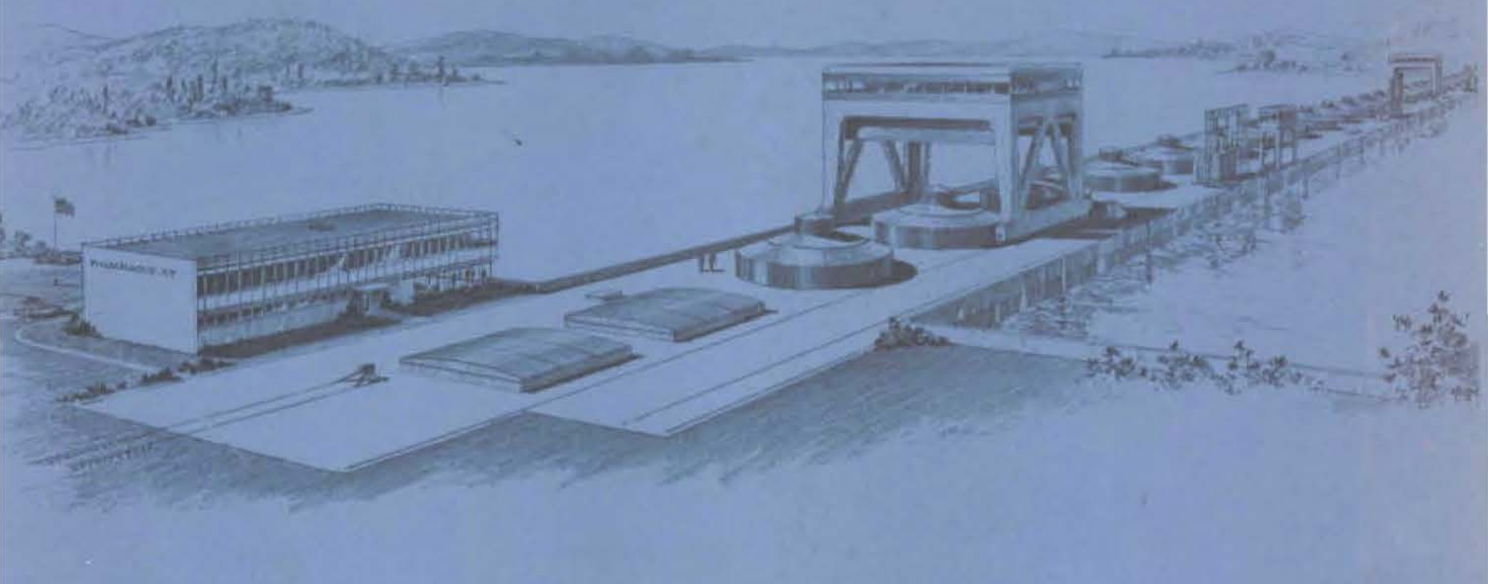
INVESTIGATION OF THE INTERNATIONAL PASSAMAQUODDY TIDAL POWER PROJECT



REPORT OF THE
INTERNATIONAL JOINT COMMISSION
DOCKET 72
INVESTIGATIONS OF THE
INTERNATIONAL PASSAMAQUODDY
ENGINEERING AND FISHERIES BOARDS

April 1961

THE

INTERNATIONAL PASSAMAQUODDY TIDAL POWER PROJECT

Washington — **Ottawa**

April 1961

SECTION A REPORT OF THE INTERNATIONAL JOINT COMMISSION

SECTION B INVESTIGATION OF THE INTERNATIONAL ENGINEERING BOARD

SECTION C INVESTIGATION OF THE INTERNATIONAL FISHERIES BOARD

INTERNATIONAL JOINT COMMISSION

United States	Canada
EDWARD A. BACON, Chairman	A. G. L. McNAUGHTON, Chairman
EUGENE W. WEBER	J. LUCIEN DANSEREAU
FRANCIS L. ADAMS	D. M. STEPHENS
Harry J. Donohue, Secretary	D. G. Chance, Secretary

INTERNATIONAL PASSAMAQUODDY ENGINEERING BOARD

United States	Canada
Lt. Gen. S. D. Sturgis, Jr. (Ret.), Chairman	G. Millar, Chairman
Frank L. Weaver	H. B. Rosenberg

