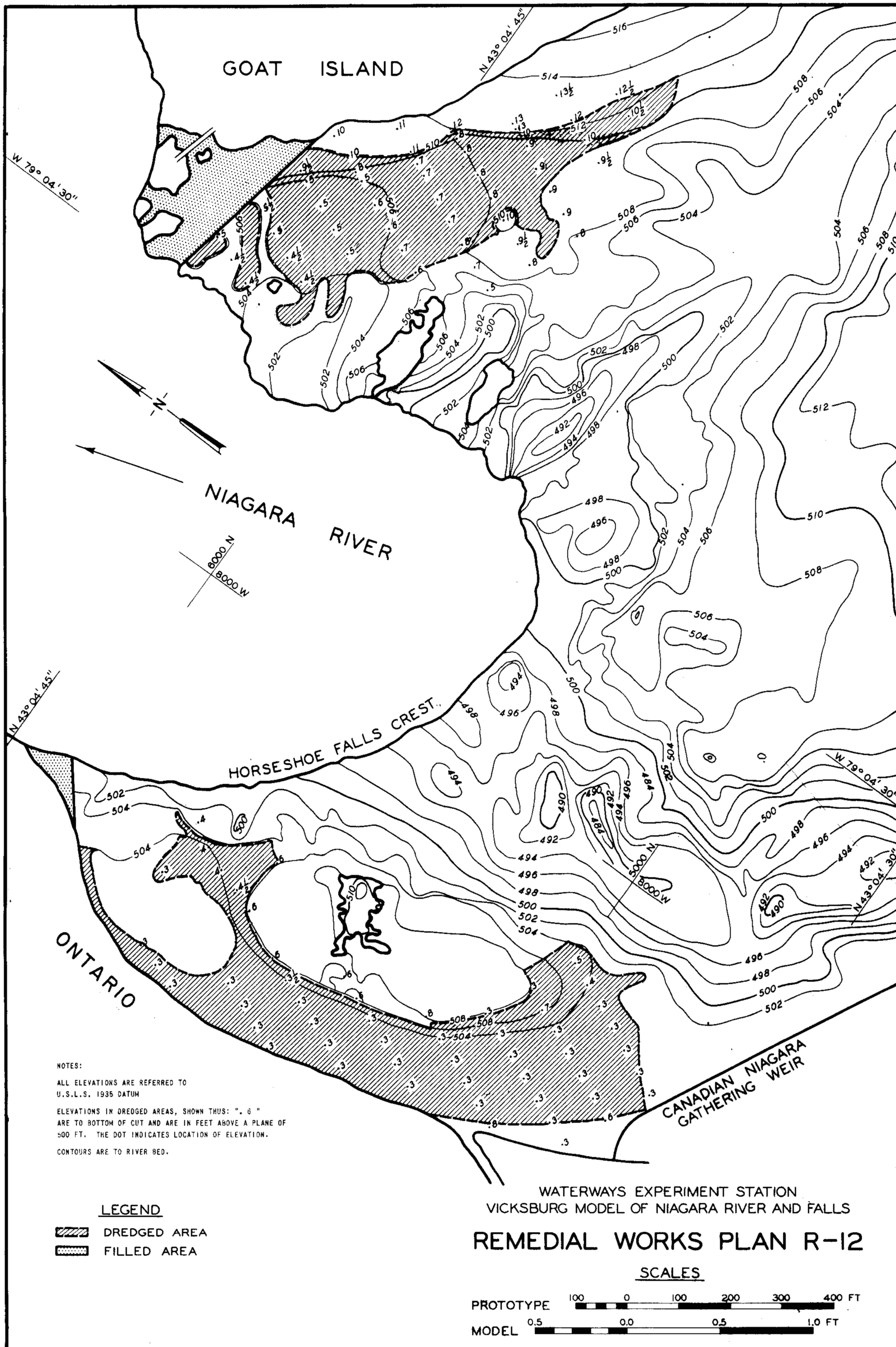
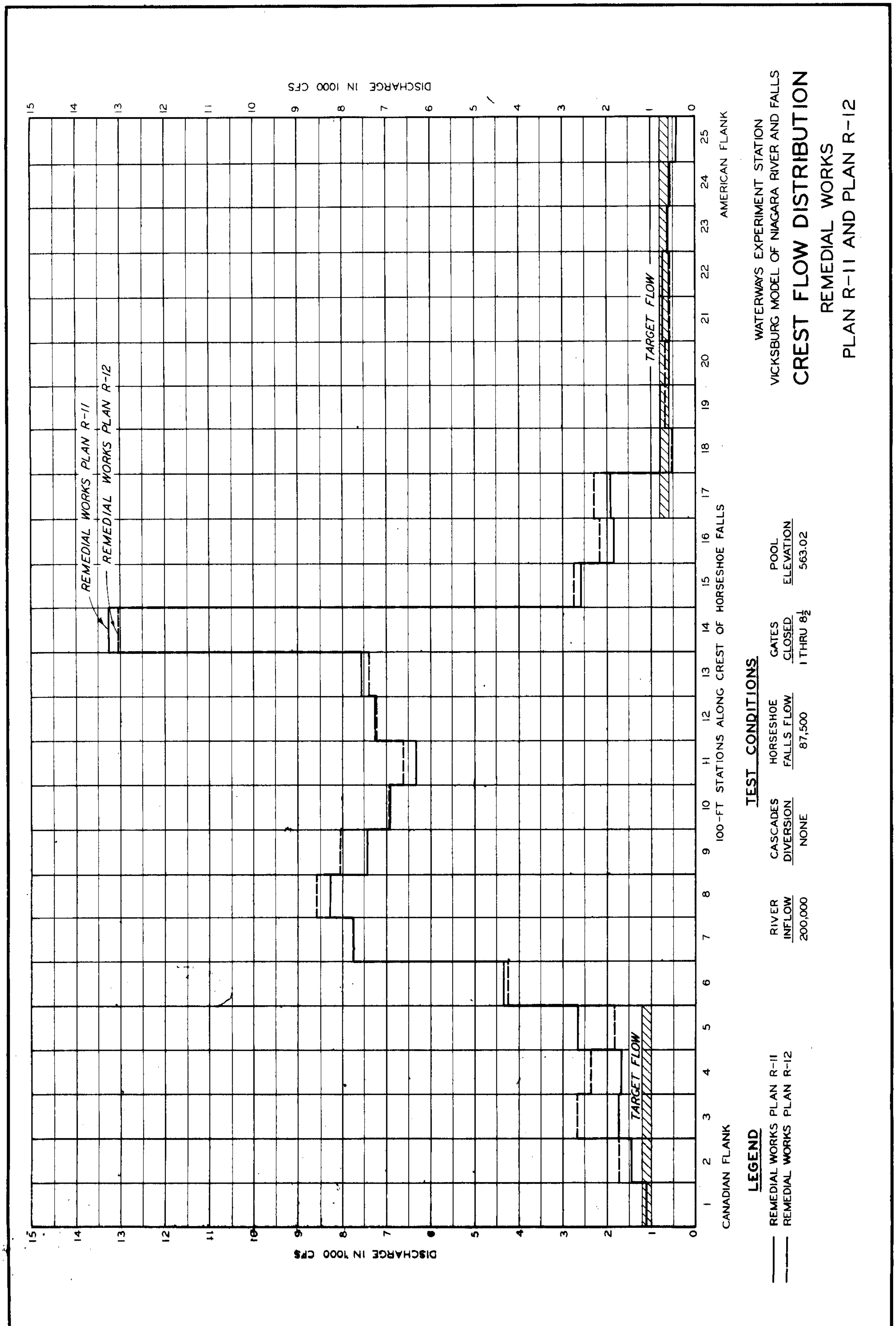
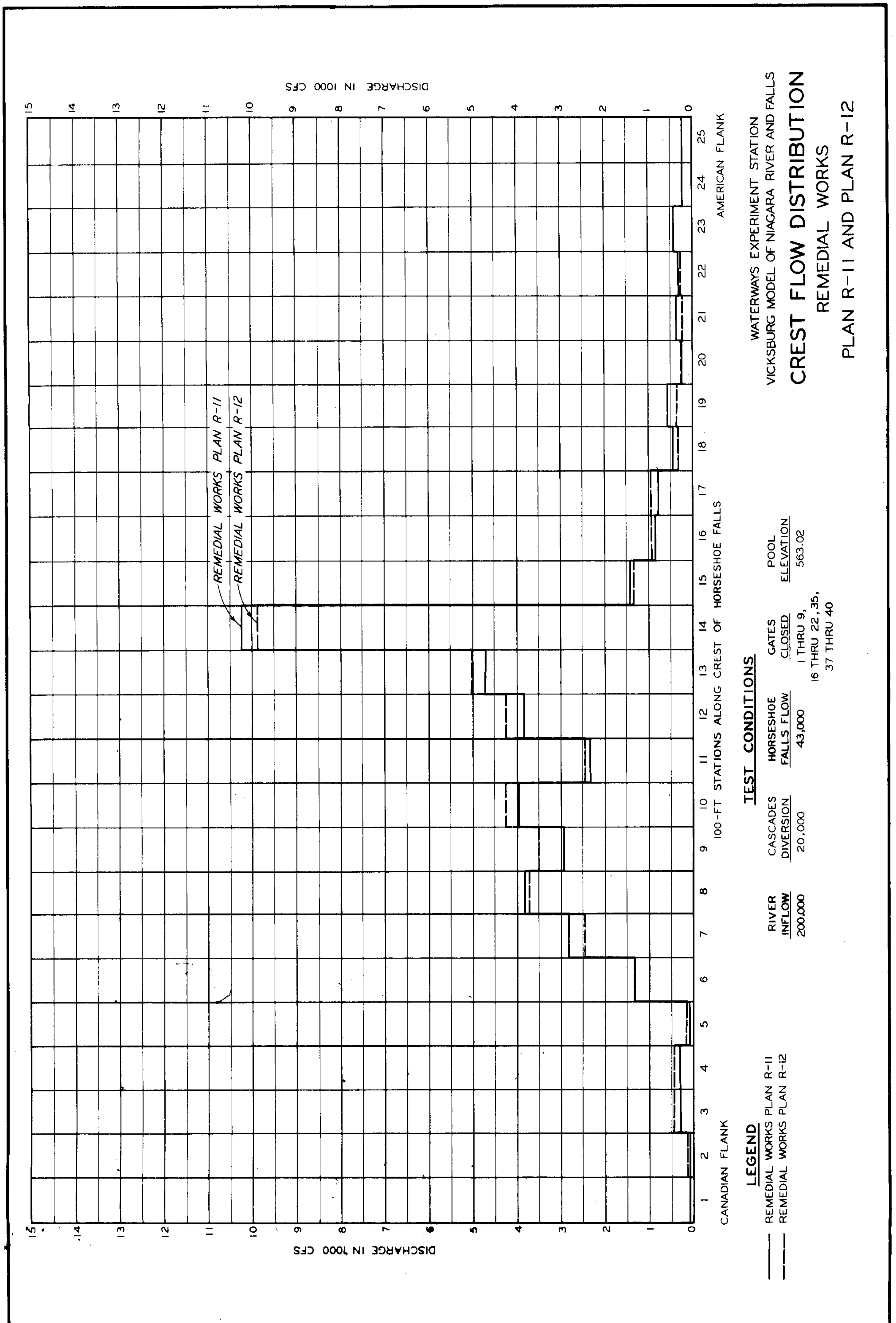
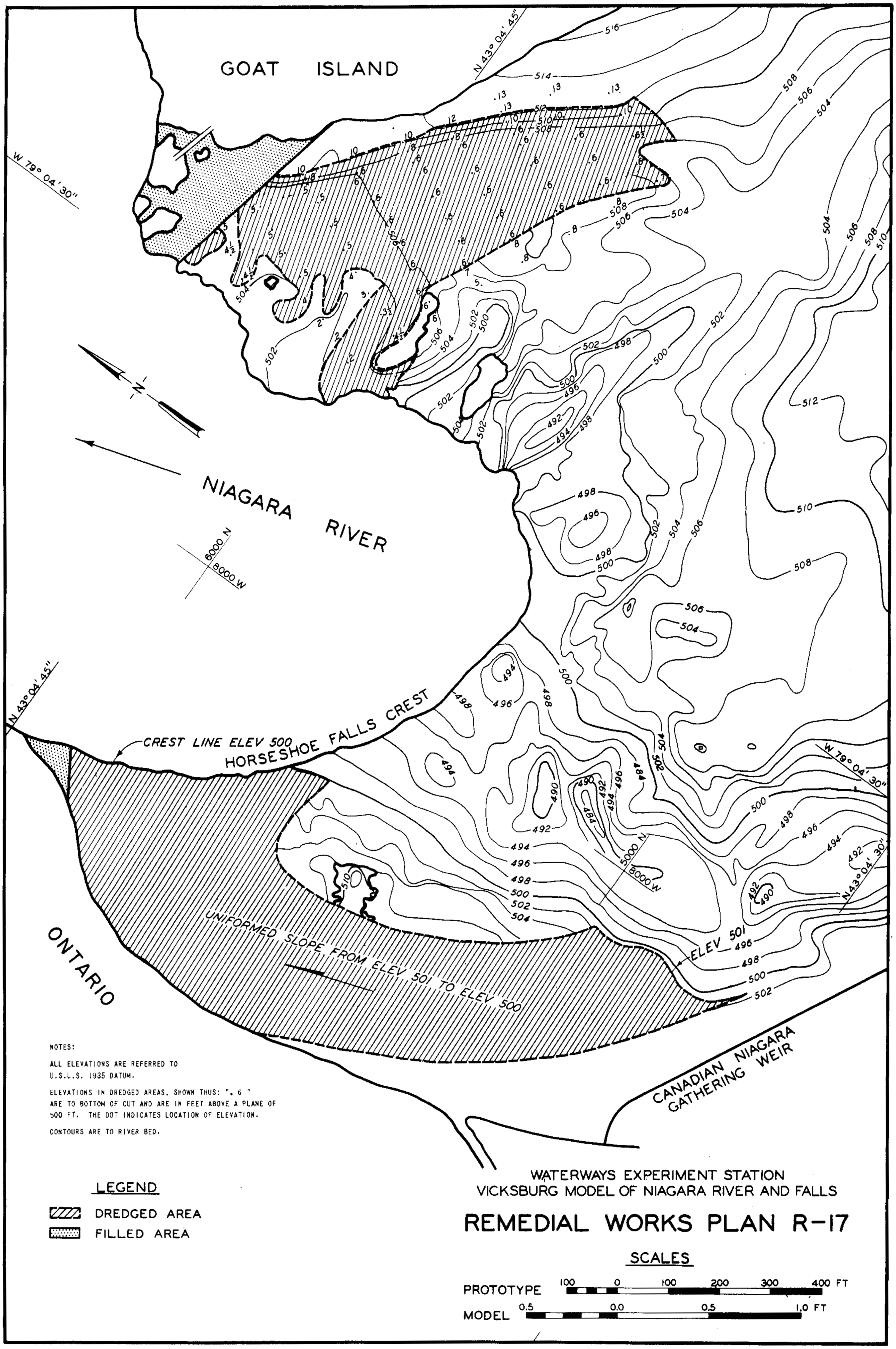

GOAT ISLAND
NIAGARA RIVER
HORSESHOE FALLS CREST
ONTARIO
CANADIAN NIAGARA GATHERING WEIR
NOTES:
ALL ELEVATIONS ARE REFERRED TO U.S.L.S. 1935 DATUM
ELEVATIONS IN DREDGED AREAS, SHOWN THUS: ". 6 " ARE TO BOTTOM OF CUT AND ARE IN FEET ABOVE A PLANE OF 500 FT. THE DOT INDICATES LOCATION OF ELEVATION.
CONTOURS ARE TO RIVER BED.
LEGEND
DREDGED AREA
FILLED AREA
WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
REMEDIAL WORKS PLAN R-12
SCALES
PROTOTYPE 100 0 100 200 300 400 FT
MODEL 0.5 0.0 0.5 1.0 FT

PLATE G-3

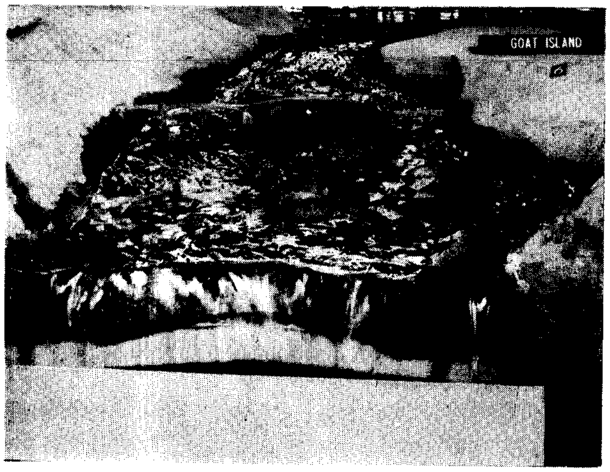

WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
CREST FLOW DISTRIBUTION
REMEDIAL WORKS
PLAN R-11 AND PLAN R-12
DISCHARGE IN 1000 CFS
100-FT STATIONS ALONG CREST OF HORSESHOE FALLS
CANADIAN FLANK
AMERICAN FLANK
REMEDIAL WORKS PLAN R-11
REMEDIAL WORKS PLAN R-12
TARGET FLOW
TARGET FLOW
LEGEND
REMEDIAL WORKS PLAN R-11
REMEDIAL WORKS PLAN R-12
TEST CONDITIONS
RIVER INFLOW
200,000
CASCADES DIVERSION
NONE
HORSESHOE FALLS FLOW
87,500
GATES CLOSED
1 THRU 8½
POOL ELEVATION
563.02


WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
CREST FLOW DISTRIBUTION
REMEDIAL WORKS
PLAN R-11 AND PLAN R-12
DISCHARGE IN 1000 CFS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
CANADIAN FLANK
AMERICAN FLANK
100-FT STATIONS ALONG CREST OF HORSESHOE FALLS
REMEDIAL WORKS PLAN R-11
REMEDIAL WORKS PLAN R-12
LEGEND
REMEDIAL WORKS PLAN R-11
REMEDIAL WORKS PLAN R-12
TEST CONDITIONS
RIVER INFLOW
200,000
CASCADES DIVERSION
20,000
HORSESHOE FALLS FLOW
43,000
GATES CLOSED
1 THRU 9, 16 THRU 22, 35, 37 THRU 40
POOL ELEVATION
563.02



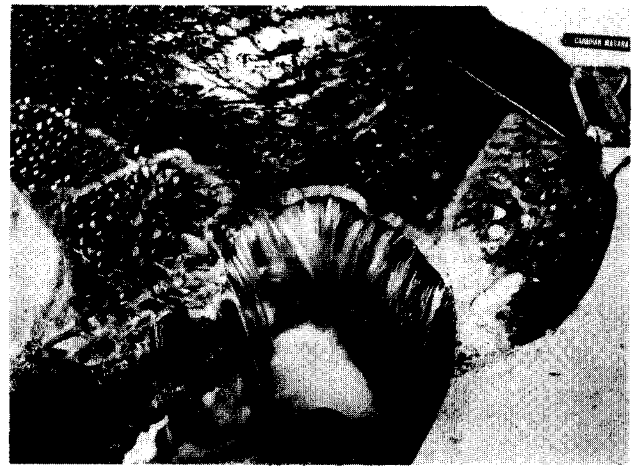
GOAT ISLAND
NIAGARA RIVER
HORSESHOE FALLS CREST
CREST LINE ELEV 500
ONTARIO
UNIFORMED SLOPE FROM ELEV 501 TO ELEV 500
ELEV 501
CANADIAN NIAGARA GATHERING WEIR
N 43° 04' 45"
W 79° 04' 30"
N 43° 04' 30"
6000 N
8000 W
5000 N
8000 W
NOTES:
ALL ELEVATIONS ARE REFERRED TO U.S.L.S. 1935 DATUM.
ELEVATIONS IN DREDGED AREAS, SHOWN THUS: ". 6 " ARE TO BOTTOM OF CUT AND ARE IN FEET ABOVE A PLANE OF 500 FT. THE DOT INDICATES LOCATION OF ELEVATION.
CONTOURS ARE TO RIVER BED.
LEGEND
DREDGED AREA
FILLED AREA
WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
REMEDIAL WORKS PLAN R-17
SCALES
PROTOTYPE 100 0 100 200 300 400 FT
MODEL 0.5 0.0 0.5 1.0 FT