INTERNATIONAL PASSAMAQUODDY FISHERIES BOARD

United States	Canada
Donald L. McKernan, Chairman	Dr. J. L. Hart, Chairman
Moses B. Pike	Dr. A. L. Pritchard

REPORT OF THE INTERNATIONAL JOINT COMMISSION

UNITED STATES AND CANADA

ON THE

INTERNATIONAL PASSAMAQUODDY TIDAL POWER PROJECT

Washington — Ottawa

April 1961

CONTENTS

TABLES

PLATES

INTERNATIONAL JOINT COMMISSION

Report to United States of America and Canada on Investigation of the International Passamaquoddy Tidal Project Maine and New Brunswick

REFERENCE TO THE INTERNATIONAL JOINT COMMISSION

The Governments of the United States and Canada forwarded on August 2, 1956, to the International Joint Commission identical letters requesting the Commission to conduct investigations and to submit a report on the proposed international Passamaquoddy Tidal Power Project. This request was made in accordance with the Boundary Waters Treaty of 1909 and with United States Public Law 401, 84th Congress, 2d Session, approved January 31, 1956. The full text of the Reference of the two Governments is quoted below:

"In accordance with the provisions of Article IX of the Boundary Waters Treaty of January 11, 1909, the Governments of Canada and the United States have agreed to refer and do hereby refer to the International Joint Commission the following matters for joint examination and advisory report, including conclusions and recommendations:

(a) It is desired that the Commission determine the estimated cost of developing the international tidal power potential of Passamaquoddy Bay in the State of Maine and the Province of New Brunswick, and determine whether such cost would allow hydroelectric power to be produced at a price which is economically feasible;

(b) The Commission is requested to determine the effects, beneficial or otherwise, which such a power project might have on the local and national economies in the United States and Canada, and to this end, to study specifically the effects which the construction, maintenance and operation of the tidal power structures might have upon the fisheries in the area.

In the discharge of its responsibilities under this reference, the Commission is requested to review and, insofar as is practicable, make advantageous use of existing reports and plans such as the Report of March 15, 1950, submitted by the International Passamaquoddy Engineering Board to the Commission and the supplemental report of May 1952 prepared by the United States Army Corps of Engineers on the details of estimate of cost of a comprehensive investigation of the Passamaquoddy tidal power project. Having regard to the foregoing, the Commission should determine the most desirable general project design from the viewpoint of the public interest in United States and Canada respectively -- such design to include plans for structure and appurtenant works in sufficient detail to form the basis of dependable cost estimates and considerations of economic feasibility.

In the conduct of its investigations, and otherwise in the performance of its duties under this reference, the Commission may utilize the services of specially qualified engineers and other experts of the technical agencies of the United States and Canada and will, so far as possible, make use of any pertinent data that may be available in such agencies or which may become available during the course of the investigations, thus avoiding duplication of effort and unnecessary expense.

The United States Government is willing, subject to the availability of funds, to incur cost in connection with this survey up to $3,000,000 and the Canadian Government is willing to incur costs up to $300,000. Each

Government has the right to participate at its own expense in all aspects of the survey to an extent appropriate with its interest. In making administrative arrangements for the necessary surveys and studies, the Commission should give suitable effect to these responsibilities.

The costs incurred by the Governments of the United States and Canada respectively under this Reference will be credited against the costs to be borne by each of the Governments in the event that the project should be constructed as a joint undertaking by the two Governments. The decision of the two Governments to refer this study to the Commission does not imply any commitment regarding the eventual construction of the project.

It is the desire of both Governments that the Commission endeavour to complete its various surveys, investigations, studies and other activities under the Reference within a three-year period. Upon completion, it is requested that the Commission prepare and submit to the Governments of the United States and Canada a comprehensive report covering the subject matter of this Reference. The Commission's report should include the details of the specific design, cost estimates, and an estimate of the benefits to be derived or the losses to result from this project."

BACKGROUND OF THE PROJECT

Power from the Tides

The ocean tides have long been envisioned as a source of power. "Tide mills" were constructed in Europe as early as the 11th century and in America as early as 1617. Such small tidal hydro-mechanical power developments were practical for grinding corn or spices as the work could be adjusted to the periodic and varying power from the tides. Electrification and the rapid industrial and economic growth of the 20th century, however, have established a heavy growth in demand for electric power, and today the economic utilization of power requires its availability on a controlled schedule. Therefore, a tidal power project must be capable of sustaining dependable power production from the tides or be interconnected with other power sources and so operated that the coordinated capability would conform to the needs of the power load.

Utilization of the tides to generate a substantial quantity of power requires provision for the storage of large quantities of water so that discharges may be made from a higher to a lower elevation through hydraulic turbines. A large single pool may be built to entrap or exclude water from the ocean, but generation of power is limited to those times in the tidal cycle when the differential in elevation between the ocean and the pool is sufficient for operation of the turbines. A combination of two storage pools for simultaneous entrapment and exclusion of water from the ocean can, however, provide for some generation at all times. Also, either single or two pool projects may be arranged to accommodate reversible units capable of pumping or generating from flow in either direction, thus further increasing the power potential and providing greater flexibility for coordinated operation with other power sources. As compared to most river hydroelectric projects the potential average hydraulic head of tidal projects is quite small; but the very large quantities of water available for power production are accurately predictable for many years in the future.

Passamaquoddy Bay located near the mouth of the Bay of Fundy experiences smaller tidal ranges than those occurring in the head of that bay in Canada. The site, by reason of adjacent Cobscook Bay and the narrow passages among islands with inter-spaced shoal areas offers many alternatives for one or two pool schemes. The large area of Passamaquoddy Bay with the substantial additional area of Cobscook Bay is favorable for a two pool plan.

Prior Surveys of the Passamaquoddy Project

From 1924 to 1934 Dexter P. Cooper, Inc. prepared plans originally for an international tidal power project at Passamaquoddy and Cobscook Bays, but later for a project located wholly in the United States. The United States' Federal Power Commission in its review of the Dexter P. Cooper, Inc. loan application to the Federal Emergency Administration of Public Works reported adversely on the project in January 1934 and the loan was not approved. The project as finally revised would have had an initial installation of 235,000 kilowatts with provision for an additional 100,000 kilowatts.

In 1927 Murray and Flood, Engineers, of New York, N. Y. reported on the international project proposed by Cooper. They estimated that an installed capacity of 400,000 kilowatts with a firm capacity of 122,000 kilowatts could deliver 1,594 million kilowatt hours annually to Woburn, Massachusetts, at an average cost of 8.09 mills per kilowatt-hour. The total estimated cost of the project at 1926-27 price levels, was $125 million.

In 1935 the Passamaquoddy Bay Tidal Project Commission of the United States' Federal Emergency Administration of Public Works recommended construction of an initial Cobscook Bay project, all within the State of Maine, at an estimated cost of $30 million. An untimate project was contemplated to embrace the Passamaquoddy Bay. The recommended initial project was approved by the United States Government and $10 million (later reduced to $7 million) was allotted to the U. S. Army, Corps of Engineers to start construction.

The Corps of Engineers estimated that the initial project with a modified design would cost $61,500,000. A review board raised this estimate to $68,158,000. Work progressed until August 1936 with an expenditure of about $7 million, and was discontinued due to lack of further appropriations by the Congress.

In 1941, the Federal Power Commission in a report prepared pursuant to Senate Resolution 62, 76th Congress, 1st Session, concluded that Passamaquoddy tidal power (development of U. S. waters only) could not compete successfully at that time with river hydroelectric power potentially available in the State of Maine, or with power from modern, efficient steam-electric plants. The Commission stated, however, that this conclusion should not preclude thorough exploration of the possibilities of a large international tidal power project at Passamaquoddy by the Governments of the United States and Canada.

Prior Activities of I.J.C. Relative to the Passamaquoddy Project

The Governments of the United States and Canada by a formal reference dated November 9, 1948, requested the International Joint Commission to review the then existing plans for the construction of tidal power plants at Passamaquoddy and Cobscook Bays and report on the scope and cost of a survey necessary to determine whether the plans then proposed or any other plans for using these waters for generation of electric power would be practicable and desirable.

The Commission appointed an International Passamaquoddy Engineering Board to advise it on the technical phases of the study. In its report to the two Governments dated October 20, 1950, the International Joint Commission concluded that the economic feasibility of an international tidal power project at Passamaquoddy Bay could be determined only after careful and detailed investigations had been made. The cost of the necessary survey was estimated to be about $3,900,000, including $300,000 for investigation of the fisheries problem.