AMERICAN FALLS



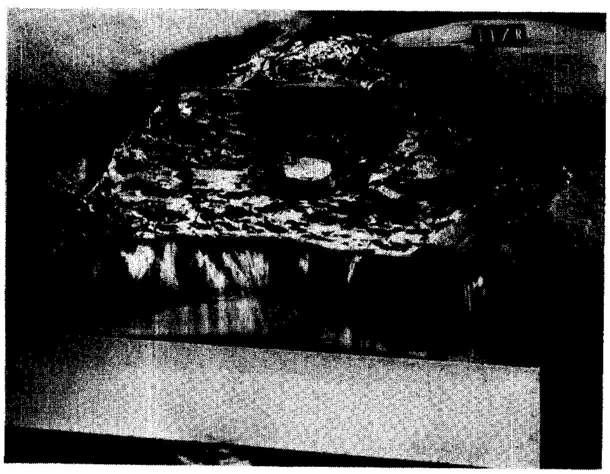
5,500 CFS

HORSESHOE FALLS



94,500 CFS

WITHOUT REMEDIAL WORKS



7,200 CFS

92,800 CFS

WITH PROPOSED REMEDIAL WORKS

1,550-Foot Control Structure and Excavations R-17 & CE

TEST CONDITIONS 117

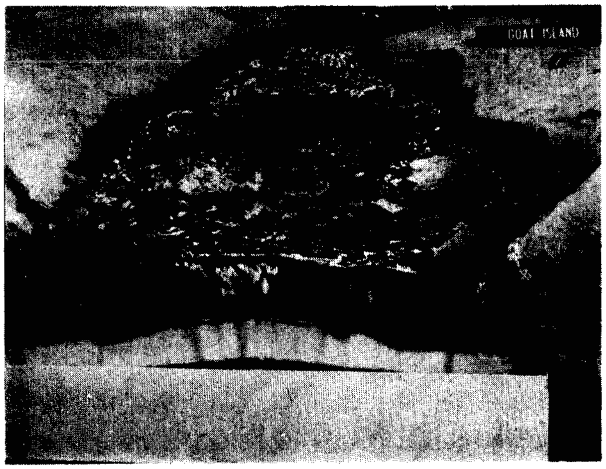
COMPARATIVE PHOTOGRAPHS OF MODEL FALLS

RIVER FLOW 170,000 CFS

TOURIST SEASON DAYS

AMERICAN FALLS

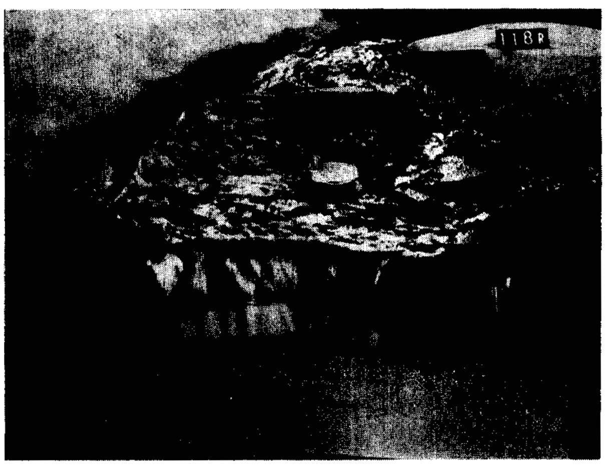
HORSESHOE FALLS



2,000 CFS

48,000 CFS

WITHOUT REMEDIAL WORKS



8,900 CFS

41,100 CFS

WITH PROPOSED REMEDIAL WORKS

1,550-Foot Control Structure and Excavations R-17 & CE

TEST CONDITIONS 118

COMPARATIVE PHOTOGRAPHS OF MODEL FALLS

RIVER FLOW 170,000 CFS

NON-TOURIST SEASON

PLATE G-8

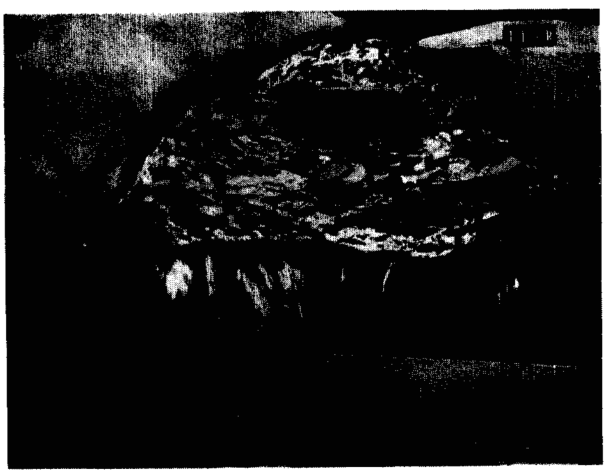
AMERICAN FALLS

HORSESHOE FALLS

5,500 CFS

94,500 CFS

WITHOUT REMEDIAL WORKS



12,000 CFS

88,000 CFS

WITH PROPOSED REMEDIAL WORKS

1,550-Foot Control Structure and Excavations R-17 & CE

TEST CONDITIONS 119

COMPARATIVE PHOTOGRAPHS OF MODEL FALLS

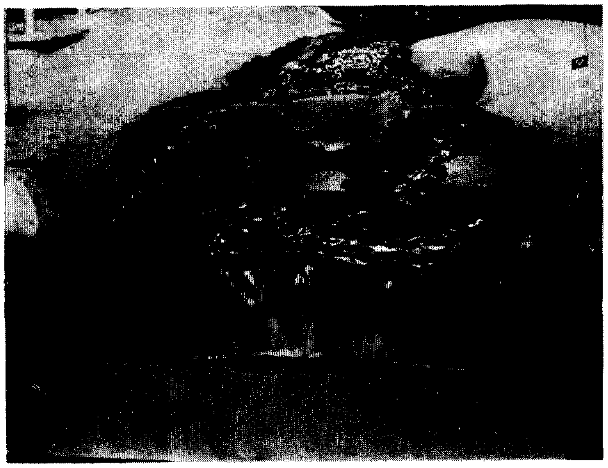
RIVER FLOW 200,000 CFS

TOURIST SEASON DAYS

PLATE G-9

AMERICAN FALLS

HORSESHOE FALLS



3,500 CFS

46,500 CFS

WITHOUT REMEDIAL WORKS

12,200 CFS

37,800 CFS

WITH PROPOSED REMEDIAL WORKS

1,550-Foot Control Structure and Excavations R-17 & CE

TEST CONDITIONS 120

COMPARATIVE PHOTOGRAPHS OF MODEL FALLS

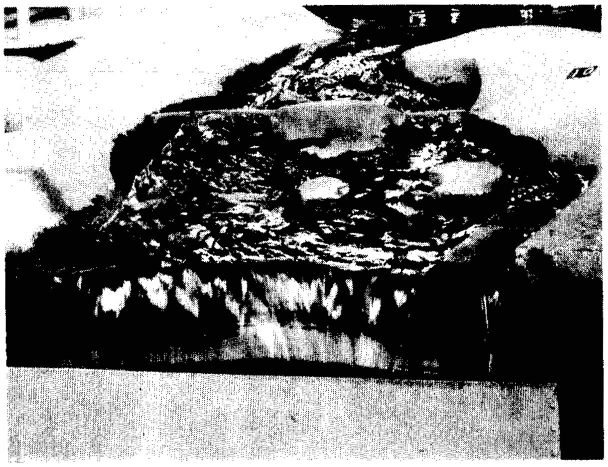
RIVER FLOW 200,000 CFS

NON-TOURIST SEASON

PLATE G-10

AMERICAN FALLS

HORSESHOE FALLS



6,000 CFS

94,000 CFS

WITHOUT REMEDIAL WORKS

18,000 CFS

82,000 CFS

WITH PROPOSED REMEDIAL WORKS

1,550-Foot Control Structure and Excavations R-17 & CE

TEST CONDITIONS 121

COMPARATIVE PHOTOGRAPHS OF MODEL FALLS

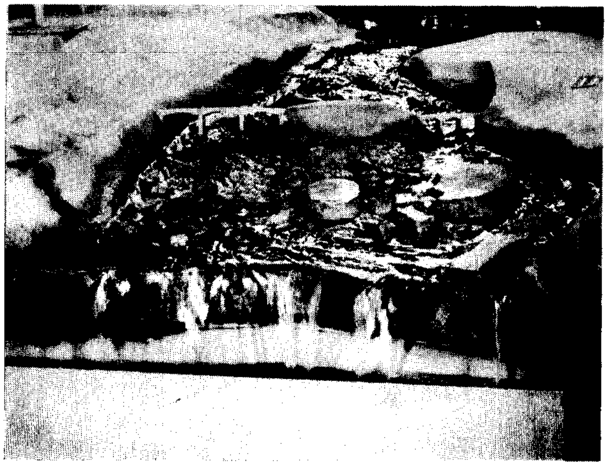
RIVER FLOW 240,000 CFS

TOURIST SEASON DAYS

PLATE G-11

AMERICAN FALLS

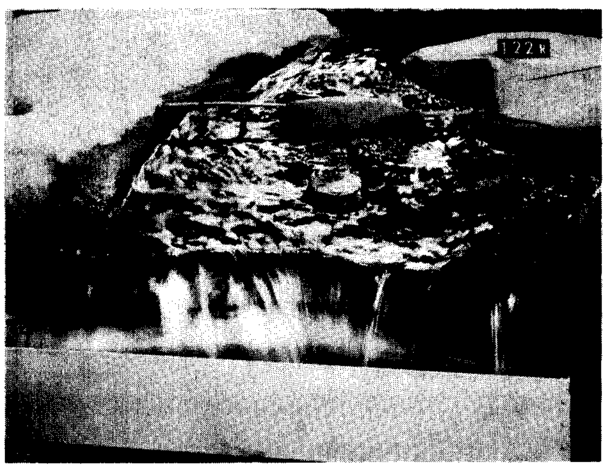
HORSESHOE FALLS



14,000 CFS

46,000 CFS

WITHOUT REMEDIAL WORKS



15,800 CFS

40,000 CFS

WITH PROPOSED REMEDIAL WORKS

1,550-Foot Control Structure and Excavations R-17 & CE

TEST CONDITIONS 122

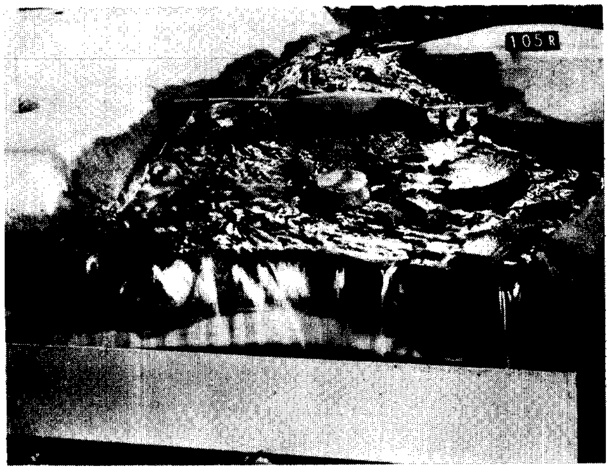
COMPARATIVE PHOTOGRAPHS OF MODEL FALLS

RIVER FLOW 240,000 CFS

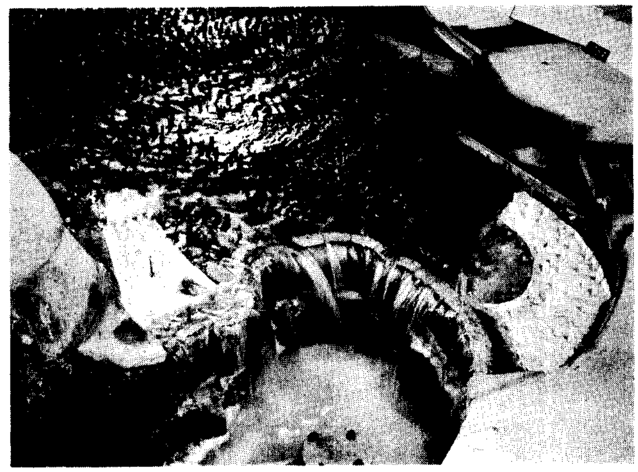
NON-TOURIST SEASON

AMERICAN FALLS

HORSESHOE FALLS



8,900 CFS



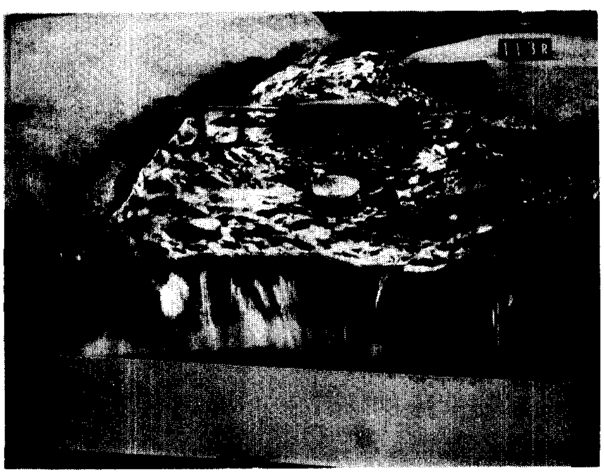
41,100 CFS

TEST CONDITION 105

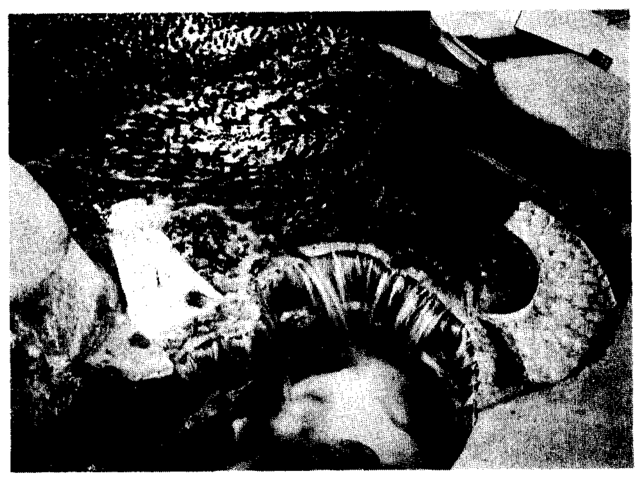
Total River Flow 180,000 CFS

Total Falls Flow 50,000 CFS

With 1,550-Foot Control Structure and Excavation R-17 & CE



12,500 CFS



57,500 CFS

TEST CONDITION 113

Total River Flow 200,000 CFS

Total Falls Flow 70,000 CFS

With 1,550-Foot Control Structure and Excavation R-17 & CE

PHOTOGRAPHS OF MODEL FALLS WITH PROPOSED REMEDIAL WORKS

PLATE G-13

AMERICAN FALLS | HORSESHOE FALLS

12,000 CFS

88,000 CFS

TEST CONDITION 101

Total River Flow 200,000 CFS | Total Falls Flow 100,000 CFS

With 1,550-Foot Control Structure and Excavation R-17 & CE

12,000 CFS

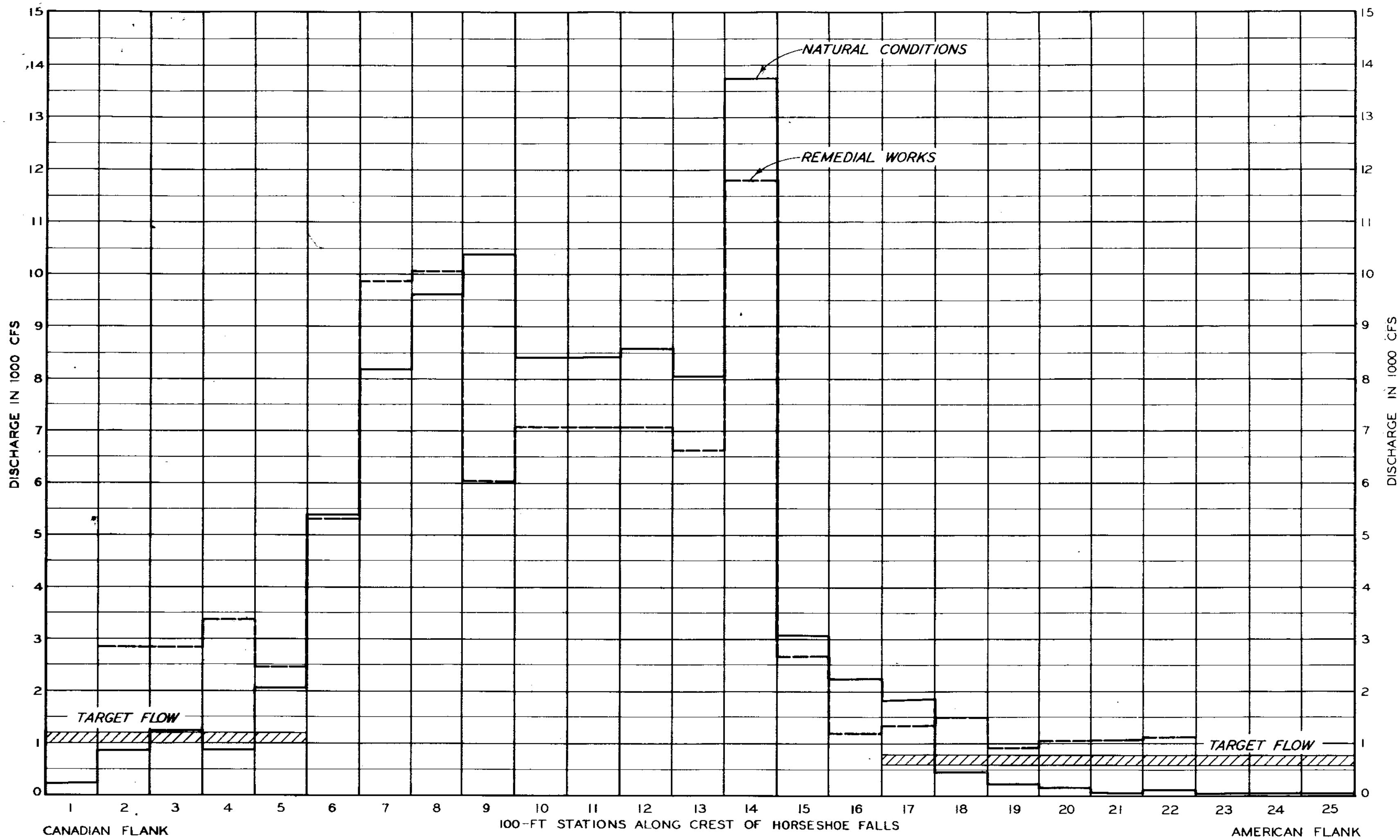
138,000 CFS

TEST CONDITION 109

Total River Flow 200,000 CFS | Total Falls Flow 150,000 CFS

With 1,550-Foot Control Structure and Excavation R-17 & CE

PHOTOGRAPHS OF MODEL FALLS WITH PROPOSED REMEDIAL WORKS



LEGEND

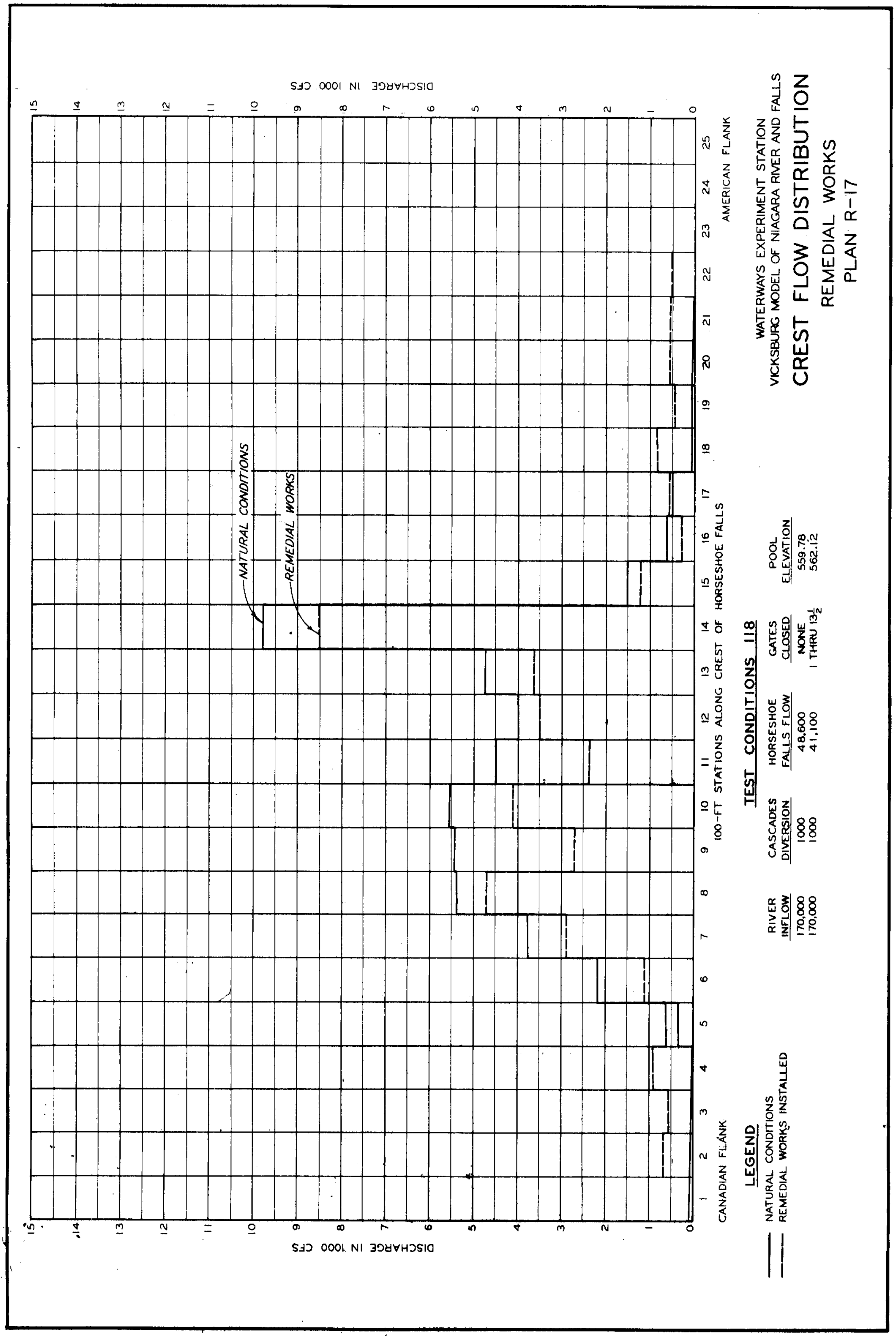
——— NATURAL CONDITIONS
——— REMEDIAL WORKS INSTALLED

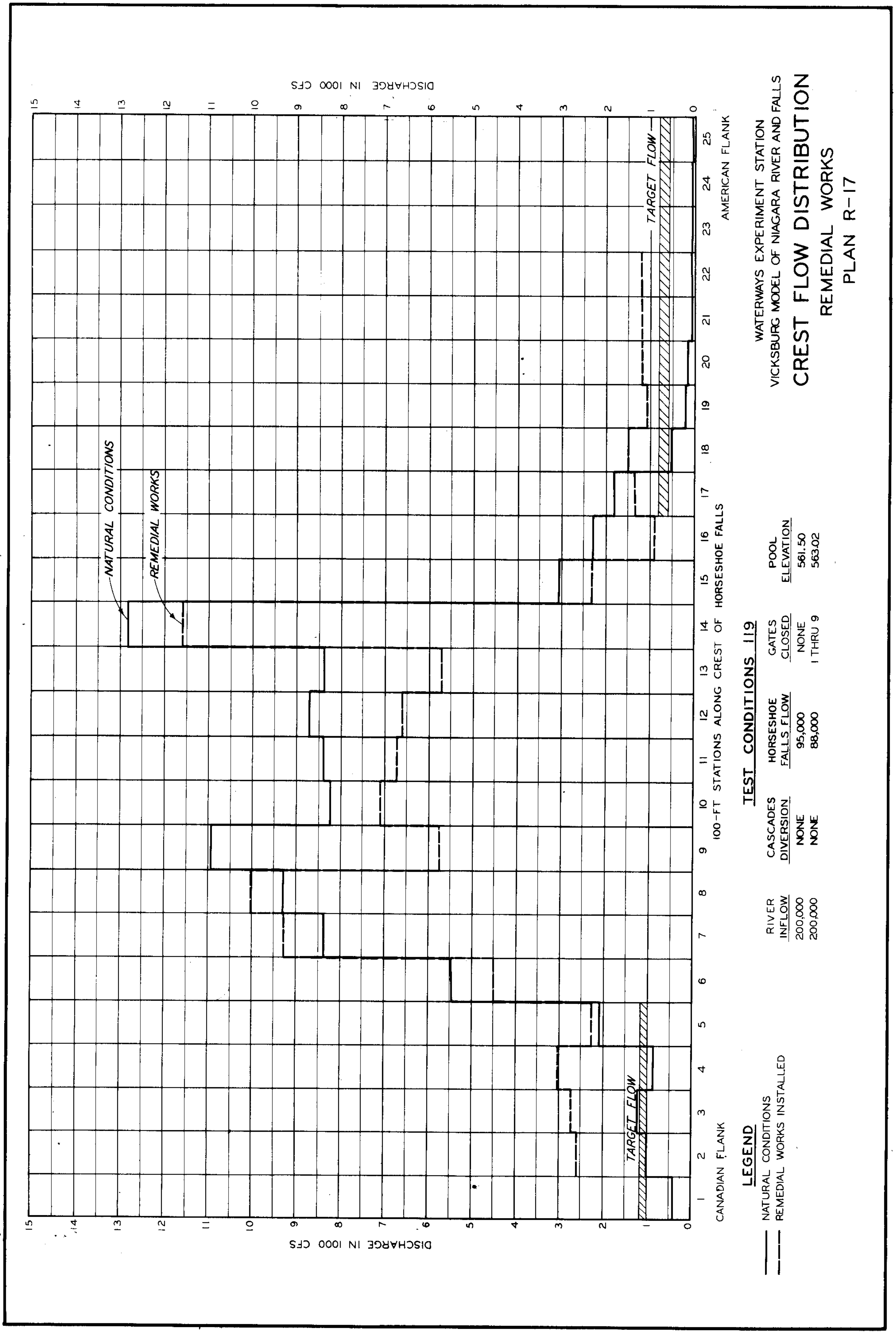
TEST CONDITIONS 117

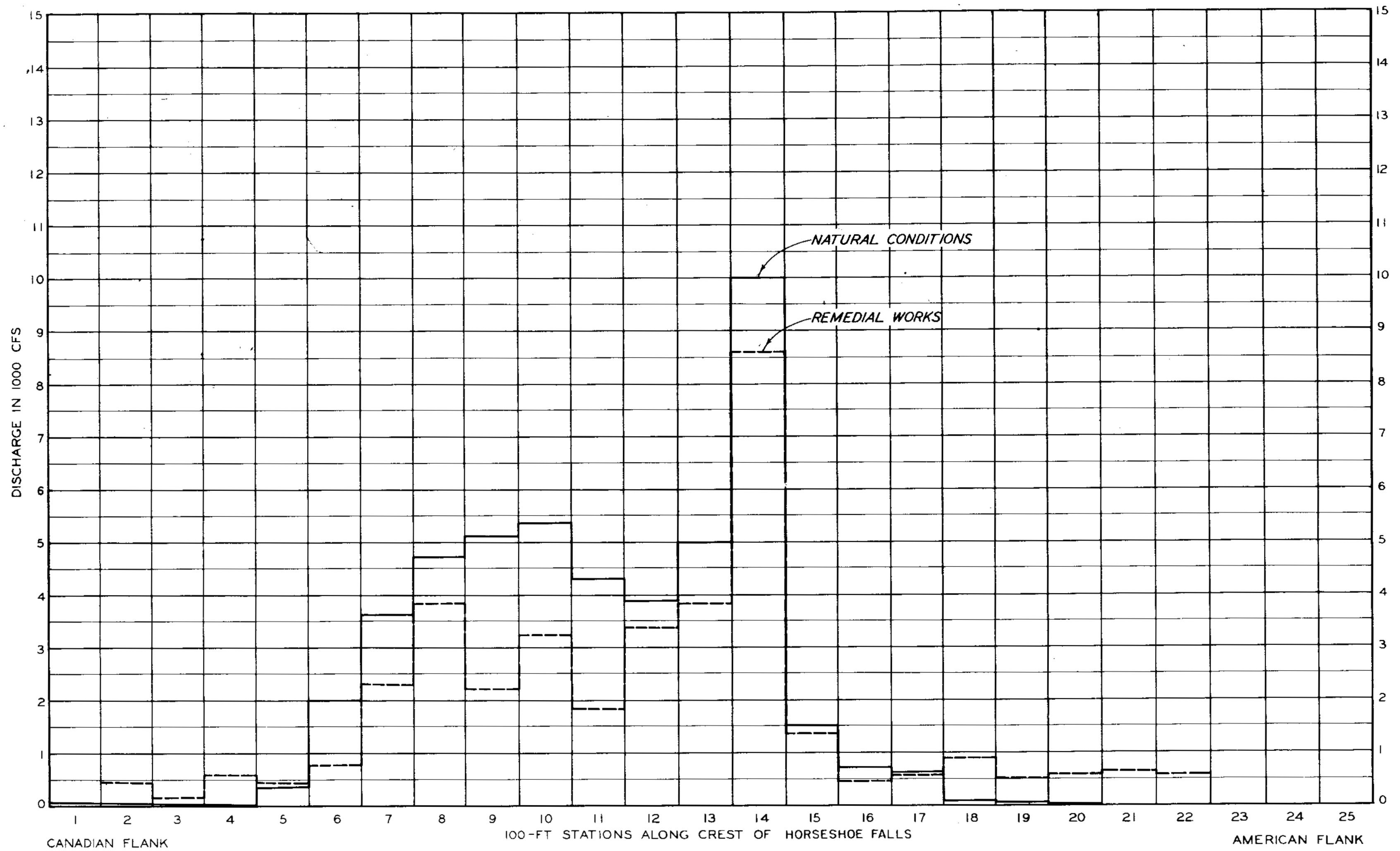
RIVER INFLOW	CASCADES DIVERSION	HORSESHOE FALLS FLOW	GATES CLOSED	POOL ELEVATION
170,000	NONE	94,500	NONE	561.58
170,000	NONE	92,800	1 THRU 4	562.12

WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS

CREST FLOW DISTRIBUTION
REMEDIAL WORKS
PLAN R-17


WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
CREST FLOW DISTRIBUTION
REMEDIAL WORKS
PLAN R-17
DISCHARGE IN 1000 CFS
100-FT STATIONS ALONG CREST OF HORSESHOE FALLS
CANADIAN FLANK
AMERICAN FLANK
NATURAL CONDITIONS
REMEDIAL WORKS
TEST CONDITIONS 118
RIVER INFLOW: 170,000; 170,000
CASCADES DIVERSION: 1000; 1000
HORSESHOE FALLS FLOW: 48,600; 41,100
GATES CLOSED: NONE; 1 THRU 13½
POOL ELEVATION: 559.78; 562.12
LEGEND
NATURAL CONDITIONS
REMEDIAL WORKS INSTALLED


WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
CREST FLOW DISTRIBUTION
REMEDIAL WORKS
PLAN R-17
DISCHARGE IN 1000 CFS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
100-FT STATIONS ALONG CREST OF HORSESHOE FALLS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
CANADIAN FLANK
AMERICAN FLANK
NATURAL CONDITIONS
REMEDIAL WORKS
TARGET FLOW
TARGET FLOW
TEST CONDITIONS 119
RIVER INFLOW
200,000
200,000
CASCADES DIVERSION
NONE
NONE
HORSESHOE FALLS FLOW
95,000
88,000
GATES CLOSED
NONE
1 THRU 9
POOL ELEVATION
561.50
563.02
LEGEND
NATURAL CONDITIONS
REMEDIAL WORKS INSTALLED



LEGEND

- ——— NATURAL CONDITIONS
- — — — REMEDIAL WORKS INSTALLED

TEST CONDITIONS 120

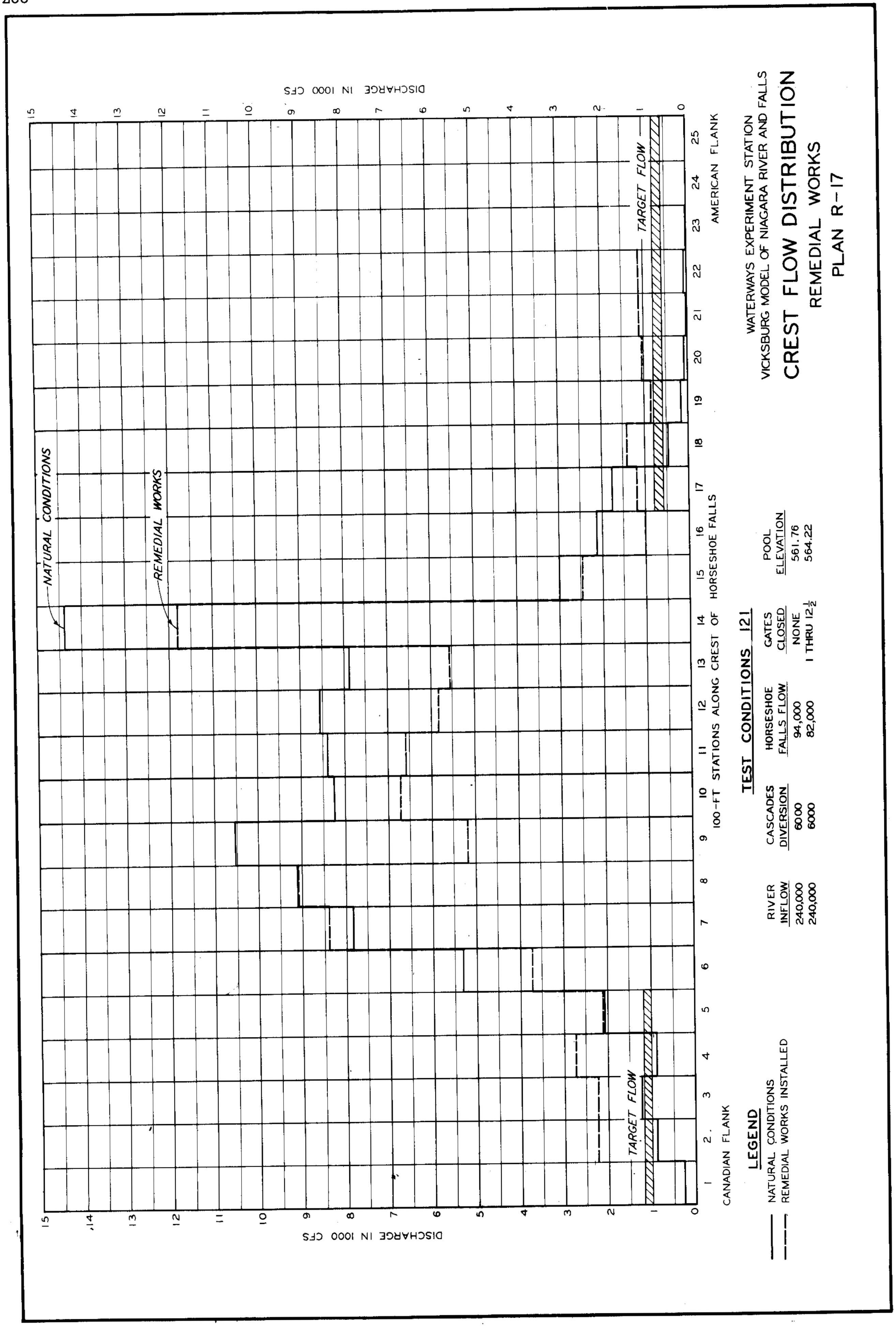
RIVER INFLOW	CASCADES DIVERSION	HORSESHOE FALLS FLOW	GATES CLOSED	POOL ELEVATION
200,000	20,000	47,400	NONE	560.26
200,000	14,000	37,800	1 THRU 14	562.90

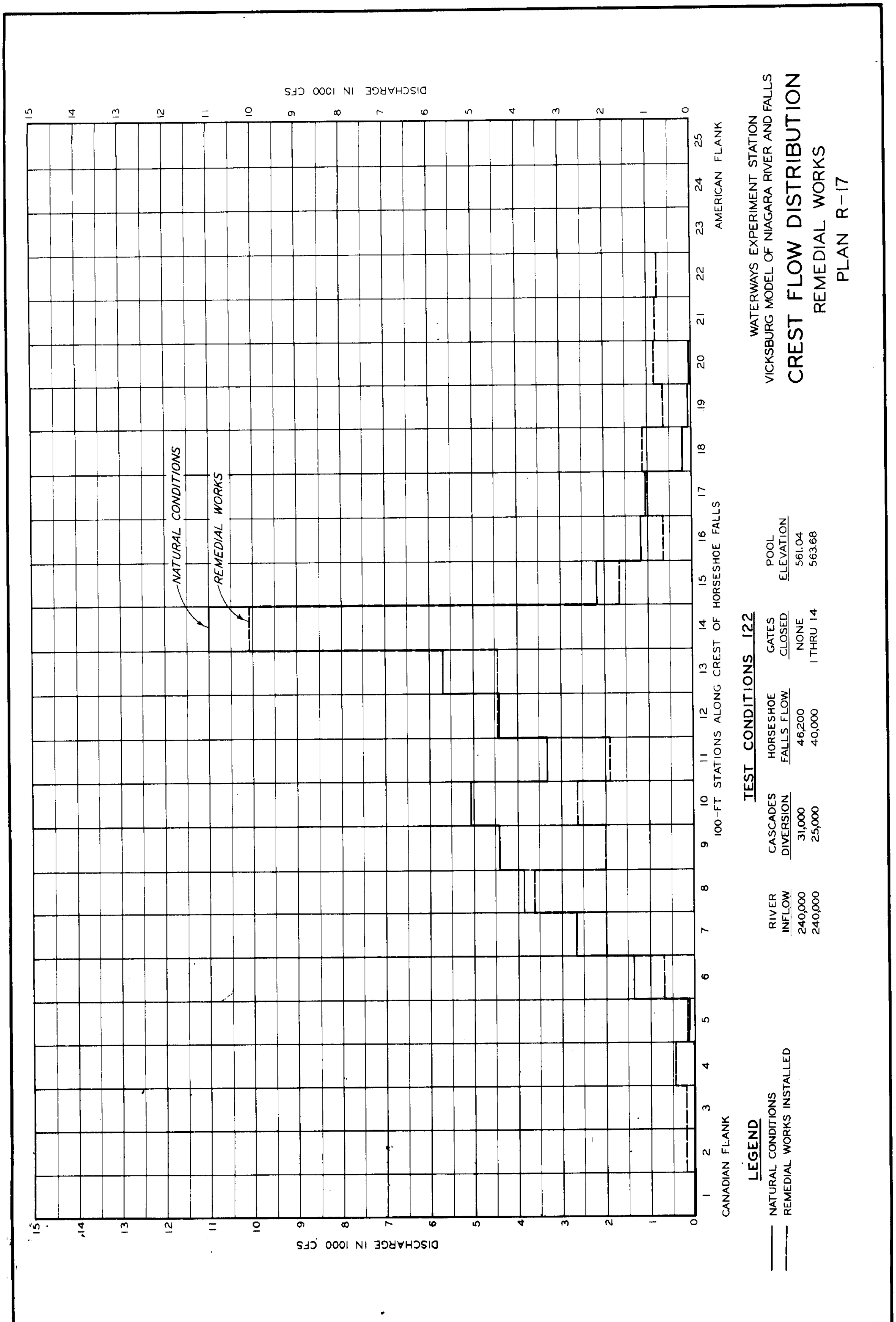
WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS

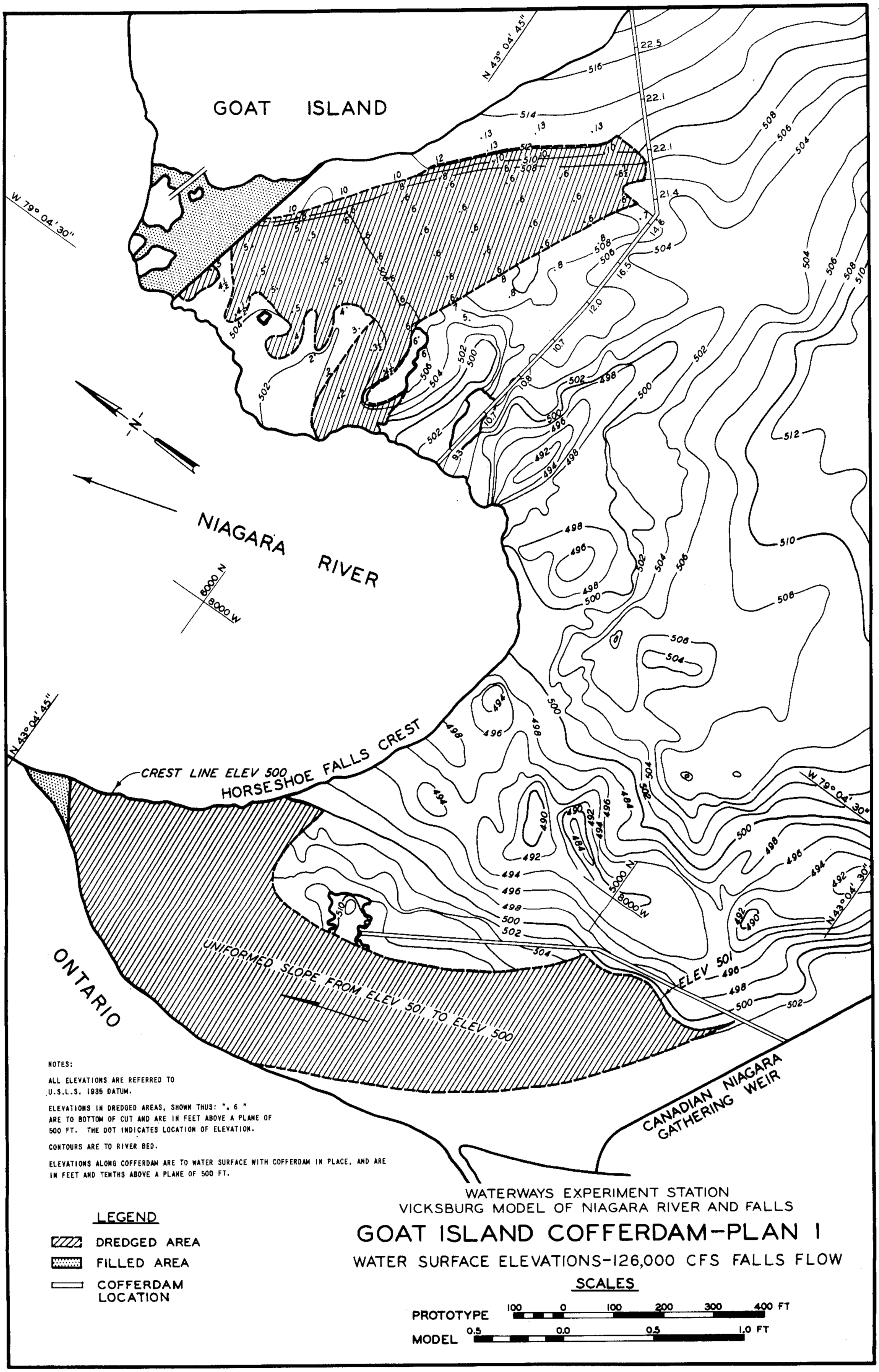
CRONT FLOW DISTRIBUTION

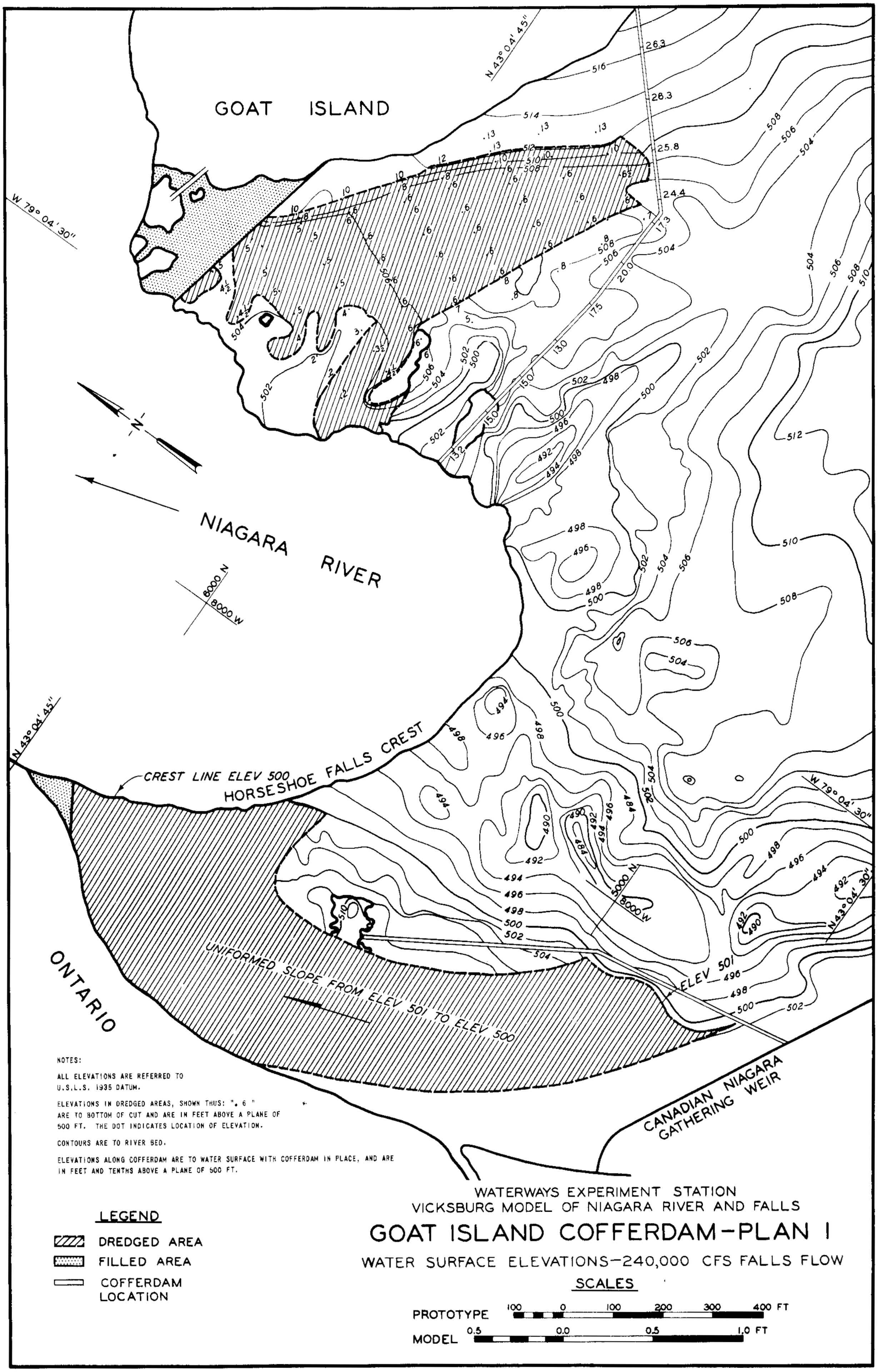
REMEDIAL WORKS
PLAN R-17

PLATE G-18


WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
CREST FLOW DISTRIBUTION
REMEDIAL WORKS
PLAN R-17
TEST CONDITIONS 121
RIVER INFLOW
240,000
240,000
CASCADES DIVERSION
6000
6000
HORSESHOE FALLS FLOW
94,000
82,000
GATES CLOSED
NONE
1 THRU 12½
POOL ELEVATION
561.76
564.22
LEGEND
NATURAL CONDITIONS
REMEDIAL WORKS INSTALLED
NATURAL CONDITIONS
REMEDIAL WORKS
TARGET FLOW
TARGET FLOW
DISCHARGE IN 1000 CFS
DISCHARGE IN 1000 CFS
CANADIAN FLANK
100-FT STATIONS ALONG CREST OF HORSESHOE FALLS
AMERICAN FLANK


WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
CREST FLOW DISTRIBUTION
REMEDIAL WORKS
PLAN R-17
DISCHARGE IN 1000 CFS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
100-FT STATIONS ALONG CREST OF HORSESHOE FALLS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
CANADIAN FLANK
AMERICAN FLANK
NATURAL CONDITIONS
REMEDIAL WORKS
LEGEND
NATURAL CONDITIONS
REMEDIAL WORKS INSTALLED
TEST CONDITIONS 122
RIVER INFLOW 240,000 240,000
CASCADES DIVERSION 31,000 25,000
HORSESHOE FALLS FLOW 46,200 40,000
GATES CLOSED NONE 1 THRU 14
POOL ELEVATION 561.04 563.68

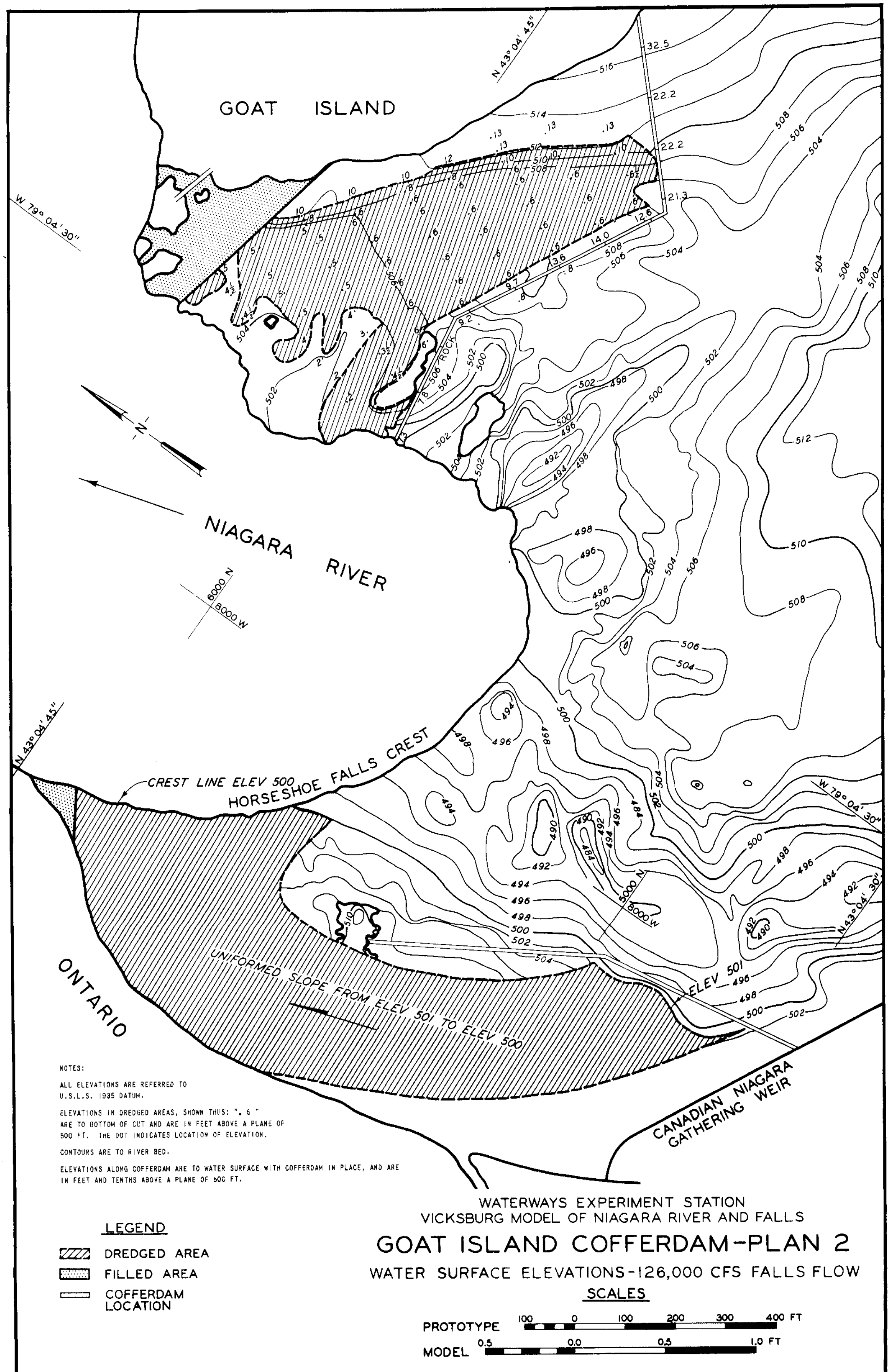

GOAT ISLAND
NIAGARA RIVER
ONTARIO
N 43° 04' 45"
W 79° 04' 30"
6000 N
8000 W
5000 N
CREST LINE ELEV 500
HORSESHOE FALLS CREST
UNIFORMED SLOPE FROM ELEV 501 TO ELEV 500
ELEV 501
CANADIAN NIAGARA GATHERING WEIR
NOTES:
ALL ELEVATIONS ARE REFERRED TO U.S.L.S. 1935 DATUM.
ELEVATIONS IN DREDGED AREAS, SHOWN THUS: ". 6 " ARE TO BOTTOM OF CUT AND ARE IN FEET ABOVE A PLANE OF 500 FT. THE DOT INDICATES LOCATION OF ELEVATION.
CONTOURS ARE TO RIVER BED.
ELEVATIONS ALONG COFFERDAM ARE TO WATER SURFACE WITH COFFERDAM IN PLACE, AND ARE IN FEET AND TENTHS ABOVE A PLANE OF 500 FT.
LEGEND
DREDGED AREA
FILLED AREA
COFFERDAM LOCATION
WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
GOAT ISLAND COFFERDAM-PLAN I
WATER SURFACE ELEVATIONS-126,000 CFS FALLS FLOW
SCALES
PROTOTYPE 100 0 100 200 300 400 FT
MODEL 0.5 0.0 0.5 1.0 FT



WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS

GOAT ISLAND COFFERDAM—PLAN I

WATER SURFACE ELEVATIONS—240,000 CFS FALLS FLOW


GOAT ISLAND
NIAGARA RIVER
HORSESHOE FALLS CREST
CREST LINE ELEV 500
ONTARIO
UNIFORMED SLOPE FROM ELEV 501 TO ELEV 500
CANADIAN NIAGARA GATHERING WEIR
ROCK
ELEV 501
N 43° 04' 45"
W 79° 04' 30"
N 43° 04' 30"
6000 N
8000 W
5000 N
8000 W
N
NOTES:
ALL ELEVATIONS ARE REFERRED TO U.S.L.S. 1935 DATUM.
ELEVATIONS IN DREDGED AREAS, SHOWN THUS: ". 6 " ARE TO BOTTOM OF CUT AND ARE IN FEET ABOVE A PLANE OF 500 FT. THE DOT INDICATES LOCATION OF ELEVATION.
CONTOURS ARE TO RIVER BED.
ELEVATIONS ALONG COFFERDAM ARE TO WATER SURFACE WITH COFFERDAM IN PLACE, AND ARE IN FEET AND TENTHS ABOVE A PLANE OF 500 FT.
LEGEND
DREDGED AREA
FILLED AREA
COFFERDAM LOCATION
WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
GOAT ISLAND COFFERDAM-PLAN 2
WATER SURFACE ELEVATIONS-126,000 CFS FALLS FLOW
SCALES
PROTOTYPE 100 0 100 200 300 400 FT
MODEL 0.5 0.0 0.5 1.0 FT

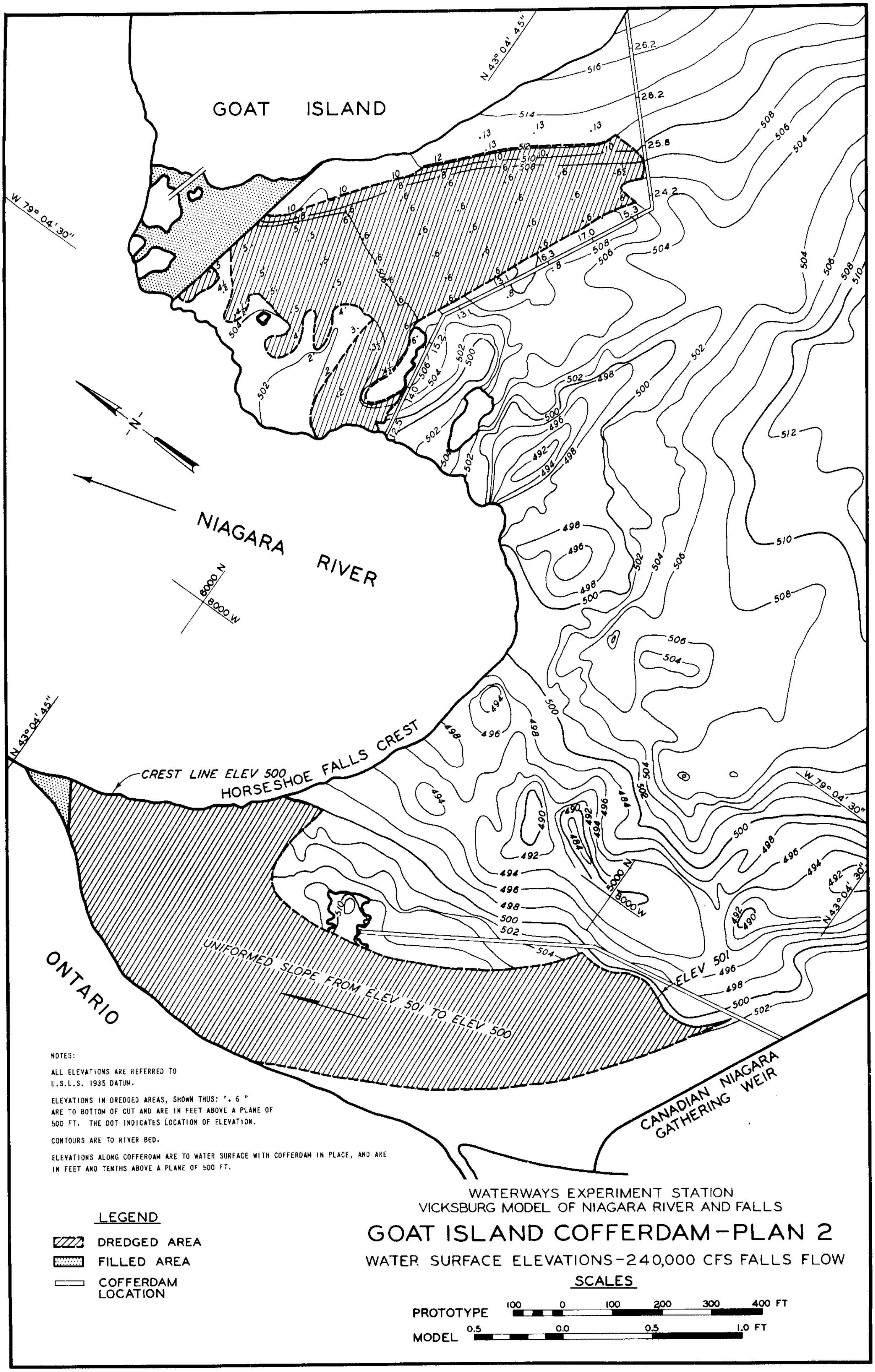
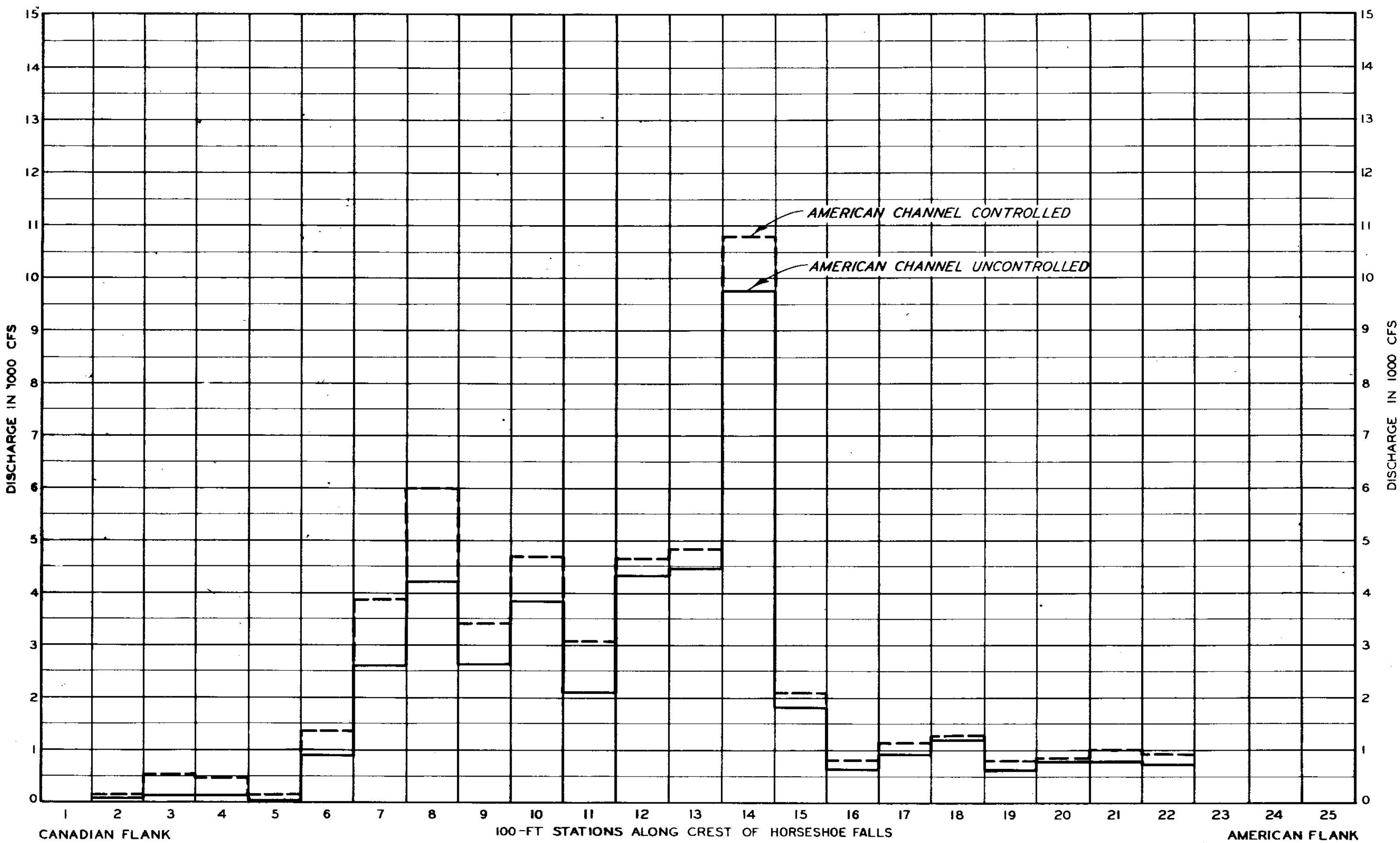

GOAT ISLAND
NIAGARA RIVER
ONTARIO
CREST LINE ELEV 500
HORSESHOE FALLS CREST
UNIFORMED SLOPE FROM ELEV 50' TO ELEV 500
CANADIAN NIAGARA GATHERING WEIR
N 43° 04' 45"
W 79° 04' 30"
N 43° 04' 30"
8000 N
8000 W
5000 N
ELEV 501
NOTES:
ALL ELEVATIONS ARE REFERRED TO U.S.L.S. 1935 DATUM.
ELEVATIONS IN DREDGED AREAS, SHOWN THUS: ". 6" ARE TO BOTTOM OF CUT AND ARE IN FEET ABOVE A PLANE OF 500 FT. THE DOT INDICATES LOCATION OF ELEVATION.
CONTOURS ARE TO RIVER BED.
ELEVATIONS ALONG COFFERDAM ARE TO WATER SURFACE WITH COFFERDAM IN PLACE, AND ARE IN FEET AND TENTHS ABOVE A PLANE OF 500 FT.
LEGEND
DREDGED AREA
FILLED AREA
COFFERDAM LOCATION
WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS
GOAT ISLAND COFFERDAM-PLAN 2
WATER SURFACE ELEVATIONS-240,000 CFS FALLS FLOW
SCALES
PROTOTYPE 100 0 100 200 300 400 FT
MODEL 0.5 0.0 0.5 1.0 FT

PLATE G-24



LEGEND

——— AMERICAN CHANNEL UNCONTROLLED
— — — AMERICAN CHANNEL CONTROLLED

TEST CONDITIONS

RIVER INFLOW	CASCADES DIVERSION	HORSESHOE FALLS FLOW	GATES CLOSED	POOL ELEVATION
240,000	24,100	43,100	1 THRU 14	563.68
240,000	24,100	53,000	1 THRU 14	563.92

WATERWAYS EXPERIMENT STATION
VICKSBURG MODEL OF NIAGARA RIVER AND FALLS

CREST FLOW DISTRIBUTION

AMERICAN FALLS CONTROL STRUCTURE

APPENDIX H

ISLINGTON MODEL
STUDIES OF REMEDIAL WORKS

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX H

ISLINGTON MODEL STUDIES OF REMEDIAL WORKS

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LIST OF TABLES (Cont'd.)

LIST OF PLATES

LIST OF PLATES (Cont'd.)

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX H

ISLINGTON MODEL STUDIES OF REMEDIAL WORKS

INTRODUCTION

1. The model studies leading to the design of remedial works necessary for the Preservation and Enhancement of Niagara Falls were carried out on two models, one at Vicksburg, Mississippi, by the Corps of Engineers, United States Army, and the other at Islington, Ontario, by The Hydro-Electric Power Commission of Ontario. This appendix contains a detailed description of the tests carried out on the Islington model, the results obtained, and the remedial plans developed. A description of the Islington model and an account of the verification tests carried out may be found in Appendices E and F. The corresponding Vicksburg model information is given in Appendices G, D and F respectively.

2. The model investigation described in this Appendix led to the design of remedial works both in the Chippawa-Grass Island Pool area, and in the Cascades above the Horseshoe Falls. While these works are somewhat interdependent, their functions are generally different, and the description of the development of each is given separately.

CHIPPAWA-GRASS ISLAND POOL CONTROL STRUCTURE TESTS

FUNCTION OF CONTROL STRUCTURE

3. The larger diversions for power purposes authorized by the Treaty of 1950 would produce substantially lower Chippawa-Grass Island Pool levels, if control works were not constructed, as all new diversions would draw from this Pool. As given in detail in Appendix E, measurements on the Niagara model at Islington determined the magnitude of this lowering for various stages of development. Also, the treaty stipulates that while in the winter or non-tourist season the flow over the Falls need not exceed 50,000 cubic feet per second, during a defined tourist season the flow between prescribed day-time hours must not be less than 100,000 cubic feet per second, but could be reduced to 50,000 cubic feet per second during the remaining night-time hours. An increase in flow over the Falls from 50,000 cubic feet per second to 100,000 cubic feet per second or vice versa would require a corresponding rise or fall in Pool elevation, and tests on the Vicksburg model indicated that, without a Pool control structure, the time required to effect such a Pool level rise, as well as the corresponding fall at night, was so great that only a small portion of larger night diversion permitted by the Treaty could be utilized.

4. The function of a control structure, therefore, would be twofold:

(1) To enable the Pool to be maintained at its present range of levels at all times, thereby preventing the adverse effects due to a lowering of the Pool as enumerated in Appendix E.

(2) To enable variations to be made in the flow over the Falls from 50,000 to 100,000 cubic feet per second, and vice versa, without loss of time or substantial Pool level change, and thereby permit full utilization of the additional diversion allowed during the night hours.

HYDRAULIC DESIGN CRITERIA

5. It was agreed that the sluice sills of any control structure on the Canadian side of Tower Island should not exceed in elevation that of the existing submerged weir, i.e., 553.5 U.S.L.S. datum, 1935 adjustment. On the United States side of Tower Island any sills should not be above river bed level. These requirements were to minimize the danger of ice lodgement against the sill. It was also considered preferable that the sluices should be 100 feet wide, and the piers as narrow as practicable. In the Islington model tests, piers 14 feet wide were used throughout the investigation.

6. The following discharge criteria for the control structure were adopted:

(1) With a high daily average discharge of 320,000 cubic feet per second and present normal diversions by existing plants, the elevation in the Pool at the Material Dock Gauge (No. 5) with the control structure in place, all gates fully open, and with new plants taking no more than 25 per cent of their combined discharge capacity, should be no higher than under present conditions of development with present normal diversions.

(2) With all but three sluices of the control structure open, the diversion through the new plants must not be assumed to exceed 50 per cent of their discharge capacity to avoid similarly exceeding the same Pool elevation.

7. At a meeting of the International Niagara Falls Engineering Board at Islington on June 23, 1952, the Board considered a method of Pool regulation recommended by the Working Committee. Briefly, the method envisaged maintaining the same Pool levels in the future that now exist for any given river flow, by operation of the gates in the control structure. The Board expressed general agreement with this proposed method.

LOCATION OF CONTROL STRUCTURES TESTED AND OUTLINE OF TESTS

8. In Plate H-1 are shown the locations of control structures tested in the Islington model. These structures were all control dams composed entirely of 100-foot wide sluices separated by 14-foot wide piers. Movable control gates were installed in all the sluices. Dams designated "A", "B", "C", "D", "M", are on the line of the existing submerged weir, while Dam "E" is some 1,000 feet downstream. Dam "F" is 250 feet downstream from the submerged weir. After some preliminary tests on the dams "A" and "E", the opinion of construction authorities was sought as to the more favourable of the two locations from a construction standpoint, as it appeared that either location would yield about the same hydraulic performance. The opinion at that time was that a dam located either on or near the submerged weir would appear to be preferable. Consequently, all subsequent intensive testing until September 1952, was conducted on dams on the line of the submerged weir and no further testing was done on Dam "E". During September 1952, however, a more intensive examination of the site indicated that a line 250 feet downstream from the weir would be more favourable. A subsequent model check on the 13 sluice dam in this new location, Dam "F", revealed that while the performance was not identical with that formerly obtained, it was sufficiently close to permit use of the previous work. The comparative performance of this dam in the new location is shown in Plate H-3.

DESCRIPTION OF CONTROL STRUCTURES

9. The control structure tests were begun following the verification of the upper portion of the model. The first tests made were to determine the minimum number of sluices necessary to fulfil the second function, paragraph 4. A dam of ten 100-foot sluices, Dam "C", Plate H-1, was found to satisfy this criterion. The dam was then successively lengthened to 13, 19 and 32 sluices, Dams "B", "D", and "A", and the performance in regard to the ability to regulate the Pool determined in each case. All these dams were tested over the full range in river flow, and the assumption was made that full development of the river was in effect and that the power diversions would be utilized to their full capacity. It was also assumed that when low river flows restricted the diversions, the flow would be utilized in the most efficient manner. Following these tests, the number of sluices was determined which would satisfy the criteria in the intermediate period; i.e. the period in which the new diversions would be confined to those utilized by the new Sir Adam Beck-Niagara Generating Station No. 2. Their performance under these conditions was also determined.

RESULTS OF CONTROL STRUCTURE TESTS

10. It was determined that ten 100-foot sluices separated by 14-foot piers, Dam "C", extending out from the Canadian shore on the line of the submerged weir were necessary to enable either 100,000 cubic feet per second or 50,000 cubic feet per second to be discharged over the falls without a change in Pool level. The minimum level at which this could be accomplished was found to be Elevation 561 at Gauge No. 5, which coincides approximately with the minimum level that occurs under present conditions. In Plate H-3 is shown the observed performance of this Dam "C" at all river flows. The corresponding performance of Dams "B", "D", and "A" with 13, 19, and 32 gates respectively is also shown. Plotted also are the Pool levels that now exist, and the levels that would exist if no control structure was constructed. It should be explained that the Pool levels indicated in all performance curves are the maximum that could be obtained for the particular number of sluices tested, except that Elevation 564.5 was considered to be the ceiling. By regulation of the gates, any levels between these maximum levels and those shown with no control structure in place, could be produced. In Plates H-2 and H-4, the observed performance of dams consisting of ten and nine 100-foot sluices respectively, located on the line of Dam "F", is given for conditions that would exist when the new Sir Adam Beck-Niagara Generating Station No. 2 comes into operation only; i.e. the intermediate period.

11. The results obtained in checking the capacity criteria, paragraph 4, are as follows for the 13-sluice dam:

(i) For the first criterion with all gates fully open and with the new plants diverting 25 per cent of their discharge capacity:

Discharge Capacity of New Plants	Change in W.S. Elevation at Gauge No. 5 from Levels with Present Normal Diversion and No Control Dam
100,000	No change
40,000	Up 0.25 foot

(ii) For the second criterion with three gates closed and the remainder open and with the new plants diverting 50 per cent of their discharge capacity:

Discharge Capacity of New Plants	Change in W.S. Elevation at Gauge No. 5 from Levels with Present Normal Diversion and No Control Dam
100,000	Down 0.30 foot
40,000	Up 0.50 foot

ANALYSIS OF CONTROL STRUCTURE TEST RESULTS

12. It may be noted from Plate H-3 that while ten sluices enable the day and night flows to be realized without a Pool level change, they fall short of achieving the second criterion of enabling present levels to be produced under future conditions, paragraph 7. Dam "B", 13 sluices, is shown to satisfy this criterion over all of the river flow range, except in the region of 240,000 cubic feet per second river flow, where it is slightly deficent. Dams "D" and "A" can produce levels much in excess of those required. The performance of all these dams was then plotted in relation to the frequency of the river flows both in the tourist and non-tourist seasons and is shown in Plate H-4. Here it may be seen that Dam "B" satisfies the level criterion for practically 100 per cent of the time in the non-tourist season and for about 85 per cent of the time in the tourist season and in this 15 per cent the deficiency is only of a very small order. In this regard, Dam "F" may be considered essentially identical with Dam "C". It was concluded that as far as regulation performance is concerned, thirteen 100-foot sluices built out from the Canadian shore sufficiently satisfy the criteria agreed upon.

13. In the intermediate period, it was found that a dam consisting of ten 100-foot sluices was required if the ability to discharge over the Falls either 50,000 cubic feet per second or 100,000 cubic feet per second without a Pool level change was to extend to the lowest river flow tested i.e. 140,000 cubic feet per second (Pool elevation 561.0). As may be noted on Plate H-2, however, nine sluices were sufficient to effect the required Pool regulation, and this number was found to be the minimum for this purpose. With nine sluices, either 50,000 cubic feet per second or 100,000 cubic feet per second could be discharged over the Falls without a Pool level change for all river flows above 150,000 cubic feet per second, but for flows below this value another sluice would be required to satisfy criterion (2) paragraph 4.

14. The results of tests for the first capacity criterion, paragraph 6, indicate no increase in levels for full power development, but show a measurable increase of about 0.25 foot if the new Sir Adam Beck plants only are in operation. The second criterion indicates a decrease in levels under full development but shows an increase of about 0.5 foot if the new Sir Adam Beck plants only are in operation. It is considered that these criteria are met sufficiently closely for safety in operation.

Observations on appearance of Pool and Upper Cascades

15. In Appendix E it was noted that without remedial works, under full power diversions authorized by the 1950 Treaty and with the Falls flow reduced to 50,000 cubic feet per second, areas of the Pool bed were exposed, particularly upstream from Goat Island. The flow in the region of the Three Sisters Islands was observed to be sharply reduced under these conditions. With the 13-sluice control structure, Dam "B" or Dam "F", in operation, the Chippawa-Grass Island Pool itself was regulated to present levels for any given river flow, therefore the appearance of the Pool area above the dam would be the same under regulation as it is at present. Under conditions of maximum diversion, closure of all or most of the gates in the control structure, depending on the river discharge, will be necessary. This will result in all or most of the outflow from the Pool passing between the outstream end of the dam and the United States shore, thus providing a satisfactory cover of the areas adjacent to Goat Island. This will provide substantial flows in the Three Sisters Island channels. With the control structure fully closed, the levels immediately downstream necessarily would be lower than those existing at present, but little lower than if no dam existed under the same diversion conditions. After rounding the end of the dam in the fully closed postion, a large proportion of the flow would move back toward the Canadian shore and the Ontario Power Company intake.

EFFECT OF POOL REGULATION ON AMERICAN FALLS FLOW

Observed American Channel flows

16. In Appendix C, an analysis was made of the present American Channel flow. In Plate H-10, this flow is shown plotted in relation to levels in the Chippawa-Grass Island Pool. Throughout the model tests on the Pool control structures, observations were made of the flow in the American Channel when the new diversions were in effect and the Pool regulated to the same levels at Gauge No. 5 for the same total river flow. In Plate H-10, the observed American Channel flow under these conditions is also plotted. Comparing the present and future flows, it may be noted that they are the same for a total river flow of 200,000 cubic feet per second. For river flows above 200,000 cubic feet per second, the future American Channel flows are somewhat greater than at present and for flows below 200,000 cubic feet per second, somewhat less. These divergencies from the present flow appear to be due to different currents and slope in the Pool with the new diversion in effect and the level regulated by the 13-sluice control dam, even though the same level exists at Gauge No. 5. However, from the standpoint of scenic appearance of the American Falls, the future conditions may be considered essentially the same as at present.

TESTS ON WORKS TO CONTROL AMERICAN CHANNEL FLOW

17. Under present conditions and under the proposed future regulation, at high river flows, the American Channel carries a flow in excess of that necessary for a satisfactory American Falls scenic spectacle. Primarily to assist the remedial works in the Cascades above the Horseshoe Falls, an attempt was made to restrict the flow into the American Channel at high Pool levels. In the Islington model, a shoreline fill upstream from the entrance to the American Channel was tested, located as shown on Plate H-10. The performance of this fill is plotted on Plate H-10 and while it was successful at high flows, it had the disadvantage of reducing the American Channel flow at low river flows also. For this reason it is considered unsatisfactory and need be considered no further. A control structure with movable gates developed for the same purpose was also tested in the Vicksburg model. The location of this structure is shown in Plate H-1. The ability of this structure to reduce the American Channel flow is shown on Plate H-10. The benefits derived from this diverted flow in connection with the Horseshoe Falls remedial works are discussed later in paragraphs 42 to 45. In so far as Pool regulation is concerned, it was found that a structure with movable gates above the Goat Island channel could not replace or reduce the main control dam.

CONCLUSIONS FROM CHIPPAWA-GRASS ISLAND POOL CONTROL STRUCTURE TESTS AND STUDY OF AMERICAN CHANNEL FLOW

18. From the Pool control structure tests and the related study of the American Falls flow, the conclusions may be summarized as follows:

(a) The best location for the Chippawa-Grass Island Pool control structure would be extending out from the Canadian shore on a line parallel to the present submerged weir and some 250 feet downstream therefrom.

(b) 13 sluices, each with a clear width of 100 feet, equipped with movable gates, and separated by piers 14 feet wide were found adequate in regulating the Pool to the schedule of levels as set forth in paragraph 7 under the full power development permitted by the 1950 Treaty. This number of sluices would also enable Falls flow of either 50,000 cubic feet per second or 100,000 cubic feet per second to be produced without any change in Pool elevation, as it was found that 10 sluices only were required for this purpose.

(c) For diversion conditions that would exist in the intermediate period following the completion of the new Sir Adam Beck-Niagara Generating Station No. 2 only, nine sluices were found sufficient to provide the necessary regulation, but 10 sluices would be required if criterion (2), paragraph 4, was to be satisfied for river flows below 150,000 cubic feet per second.

(d) In all cases these control structures are considered to be capable of safe operation under all conditions of river flow and diversions.

(e) Under Pool regulation by the control structure, the appearance of the Pool would remain unchanged, and the areas upstream from Goat Island and in the vicinity of the Three Sisters Islands would be covered with a satisfactory flow of water.

(f) With the Pool regulated by the control structure, the flow in the American Channel and over the American Falls was found to be essentially the same as under present conditions, except for a slight increase at high river flows and a slight decrease at low river flows.

(g) Tests made to determine whether measures could be devised to divert surplus American Channel flows at high Pool levels into the Horseshoe Falls Cascades indicated that fixed structures would be unsatisfactory but that a structure with movable gates upstream from the Channel entrance would exert the necessary control. Such a structure, however, would not replace or reduce the length of the main control dam and, therefore, would not be justified.

TESTS ON HORSESHOE FALLS REMEDIAL WORKS

Consideration of problem

19. By the terms of the 1950 Treaty, remedial works are required which will "enhance the beauty of the Falls by distributing the waters so as to produce an unbroken crestline on the Falls". In the preliminary model tests described in Appendix E, it was established that without remedial works the flanks of the Horseshoe Falls would be dry at the minimum Falls flow permitted by the Treaty, i.e., 50,000 cubic feet per second, and either dry or inadequately supplied at 100,000 cubic feet per second, the minimum permitted during the daylight hours of the tourist season. The function of the Horseshoe Falls remedial works would be, then, to cover adequately the flanks with water at these minimum flows and by so doing produce an unbroken crestline from shore to shore. In observing the prototype and model Cascades, it appeared evident that the only available source of supply for the flanks of the Horseshoe Falls would be the two deep streams, one on each side of the Cascades, which converge near the centre of the Horseshoe. To accomplish the diversion of water from these streams to the flanks, it was considered that two main types of remedial works should be investigated: (1) Excavations on the flanks extending upstream to the deep channels to induce flow to the flanks; and (2) Submerged weirs in the Cascades to intercept the deep streams and deflect flow to the flanks. It was considered also that combinations of excavations and weirs might prove effective and economical. Crest fills to shorten and improve the flanks were also to be investigated in conjunction with the other measures investigated.

Adequacy criteria

20. It was originally agreed that the Horseshoe Falls remedial works should produce a flow of six to eight cubic feet per second per foot on the Goat Island flank and 12 cubic feet per second per foot on the Canadian flank with a total Falls flow of 100,000 cubic feet per second. Subsequent testing indicated that this might be realized without also producing an adequate unbroken sheet from shore to shore at 50,000 cubic feet per second Falls flow. At the meeting of the International Niagara Falls Engineering Board at Islington on June 23, 1952, it was decided, therefore, that a satisfactory remedial scheme should provide complete coverage of both flanks with an unbroken sheet of water at a total Falls flow of 50,000 cubic feet per second, and also provide the target flows over the flanks at 100,000 cubic feet per second, which were defined as being six to eight cubic feet per second per foot on the Goat Island flank and 10 to 12 cubic feet per second per foot on the Canadian flank.

General outline of tests on Islington model

21. The tests on the Islington model commenced with excavations in the Cascades above the flanks of the Horseshoe Falls, with crest fills in place. When these had progressed to the point where the feasibility of such schemes was indicated, preliminary tests on submerged weirs were made which showed that they too were promising. Tests on weirs were then carried through, both alone and in conjunction with excavations, with crest fills in place. Essentially successful remedial schemes involving submerged weirs with and without excavations were developed, but from the standpoint of economy, feasibility of construction, and appearance, they were found to be inferior to plans involving excavations only. Consequently, all further effort was devoted to the development of a successful scheme involving excavations and crest fills only. A plan resulted which is considered to be satisfactory in every regard. For purposes of clarity on this appendix, the tests on the schemes involving excavations are described separately from those involving submerged weirs.

REMEDIAL WORKS TESTS INVOLVING EXCAVATIONS AND CREST FILLS ONLY

Test programme followed

22. The general policy followed in developing remedial schemes, comprised of excavations on the flanks of the Horseshoe Falls, was to start with light excavations which were progressively

increased until the target flows over the flanks were reached. To minimize the variable conditions, it was assumed that the crest fills would be in place and the thirteen 100-foot sluice control dam would be in operation. Also, the tests would be confined to 50,000 cubic feet per second and 100,000 cubic feet per second over the Falls, each produced in two ways by varying the diversions so that the maximum Pool diversion would be effected in one case, and the maximum Cascades plants diversion in the other. In all these cases, the average river flow of 200,000 cubic feet per second would be used. It was the intention to obtain successful schemes under these conditions, and then determine their adequacy under a full range of river flow and corresponding diversions and under any other operating conditions considered desirable. Any inadequacies revealed by this more comprehensive testing would then be rectified. The effect of the crest fills on the performance would also be determined.

23. Prior to the meeting of the Engineering Board at Islington on June 23, 1952, two schemes of excavation were tested. These were CA and GA, and CB and GB, the letters signifying Canadian flank-A scheme and Goat Island flank-A scheme, and similarily with the B scheme. These plans are shown in Plates H-5 and H-6. CA and GA were tested first and found inadequate. The excavation was then increased and CB and GB tested. These were found to achieve very nearly the target flows with 100,000 cubic feet per second over the Falls, but were obviously unsatisfactory with a Falls flow of 50,000 cubic feet per second. At the Board meeting, the criterion of an unbroken curtain of flow from shore to shore at 50,000 cubic feet per second was agreed upon. After this date it was decided that in the Islington tests, only schemes that met this latter criterion would be thoroughly tested and documented. Accordingly, the excavations were progressively increased until schemes CD and GD were evolved, Plate H-7. More comprehensive testing indicated these excavations to be inadequate over a portion of the full flow range, therefore the excavations were increased once more and plans CE and GE (R17), Plate H-8, were produced, (R17) signifying the scheme developed in the Vicksburg model. These were then tested under a variety of conditions, and found to be fully satisfactory. Cofferdams for this scheme located as shown on Plate H-8 were also tested for a variety of flows.

Test procedure

24. In each test on the remedial schemes the following data were obtained:

(1) Readings of all river gauges shown on Plates E-4 and E-5, Appendix E, and all Cascades gauges shown on Plate F-5, Appendix F.

(2) Measurements of the flow in each 100-foot crest panel, Plate E-21, Appendix E.

(3) One photograph of each Falls from vantage points PO, PN, Plate E-4, Appendix E.

(4) Measurements of the total flow over both Falls and of all inflow and outflow to and from the model to assure correct conditions.

25. The preliminary remedial schemes CA, GA and CB, GB were subjected to tests 101, 104, 107, and 108, Table H-1. Thereafter, the general procedure was to construct a scheme of excavation, install it in the model, and visually determine whether it appeared satisfactory under conditions of test 108. If so, the remaining tests were completed and the scheme was documented if it proved satisfactory. Plan CD, GD was thus tested, and then subjected to the greater flow range covered by tests 120, 121, 122, and 123, Table H-1. For the final plan CE, GE (R17), a new series of tests, 207 to 212 inclusive, Table H-1, was developed, which covered the normal range of river flow and included the likely diversions. A similar series of tests 201 to 206 inclusive, Table H-1, was also made without the Horseshoe Falls remedial works in place and with the Chippawa-Grass Island Pool control structure fully open. These were made to provide an accurate comparison of conditions with and without remedial works.

26. The cofferdams for scheme CE, GE (R17), Plate H-8, were tested under three river flows, 210,000 cubic feet per second, 240,000 cubic feet per second, and 320,000 cubic feet per second, and present power diversions only were assumed to be in effect. Tests were made first with one cofferdam in place only, then the other cofferdam in place only, and finally with both cofferdams in place. Water surface elevations along the cofferdams were observed at 100-foot stations, Table H-28.

TEST RESULTS

27. The detailed test results are given in Tables H-2 to H-11, H-14 to H-17, and H-20 to H-27. Tables H-2 to H-11 inclusive record the performance of the preliminary scheme CA, GA and CB, GB, in various combinations with each other and with the natural flank bottom. For convenience in comparison, the corresponding performance with no remedial works in place is repeated in some of these tables. Some figures are also given to show the effect of the Pool control structure with no excavations in place, and also with excavations in place, but with no Pool control. Tables H-14 to H-17 and H-20 to H-23 inclusive record the performance of schemes CD, GD, with and without crest fills. Tables H-24 to H-27 inclusive give the results of the comprehensive testing on the final excavation scheme CE, GE (R17) and also record the comparable conditions if no remedial works were constructed. Plates H-11 to H-13 inclusive are graphic representations of the crest flows measured in these tests in the final scheme evolved. The results of the cofferdam tests for this scheme are presented in Table H-28, and photographs of the cofferdam in place with a flow of 210,000 cubic feet per second are shown in Plate H-23.

28. While a complete set of photographs was taken for all tests on the excavation schemes, only the following are included in this report:

(1) Photographs of the performance of the A, B, and D excavation schemes, Plates H-14 and H-15, with 200,000 cubic feet per second river flow and with a flow over the Falls of both 50,000 cubic feet per second and 100,000 cubic feet per second, test 107 and test 101 conditions respectively. The American Falls flow is shown only for the A scheme, as with a regulated Pool, its flow and appearance is identical for all these schemes.

(2) Photographs of the final scheme CE, GE (R17), Plates H-17 to H-22, with both 50,000 cubic feet per second and 100,000 cubic feet per second Falls flow, for river flows of 170,000 cubic feet per second, 200,000 cubic feet per second, and 240,000 cubic feet per second, test 207 to 212 conditions. For comparison purposes, photographs were taken with no Horseshoe Falls remedial works in place for the same river flows and corresponding diversions, test 201 to 206 conditions. In all these latter tests, the Chippawa-Grass Island Pool control dam was in place but fully open.

ANALYSIS AND DISCUSSION OF TEST RESULTS

29. In the analysis of the test results, the Canadian flank was considered to extend from Panel 1 to Panel 5 inclusive, Plate E-21. The Goat Island flank was similarly considered to extend from Panel 18 to Panel 25 inclusive. The measured flows per foot over these lengths were averaged, and this average was considered to be the flank average which would be compared to the target flow. In all tests up to and including some of the D schemes, the crest fill on the Canadian flank extended 50 feet out into Panel 1, while the Goat Island crest fill extended from station 22+30 to the end of Panel 25. In August 1952, it was decided that these fills should be 100 feet and 300 feet in length, respectively, and after this date the new fill lengths were used.

PRELIMINARY TESTS

30. In Tables H-2 to H-6 inclusive and H-7 to H-11 inclusive, respectively, there are listed the discharge and elevation results of the preliminary excavation tests. In each set there are listed

the flows and levels observed in the model with no remedial works in place. It may be noted that for this condition, with 50,000 cubic feet per second over the Falls, both flanks of the Horseshoe Falls are either dry or only show a trace of flow. With 100,000 cubic feet per second Falls flow, both flanks average less than the target flows, and stretches of the Goat Island crest are dry. Two tests were made to determine whether the operation of the Pool control structure affected the flank flow distribution. Tables H-5 and H-6, columns 2 and 3, show that the action of the control structure reduces slightly the flow over the Canadian flank, while slightly increasing the flow over the Goat Island flank. It should be noted, however, that the Pool regulation results in a considerable increase in the American Channel flow with a consequent reduction in the total Horseshoe Falls flow, compared with no Pool regulation. This indicated that the operation of the Pool control structure would be a factor in the performance of the Horsehoe Falls remedial schemes.

Schemes CA, GA and CB, GB.

31. The test results on these schemes are recorded in detail in Tables H-2 to H-11. The first excavation plans tried were schemes CA and GA. With 50,000 cubic feet per second over the Falls, tests 107 and 108, Tables H-2 and H-3, demonstrated that the Canadian flank was dry, while the Goat Island flank was nearly so. With a Falls flow of 100,000 cubic feet per second, tests 101 and 104, Tables H-5 and H-6, showed that the flow on both flanks was still well below the target. Tests 107 and 108 on CB and GB, Tables H-2 and H-3, similarly indicated a deficiency on the Canadian flank with 50,000 cubic feet over the Falls, but showed a cover on the Goat Island flank. With a Falls flow of 100,000 cubic feet per second, both flanks reached the target flow with 140,000 cubic feet per second river flow, test 120, Table H-4. With 200,000 cubic feet per second river flow, Tables H-5 and H-6, the target flows are reached except on the Goat Island flank in test 101, and on the Canadian flank in test 107, where a slight deficiency exists in each case. Also recorded in these tables are tests on combinations of the schemes to reveal any interdependency. Within the limits of experimental accuracy, there appeared to be no evidence from these tests that an excavation scheme by increasing the flow on one flank would adversely affect the flow on the other flank. It was concluded therefore that each flank improvement could proceed independently without an effect on the other flank. At this stage in the testing, the criterion of a continuous sheet at 50,000 cubic feet per second over the Falls was decided upon, and as all these schemes were deficient in this regard they were all rejected.

Schemes CD, GD.

32. The tests results on excavation schemes CD, GD, with and without crest fills, are recorded in Tables H-14 to H-17 and H-20 to H-23. When tested first with 200,000 cubic feet per second river flow, tests 107 and 108 indicated a substantial cover at 50,000 cubic feet per second Falls flow with the crest fills in place. Without the crest fills, a complete though thinner cover existed. With 100,000 cubic feet per second over the Falls, tests 101 and 107 showed the target flows reached or exceeded on both flanks with the crest fills in place, while without the crest fills the Goat Island flank was slightly deficient. While not indicated in the tables, due to its location at the juncture of the crest panels 17 and 18, a break in the cover was noted with a Falls flow of 50,000 cubic feet per second. When tested under the low extreme of river flow, 140,000 cubic feet per second, tests 120 and 121 indicated that CD was adequate with or without a crest fill, but GD was deficient unless the crest fill was present. Again the break in cover between panels 17 and 18 occurred with a Falls flow of 50,000 cubic feet per second. When tested with a river flow of 240,000 cubic feet per second, CD proved inadequate under the minimum Falls flow, test 123, while GD required the crest fill to meet the target flows in test 122. Again, the break in crest cover occurred on the Goat Island flank with test 123. It was concluded from these tests that excavations CD, GD were not adequate under the full range of river flows. Even with crest fills, CD was inadequate with maximum river flows and minimum Falls flow, while GD was unimpressive at minimum river flows and minimum Falls flow. In addition, the break in cover on the Goat Island flank needed correction.

SCHEMES CE, GE (R17).

33. To correct these deficiencies, CE, GE (R17) were developed and tested, Tables H-25 and H-27. Before these schemes were tested, it was decided that on the evidence submitted by the two models, crest fills were necessary for an economic solution, therefore the fills were in place throughout the tests on the final excavation schemes. As may be noted from the tables, at all river discharges the target flows were exceeded on both flanks with a Falls flow of 100,000 cubic feet per second. Under the minimum Falls flow conditions, tests 207, 209 and 211, a complete and substantial cover existed from shore to shore, with no breaks occurring at any point.

COFFERDAM TESTS.

34. The cofferdam tests indicated that the locations shown on Plate H-8 would be satisfactory. It was noted that at high flows, when both cofferdams were in place, the cofferdam for GE (R17) appreciably raised the levels along the cofferdam for CE above those which were found when only the latter was in place. As the depths along the cofferdam for CE are relatively great and the velocities high, it is recommended that only one cofferdam be in place at a time.

CONCLUSIONS FROM TESTS ON EXCAVATION SCHEMES

35. From these test results it was concluded that excavations CE, GE (R17) were the minimum excavations in conjunction with crest fills that would produce the required result. It was concluded that these tests proved that any lesser excavations would be deficient under the full range of river flow.

REMEDIAL WORKS TESTS INVOLVING SUBMERGED WEIRS AND EXCAVATIONS

SUMMARY OF TESTING PROGRAMME

36. Preliminary tests of submerged wiers, by which some of the flow in the deep Cascades streams was deflected to the Horseshoe Falls flanks, appeared to offer considerable promise. It was decided, therefore, to test such weirs, both in combination with flank excavation and by themselves, to determine whether such combinations might result in a more economical scheme. In selecting weirs for testing, no particular effort was made to limit the weirs to those believed economical or practicable from a construction standpoint, the main consideration being their ability to produce a successful remedial scheme. In all, 11 weirs were tested in this series, their extent and location being shown on Plate H-9. Four schemes were developed, using combinations of weirs and excavations, which appeared to be essentially successful in satisfying the flank flow criteria when tested with the average river flow of 200,000 cubic feet per second and with crest fills in place. Comprehensive testing of these schemes, however, was not carried out and further refinements were not made, as at this point in the testing programme it was decided, for the reasons given in paragraph 41 below, that schemes involving weirs would not prove satisfactory.

TEST PROCEDURE

37. The adequacy criteria used in the tests in the excavation schemes, paragraph 19, were also used in this series of tests. The test procedure was also the same as that described in paragraphs 24 and 25 for the preliminary excavation tests. Again only those schemes appearing visually acceptable under minimum flow conditions were thoroughly tested and documented. The best weir locations were obtained by trial, and the minimum weir lengths to give the target flows were used in each case. The heights of the weirs were adjusted so that an overfall just occurred under minimum Cascades levels.

TEST RESULTS

38. The results of the tests involving submerged weirs are tabulated in Tables H-12, H-13, H-18 and H-19. While photographs of all the weir schemes tested were taken, only those showing

the performance of two schemes are shown: Weirs 7 and 11; and Weirs 8 and 9 in conjunction with excavation CB and GB. These photographs are shown in Plate H-16. In general, it was found that to be successful the weirs must be relatively long, and extend well out into or across the deep streams. While in many cases this resulted in flank flows considerably above the target flows, any appreciable shortening of the weirs destroyed most of their effect. Another effect noted was that local gaps in the crest flow occurred more readily than in the excavation schemes, even though the average flow was satisfactory, due to the diverted stream at high velocity being more concentrated and more easily deflected by local unexcavated obstructions near the crest.

Analysis and discussion of test results

39. A study of the test results indicated that satisfactory flows on the Goat Island flank could be produced by the construction of Weir 7 alone. The substitution of excavation GB and Weir 9 increased these flows somewhat, but did not enable an appreciable reduction in the weir to be made, as it was found that Weir 9 must be essentially the same as Weir 7. On the Canadian flank, satisfactory flows were produced by Weir 11 alone. The addition of excavation CA to Weir 11 increased the Canadian flank flow but even with excavation CB in place it was found that no lesser weirs than 8 or 10 would give satisfactory results, and these weirs were almost as long and as difficult to construct as Weir 11.

Conclusions from submerged weir tests

40. It may be concluded from the tests on schemes involving submerged weirs, that satisfactory flank flows could be obtained from such schemes, and of the schemes tested, Weir 7 on the Goat Island flank and Weir 11 on the Canadian flank appear to be the most satisfactory. The incorporation of flank excavation along with weirs appeared to be of little value, as it did not enable an appreciable reduction to be made in the weirs and was not required for flank flow, and therefore would only add to the magnitude and cost of the scheme. Local excavations in the vicinity of the crest, however, probably would be necessary if an unbroken curtain of flow was to be produced.

Consideration of submerged weir schemes

41. On August 21, 1952, the Working Committee reviewed the data obtained in these tests, and considered generally schemes involving submerged weirs. Comparative estimates indicated such schemes would be as costly initially as excavation schemes, and their construction would be difficult and hazardous. They compared unfavourably with excavation schemes from several other standpoints: maintenance costs probably would be high, as weirs would be vulnerable to erosion from the high velocity water and destruction from ice impact; an artificial appearance could not be avoided with such structures close to the brink of the Falls. As excavation schemes had none of these disadvantages, it was decided that schemes involving submerged weirs would be rejected and no further weir testing would be done.

TESTS ON EFFECT OF AMERICAN CHANNEL CONTROL STRUCTURE

Function of control structure

42. The flow in the channel leading to the American rapids and Falls depends on the level of the Chippawa-Grass Island Pool. As it is planned that the Pool will be regulated to the same level in the future as it is at present for any given river flow, the American Channel flow will be essentially the same in the future as it is at present, Plate H-10, even when the total Falls flow is reduced. As at high river flows and correspondingly high Pool levels there is an excess of flow over the American Falls beyond that necessary for a scenic spectacle, a structure was developed on the Vicksburg model to control the flow into this Channel. The structure consisted entirely of submersible gates and was located as shown on Plate H-1. It would be operated whenever the flow in the Channel exceeded some figure considered to be adequate for a scenic spectacle, such as 7,000 cubic feet per second.

TESTS ON CONTROL STRUCTURE

43. This structure was placed in the Islington model and a limited series of tests carried out. At total river flows of 200,000, 225,000 and 240,000 cubic feet per second, tests were made with and without the control structure in operation and observations were made of the following:

(1) The flow diverted from the American Channel to the Horseshoe Falls by the control structure.

(2) The corresponding increase in flow on both flanks of the Horseshoe Falls.

(3) The reduction in number of gates required on the main control structure to keep the same Chippawa-Grass Island Pool level.

To obtain strictly comparable results, all diversions, flows and Pool levels were kept exactly the same with and without the American Channel control structure in operation. Excavation scheme CE, GE(R17) was in place, the thirteen 100-foot sluice main control structure was in operation, and the minimum future flow over the Falls was produced.

TESTS RESULTS

44. The results are arranged in tabular form below:

	Total River Flow — cfs		
	200,000 Test 209	225,000	240,000 Test 211
Flow diverted from American Channel to Horseshoe Falls — cubic feet per second	4,900	6,000	7,100
Increase in flow on Goat Island flank (Panels 18 - 22)	500	300	500
Increase in flow on Canadian flank (Panels 1 - 5)	1,000	1,375	1,250
Reduction in number of gates closed in main control structure	¼ gate	½ gate	½ gate

CONSIDERATION OF BENEFITS FROM AMERICAN CHANNEL CONTROL STRUCTURE

45. The main benefits from the American Channel control structure would be a possible reduction in the flank excavations required above the Horseshoe Falls, and a possible reduction in the number of gates required in the main Pool control structure. As indicated by the test results, the construction of the American Channel structure would not enable a reduction of one full gate to be made in the main structure and still maintain the required regulation. A small increase in flow is noted on the Goat Island flank from the operation of the control structure, but as minimum flows occur on this flank at low river flows when the American Channel structure could not be operated, no reduction in this flank excavation would be possible. A moderate increase in flow is noted on the Canadian flank and as minimum flows occur on this flank at maximum river flows, a reduction in excavation would be possible if the American Channel flow was thus regulated. A study of the relative costs of the control structure and of the corresponding reduction in flank excavation showed the costs of the dam to be grossly in excess of the saving in excavation. In view of these considerations, it was decided that any benefits from the American Channel control structure were incommensurate with its cost and it would not be considered further.

CONCLUSIONS FROM MODEL STUDIES OF REMEDIAL WORKS

46. It is concluded from a study of the tests and results described in this appendix that remedial works have been developed which will preserve and enhance the beauty of Niagara Falls and will satisfy the terms and intent of the 1950 Treaty. The specific remedial works found to be necessary are as follows:

(1) A Chippawa-Grass Island Pool control structure extending out from the Canadian shore some 1,550 feet and located about 250 feet downstream from the present submerged weir. In the Islington model this structure was composed of thirteen 100-foot gated sluices separated by 14-foot piers. This structure, designated "Dam F" in Plate H-1, is shown in more detail in Plate 6 of the main report.

(2) A plan of excavation on the Canadian flank of the Horseshoe Falls, designated CE on Plate H-8 and shown in more detail in Plate 7 of the main report. Associated with this excavation is a 100-foot crest fill on the shoreward end of the Canadian flank.

(3) A plan of excavation on the Goat Island flank of the Horseshoe Falls, designated GE (R17) on Plate H-8 of this appendix and shown in more detail in Plate 7 of the main report. Again with this excavation is included a crest fill of 300 feet on the shoreward end of the Goat Island flank.

47. Tests on Chippawa-Grass Island Pool control works indicated that the 1,550-foot structure would fulfil all the requirements. Under maximum future diversions, this structure would enable the Pool to be regulated to the same levels that now exist for the same total river flows and would thereby preserve the present Pool appearance and the present satisfactory American Falls flow and appearance. In addition, the outflows from Lake Erie and the present range of Lake Erie levels would remain unaffected. The Three Sisters Islands area, and the area in the vicinity of Goat Island, would also be adequately supplied. At any Pool level, this control structure would be capable of regulating the combined flow over the Falls to either 50,000 cubic feet per second or 100,000 cubic feet per second without any change in Pool level. The model tests indicated, also, that this would be the minimum structure that would fulfil all these requirements. In the intermediate period, when the new Sir Adam Beck-Niagara Generating Station only is completed, it was found that 10 of the final 13 sluices would be required to achieve the same control.

48. The tests on the Horseshoe Falls remedial works showed that the two excavations CE and GE (R17), with their associated crest fills, would ensure an unbroken crestline from shore to shore under the minimum Falls flow permitted by the 1950 Treaty. They would produce also crest flows adequate for a scenic spectacle under the minimum total Falls flows stipulated by the Treaty during the tourist season. The tests showed that no lesser excavations would be adequate over the full range of river flows and diversions. Tests on submerged weirs in the Cascades as an alternative to excavations indicated that they might be capable of producing the desired result but were inferior in many regards, and were rejected also from the standpoints of economy and feasibility.

49. Investigation into the benefits to be derived from control of the American Channel flow showed that any benefits obtained would be incommensurate with the costs of obtaining such control.

TABLE H-1

A. PRELIMINARY REMEDIAL WORKS — TEST CONDITIONS

Test No.	River Flow	Falls Flow	Diversions U.S. Pool	Diversions Can. Pool	Diversions Can. Cascades	W.S.E. Ga. #5 Regulated Pool
107	200,000	50,000	75,000	55,000	20,000	562.8
101	200,000	100,000	50,000	50,000	-	562.8
108	200,000	50,000	75,000	40,000	35,000	562.8
104	200,000	100,000	50,000	15,000	35,000	562.8
121	140,000	50,000	45,000	45,000	-	560.7
120	140,000	100,000	20,000	20,000	-	560.7
123	240,000	50,000	95,000	60,000	35,000	564.2
122	240,000	100,000	70,000	60,000	10,000	564.2

B. FINAL TESTING PROGRAMME — NATURAL CONDITIONS

Test No.	River Flow	Falls Flow	Diversions U.S. Pool	Diversions Can. Pool	Diversions Can. Cascades	W.S.E. Ga. #5 Regulated Pool
201	170,000	50,000	60,000	54,000	6,000	
202	170,000	100,000	35,000	35,000	-	
203	200,000	50,000	75,000	57,700	17,300	
204	200,000	100,000	50,000	50,000	-	
205	240,000	53,200	95,000	56,800	35,000	
206	240,000	100,000	70,000	58,600	11,400	

C. FINAL TESTING PROGRAMME — REMEDIAL WORKS CE GE (R17)

Test No.	River Flow	Falls Flow	Diversions U.S. Pool	Diversions Can. Pool	Diversions Can. Cascades	W.S.E. Ga. #5 Regulated Pool
207	170,000	50,000	60,000	59,000	1,000	561.80
208	170,000	100,000	35,000	35,000	-	561.80
209	200,000	50,000	75,000	61,000	14,000	562.80
210	200,000	100,000	50,000	50,000	-	562.80
211	240,000	60,000	92,500	63,400	24,100	564.05
212	240,000	100,000	70,000	63,400	6,600	564.15

TABLE H-2

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

PRELIMINARY REMEDIAL WORKS

Test No. 107

Crest Panel Number	Crest Panel Discharge for Condition and/or Remedial Schemes on Flanks							
	No Pool Control	Regulated Pool					No Pool Control	
	Natural Bottom	Nat. Btm.	CA GA	CB GB	CB GA	CB G Nat.	CA GA	CA GB
			Blocked to 0+50	Blocked to 0+50	Blocked to 0+50	Blocked to 0+50		
Can. 1	–		–	–	–	–	–	–
2	–		–	–	–	1	2	1
3	–		–	–	–	1	3	2
4	–		–	–		–	–	–
5	1		–	1	1	2	–	–
Av. (1–5)	Av. 0.2		Av. 0	Av. 0.22	Av. 0.22	Av. 0.89	Av. 1.0	Av. 0.6
6	22		8	7	8	12	21	14
7	64		37	36	36	41	65	60
8	71		55	50	52	54	72	69
9	43		39	36	39	41	51	48
10	34		29	27	26	28	41	39
11	38		16	13	16	17	35	31
12	33		24	21	22	26	30	28
13	39		38	35	38	41	40	36
14	110		107	102	106	112	115	108
15	18		17	15	16	20	16	18
16	9		12	9	12	14	12	12
17	3		5	2	3	6	7	6
18	2		–	1	–	1	–	2
19	–		–	1	–	–	–	2
20	–		–	1	–	–	–	–
21	–		–	1	–	–	–	2
22	–		–	3	–	–	–	1
23	–		–	6	–	–	–	2
24	–		Blocked from 22+30	Blocked from 22+30	Blocked from 22+30	–	–	2
G.I. 25	–					–	–	–
Av. (18–25)	Av. 0.25		Av. 0	Av. 1.66	Av. 0	Av. 0.12	Av. 0	Av. 1.37
Can. Falls	47,600		38,900	37,200	38,000	38,400	49,600	47,100
Amer. Falls	2,600		12,300	11,900	12,200	12,000	2,500	2,400

TABLE H-3

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

PRELIMINARY REMEDIAL WORKS

Test No. 108

Crest Panel Number	Crest Panel Discharge for Condition and/or Remedial Schemes on Flanks					
	No Pool Control	Regulated Pool				
	Natural Bottom	Nat. Btm.	CA GA	CB GB	CB GA	CB G Nat.
			Blocked to 0+50			
Can. 1	–		–	–	–	–
2	–		–	–	–	–
3	– (Av. 0, panels 1–5)		– (Av. 0, panels 1–5)	– (Av. 0, panels 1–5)	– (Av. 0, panels 1–5)	– (Av. 0, panels 1–5)
4	–		–	–	–	–
5	–		–	–	–	–
6	19		4	15	4	4
7	48		31	32	30	34
8	65		48	48	44	49
9	40		36	36	35	37
10	35		24	23	22	23
11	36		10	8	10	9
12	34		28	27	28	30
13	47		46	41	43	46
14	119		118	114	116	119
15	18		21	18	22	23
16	14		17	12	16	16
17	5		8	4	3	6
18	–		2	2	2	2
19	3		2	3	2	2
20	–		–	1	–	–
21	– (Av. 0.37, panels 18–25)		– (Av. 0.75, panels 18–23)	3 (Av. 3.02, panels 18–23)	– (Av. 0.75, panels 18–23)	– (Av. 0.5, panels 18–25)
22	–		–	4	–	–
23	–		–	10	–	–
24	–		Blocked from 22+30			–
G.I. 25	–					–
Can. Falls	48,100		39,000	39,600	38,100	37,600
Amer. Falls	3,500		12,000	12,000	12,000	11,800

TABLE H-4

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

PRELIMINARY REMEDIAL WORKS

Test No. 120

Crest Panel Number	Crest Panel Discharge for Condition and/or Remedial Schemes on Flanks					
	No Pool Control	Regulated Pool				
	Natural Bottom	Nat. Btm.	CA GA	CB GB	CB GA	CB G Nat.
			Blocked to 0+50			
Can. 1		2	4	4	4	2
2		6	7	6	7	6
3		12 (Av. 8.0, panels 1–5)	12 (Av. 8.22, panels 1–5)	14 (Av. 11.33, panels 1–5)	11 (Av. 10.0, panels 1–5)	12 (Av. 8.66, panels 1–5)
4		6	5	10	8	6
5		14	11	19	17	14
6		61	66	72	74	61
7		123	117	121	122	123
8		133	123	123	123	133
9		97	94	93	93	97
10		66	63	62	64	66
11		85	76	82	79	85
12		70	65	64	67	70
13		80	74	73	73	80
14		155	148	152	149	155
15		34	32	29	33	34
16		27	24	22	24	27
17		13	11	10	10	13
18		4	4	4	6	4
19		4	2	5	3	4
20		2	1 (Av. 1.86, panels 18–23)	4 (Av. 6.98, panels 18–23)	1 (Av. 2.43, panels 18–23)	2
21		2 (Av. 1.75, panels 18–25)	1	8	1	2 (Av. 1.75, panels 18–25)
22		2	1	10	1	2
23		–	3	20	3	0
24		–	Blocked from 22+30			–
G.I. 25		–				–
Can. Falls		96,500	94,500	95,900	96,700	96,500
Amer. Falls		5,000	4,700	4,800	5,100	5,000

TABLE H-5

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

PRELIMINARY REMEDIAL WORKS

Test No. 101

Crest Panel Number	Crest Panel Discharge for Condition and/or Remedial Schemes on Flanks							
	No Pool Control	Regulated Pool					No Pool Control	
	Natural Bottom	Nat. Btm.	CA GA	CB GB	CB GA	CB G Nat.	CA GA	CA GB
			Blocked to 0+50					
Can. 1	1	W	4	4	4	2	2	1
2	9	6	8	10	8	9	9	8
3	11 Av. 8.8	9 Av. 5.4	11 Av. 7.33	13 Av. 11.33	13 Av. 10.22	18 Av. 10.88	13 Av. 10.22	12 Av. 8.66
4	3	1	4	6	6	5	5	6
5	20	11	8	20	17	16	17	12
6	65	63	64	72	66	69	67	60
7	118	108	111	116	114	115	126	122
8	138	115	114	114	113	110	131	127
9	89	87	90	88	89	85	99	94
10	62	63	62	60	61	59	69	64
11	81	77	76	74	72	73	83	80
12	81	62	61	60	62	61	69	66
13	81	68	70	70	69	67	75	70
14	159	150	143	141	144	147	143	148
15	33	35	30	27	32	29	33	31
16	24	23	24	22	24	23	25	22
17	9	10	7	10	9	9	11	11
18	1	4	3	2	3	5	5	4
19	5	4	4	4	3	3	5	4
20	3	1	2 Av. 3.0	4 Av. 4.9	1 Av. 2.64	3	3	3
21	– Av. 1.12	2 Av. 1.5	2	7	2	1 Av. 1.5	3 Av. 2.62	5 Av. 4.5
22	–	1	3	8	3	–	3	8
23	–	–	6	2	6	–	1	6
24	–	–	Blocked from 22+30			–	1	4
G.I. 25	–	–				–	–	2
Can. Falls	96,500	87,700	88,700	91,500	90,800	90,500	98,000	97,000
Amer. Falls	5,000	12,000	11,500	10,800	10,600	10,700	4,900	4,800

TABLE H-6

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

PRELIMINARY REMEDIAL WORKS

Test No. 104

Crest Panel Number	Crest Panel Discharge for Condition and/or Remedial Schemes on Flanks					
	No Pool Control	Regulated Pool				
	Natural Bottom	Nat. Btm.	CA GA	CB GB	CB GA	CB G Nat.
			Blocked to 0+50			
Can. 1	1	2	2	6	6	1
2	6	4	6	9	9	8
3	8	8	8	12	12	11
4	–	2	3	6	6	5
5	14	8	6	14	14	14
Av. (1–5)	Av. 5.8	Av. 4.8	Av. 5.33	Av. 9.77	Av. 9.77	Av. 8.55
6	59	60	47	59	60	60
7	108	110	100	108	98	106
8	126	118	106	105	105	109
9	82	88	87	81	84	81
10	60	66	61	58	62	62
11	69	72	63	61	62	63
12	73	63	57	56	58	51
13	75	83	74	72	72	76
14	161	154	157	156	160	151
15	35	42	36	34	37	35
16	30	27	28	25	30	29
17	8	12	12	8	10	8
18	3	4	4	5	6	6
19	5	5	4	5	6	6
20	2	2	4	5	4	4
21	–	3	3	11	4	4
22	–	1	4	13	4	4
23	–	1	13	3	13	–
24	–	1	Blocked from 22+30			–
G.I. 25	–	1				–
Av. (18–end)	Av. 1.25	Av. 2.25	Av. 4.33	Av. 7.54	Av. 5.28	Av. 3.0
Can. Falls	91,800	89,000	89,200	88,900	87,800	88,400
Amer. Falls	8,000	12,000	11,200	11,100	10,800	11,200

TABLE H-7

OBSERVED WATER LEVELS

PRELIMINARY REMEDIAL WORKS

Test No. 107

Gauge	W.S. Elev. for Condition and/or Remedial Scheme on Flank					
	No Pool Control	Regulated Pool				
	Natural Bottom	Nat. Btm.	CA GA	CB GB	CB GA	CB G Nat.
Slaters Pt.	561.0		563.1	563.1	563.1	563.1
Ga. No. 5	560.0		562.85	562.8	562.85	562.9
Ga. No. 3	559.25		562.6	562.55	562.6	562.7
Ga. No. 51	559.0		562.6	562.55	562.6	562.7
Ga. No. 45	555.5		554.4	554.5	554.5	554.6
O. P. 'B'	554.1		553.0	553.1	552.85	553.4
Tor. Power	530.4		529.6	529.6	529.2	529.8
Can. Niagara	511.0		508.4	509.1	508.4	508.4
Conners Isl.	561.0		563.15	563.05	563.15	563.3
Grass Island	559.45		562.65	562.55	562.65	562.8
Willow Island	558.4		560.9	560.95	561.0	561.1

TABLE H-8

Test No. 108

Gauge	W.S. Elev. for Condition and/or Remedial Scheme on Flank					
	No Pool Control	Regulated Pool				
	Natural Bottom	Nat. Btm.	CA GA	CB GB	CB GA	CB G Nat.
Slaters Pt.	561.2		563.05	563.1	563.1	563.1
Ga. No. 5	560.45		562.8	562.85	562.8	562 85
Ga. No. 3	559.85		562.55	562.6	562.55	562.65
Ga. No. 51	559.5		562.45	562.55	562.5	562.6
Ga. No. 45	556.1		554.4	555.4	555.4	555.4
O. P. 'B'	554.85		554.2	554.2	553.8	553.9
Tor. Power	528.2		519.7	—	—	—
Can. Niagara	509.8		507.2	508.45	507.3	507.2
Conners Isl.	561.3		563.1	563.2	563.15	563.15
Grass Island	559.8		562.6	562.6	562.6	562.65
Willow Island	558.8		560.85	560.95	560.95	560.95

TABLE H-9

OBSERVED WATER LEVELS

PRELIMINARY REMEDIAL WORKS

Test No. 120

Gauge	No Pool Control	W.S. Elev. for Condition and/or Remedial Scheme on Flank				
		Regulated Pool				
	Natural Bottom	Nat. Btm.	CA GA	CB GB	CB GA	CB G Nat.
Slaters Pt.		561.5	561.3	561.5	561.5	561.45
Ga. No. 5		561.5	560.95	561.05	561.05	561.1
Ga. No. 3		560.5	560.4	560.55	560.6	560.6
Ga. No. 51		560.2	560.1	560.2	560.2	560.25
Ga. No. 45		557.2	556.8	557.15	557.0	557.2
O. P. 'B'		556.4	556.35	556.4	556.5	556.4
Tor. Power		531.6	531.5	531.55	531.55	531.6
Can. Niagara		515.4	515.4	515.4	515.4	515.5
Conners Isl.		561.55	561.5	561.6	561.6	561.6
Grass Island		560.65	560.55	560.65	560.6	560.7
Willow Island		559.45	559.3	559.45	559.45	559.4

TABLE H-10

Test No. 101

Gauge	No Pool Control	W.S. Elev. for Condition and/or Remedial Scheme on Flank				
		Regulated Pool				
	Natural Bottom	Nat. Btm.	CA GA	CB GB	CB GA	CB G Nat.
Slaters Pt.	561.9	563.2	563.2	563.1	563.1	563.15
Ga. No. 5	561.1	562.8	562.8	562.7	562.65	562.7
Ga. No. 3	560.45	562.4	562.4	562.2	562.2	562.3
Ga. No. 51	560.15	562.35	562.25	562.1	562.1	562.1
Ga. No. 45	557.25	555.7	556.7	556.75	556.7	556.35
O. P. 'B'	556.6	555.9	556.1	556.25	556.25	556.25
Tor. Power	531.5	531.2	531.3	531.45	531.4	531.5
Can. Niagara	515.35	515.2	515.3	515.35	515.3	515.4
Conners Isl.	562.0	563.25	563.25	563.2	563.15	563.25
Grass Island	560.6	562.5	562.45	562.35	562.3	562.4
Willow Island	559.35	560.8	560.80	560.65	560.65	560.75

TABLE H-11

Test No. 104

Gauge	No Pool Control	W.S. Elev. for Condition and/or Remedial Scheme on Flank				
		Regulated Pool				
	Natural Bottom	Nat. Btm.	CA GA	CB GB	CB GA	CB G Nat.
Slaters Pt.	562.5	563.25	563.15	563.2	563.1	563.2
Ga. No. 5	561.0	562.8	562.8	562.85	562.8	562.85
Ga. No. 3	561.6	562.55	562.4	562.5	562.5	562.5
Ga. No. 51	560.9	562.25	562.0	562.0	562.0	562.0
Ga. No. 45	557.7	557.7	556.9	557.0	557.5	557.0
O. P. 'B'	555.5	556.3	556.5	556.6	556.6	556.6
Tor. Power	530.1	530.2	530.2	530.1	530.1	530.1
Can. Niagara	513.7	513.5	513.6	513.8	513.8	513.7
Conners Isl.	562.6	563.25	563.2	563.3	563.3	563.3
Grass Island	561.5	562.45	562.4	562.5	562.4	562.45
Willow Island	560.0	560.8	560.65	560.8	560.7	560.8

TABLE H-12

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

PRELIMINARY REMEDIAL WORKS

Tests Nos. 107 and 108

Crest Panel Number	Excavation CA Weirs 11 & 7 107	Excavation CA Weirs 11 & 7 108	Excavations CB, GB Weirs 8 and 9 107	Excavations CB, GB Weirs 8 and 9 108	Excavations CB, GB Weirs 10 and 9 107	Excavations CB, GB Weirs 10 and 9 108	Natural Bottom Weirs 7 and 11 107
	Blocked to 0+50						
Can. 1	6	8	0	0	2	2	Blocked to 1+00
2	13	12	3	3	7	7	11
3	19	18	5	4	11	9	14
4	7	7	1	–	4	11	3
5	9	7	5	5	8	2	3
Av. (1–5; Natural Bottom 2–5)	Av. 11.31	Av. 10.66	Av. 3.11	Av. 2.66	Av. 6.88	Av. 6.66	Av. 7.75
6	7	6	8	6	9	8	2
7	13	13	31	28	21	8	11
8	23	24	41	39	35	20	22
9	16	15	32	30	23	33	13
10	9	6	28	22	11	23	4
11	9	11	12	8	7	9	12
12	38	39	18	20	25	7	35
13	57	58	30	35	44	27	54
14	118	117	97	101	105	45	122
15	23	23	14	14	18	114	26
16	12	12	3	4	4	19	7
17	7	7	4	3	4	6	6
18	4	6	4	3	3	5	5
19	7	7	5	4	5	5	6
20	3	5	5	4	4	6	3
21	5	8	9	9	8	12	7
22	4	9	9	8	9	11	9
23	10	17	7	7	–	3	Blocked from 22+00
Av. (18–23; Natural Bottom 18–22)	Av. 4.9	Av. 7.55	Av. 6.42	Av. 5.66	Av. 5.47	Av. 6.6	Av. 6.0
24	Blocked from 22+30						
G.I. 25							
Can. Falls	37,700	38,800	37,100	37,400	38,900	39,600	37,400
Amer. Falls	11,900	11,900	13,000	12,900	12,100	12,200	13,200

TABLE H-13

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

PRELIMINARY REMEDIAL WORKS

Tests Nos. 101 and 104

Crest Panel Number	Excavation CA Weirs 11 & 7 101	Excavation CA Weirs 11 & 7 104	Excavations CB, GB Weirs 8 and 9 101	Excavations CB, GB Weirs 8 and 9 104	Excavations CB, GB Weirs 10 and 9 101	Excavations CB, GB Weirs 10 and 9 104	Natural Bottom Weirs 7 and 11 101
	Blocked to 0+50						
Can. 1	16	2	0	0	8	8	Blocked to 1+00
2	22	19	17	14	13	13	19
3	22	34	26	21	19	19	29
4	39	27	12	9	10	8	18
5	35	23	17	14	15	14	15
Av.	Av. 28.0	Av. 24.2	Av. 16.0	Av. 12.88	Av. 13.55	Av. 12.88	Av. 20.2
6	24	15	56	49	34	30	19
7	8	44	103	89	80	74	56
8	50	57	105	103	92	88	84
9	64	46	77	73	71	64	62
10	53	40	63	59	62	59	58
11	78	50	73	63	68	53	62
12	86	87	56	49	71	73	75
13	109	105	65	64	92	90	97
14	183	183	136	145	168	155	168
15	45	44	29	29	37	34	45
16	31	31	16	19	25	26	24
17	15	15	11	11	13	12	11
18	10	8	11	11	10	11	10
19	9	8	11	8	9	9	7
20	5	6	10	11	10	10	3
21	11	12	18	22	18	22	8
22	15	18	19	24	19	22	15
23	20	23	23	13	20	16	Blocked from 22+00
Av.	Av. 10.6	Av. 11.1	Av. 14.33	Av. 15.09	Av. 11.69	Av. 12.64	Av. 8.6
24	Blocked from 22+30						
G.I. 25							
Can. Falls	90,600	89,000	88,500	88,500	90,500	90,500	86,400
Amer. Falls	12,200	11,400	11,500	11,500	12,300	12,300	12,400

TABLE H-14

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

PRELIMINARY REMEDIAL WORKS — SCHEME CD AND GD

Tests Nos. 107 and 108

Crest Panel Number	Excavation Only				Excavation Plus Fills			
	107	Av.	108	Av.	107	Av.	108	Av.
					Blocked to 0+50			
Can. 1	2	Av. 3.6	1	Av. 1.8	4	Av. 4.0	2	Av. 2.45
2	4		2		4		3	
3	4		2		4		3	
4	4		2		4		4	
5	4		2		4		4	
6	6		4		4		4	
7	39		34		38		33	
8	49		47		49		46	
9	36		33		33		33	
10	25		21		24		21	
11	14		8		12		10	
12	21		24		18		23	
13	35		40		29		40	
14	103		110		96		107	
15	17		15		9		15	
16	11		12		7		14	
17	2		4		2		7	
18	2	Av. 1.5	2	Av. 3.5	2	Av. 4.3	3	Av. 4.9
19	3		4		4		4	
20	1		2		4		3	
21	3		4		4		6	
22	2		8		7		9	
23	2		6		4		10	
24	1		3		Blocked from 22+30			
G.I. 25	½		2					
Can. Falls	38,600		39,200		36,500		38,200	
Amer. Falls	12,000		12,000		12,000		12,100	

TABLE H-15

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

PRELIMINARY REMEDIAL WORKS — SCHEME CD AND GD

Tests Nos. 101 and 104

Crest Panel Number	Excavation Only 101	Excavation Only 104	Excavation Plus Fills 101	Excavation Plus Fills 104
			Blocked to 0+50	Blocked to 0+50
Can. 1	11	11	26	24
2	18	19	20	19
3	19	19	22	20
4	18	19	20	20
5	22	20	22	18
(1–5)	Av. 17.6	Av. 17.6	Av. 21.55	Av. 19.77
6	60	53	52	46
7	103	103	106	100
8	107	99	106	99
9	81	75	79	77
10	57	59	56	59
11	62	59	62	55
12	48	48	48	51
13	57	62	57	63
14	135	152	135	148
15	26	31	25	31
16	20	25	20	25
17	8	8	7	15
18	3	3	4	7
19	5	5	5	6
20	4	5	5	7
21	7	9	12	14
22	10	12	14	16
23	7	8	15	27
(18–23)			Av. 8.49	Av. 11.13
24	6	3	Blocked from 22+30	Blocked from 22+30
G.I. 25	2	1	Blocked from 22+30	Blocked from 22+30
(18–25)	Av. 5.1	Av. 5.75		
Can. Falls	88,100	89,500	89,000	88,200
Amer. Falls	11,400	11,500	12,000	11,500

TABLE H-16

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

PRELIMINARY REMEDIAL WORKS — SCHEME CD AND GD

Tests Nos. 120 and 121

Crest Panel Number	Excavation Only 120	Excavation Only 121	Excavation Plus Fills 120	Excavation Plus Fills 121
Can. 1	11 } Av. 18.8 (panels 1–5)	5 } Av. 8.2 (panels 1–5)	Blocked to 1+00	Blocked to 1+00
2	19	9	25 } Av. 23.5 (panels 2–5)	10 } Av. 10.0 (panels 2–5)
3	21	10	22	11
4	20	9	22	10
5	23	8	25	9
6	54	14	54	14
7	116	61	116	61
8	117	65	117	65
9	88	44	88	44
10	59	32	59	32
11	65	29	65	29
12	51	21	51	21
13	62	27	62	27
14	142	91	142	91
15	29	12	29	12
16	21	7	21	7
17	10	4	10	4
18	3 } Av. 5.25 (panels 18–25)	W } Av. 0.5 (panels 18–25)	5 } Av. 8.4 (panels 18–22)	1 } Av. 1.8 (panels 18–22)
19	3	1	6	1
20	3	W	5	W
21	7	W	12	2
22	10	1	14	5
23	8	1	Blocked from 22+00	Blocked from 22+00
24	5	1		
G.I. 25	3	Dry		
Can. Falls	93,700	44,600	93,700	44,300
Amer. Falls	5,100	4,900	5,100	4,700

(W indicates trace of flow)

TABLE H-17

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

PRELIMINARY REMEDIAL WORKS — SCHEME CD AND GD

Tests Nos. 122 and 123

Crest Panel Number	Excavation Only 122	Excavation Only 123	Excavation Plus Fills 122	Excavation Plus Fills 123
			Blocked to 1+00	Blocked to 1+00
Can. 1	9 (Av. 14.0)	0 (Av. W)	21 (Av. 18.0)	W (Av. W)
2	15	W	18	W
3	15	W	17	W
4	15	W	16	W
5	16	W	44	1
6	43	2	102	27
7	99	23	96	38
8	92	38	72	27
9	71	28	52	17
10	47	13	50	10
11	47	9	42	24
12	41	24	54	38
13	51	41	140	119
14	137	117	24	18
15	23	17	18	14
16	15	12	7	8
17	6	7	6 (Av. 8.4)	3 (Av. 5.8)
18	3 (Av. 5.62)	1 (Av. 3.62)	7	5
19	5	4	6	5
20	4	2	11	7
21	7	5	12	9
22	10	8	Blocked from 22+00	Blocked from 22+00
23	10	5		
24	6	3		
G.I. 25	W	1		
Can. Falls	80,500	36,400	81,500	36,400
Amer. Falls	18,300	17,000	19,200	17,000

(W indicates trace of flow)

TABLE H-18

OBSERVED WATER LEVELS THROUGHOUT THE MODEL

PRELIMINARY REMEDIAL WORKS

Tests Nos. 107 and 108

Gauge	Excavation CA Weirs 11 & 7		Excavations CB, GB Weirs 8 & 9		Excavations CB, GB Weirs 10 & 9	
	107	108	107	108	107	108
Slaters Point	563.05	563.1	563.05	563.1	563.1	563.1
Gauge No. 5	562.75	562.8	562.8	562.8	562.8	562.8
Gauge No. 3	562.5	562.5	562.55	562.6	562.55	562.5
Gauge No. 51	562.45	562.4	562.55	562.6	562.5	562.45
Gauge No. 45	554.9	555.7	554.4	555.0	554.9	555.4
O.P. 'B'	553.3	554.4	553.1	554.1	553.4	554.6
T.P.	530.0	—	529.6	—	530.0	518.2
C.N.	511.8	511.9	508.3	507.4	510.7	511.3
Conners Island	563.0	563.1	563.1	563.1	563.1	563.0
Grass Island	562.5	562.5	562.55	562.65	562.5	562.5
Willow Island	560.85	560.8	561.0	560.9	560 9	560.8
a	530.0	526.5	529.6	526.1	530.1	526.6
b	512.9	512.5	510.0	508.9	512.4	511.8
c	508.9	508.6	506.4	506.6	507.3	507.5
d	551.8	552.8	551.3	552.5	552.1	553.1
e	515.5	513.6	513.4	512.1	514.8	513.7
f	512.7	512.5	509.3	508.7	512.4	511.9
g	500.0	500.0	502.0	501.4	502.2	501.8
h	517.3	517.6	517.1	517.7	517.4	517.8
j	550.3	550.5	550.4	550.5	550.5	550.6
k	518.6	519.4	519.0	519.5	519.0	519.5
l	514.5	515.3	514.4	515.1	514.7	515.4
m	508.6	508.7	506.5	507.8	508.1	508.2
n	526.6	526.7	526.4	526.2	526.5	526.6
o	512.7	513.6	510.2	511.4	510.8	511.7
p	536.6	536.2	535.4	536.0	535.8	536.1

TABLE H-19

OBSERVED WATER LEVELS THROUGHOUT THE MODEL

PRELIMINARY REMEDIAL WORKS

Tests Nos. 101 and 104

Gauge	Excavation CA Weirs 11 & 7		Excavations CB, GB Weirs 8 & 9		Excavations CB, GB Weirs 10 & 9	
	101	104	101	104	101	104
Slaters Point	563.2	563.2	563.1	563.15	563.2	563.25
Gauge No. 5	562.85	562.8	562.75	562.8	562.85	562.95
Gauge No. 3	562.5	562.5	562.3	562.5	562.5	562.65
Gauge No. 51	562.35	562.0	562.1	562.05	562.3	562.2
Gauge No. 45	556.6	557.4	556.2	557.5	556.7	557.2
O.P. 'B'	556.4	556.7	556.1	556.45	556.4	556.8
T.P.	531.5	530.0	531.3	530.2	531.5	530.3
C.N.	517.0	515.7	515.3	513.8	516.2	514.8
Conners Island	562.3	562.2	563.1	563.2	563.3	563.4
Grass Island	562.55	562.4	562.3	562.5	562.6	562.6
Willow Island	560.9	560.7	560.7	560.85	561.0	561.2
a	531.7	531.2	531.5	531.5	532.0	531.4
b	517.0	516.5	515.3	514.7	516.6	515.7
c	511.0	511.0	509.0	509.3	509.1	509.0
d	554.8	555.7	554.7	555.7	555.0	555.8
e	519.5	519.2	518.4	517.7	520.2	518.3
f	516.6	516.3	514.8	514.2	516.4	515.8
g	504.5	503.8	506.9	506.6	506.3	506.0
h	518.7	519.4	518.7	519.5	518.9	519.5
j	551.8	552.1	551.1	551.9	551.1	552.1
k	521.0	522.5	521.0	522.5	521.4	522.0
l	516.5	517.5	516.4	517.4	516.8	517.4
m	511.0	511.2	509.4	509.5	510.6	510.5
n	526.8	528.0	526.3	528.0	526.5	527.8
o	514.3	514.5	512.6	513.4	513.0	513.1
p	536.8	537.3	536.6	537.2	536.9	537.7

TABLE H-20

OBSERVED WATER LEVELS THROUGHOUT THE MODEL

PRELIMINARY REMEDIAL WORKS — SCHEME CD AND GD

Tests Nos. 107 and 108

Gauge	Excavation Only		Excavation Plus Fills	
	107	108	107	108
Slaters Point	563.0	563.0	563.0	563.0
Gauge No. 5	562.8	562.8	562.8	562.8
Gauge No. 3	562.55	562.5	562.5	562.5
Gauge No. 51	562.55	562.4	562.5	562.5
Gauge No. 45	554.9	555.4	554.7	555.5
O.P. 'B'	553.3	554.6	553.1	554.3
T.P.	529.9	N.G.	529.9	508.0
C.N.	508.6	508.6	508.5	—
Conners Island	563.1	563.1	563.0	563.1
Grass Island	562.6	562.55	562.5	562.5
Willow Island	560.9	560.85	560.9	561.0
a	530.0	526.6	530.1	527.0
b	510.2	509.6	510.2	509.1
c	504.0	503.5	503.9	503.5
d	551.9	552.8	551.8	552.8
e	513.5	512.1	514.0	512.6
f	509.4	508.8	509.2	508.8
g	503.0	502.9	503.2	502.7
h	517.3	517.6	517.4	517.8
j	550.4	550.5	550.4	550.5
k	518.6	519.3	518.6	519.5
l	513.5	514.1	513.4	514.4
m	507.0	507.5	507.3	508.0
n	526.1	526.4	526.4	526.2
o	509.4	510.0	509.3	510.1
p	535.6	536.4	535.6	536.2

TABLE H-21

OBSERVED WATER LEVELS THROUGHOUT THE MODEL

PRELIMINARY REMEDIAL WORKS — SCHEME CD AND GD

Tests Nos. 101 and 104

Gauge	Excavation Only		Excavation Plus Fills	
	101	104	101	104
Slaters Point	563.1	563.2	563.2	563.2
Gauge No. 5	562.75	562.8	562.8	562.8
Gauge No. 3	562.4	562.5	562.45	562 5
Gauge No. 51	562.2	561.9	562.3	561.9
Gauge No. 45	556.2	558.5	556.0	557.8
O.P. 'B'	556.4	556.7	556.3	556.5
T.P.	531.4	530.5	531.5	530.3
C.N.	515.3	514.0	515.3	513.9
Conners Island	563.1	563.25	563.3	563.3
Grass Island	562.4	562.4	562.5	562.45
Willow Island	560.7	560.9	560.85	560.65
a	531.7	531.5	531.7	531.4
b	515.3	514.9	515.4	514.4
c	507.4	507.3	507.2	507.0
d	554.7	555.7	554.8	555.6
e	518.5	517.4	518.0	517.5
f	514.0	513.6	514.0	513.5
g	507.1	506.9	507.4	506.4
h	518.5	519.2	518.3	519.2
j	550.8	552.0	551.0	552.0
k	520.3	522.3	521.6	522.1
l	515.6	516.5	515.5	516.5
m	509.4	509.8	508.9	509.6
n	526.2	528.2	526.1	527.7
o	511.0	511.4	511.0	511.3
p	536.7	537.0	536.8	537.2

TABLE H-22

OBSERVED WATER LEVELS THROUGHOUT THE MODEL

PRELIMINARY REMEDIAL WORKS — SCHEME CD AND GD

Tests Nos. 120 and 121

Gauge	Excavation Only		Excavation Plus Fills	
	120	121	120	121
Slaters Point	561.3	561.15	561.3	561.15
Gauge No. 5	560.85	560.7	560.85	560.7
Gauge No. 3	560.4	560.5	560.4	560.5
Gauge No. 51	560.05	560.45	560.05	560.45
Gauge No. 45	556.6	554.3	556.6	554.3
O.P. 'B'	556.1	553.75	556.1	553.75
T.P.	531.3	530.2	531.3	530.2
C.N.	515.15	513.5	515.15	513.5
Conners Island	561.4	561.3	561.4	561.3
Grass Island	560.5	560.5	560.5	560.5
Willow Island	559.2	559.3	559.2	559.3
a	531.7	530.1	531.7	530.1
b	515.4	513.5	515.2	513.6
c	507.4	505.4	507.5	505.5
d	554.8	552.15	554.8	552.15
e	519.0	514.7	519.0	514.7
f	513.6	511.5	513.8	511.5
g	507.4	504.5	507.5	504.5
h	518.5	517.35	518.5	517.35
j	550.9	dry	550.9	dry
k	520.7	517.8	520.7	517.8
l	515.5	512.6	515.5	512.6
m	509.3	506.4	509.0	506.5
n	526.0	526.0	526.0	526.0
o	511.0	508.95	510.9	509.05
p	536.5	535.8	536.5	535.8

TABLE H-23

OBSERVED WATER LEVELS THROUGHOUT THE MODEL

PRELIMINARY REMEDIAL WORKS — SCHEME CD AND GD

Tests Nos. 122 and 123

Gauge	Excavation Only		Excavation Plus Fills	
	122	123	122	123
Slaters Point	564.3	564.3	564.4	564.3
Gauge No. 5	564.2	564.0	564.15	564.0
Gauge No. 3	563.65	563.8	563.9	563.8
Gauge No. 51	563.6	563.8	563.85	563.8
Gauge No. 45	554.45	554.8	555.7	554.8
O.P. 'B'	554.7	553.75	554.8	553.75
T.P.	530.65	N.G.	530.6	N.G.
C.N.	514.7	506.7	514.6	506.7
Conners Island	564.3	564.3	564.4	564.3
Grass Island	563.65	563.8	563.9	563.8
Willow Island	561.7	561.9	561.95	561.9
a	531.0	526.1	530.8	526.1
b	514.9	508.0	514.8	508.25
c	506.6	502.8	506.7	503.0
d	553.7	552.1	553.5	552.1
e	518.0	511.75	516.7	511.75
f	513.5	508.0	513.4	508.0
g	506.5	502.0	507.0	502.2
h	518.35	517.7	518.2	517.7
j	551.4	551.35	551.5	551.35
k	521.1	520.2	521.2	520.2
l	515.7	515.0	515.8	515.0
m	509.0	507.7	509.0	508.2
n	525.8	526.5	526.0	526.5
o	511.0	510.0	511.0	510.4
p	536.3	535.85	536.1	535.85

TABLE H-24

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

NO CASCADES REMEDIAL WORKS — CONTROL DAM FULLY OPEN

Crest Panel Number	Test Number 201	202	203	204	205	206
Can. 1	–	1	–	1	–	1
2	w	8	–	6	–	6
3	w	12	–	11	–	10
4	w	4	–	4	–	2
5	–	17	w	15	–	14
6	25	71	21	73	13	68
7	71	124	65	115	53	119
8	75	134	71	127	66	121
9	49	98	49	96	44	94
10	40	69	40	67	35	66
11	39	87	39	83	25	82
12	27	71	29	67	30	66
13	29	76	36	73	47	72
14	96	155	107	152	127	150
15	13	40	21	37	26	36
16	5	25	11	23	17	24
17	3	11	5	10	5	10
18	–	3	w	4	1	4
19	w	6	w	4	1	4
20	–	2	–	1	w	1
21	–	3	–	3	w	1
22	–	2	–	1	–	1
23	–	–	–	–	–	–
24	–	–	–	–	–	–
G.I. 25	–	–	–	–	–	–
Can. Falls	47,600	95,700	46,900	93,500	48,200	93,500
Amer. Falls	1,600	5,800	2,500	5,700	4,700	6,600

(W indicates trace of flow)

TABLE H-25

OBSERVED CREST PANEL DISCHARGES IN CFS PER FOOT OF CREST

FINAL REMEDIAL WORKS PLAN — SCHEMES CE AND GE (R17)

Crest Panel Number	Test Number 207	208	209	210	211	212
Can. 1	Blocked to 1+00					
2	6 (Av. 9.75)	19 (Av. 29.3)	2 (Av. 3.0)	19 (Av. 26.0)	3 (Av. 4.0)	16 (Av. 20.5)
3	11	28	3	26	4	21
4	12	30	4	27	5	22
5	10	40	3	32	4	23
6	12	61	3	55	4	40
7	43	108	24	93	26	87
8	57	109	42	100	43	88
9	41	82	30	75	31	64
10	31	58	15	56	16	52
11	21	66	11	60	10	45
12	19	48	23	47	28	39
13	30	57	35	55	45	56
14	95	131	104	129	123	139
15	14	31	22	31	23	32
16	12	21	17	24	19	22
17	10	16	15	19	17	17
18	8 (Av. 5.2)	10 (Av. 11.4)	11 (Av. 8.0)	13 (Av. 12.2)	12 (Av. 11.4)	12 (Av. 13.0)
19	6	13	8	13	12	14
20	5	13	8	11	12	15
21	3	12	7	13	12	15
22	4	9	6	11	9	9
23	Blocked from 23+00					
24						
G.I. 25						
Can. Falls	43,700	94,100	37,000	88,900	43,700	82,100
Amer. Falls	8,100	7,300	12,100	12,100	17,000	18,200

TABLE H-26

OBSERVED WATER LEVELS THROUGHOUT THE MODEL

NO CASCADES REMEDIAL WORKS — CONTROL DAM FULLY OPEN

Gauge	Test Number 201	202	203	204	205	206
Slaters Pt.	560.75	562.15	561.25	562.3	562.0	562.75
Ga. No. 5	559.7	561.55	560.2	561.55	561.1	561.85
Ga. No. 3	559.05	560.95	559.55	560.85	560.5	561.2
Ga. No. 51	558.9	560.75	559.35	560.7	560.35	561.0
Ga. No. 45	554.3	557.15	554.95	557.0	555.7	556.9
O.P. 'B'	553.5	556.45	553.65	556.4	554.7	555.5
Tor. Power	530.1	531.7	529.3	531.55	528.5	531.6
Can. Niagara	513.8	515.4	513.2	515.35	509.2	515.4
Conners Island	560.75	562.3	561.25	562.4	562.1	562.65
Grass Island	559.05	561.0	559.65	560.95	560.6	561.2
Willow Island	557.75	559.6	558.2	559.6	559.2	559.7
a	530.1	531.85	529.8	531.8	529.5	531.6
b	513.8	515.5	513.4	515.5	510.9	515.5
c	504.2	507.4	dry	507.4	dry	507.2
d	552.2	555.2	552.3	555.2	554.2	554.8
e	514.3	518.3	514.3	519.2	514.5	518.2
f	512.0	514.8	511.3	514.4	510.2	514.0
g	505.3	508.6	514.4	508.4	504.6	508.1
h	517.0	u	u	u	u	u
j	549.0	551.5	549.1	551.4	505.6	551.3
k	517.4	521.5	518.2	521.0	519.9	521.0
l	513.1	516.4	513.8	516.1	515.0	516.1
m	506.5	510.0	517.2	509.9	508.4	509.5
n	dry	526.4	525.8	526.2	526.0	525.9
o	dry	512.0	511.0	511.9	511.6	511.7
p	535.5	536.8	535.8	536.6	536.1	536.7

u - unobtainable

TABLE H-27

OBSERVED WATER LEVELS THROUGHOUT THE MODEL

FINAL REMEDIAL WORKS PLAN — SCHEMES CE AND GE (R17)

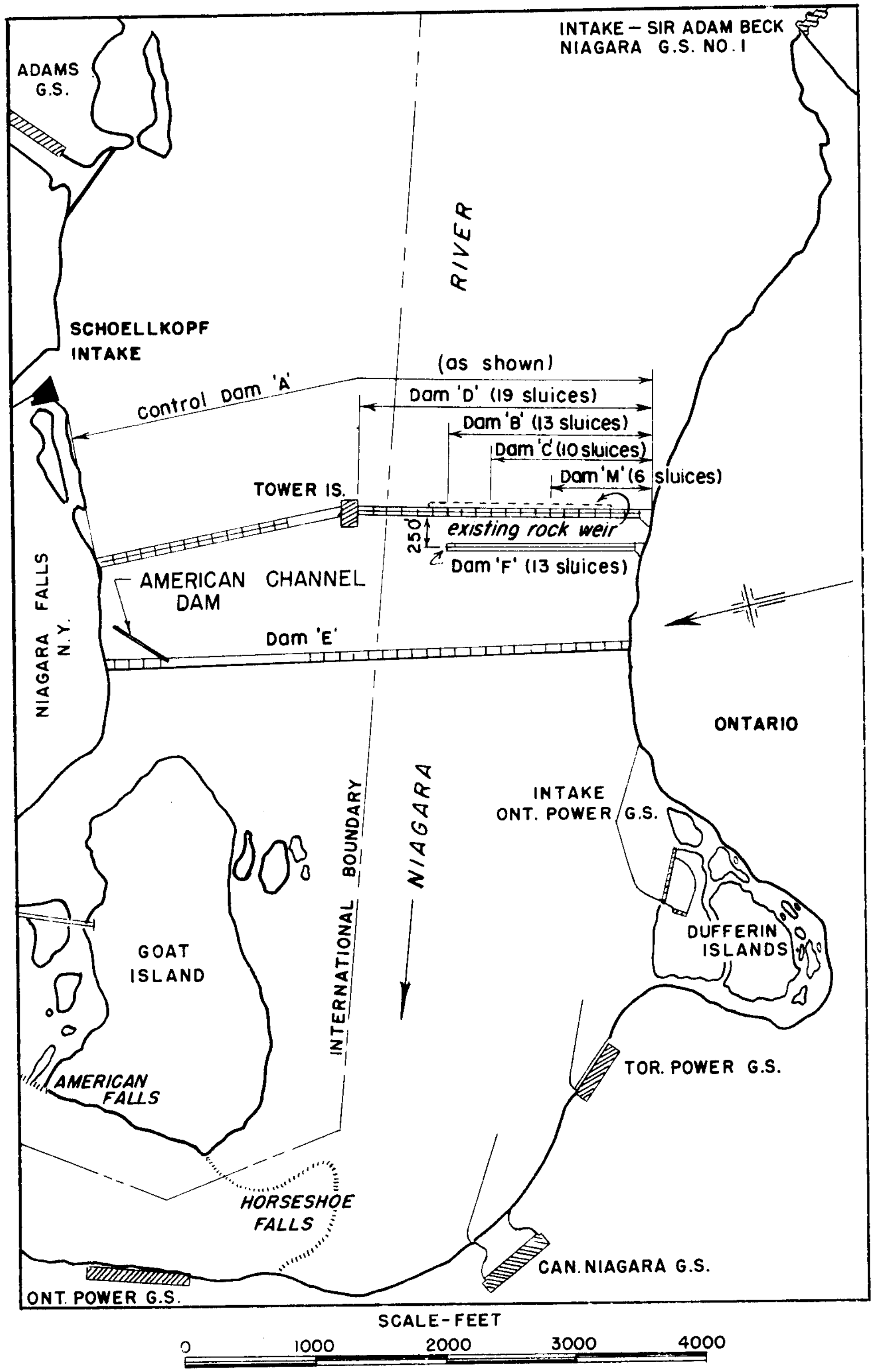
	Test Number					
Gauge	207	208	209	210	211	212
Slaters Pt.	562 15	562.25	563.0	563 2	564.2	564.45
Ga. No. 5	561.8	561 8	562.8	562.8	563.9	564.15
Ga. No. 3	561 55	561.25	562.5	562 5	563 65	563.9
Ga. No. 51	561.5	561.1	562 5	562 3	563.65	563 9
Ga. No. 45	553.1	556.85	553.8	556 7	553.7	555.8
O.P. 'B'	553 1	556.35	552 8	555 85	552 5	555.05
Tor. Power	529.5	531.55	527 3	531.25	525.55	530.65
Can. Niagara	512 6	515.35	507.8	515 0	507.95	514.55
Conners Island	562.15	562.3	563.0	563.25	564.1	564 5
Grass Island	561.6	561.35	562.5	562 5	563.65	563.8
Willow Island	560.3	560.0	561.0	561.0	561.7	562.0
a	529.4	531.6	528.7	531 5	527.2	530.5
b	512.5	515 4	510.0	515.5	508.2	514.7
c	503.2	505.7	502.4	506 4	502.2	505.2
d	551.3	555.0	550.5	554.6	550.9	553 3
e	514.6	518.1	512.0	518 0	511.6	516.9
f	510.6	514.3	509.7	514.4	508.0	513.7
g	503.1	507.3	502.6	507.0	502.1	506.4
h	527.0	518.5	517.0	518.7	517.5	518 4
j	550.5	551.2	551.2	551.0	551.8	551.9
k	528.5	520.8	518.9	521.3	521.0	522.3
l	512.9	515.5	513.7	515 8	515.3	516.2
m	506.5	508.5	506.7	509.2	508.1	509 3
n	525.9	525.7	526.5	526.5	526.7	526.6
o	509.4	511.2	509.9	510.5	510.0	511 0
p	535.0	536.7	534.9	536.7	535.2	536.2

TABLE H-28

OBSERVED WATER SURFACE ELEVATIONS ALONG PROPOSED COFFERDAMS FOR FINAL REMEDIAL WORKS PLAN — SCHEME CE AND GE (R17)

Cofferdam Station Plate H-8	Cofferdam for CE only In Place			Cofferdams for CE & GE (R17) Both In Place			Cofferdam for GE (R17) Only In Place		
	River flow in Thousands of cfs								
	210	240	320	210	240	320	210	240	320
1	514.2	517.0	520.5	515.8	518.4	521.4			
2	514.7	517.1	520.2	516.0	518.0	521.5			
3	514.2	516.2	520.0	515.7	517.8	521.4			
4	513.7	515.8	519.3	514.8	516.8	520.6			
5	512.7	514.8	518.3	514.8	516.1	519.7			
6	509.5	512.6	514.8	511.2	512.7	516.6			
7	510.4	513.2	516.5	511.6	513.7	518.5			
8	509.9	512.8	515.4	511.1	512.9	516.6			
9	510.5	512.8	516.0	511.6	513.5	517.5			
10	510.4	512.0	516.0	511.2	513.2	517.6			
11	509.6	512.3	517.3	511.1	513.6	518.7			
12	508.5	511.0	515.3	509.7	511.5	516.4			
13	505.4	506.5	509.6	506.7	506.8	510.8			
1A	515.0	517.9	521.2	516.7	518.6	522.0			
14				523.9	525.9	528.8	524.3	525.6	529.1
15				523.8	525.0	528.2	523.5	524.8	527.8
16				522.5	524.3	527.8	522.5	524.1	527.5
17				521.7	523.4	526.5	521.9	523.1	526.5
18				520.7	522.0	525.9	520.5	521.8	525.9
19				517.6	519.5	522.2	517.8	518.9	523.2
20				516.7	517.3	519.1	517.0	516.9	520.9
21				516.1	517.8	519.0	515.9	517.7	519.2
22				514.3	515.4	517.5	514.3	514.6	517.0
23				511.4	511.5	514.2	510.8	511.4	514.5
24				509.2	510.4	512.5	508.8	509.3	510.8
25				510.5	510.8	512.9	509.9	510.7	511.9
26				508.9	509.5	511.4	508.3	509.2	510.4
27				505.5	506.1	507.8	505.4	505.7	507.0

Note: Present Power Diversions in effect.



ISLINGTON MODEL

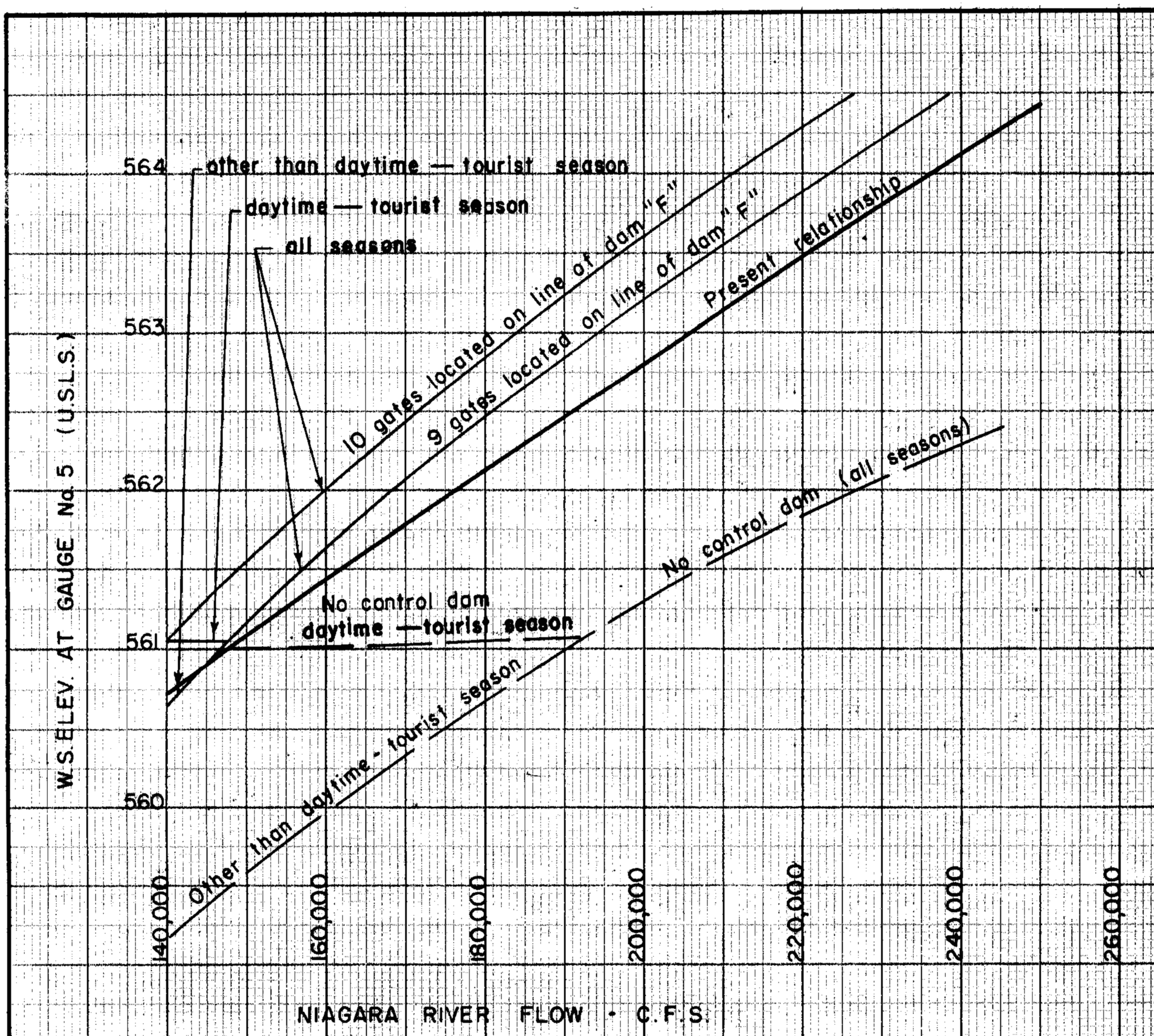
HYDRO ELECTRIC POWER COMMISSION OF ONTARIO

LOCATION OF

CHIPPAWA-GRASS ISLAND POOL CONTROL DAMS

TESTED IN MODEL

PLATE H-1



NOTE

Curves show maximum pool levels possible up to Elev. 564·5 with each dam consistent with ability to discharge 50,000 c.f.s. or 100,000 c.f.s. over the falls at any pool elevation, except where indicated.

Maximum power diversions for the Intermediate Period Of Power Development assumed to be

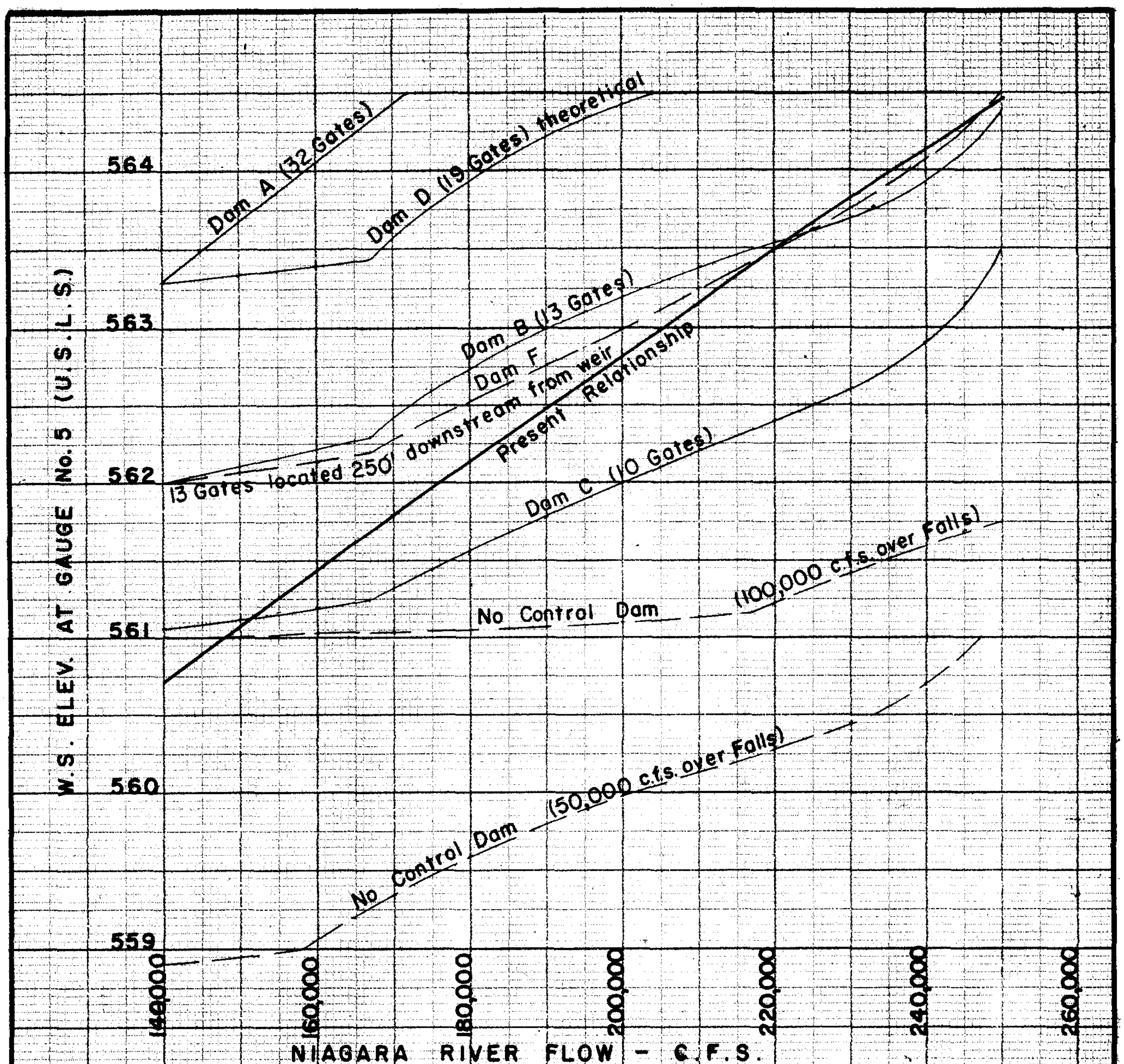
Total American Diversion Capacity = 32,500 c.f.s.
S. A. B. " " = 64,000 "
O.P. " " = 10,700 "
C.N. " " = 10,700 "
T.P. " " = 15,200 "

With no control dam, curves show observed levels for the daytime - tourist season, and for the remainder of the time.

ISLINGTON MODEL

HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

CHIPPAWA - GRASS ISLAND POOL CONTROL DAM
PERFORMANCE OF CONTROL DAMS
INTERMEDIATE PERIOD OF POWER DEVELOPMENT



NOTE.

Curves show maximum pool levels possible up to Elev. 564·5 with each dam consistent with ability to discharge 50,000 c.f.s. or 100,000 c.f.s. over the falls at any pool elevation.

Maximum power diversions for Full Power Development assumed to be:

Total American Diversion cap.	=	*92,500 c.f.s.*
S.A.B	=	*64,000 ..*
O.P		*10,700 ..*
C.N		*10,700 ..*
T.P		*15,200 ..*

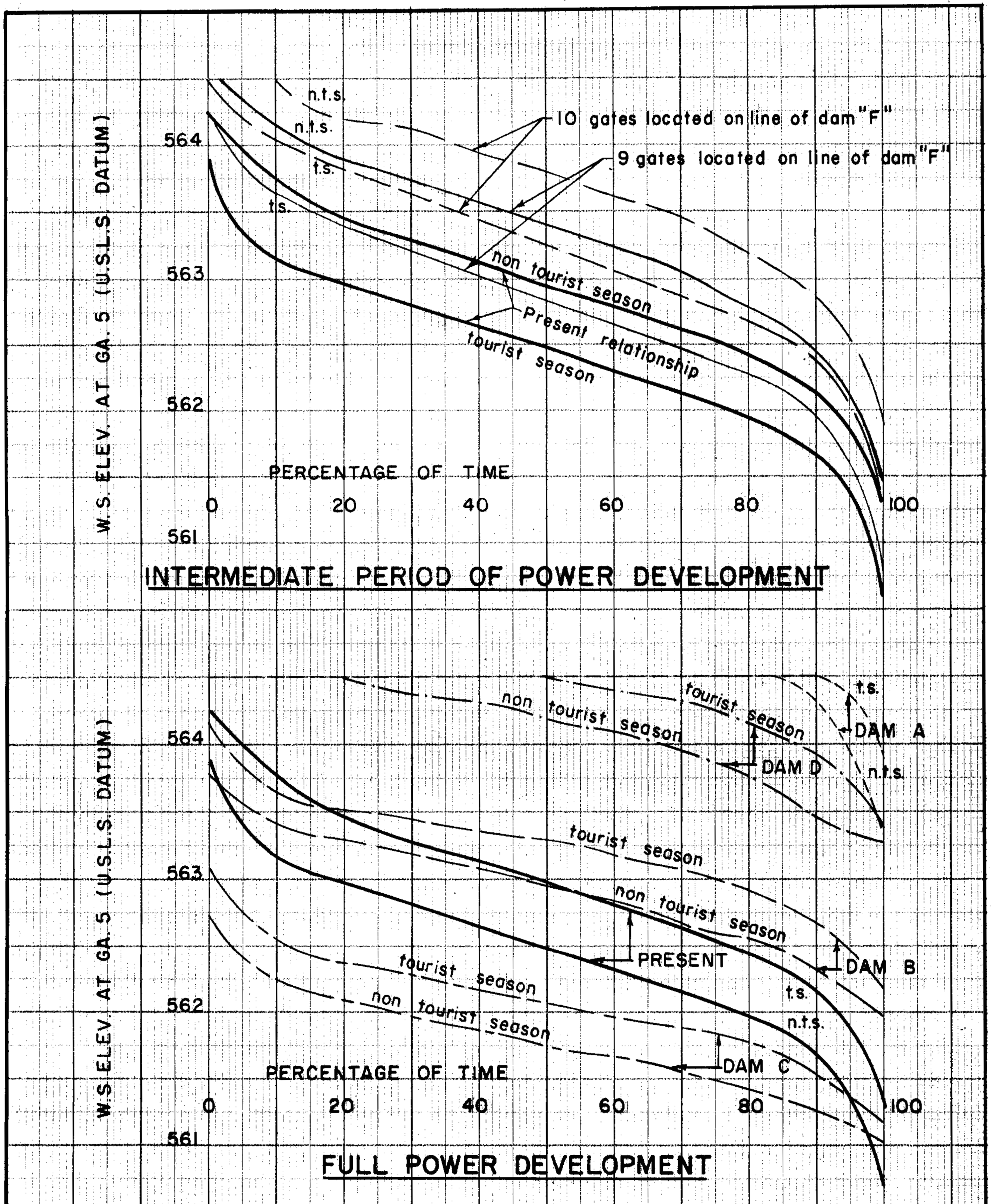
With no control dam, curves show observed levels for 50,000 or 100,000 c.f.s. over falls.

ISLINGTON MODEL

HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

CHIPPAWA - GRASS ISLAND POOL CONTROL DAM
PERFORMANCE OF CONTROL DAMS
FULL POWER DEVELOPMENT

PLATE H-3

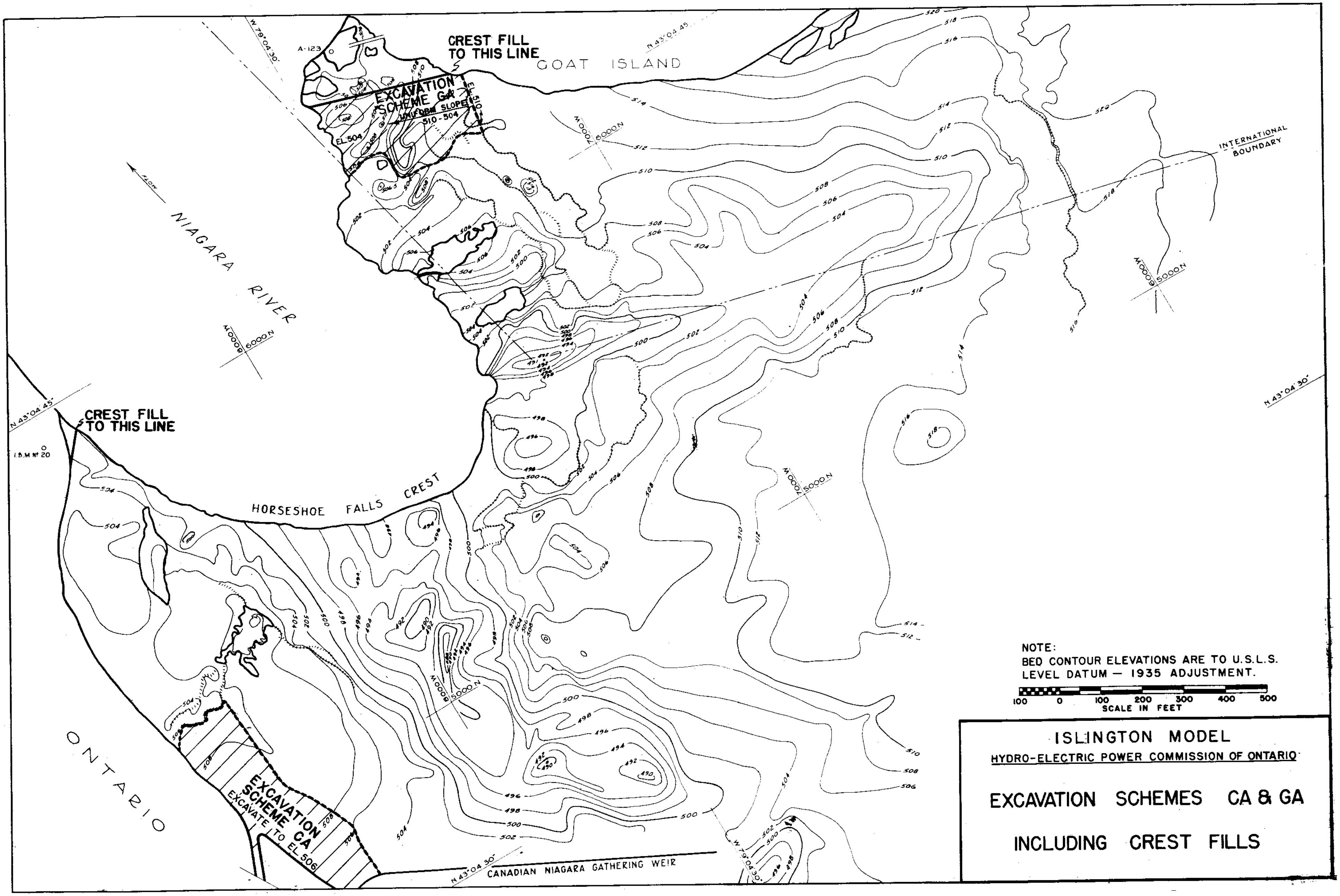


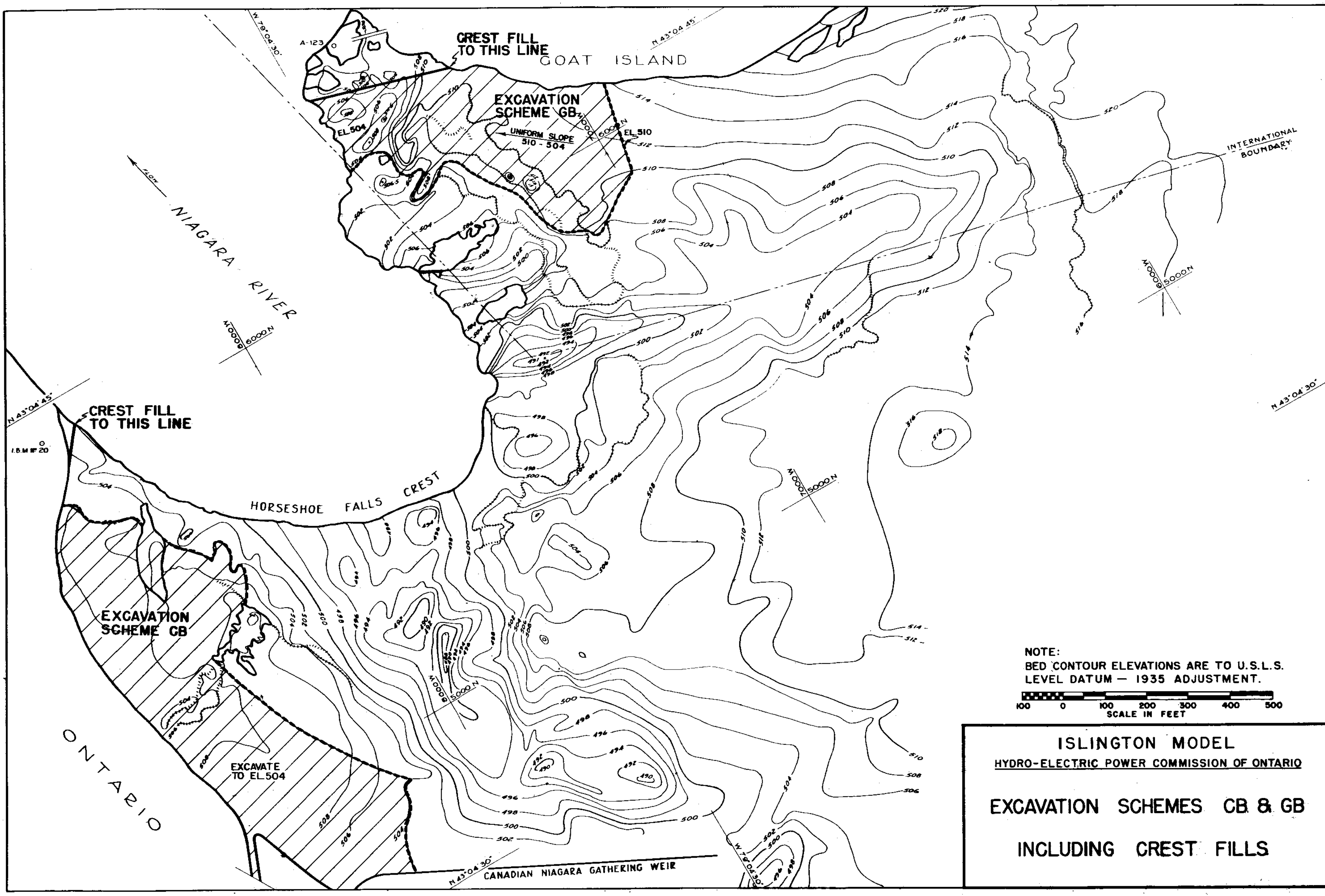
ISLINGTON MODEL

HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

CHIPPAWA - GRASS ISLAND POOL CONTROL DAM

DURATION CURVE OF THE MAXIMUM LEVELS POSSIBLE WITH DAMS TESTED


CREST FILL TO THIS LINE
GOAT ISLAND
A-123
EXCAVATION SCHEME GA
UNIFORM SLOPE 510-504
EL 504
EL 510
N 43°04'45"
W 79°04'30"
FLOW
NIAGARA RIVER
INTERNATIONAL BOUNDARY
N 43°04'45"
CREST FILL TO THIS LINE
I.B.M. No 20
HORSESHOE FALLS CREST
N 43°04'30"
ONTARIO
EXCAVATION SCHEME CA
EXCAVATE TO EL 506
N 43°04'30"
CANADIAN NIAGARA GATHERING WEIR
W 79°04'30"
NOTE:
BED CONTOUR ELEVATIONS ARE TO U.S.L.S. LEVEL DATUM — 1935 ADJUSTMENT.
100 0 100 200 300 400 500
SCALE IN FEET
ISLINGTON MODEL
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
EXCAVATION SCHEMES CA & GA
INCLUDING CREST FILLS



ISLINGTON MODEL

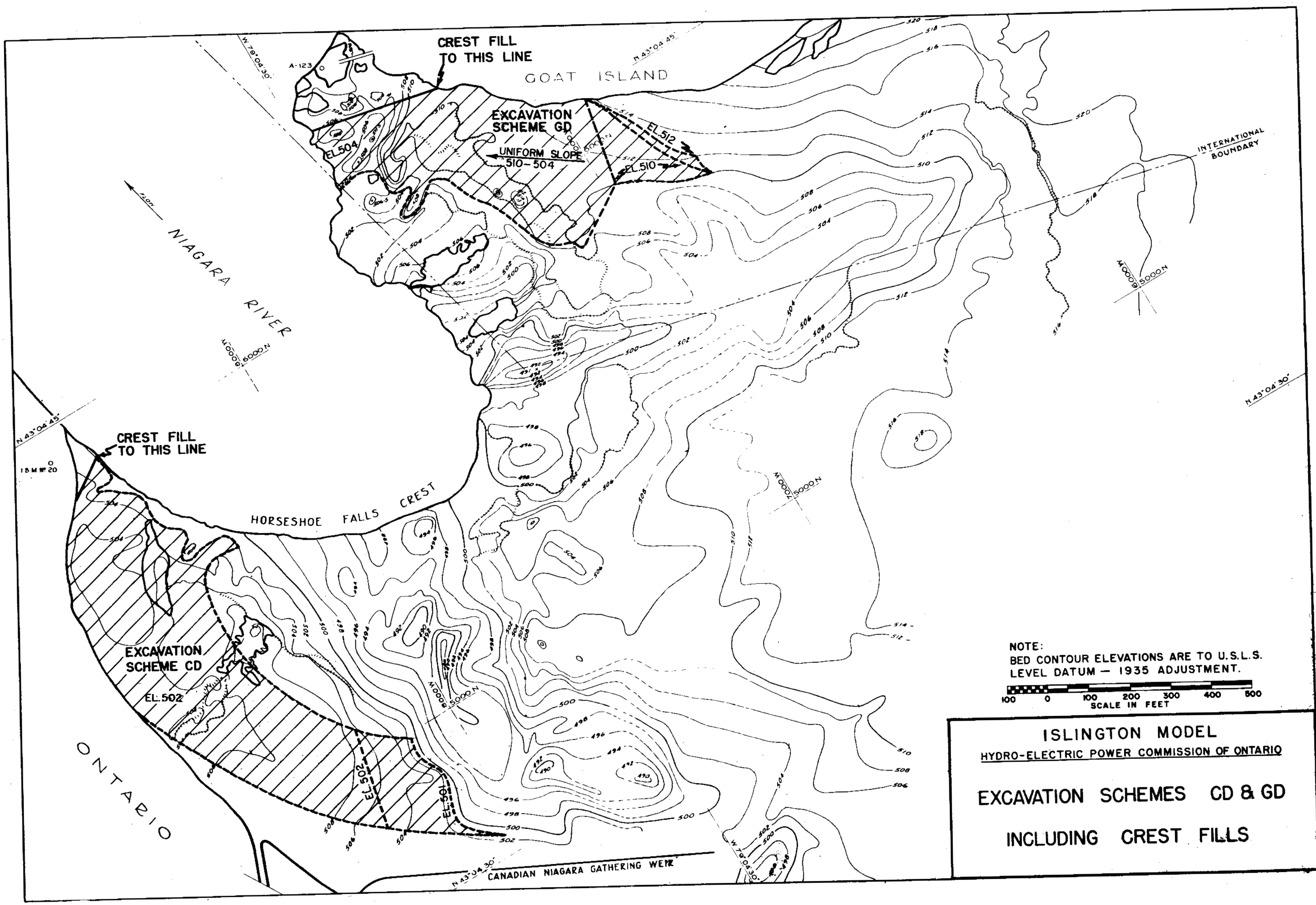
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

EXCAVATION SCHEMES CB & GB

INCLUDING CREST FILLS

PLATE H-6

PLATE H-7


CREST FILL TO THIS LINE
GOAT ISLAND
EXCAVATION SCHEME GD
UNIFORM SLOPE 510-504
EL.504
EL.512
EL.510
INTERNATIONAL BOUNDARY
NIAGARA RIVER
FLOW
CREST FILL TO THIS LINE
HORSESHOE FALLS CREST
EXCAVATION SCHEME CD
EL.502
EL.502
EL.501
ONTARIO
CANADIAN NIAGARA GATHERING WEIR
NOTE:
BED CONTOUR ELEVATIONS ARE TO U.S.L.S. LEVEL DATUM — 1935 ADJUSTMENT.
SCALE IN FEET
ISLINGTON MODEL
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
EXCAVATION SCHEMES CD & GD
INCLUDING CREST FILLS

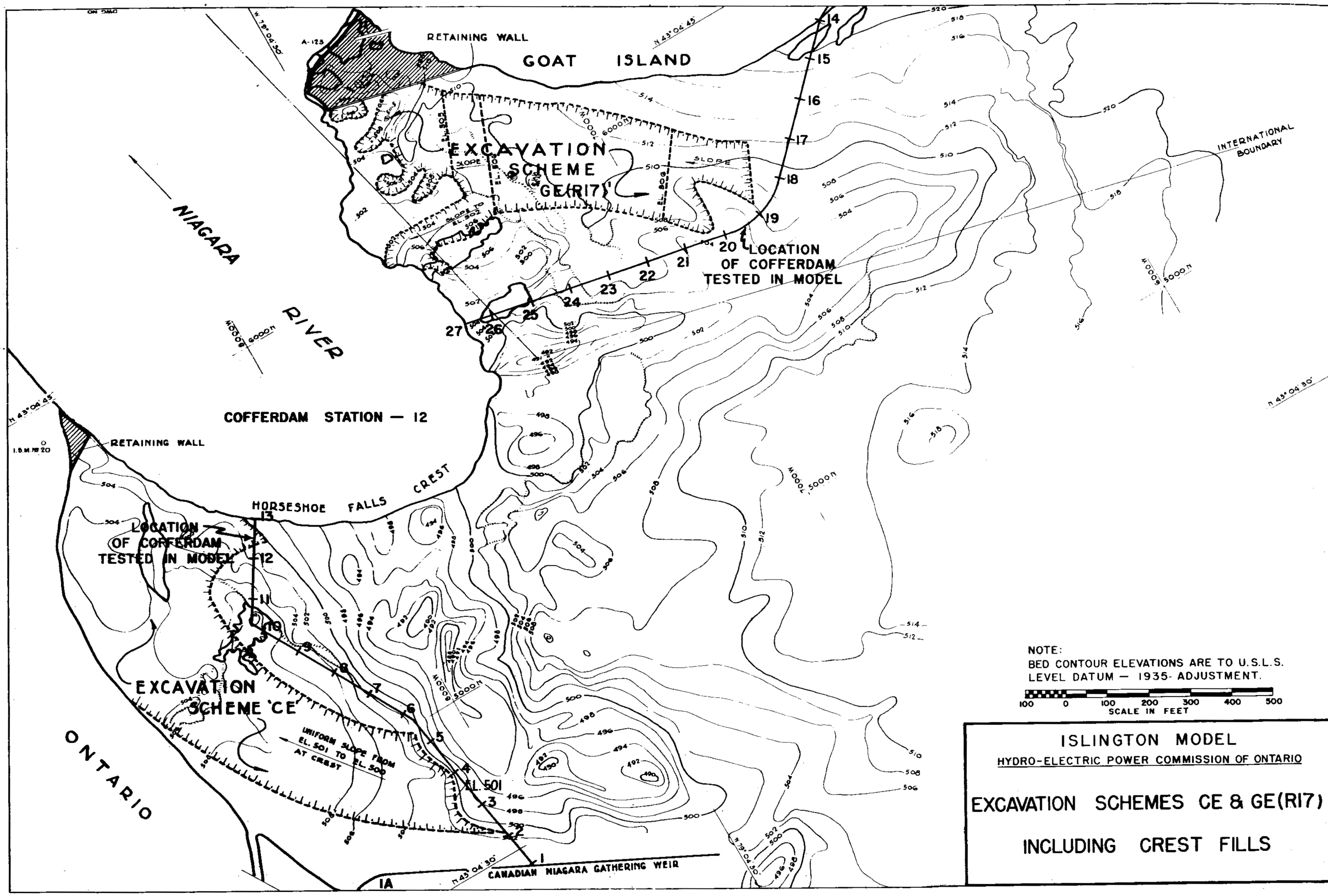
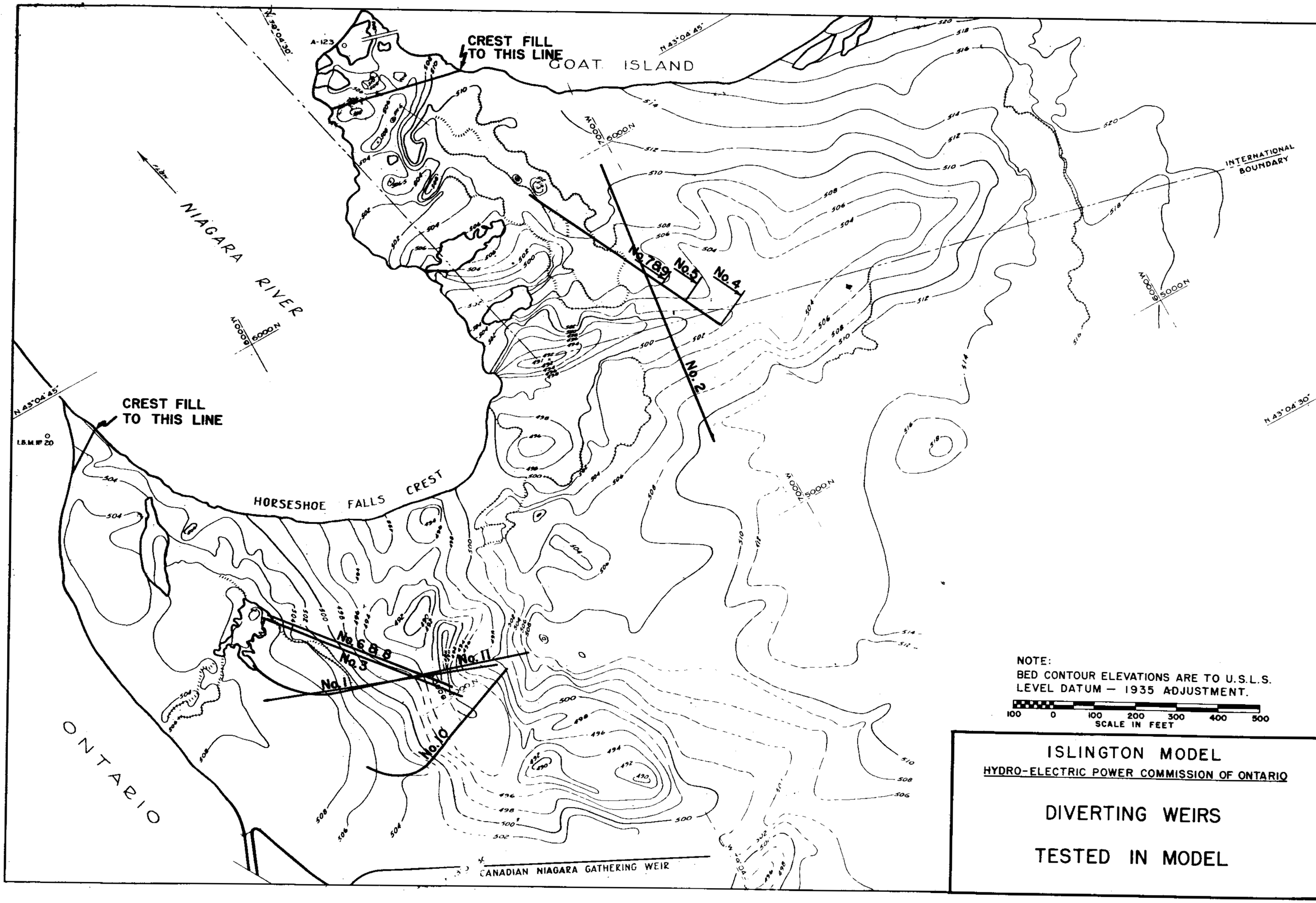
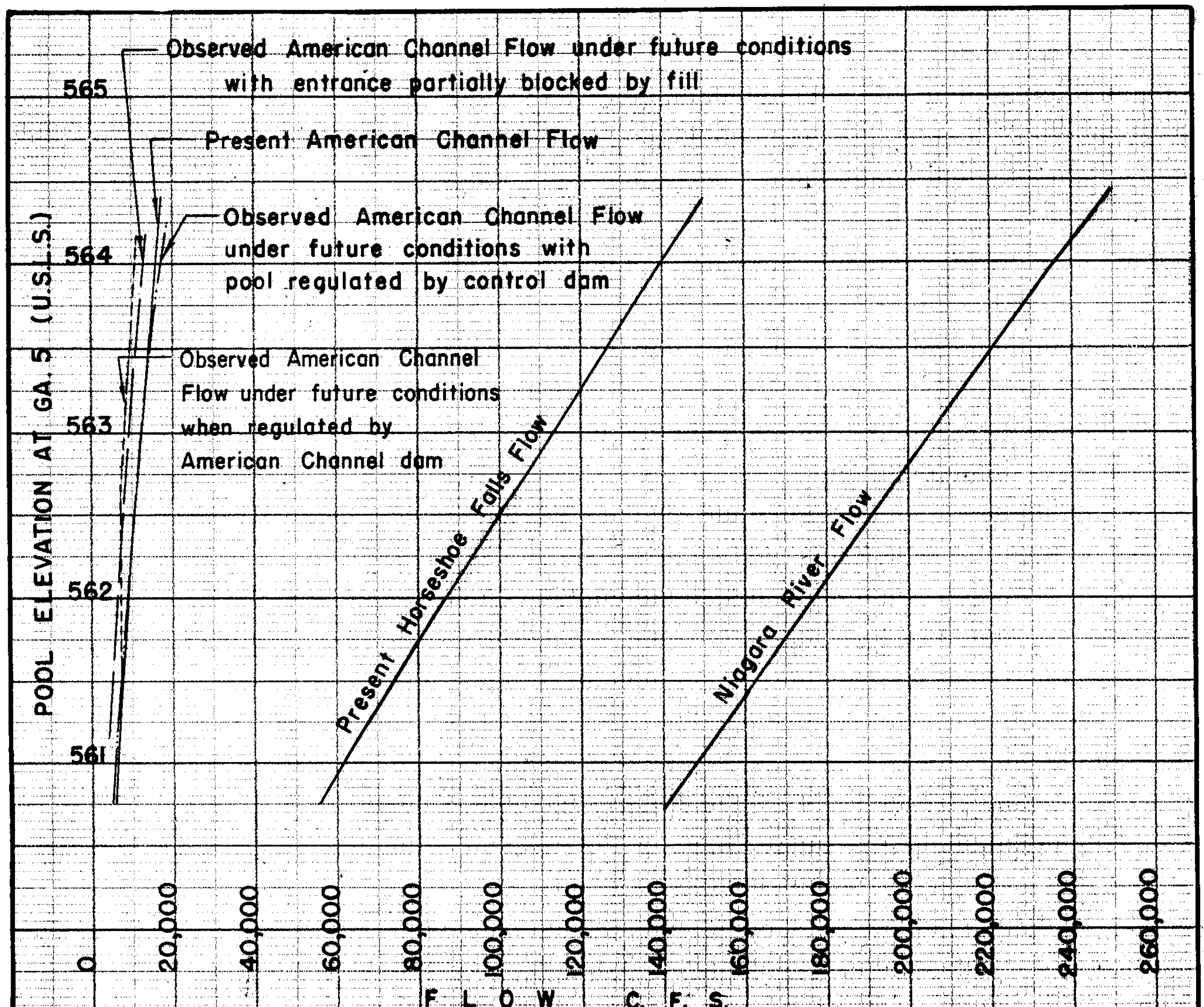
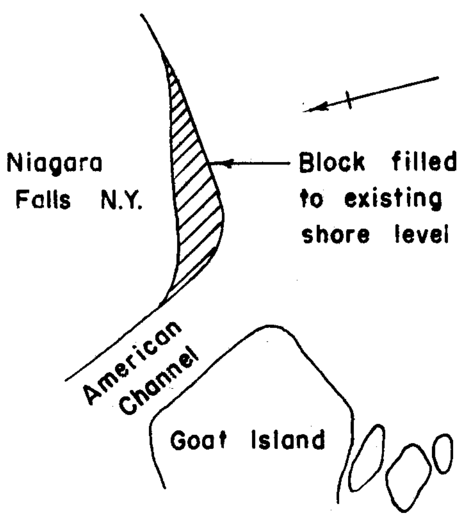

GOAT ISLAND
RETAINING WALL
EXCAVATION SCHEME GE(R17)
LOCATION OF COFFERDAM TESTED IN MODEL
NIAGARA RIVER
COFFERDAM STATION — 12
INTERNATIONAL BOUNDARY
RETAINING WALL
HORSESHOE FALLS CREST
LOCATION OF COFFERDAM TESTED IN MODEL
EXCAVATION SCHEME 'CE'
UNIFORM SLOPE FROM EL. 501 TO EL. 500 AT CREST
EL. 501
ONTARIO
CANADIAN NIAGARA GATHERING WEIR
NOTE:
BED CONTOUR ELEVATIONS ARE TO U.S.L.S. LEVEL DATUM — 1935- ADJUSTMENT.
100 0 100 200 300 400 500
SCALE IN FEET
ISLINGTON MODEL
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
EXCAVATION SCHEMES CE & GE(R17)
INCLUDING CREST FILLS

PLATE H-8



ISLINGTON MODEL
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
DIVERTING WEIRS
TESTED IN MODEL
NOTE:
BED CONTOUR ELEVATIONS ARE TO U.S.L.S.
LEVEL DATUM — 1935 ADJUSTMENT.
100 0 100 200 300 400 500
SCALE IN FEET
GOAT ISLAND
CREST FILL TO THIS LINE
NIAGARA RIVER
HORSESHOE FALLS CREST
CREST FILL TO THIS LINE
ONTARIO
CANADIAN NIAGARA GATHERING WEIR
INTERNATIONAL BOUNDARY
No. 1
No. 2
No. 3
No. 4
No. 5
No. 6 & 8
No. 7 & 9
No. 10
No. 11





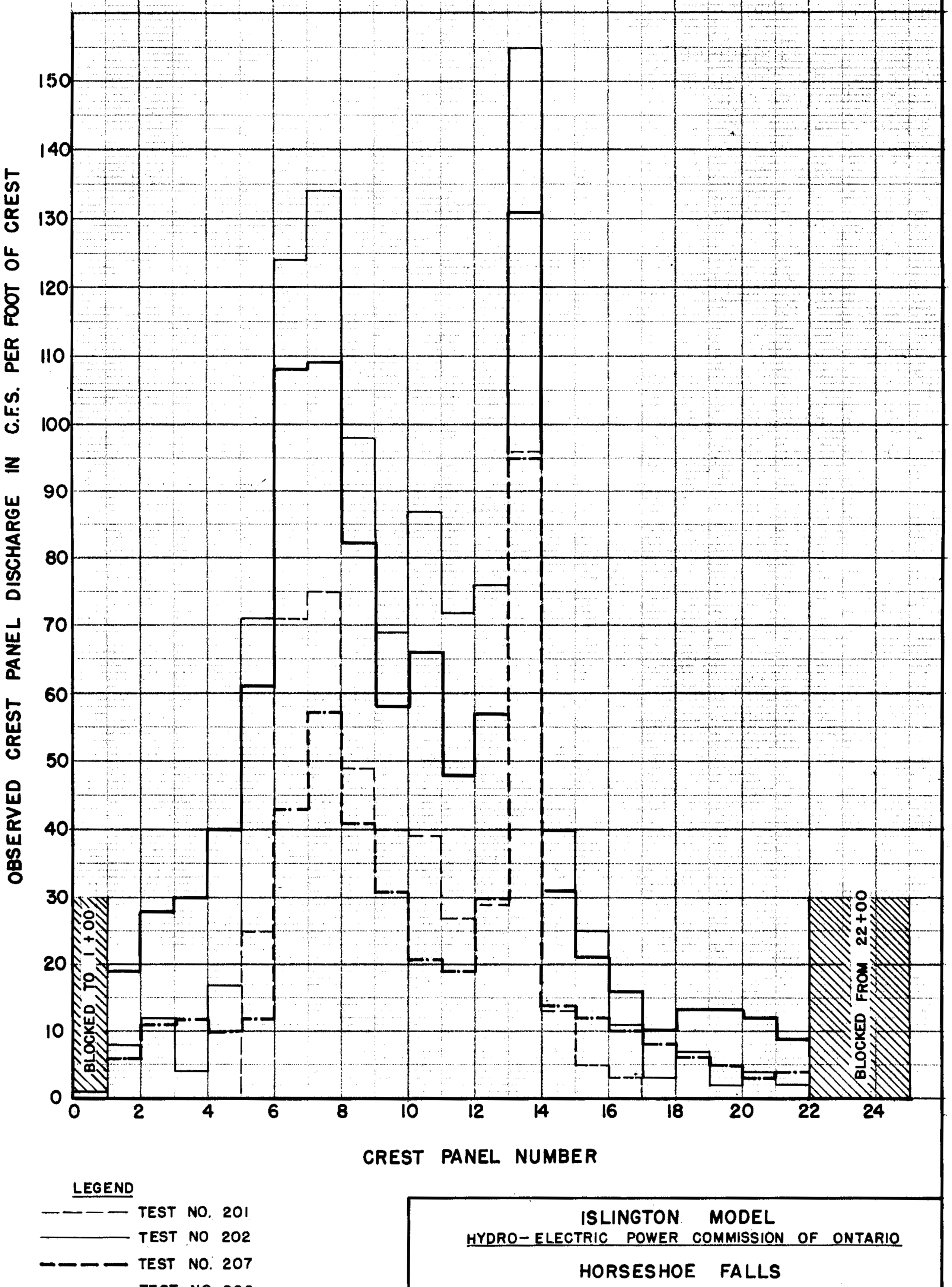
PARTIAL BLOCK IN AMERICAN CHANNEL

Scale: 1 in. = 1000 ft.

ISLINGTON MODEL
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

CHIPPAWA - GRASS ISLAND POOL LEVELS AND CORRESPONDING FLOWS PRESENT AND FUTURE CONDITIONS

PLATE H-10



ISLINGTON MODEL

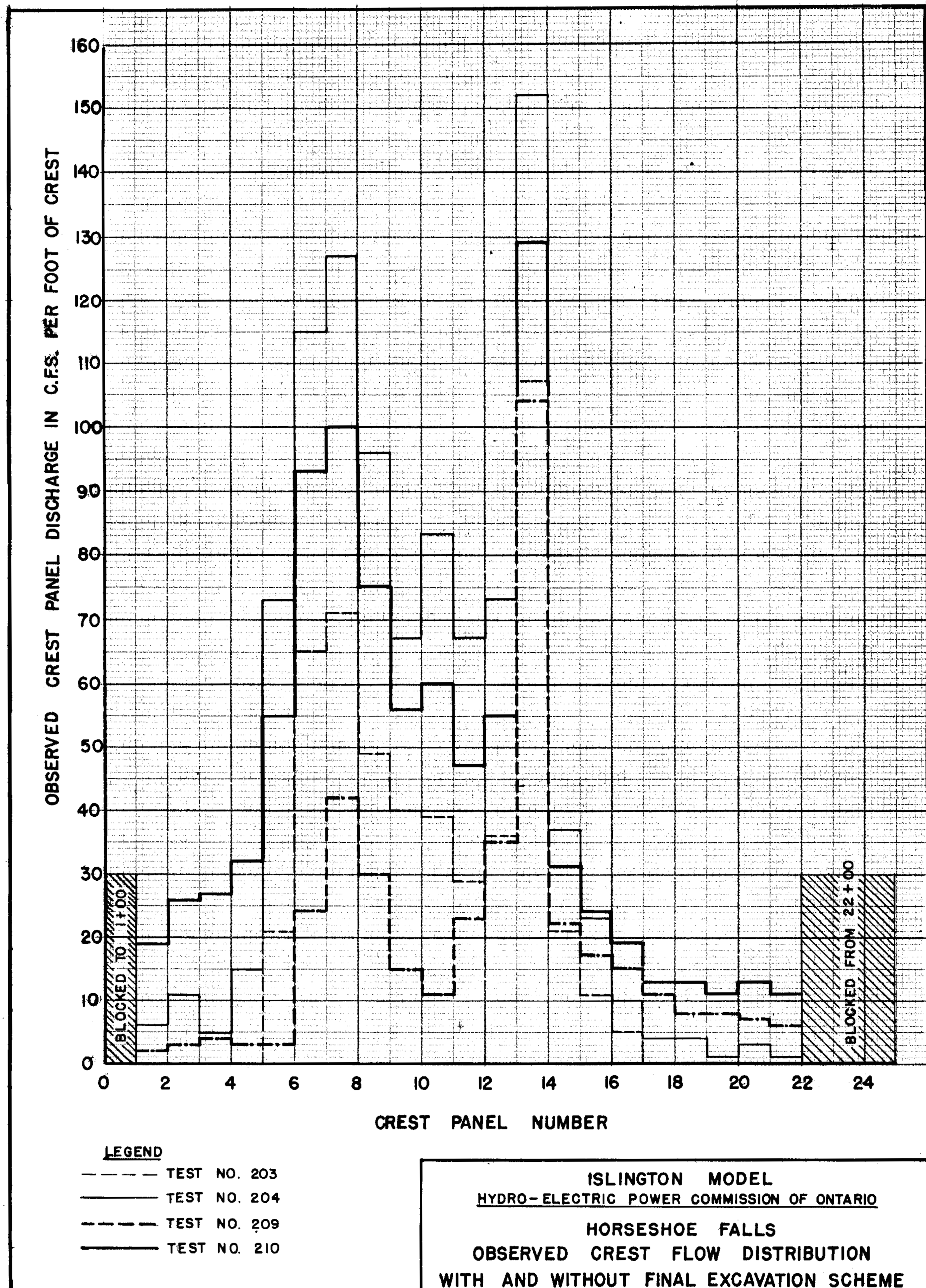
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

HORSESHOE FALLS

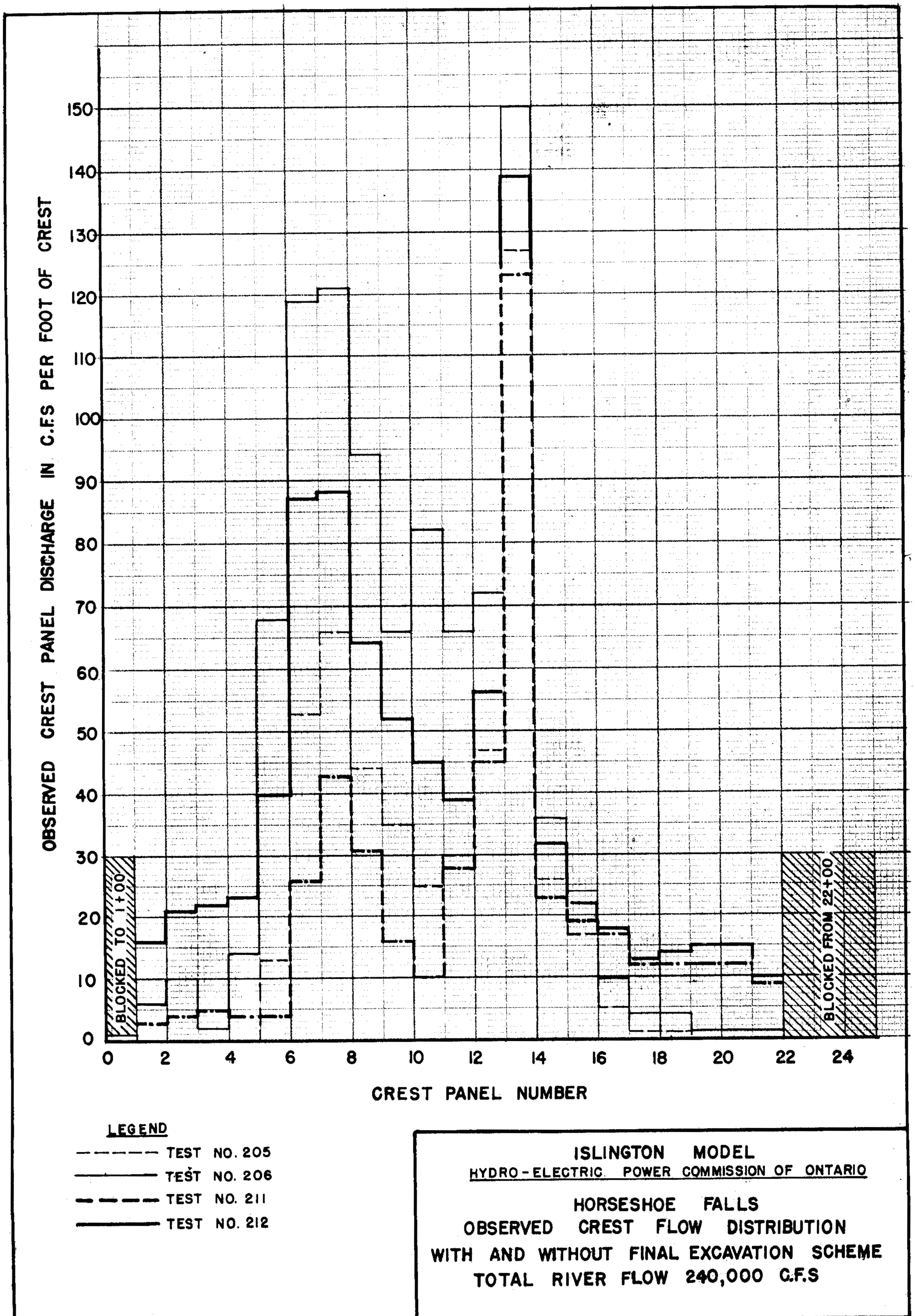
OBSERVED CREST FLOW DISTRIBUTION

WITH AND WITHOUT FINAL EXCAVATION SCHEME

TOTAL RIVER FLOW 170,000 C.F.S.



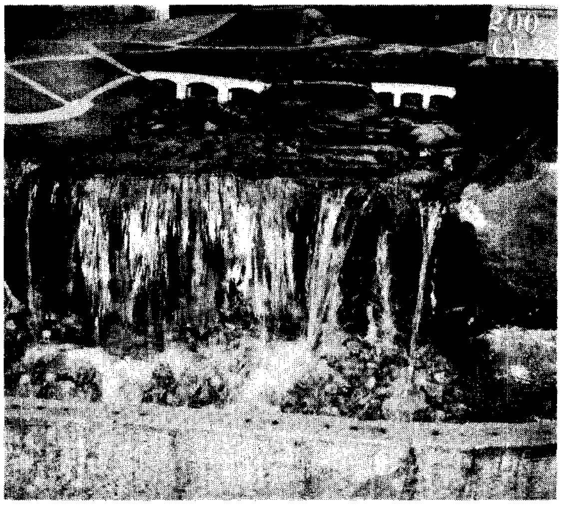
ISLINGTON MODEL
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
HORSESHOE FALLS
OBSERVED CREST FLOW DISTRIBUTION
WITH AND WITHOUT FINAL EXCAVATION SCHEME
TOTAL RIVER FLOW 200,000 C.F.S.



OBSERVED CREST PANEL DISCHARGE IN C.F.S PER FOOT OF CREST
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
BLOCKED TO 1+00
BLOCKED FROM 22+00
0
2
4
6
8
10
12
14
16
18
20
22
24
CREST PANEL NUMBER
LEGEND
TEST NO. 205
TEST NO. 206
TEST NO. 211
TEST NO. 212
ISLINGTON MODEL
HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
HORSESHOE FALLS
OBSERVED CREST FLOW DISTRIBUTION
WITH AND WITHOUT FINAL EXCAVATION SCHEME
TOTAL RIVER FLOW 240,000 C.F.S

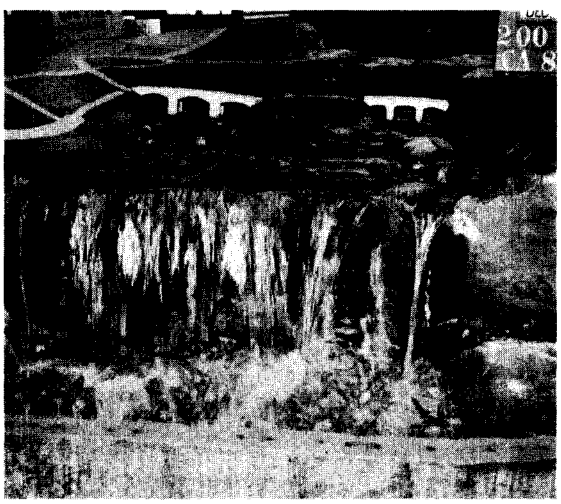
PLATE H-13

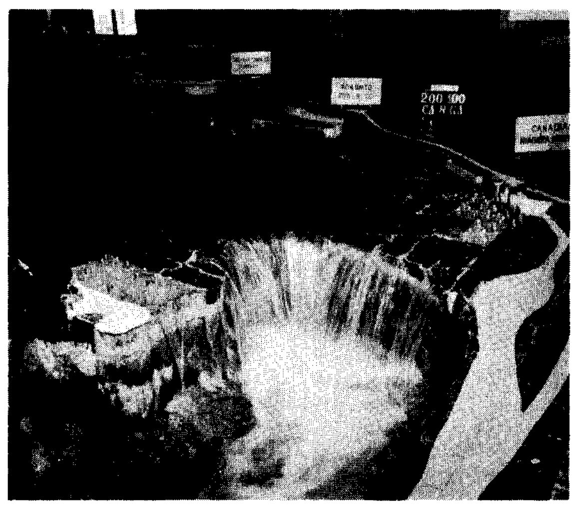
AMERICAN FALLS HORSESHOE FALLS



NON-TOURIST SEASON

TEST 107





TOURIST SEASON DAYS

TEST 101

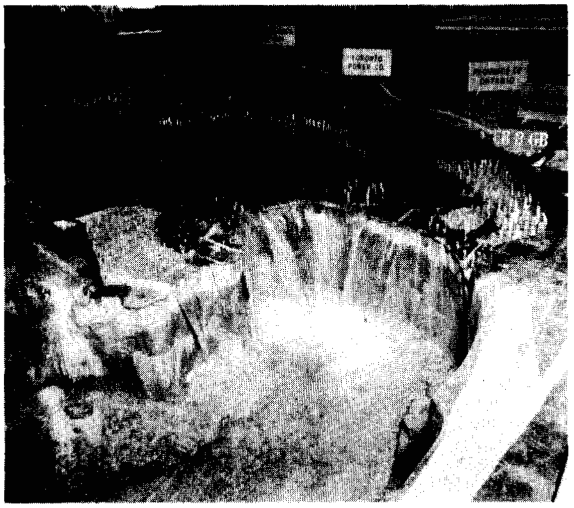
EXCAVATION SCHEMES CA and GA

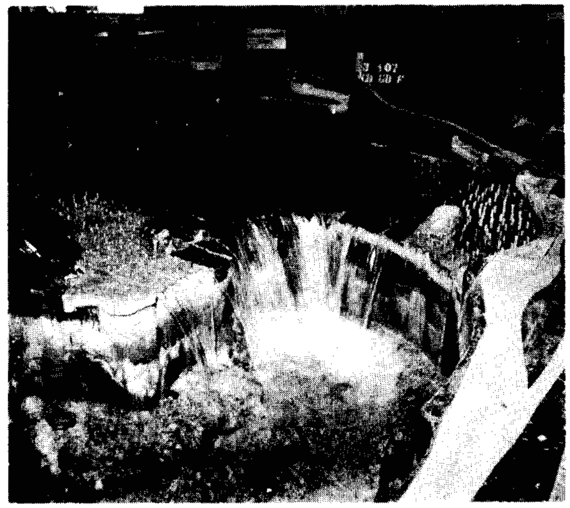
Total River Flow 200,000 c.f.s.

HORSESHOE FALLS REMEDIAL WORKS

ISLINGTON MODEL PHOTOGRAPHS

AMERICAN FALLS | HORSESHOE FALLS





NON-TOURIST SEASON

TEST 107

TOURIST SEASON DAYS

TEST 101

EXCAVATION SCHEMES CB and GB | EXCAVATION SCHEMES CD and GD

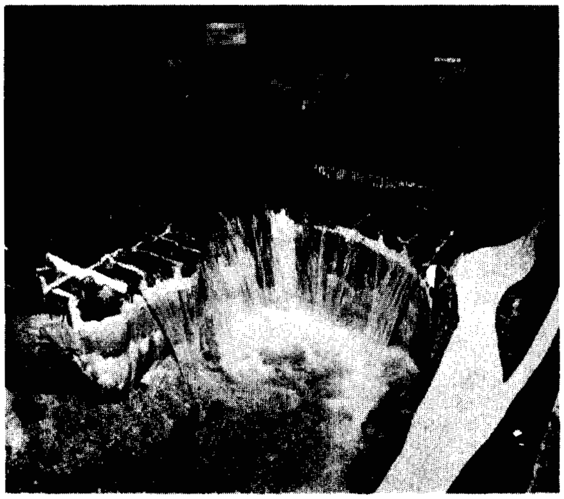
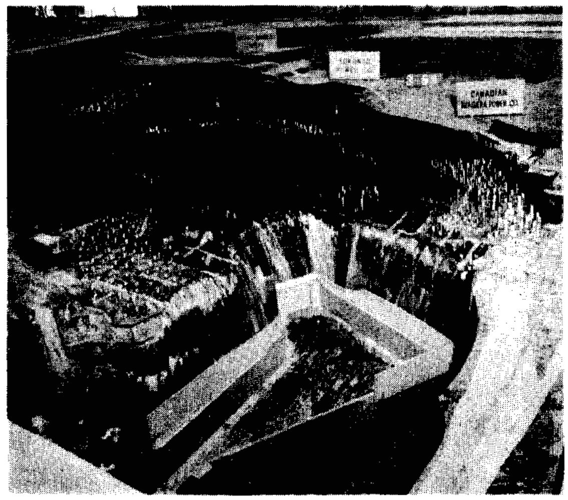
Total River Flow 200,000 c.f.s.

HORSESHOE FALLS REMEDIAL WORKS

ISLINGTON MODEL PHOTOGRAPHS

PLATE H-15

HORSESHOE FALLS

NON-TOURIST SEASON

TEST 107


TOURIST SEASON DAYS

TEST 101

WEIRS 7 and 11

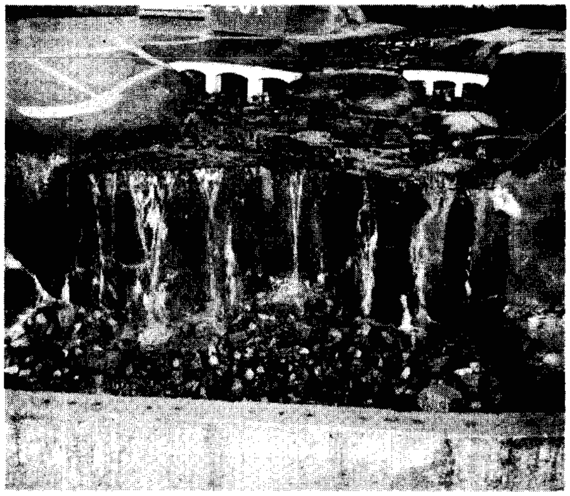
WEIRS 8 and 9
EXCAVATIONS CB and GB

Total River Flow 200,000 c.f.s.

HORSESHOE FALLS REMEDIAL WORKS

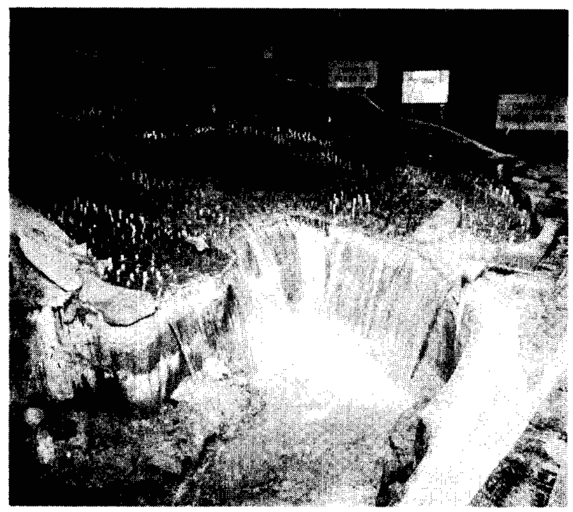
ISLINGTON MODEL PHOTOGRAPHS

AMERICAN FALLS HORSESHOE FALLS



NO REMEDIAL WORKS

TEST 201



REMEDIAL EXCAVATION SCHEMES CE and GE (R-17)

TEST 207

NON-TOURIST SEASON

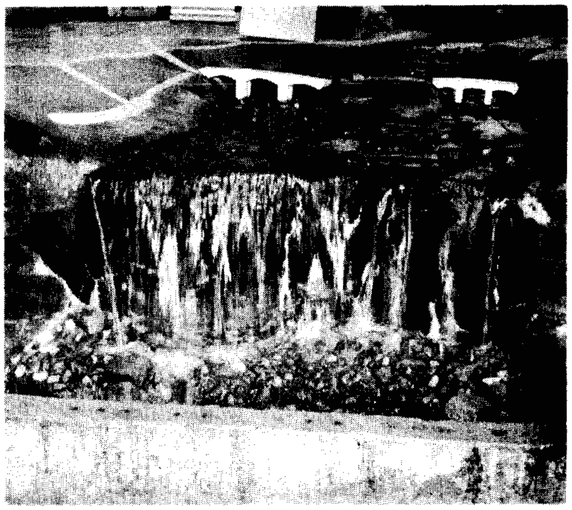
Total River Flow 170,000 c.f.s.

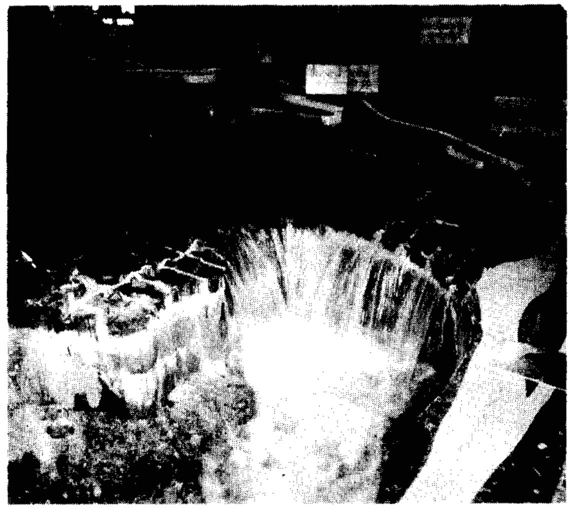
HORSESHOE FALLS REMEDIAL WORKS

ISLINGTON MODEL PHOTOGRAPHS

PLATE H-17

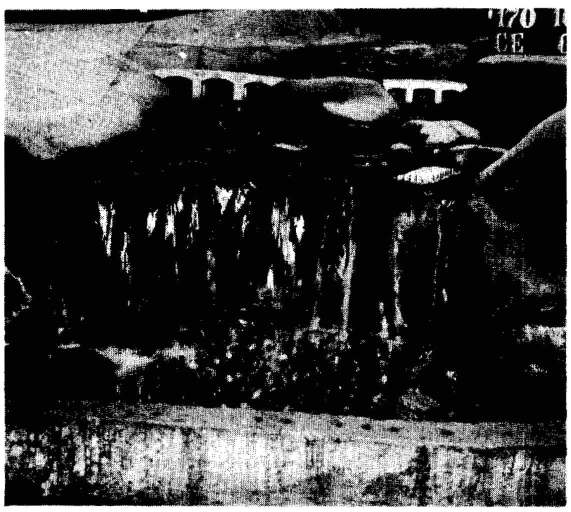
AMERICAN FALLS HORSESHOE FALLS





NO REMEDIAL WORKS

TEST 202



REMEDIAL EXCAVATION SCHEMES CE and GE (R-17)

TEST 208

TOURIST SEASON DAYS

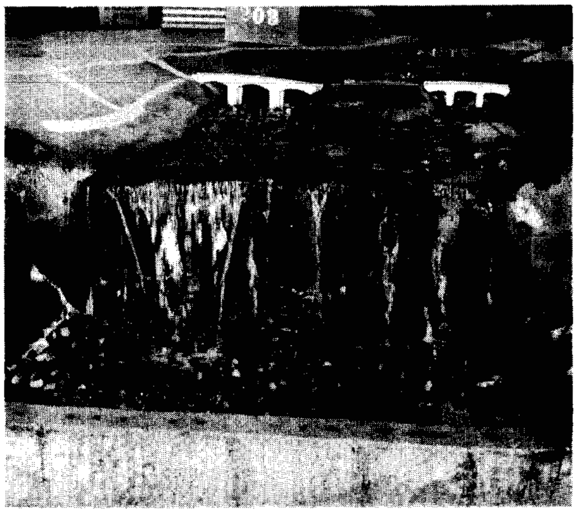
Total River Flow 170,000 c.f.s.

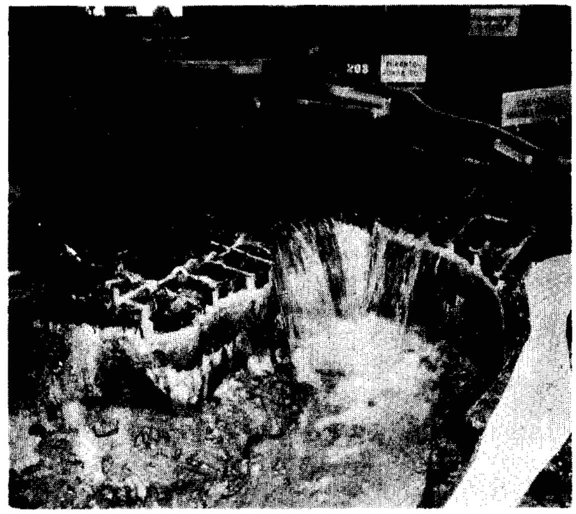
HORSESHOE FALLS REMEDIAL WORKS

ISLINGTON MODEL PHOTOGRAPHS

PLATE H-18

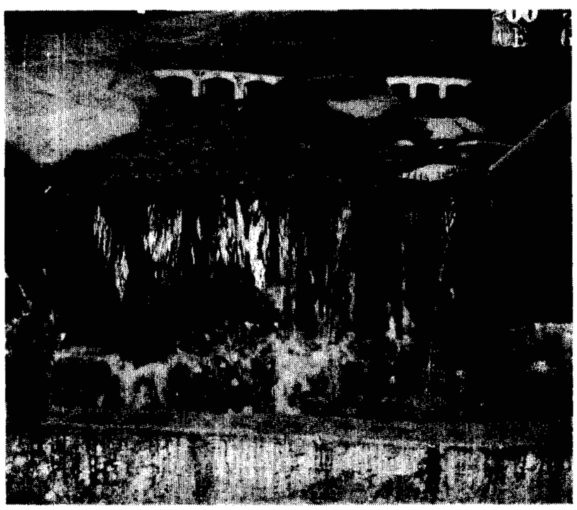
AMERICAN FALLS HORSESHOE FALLS

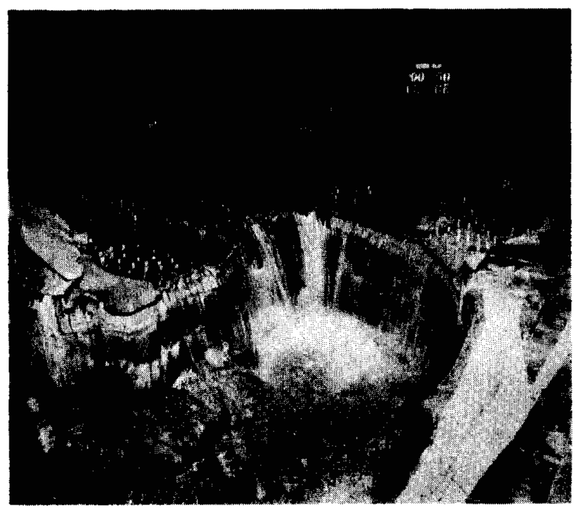




NO REMEDIAL WORKS

TEST 203





REMEDIAL EXCAVATION SCHEMES CE and GE (R-17)

TEST 209

NON-TOURIST SEASON

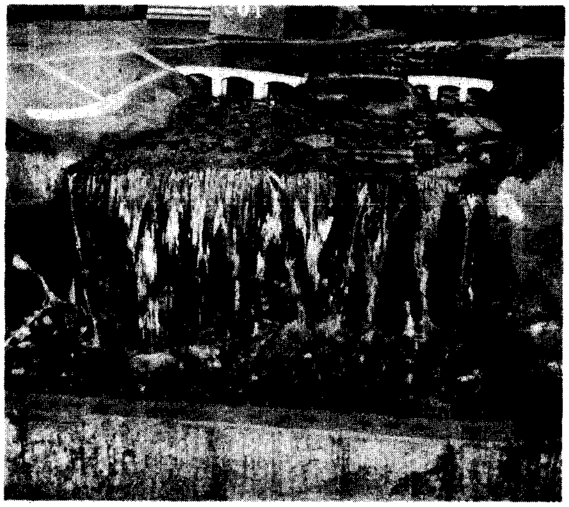
Total River Flow 200,000 c.f.s.

HORSESHOE FALLS REMEDIAL WORKS

ISLINGTON MODEL PHOTOGRAPHS

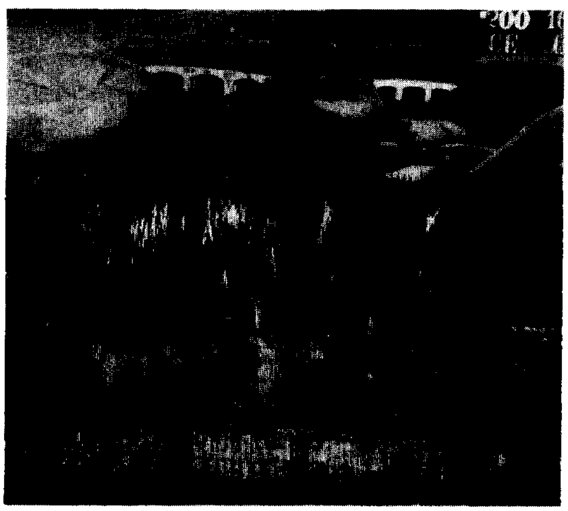
AMERICAN FALLS

HORSESHOE FALLS



NO REMEDIAL WORKS

TEST 204



REMEDIAL EXCAVATION SCHEMES CE and GE (R-17)

TEST 210

TOURIST SEASON DAYS

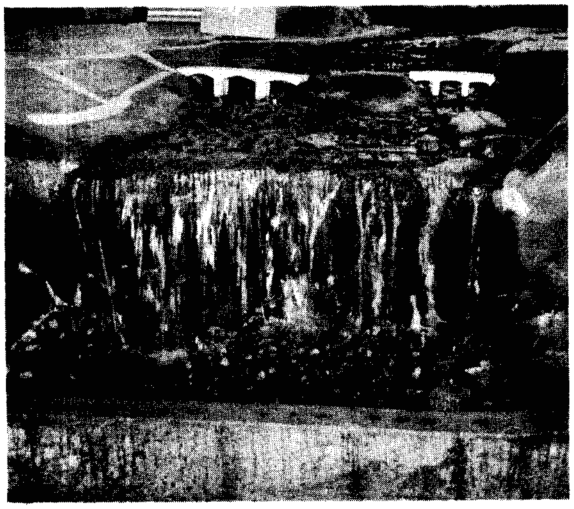
Total River Flow 200,000 c.f.s.

HORSESHOE FALLS REMEDIAL WORKS

ISLINGTON MODEL PHOTOGRAPHS

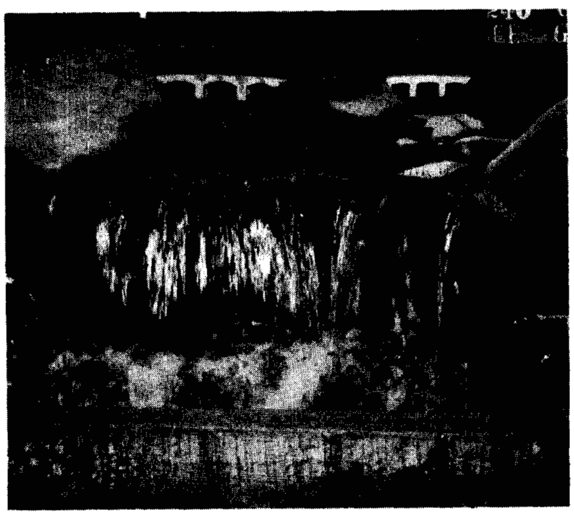
AMERICAN FALLS

HORSESHOE FALLS



NO REMEDIAL WORKS

TEST 205



REMEDIAL EXCAVATION SCHEMES CE and GE (R-17)

TEST 211

NON-TOURIST SEASON

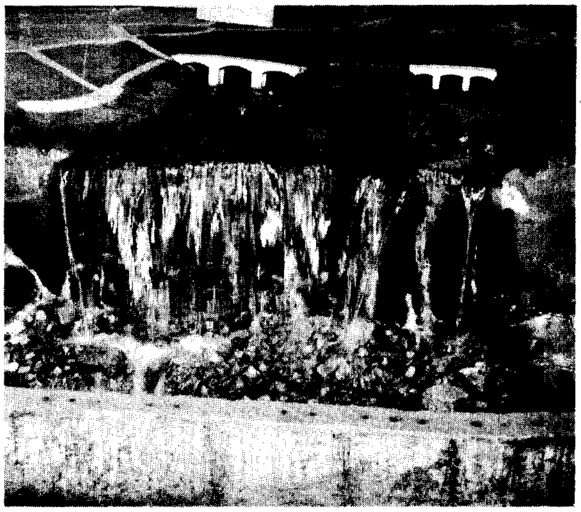
Total River Flow 240,000 c.f.s.

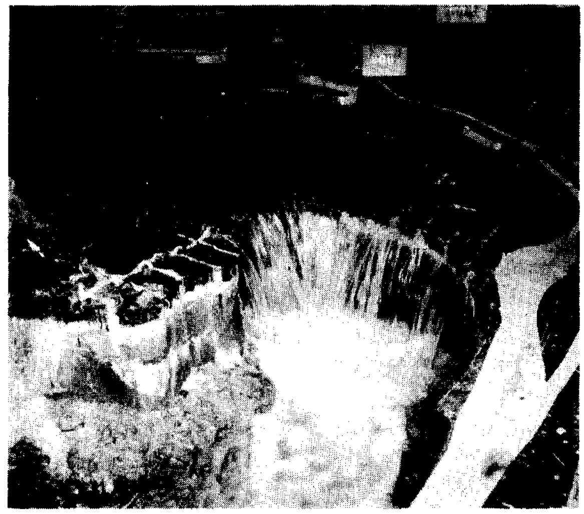
HORSESHOE FALLS REMEDIAL WORKS

ISLINGTON MODEL PHOTOGRAPHS

AMERICAN FALLS

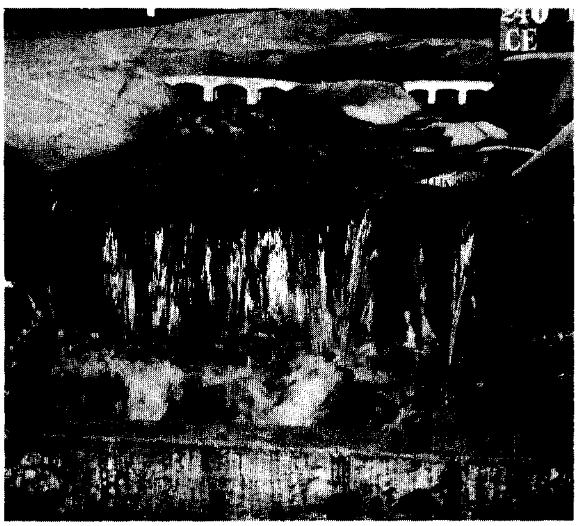
HORSESHOE FALLS





NO REMEDIAL WORKS

TEST 206



REMEDIAL EXCAVATION SCHEMES CE and GE (R-17)

TEST 212

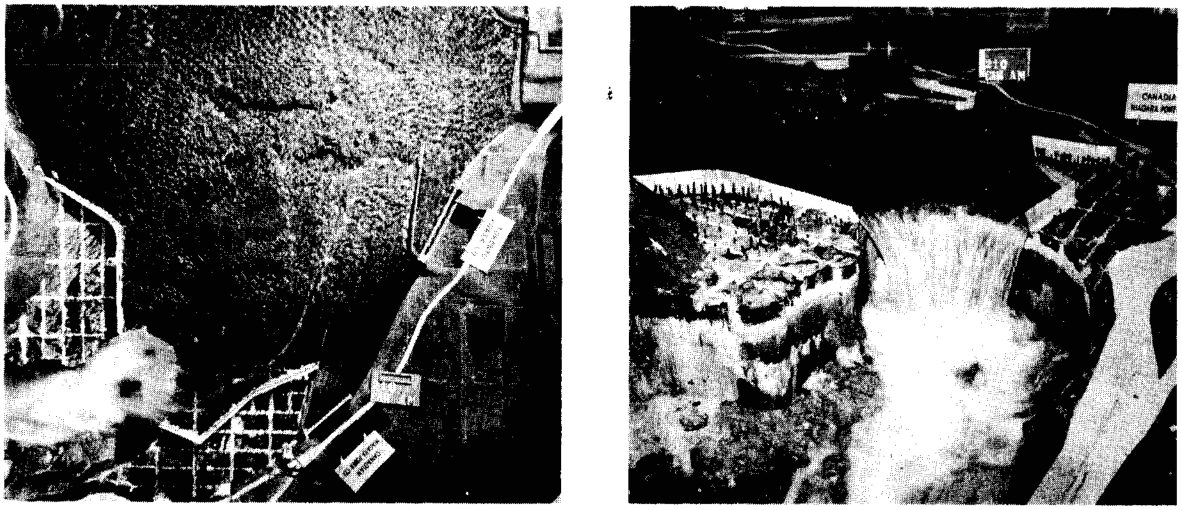
TOURIST SEASON DAYS

Total River Flow 240,000 c.f.s.

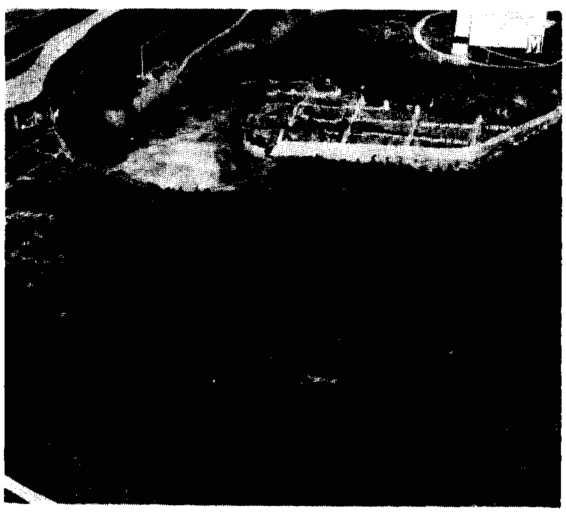
HORSESHOE FALLS REMEDIAL WORKS

ISLINGTON MODEL PHOTOGRAPHS

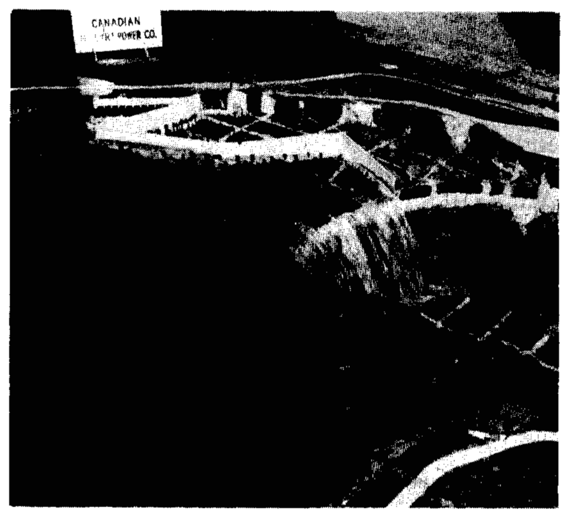
HORSESHOE FALLS



COFFERDAMS FOR CE and GE (R-17)
BOTH IN PLACE



COFFERDAM FOR GE (R-17)
ONLY IN PLACE



COFFERDAM FOR CE
ONLY IN PLACE

REMEDIAL EXCAVATION SCHEMES CE and GE (R-17)

Total River Flow 210,000 c.f.s.

HORSESHOE FALLS REMEDIAL WORKS

ISLINGTON MODEL PHOTOGRAPHS

PLATE H-23

APPENDIX J

DESIGN AND CONSTRUCTION FEATURES
AND ESTIMATES OF COSTS
OF PROPOSED REMEDIAL WORKS

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX J

DESIGN AND CONSTRUCTION FEATURES AND ESTIMATES OF COSTS OF PROPOSED REMEDIAL WORKS

CONTENTS

LIST OF TABLES

LIST OF PLATES

PRESERVATION AND ENHANCEMENT OF NIAGARA FALLS

APPENDIX J

DESIGN AND CONSTRUCTION FEATURES AND ESTIMATES OF COSTS OF PROPOSED REMEDIAL WORKS

SCOPE

1. This appendix presents a description and estimate of cost of the proposed remedial works. Estimates are based on construction cost levels of July 1952, assuming that construction on the United States side would be accomplished by United States organizations and that on the Canadian side by Canadian organizations. Unit prices and construction methods are based on actual construction experience in each country on other projects of a generally similar nature. Features for which estimates are given are shown on Plates 3, 6, and 7 of the main report and are itemized below:

(1) A Chippawa-Grass Island Pool control structure.

(2) An excavation in the Horseshoe Cascades lying immediately upstream from the Canadian flank, and a 100-foot crest fill on the Canadian flank.

(3) An excavation in the Horseshoe Cascades lying immediately upstream from the Goat Island flank, and a 300-foot crest fill on the Goat Island flank.

CONTROL STRUCTURE IN THE CHIPPAWA-GRASS ISLAND POOL

DESCRIPTION

2. The control structure in the Chippawa-Grass Island Pool would extend out from the Canadian shore some 1,550 feet into the river on a line parallel to the present submerged weir and 200 to 250 feet downstream. With the exception of an approach fill adjacent to the Canadian shore, the structure would consist entirely of piers and movable control gates. A service deck spanning the piers would provide access for operation and maintenance, and might take the form of a series of flat arches between the piers. Operating machinery would be enclosed in the piers.

DESIGN FEATURES

3. Operational considerations. — The most severe operating conditions would take place during periods of heavy ice flow in the Niagara River. Such ice flows of a few days duration may occur anytime between December and May. In general, the gates should be capable of passing ice during those periods while still properly controlling the level of Chippawa-Grass Island Pool. In addition to individual operation of each gate from the structure itself, provision should be made for remote operation of gates from a central location on the Canadian shore.

4. Structural design. — To avoid serious ice jams, the control structure must present a minimum of obstruction to the passage of ice, and the sluice openings have been assumed as wide as possible within gate design limitations. The pier sections have been designed both for structural stability and with suitable space for housing the appropriate machinery.

5. Gate design. — Gate designs are based on preliminary data furnished by experienced gate manufacturers or data from generally similar existing gates. The following design types have been studied:

(1) Overhead or lift type:

(a) Tainter gates — 80-foot clear openings.

(b) Standard vertical lift sluice gates — 100-foot clear openings.

(2) Submersible or overflow type:

(a) Bascule gates — 100-foot clear openings.

(b) Fishbelly or flap gates — 100-foot clear openings.

6. DESIGN CRITERIA.— The submersible gates are assumed to incorporate an automatic pressure release mechanism to lower the gates in order to avoid excessive ice thrusts, a feature which cannot be incorporated in overhead or lift type of gate. It is also assumed that the stop logs used for sluice dewatering purposes will not be in place during the ice flow season. The stop logs, therefore, are not designed for ice forces. All structures and gates have been designed on the following criteria:

Ice Thrust

On piers:	40,000 lbs. per foot, acting at ice level.
On overhead or lift gates:	10,000 lbs. per foot, distributed over 4-foot depth.
On submersible or overflow gates:	5,000 lbs. per foot, acting at crest.

Steel Stress

Allowable, for ordinary loadings:	18,000 psi.
Allowable, for ice loading:	23,400 psi.

Elevations (U.S.L.S. 1935 datum.)
Top of gate in closed position:

Vertical lift gate	567.5
Others	564.0
Sill, all gates:	553.5
Maximum headwater:	566.0
Minimum tailwater:	553.2

Bridge loading — To carry 60 ton crawler crane.

Uplift — Full uplift under structure.

CONSTRUCTION FEATURES

7. It was first considered that the structure should be constructed on the same alignment as the existing rock weir so as to take advantage of the lower water velocities for the construction of the upstream cofferdams. Futher study indicated that this location would involve underwater removal of the rock weir in several places to allow for upstream-downstream cofferdams. It was therefore concluded that the center line of the control structure should be located 200 to 250 feet downstream from the center line of the existing rock weir.

8. The nature of the rock is such that it will likely require special provisions for grouting, as experienced in the unwatering of the intake area for the Sir Adam Beck-Niagara Generating Station No. 2 about 2,000 feet upstream from the site of the proposed Chippawa-Grass Island Pool control structure. This operation was considered in estimating the cost of construction.

9. The estimate for dewatering is based on cofferdams consisting of stone-filled, rough cut, soft timber cribs faced with steel sheet piling driven about 2 feet into rock along the outside face. These cribs, the top surface of which would serve as a roadway, would be constructed in 20-foot by 30-foot sections. Estimates are based on removal of cofferdams at the end of each construction season by means of a dragline and on the use of new materials for each cofferdam. Other types of cofferdams will be considered further before actual construction commences.

10. Work within the cofferdams would be accomplished by standard equipment. Access to all cofferdams except the first, which would be adjacent to the shore would be by means of the permanent bridge structure, widened where necessary for construction traffic.

ESTIMATES

11. The total estimated construction cost of the structure for the bascule type of gate including a preliminary estimate of cost for the gate, and including contingencies, engineering, supervision and inspection and overhead, is $14,594,000. A detailed estimate of this structure is given in Table J-1 and a typical section is shown on Plate 6 of the main report. Preliminary estimates of the control structure with other types of gates indicate that the cost would be substantially the same as with the bascule gate. Typical sections of the other types investigated are shown on Plate J-1.

REMEDIAL WORKS IN THE CASCADES

DESCRIPTION

12. Excavation upstream from Canadian flank.—This excavation would lie in the Horseshoe Cascades in the area upstream from the Canadian flank. Its purpose would be to tap the deep stream on the Canadian side of the Horseshoe Cascades and divert flow to the Canadian flank in quantities adequate to preserve the spectacle under all future conditions. The detailed plans of this excavation are shown on Plate 7 of the main report which shows also the details of the items described in paragraphs 14, 15 and 16, below. The estimated quantity of excavation is 64,000 cubic yards of rock. To accomplish this excavation, cofferdams would be necessary to dewater the area.

13. Canadian flank crest fill.—The 100-foot crest fill on the Canadian flank adjacent to the Canadian shore would merge with the present shoreline about 100 feet upstream. It is contemplated that a concrete retaining wall faced with stone to blend into the surroundings would surround this fill. Inside the wall, fill would be placed to the grade of the existing observation area and the whole landscaped to provide an attractive area for viewing the Falls and Cascades.

14. Excavation upstream from Goat Island flank.—The function of the excavation upstream from the Goat Island flank would be to divert an adequate volume of flow over the Goat Island flank under all future conditions in a manner similar to the excavation on the Canadian side. Here also, cofferdams would be necessary to dewater the area to accomplish the excavation of some 24,000 cubic yards of rock.

15. Goat Island flank crest fill.—On the Goat Island flank of the Horseshoe Falls, the proposed 300-foot crest fill adjoining Goat Island would merge with the present shoreline about 300 feet upstream. A concrete retaining wall suitably faced with rock would surround the fill which would be so graded as to be accessible from Goat Island. This area suitably landscaped would provide a good vantage point from which to view the Falls and Cascades.

CONSTRUCTION FEATURES

16. The estimate for the proposed Cascades remedial works on either the Canadian or Goat Island flank of the Horseshoe Falls is based on one stage of construction within one construction season. As a result of differences in labour costs and in availability and costs of materials, the estimates for cofferdam construction on the Canadian side are based on rock-filled timber cribs faced with steel sheet piling, and on the United States side are based on steel frame units with stop logs and precast concrete ballast. Rock fill dikes were figured for reaches in shallow water.

17. The basis of the estimate for the timber crib cofferdam is the same as for the control structure (see para. 9). The basis of the estimate for the steel frame cofferdam is based generally on the method used for construction of the intake for the Canadian-Niagara plant some 15 years ago. Estimates are based on steel frame units which would be loaded with reinforced concrete ballast blocks to provide stability. The frame legs, cut to the proper length on the basis of soundings to the existing bottom, would be pinned to the bottom to ensure against sliding and timber stop logs would be set in slots provided in the frames.

18. The area of excavation on the Canadian flank would be 8.4 acres with an average cut of approximately 4.7 feet and a maximum cut of 9.5 feet. While a small portion of the excavated material could be deposited in the adjacent fill area, disposal of rock excavation, in general, would involve an access bridge and haulage for a distance of from one and one-half to three and one-half miles, mostly through park areas, which may involve considerable costs for road restoration. Costs of such road restoration and the access bridge are reflected in the unit costs for rock excavation. The excavation on the Goat Island flank is divided into two quantities at different unit prices on the basis that 14,000 cubic yards of the total of 24,000 cubic yards of excavation would be deposited on the adjacent proposed crest fill area while the remainder would have to be hauled approximately five miles to a spoil area. The average cut over the 5.4 acre area of excavation would be approximately 2.8 feet and the maximum cut 6 feet.

ESTIMATES

19. Detailed estimates of the proposed features of the remedial works in the Cascades are given in Tables J-2 and J-3.

TABLE J-1

ESTIMATED COST OF GRASS ISLAND POOL CONTROL STRUCTURE WITH BASCULE GATES

Item	Quantity	Unit Price	Amount	Total, say
Dewatering				
Cofferdam	134,000 c.y.	$ 25.00	$3,350,000	
Pumping		L.S.	400,000	
Grouting		L.S.	500,000	$ 4,250,000
Excavation - rock	28,500 c.y.	15.00		427,500
Piers				
Concrete	14,700 c.y.	60.00	882,000	
Cement	22,000 bbl.	4.25	93,500	
Reinforcing steel	588,000 lb.	0.12	70,560	
Steel nosing for piers	80,000 lb.	0.20	16,000	1,062,000
Sluices				
Concrete	37,300 c.y.	40.00	1,492,000	
Cement	56,000 bbl.	4.25	238,000	
Reinforcing	746,000 lb.	0.12	89,520	1,819,500
Superstructure				
Deck slab and beams				
Concrete	4,000 c.y.	160.00	640,000	
Cement	6,000 bbl.	4.25	25,500	
Reinforcing steel	416,000 lb.	0.12	49,920	
Railing	3,000 l.f.	12.00	36,000	751,500
Retaining wall at shore end and outer gravity wall				
Concrete	700 c.y.	60.00	42,000	
Cement	1,050 bbl.	4.25	4,463	
Reinforcing steel	14,000 lb.	0.12	1,680	
Rock fill (shore end)	4,200 c.y.	1.50	6,300	54,500
Gates and hydraulic equipment				
Purchase and erection of gates and machinery	3,674,000 lb.	0.52	1,910,480	
Contingencies for gate design		L.S.	191,000	
Stop logs (2 sets)	740,000 lb.	0.25	185,000	
Stop log handling equipment		L.S.	130,000	2,416,500
Operating Building		L.S.		50,000
Landscaping		L.S.		25,000
Siding and road diversion improvement and repair		L.S.		100,000
Contingencies				2,191,500
Indirect costs				
Engineering			263,000	
Field engineering			789,000	
Administration			394,000	1,446,000
Total				$14,594,000

TABLE J-2

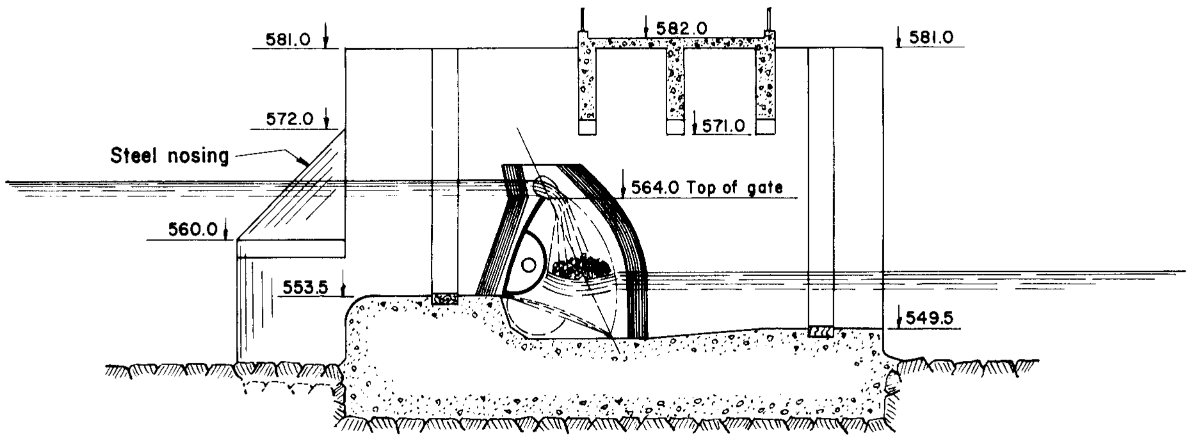
ESTIMATED COST OF EXCAVATION AND CREST FILL ON CANADIAN FLANK — SCHEME "CE"

Item	Quantity	Unit Price	Amount	Total, say
Cofferdam				
Timber crib	14,200 c.y.	$ 25.00	$ 355,000	
Steelframe, including purchase, placing and removal of frames, concrete slabs, and stop logs		L.S.	205,000	$ 560,000
Rock Excavation	64,000 c.y.	8.00		512,000
Pumping and Drainage		L.S.		25,000
Retaining Wall				
Trimming rock surface under wall	100 c.y.	12.00	1,200	
Concrete	950 c.y.	40.00	38,000	
Cement	1,425 bbl.	4.25	6,056	
Reinforcing steel	19,000 lb.	0.12	2,280	
Rock facing	5,400 s.f.	5.00	27,000	
Railing	200 l.f.	2.25	495	75,000
Landscaping		L.S.		15,000
Contingencies				238,000
Indirect costs				
Engineering			29,000	
Field engineering			85,000	
Administration			43,000	157,000
Total				$ 1,582,000

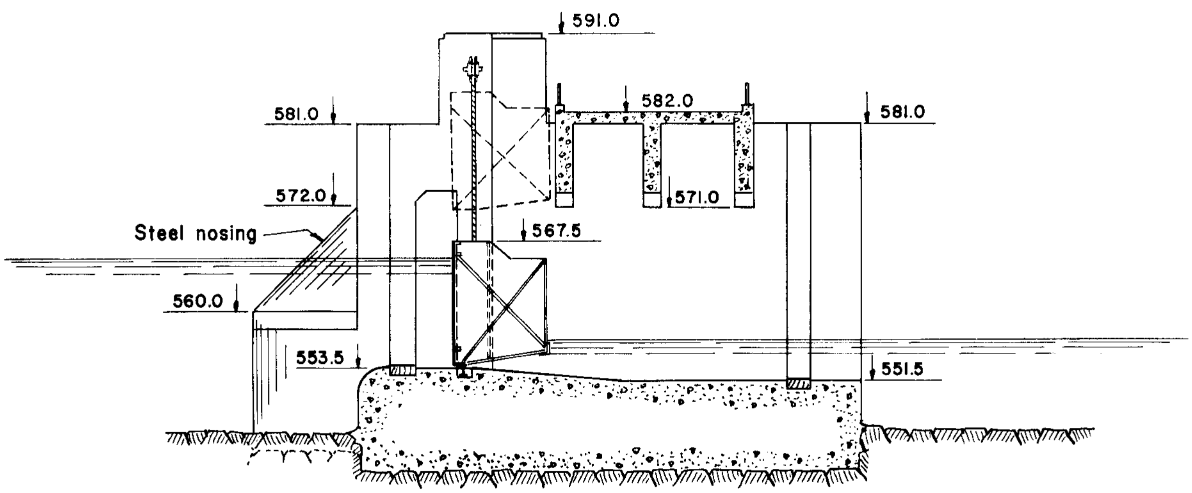
TABLE J-3

ESTIMATED COST OF EXCAVATION AND CREST FILL ON GOAT ISLAND FLANK — SCHEME "R17"

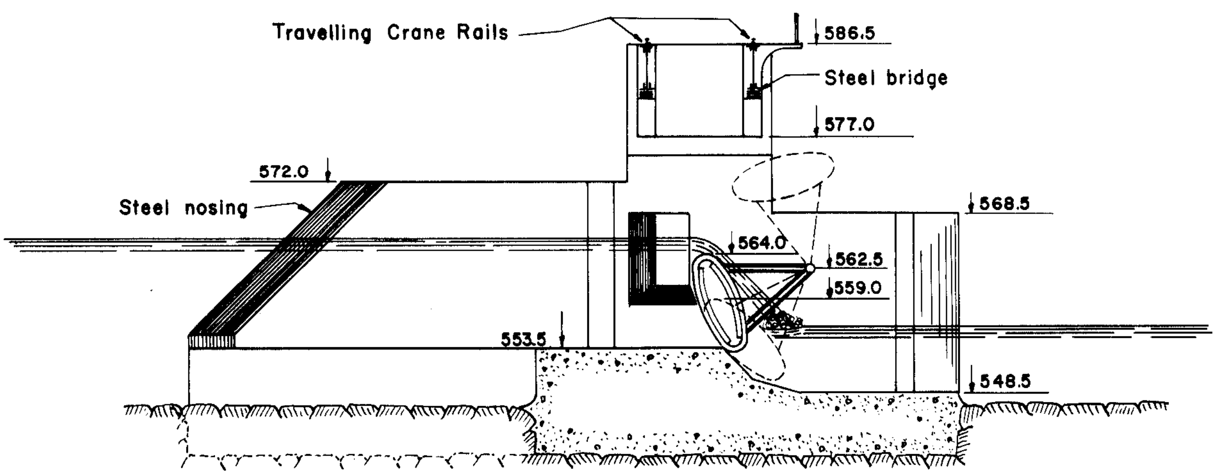
Item	Quantity	Unit Price	Amount	Total, say
Cofferdam				
Drilling and Pinning		L.S.	$ 12,000	
Placing frames incl. materials		L.S.	419,000	
Removing frames incl. salvage		L.S.	65,000	
Stop logs		L.S.	80,000	
Rock fill (dike)	1,900 c.y.	12.00	22,800	
Access roads and repair		L.S.	75,000	$ 674,000
Excavation				
Drainage ditches		L.S.	25,000	
Rock excavation and fill	14,200 c.y.	10.00	142,000	
Rock excavation (haul)	10,100 c.y.	12.00	121,200	288,000
Retaining Wall				
Trimming rock surface under wall	110 c.y.	15.00	1,650	
Concrete	370 c.y.	50.00	18,500	
Cement	600 bbls.	4.25	2,550	
Reinforcing steel	9,600 lbs.	0.12	1,152	
Rock facing	3,500 s f.	5.00	17,500	
Railing	770 l.f.	5.00	3,850	45,000
Landscaping		L.S.		15,000
Contingencies				204,000
Indirect costs				
Engineering			24,000	
Field engineering			73,000	
Administration			37,000	134,000
Total				$ 1,360,000



FISHBELLY GATE — 100-FT. SPAN



STANDARD SLUICE GATE — 100-FT. SPAN



TAINTER GATE — 80-FT. SPAN

PRESERVATION & ENHANCEMENT OF NIAGARA FALLS

CHIPPAWA-GRASS ISLAND POOL CONTROL STRUCTURE

ADDITIONAL GATE TYPES CONSIDERED

INTERNATIONAL NIAGARA FALLS ENGINEERING BOARD

SCALE OF FEET

10 5 0 10 20

To accompany report dated 1st March 1953