Subsequent to completion of the Commission's 1950 report on the Passamaquoddy project, the Corps of Engineers and the United States Geological Survey concluded from experiments with modern techniques in underwater foundation exploration that the over-all survey cost could be reduced. Accordingly, the Corps submitted in May 1952 to the International Joint Commission a revised cost estimate of $3,000,000, including $300,000 for fisheries investigations.

Objectives of the Current Survey

The objectives of the current survey are to determine the cost of developing an international tidal power project in Passamaquoddy and Cobscook Bays and whether such a project would be economically feasible. More specifically: to determine the most desirable general project design in sufficient detail for preparation of dependable cost estimates; to determine the effects which such a project might have on the local and national economies in the United States and Canada; to determine the present and future electric power requirements in Maine and New Brunswick and the ability of the tidal project to supply these requirements; to determine the value of the tidal power in the market area, as compared to the cost of its development; and to study the effects which the construction, maintenance and operation of the tidal power structures might have upon the fisheries in the area.

INVESTIGATION PROCEDURE

International Passamaquoddy Engineering Board and International Passamaquoddy Fisheries Board

To assist in the investigation, the Commission established two separate boards, the International Passamaquoddy Engineering Board and the International Passamaquoddy Fisheries Board. Membership on the Boards included two representatives each from Canada and the United States. On October 3, 1956, the International Joint Commission issued the following directive to the two Boards:

"(a) The Engineering Board will carry out all the engineering investigations and studies necessary to enable the Commission to prepare and submit to the Governments of the United States and Canada a comprehensive report on the proposed Passamaquoddy Tidal Power Project, as requested by the two Governments in a Reference to the Commission dated 2 August, 1956.

(b) The Fisheries Board will study specifically the effects which the construction, maintenance and operation of the tidal power structures, proposed, might have upon the fisheries in the area.

(c) In order to enable the Fisheries Board to commence its studies and investigations without delay, the Engineering Board is requested to forward to the Commission as soon as possible, for transmittal to the Fisheries Board, an outline of the various project plans which the Engineering Board proposes to investigate. Pending the submission of this information it is suggested that the Fisheries Board proceed with its studies on the basis of the general plans outlined in the March 15, 1950 Report of the previous International Passamaquoddy Engineering Board.

(d) In order that each of the Boards may be fully aware at all times of the progress being made in the investigations and studies carried out by the other Board, each Board is requested to keep the Commission currently informed regarding the investigations and studies it is conducting. The Commission will undertake responsibility for promptly transmitting the information thus received to the other Board, together with such suggestions or instructions as may appear to be appropriate.

(e) In accordance with the desire of the two Governments as evidenced by the terms of the Reference the Engineering Board is requested to review and to utilize, insofar as is practicable, existing reports and plans such as the Report of 15 March 1950, submitted to the Commission by the previous International Passamaquoddy Engineering Board, and the supplemental report of May, 1952 prepared by the Corps of Engineers, United States Department of the Army.

(f) Each Board is authorized to establish such committees and working groups as may be required to effectively discharge the Board's responsibilities.

(g) In accordance with the desire expressed by the two Governments, the Commission will endeavor to complete its various investigations and studies under the Reference within a three year period and submit a comprehensive report covering the subject matter of the Reference as soon as possible thereafter. In order that this may be done, the Commission would appreciate receiving the final reports of both Boards prior to 1 October, 1959.

(h) Each Board will prepare and submit semi-annual progress reports to the Commission on or about 31 March and 30 September of each year and such other reports from time to time as the Commission may direct or as the Board may consider desirable."

The Engineering Board established an Engineering Committee to supervise the detailed engineering studies of the tidal power project. These studies were carried out primarily by the U. S. Army Engineer Division, New England, Corps of Engineers, and the Regional Office of the United States Federal Power Commission, New York. Canadian aspects of the engineering studies were conducted by the Department of Public Works, the

Department of Northern Affairs and National Resources, and other agencies of the Governments of Canada and New Brunswick. The Fisheries Board appointed a Research Committee of Canadian and United States Scientists to develop plans and to conduct the necessary research on the fisheries of the Passamaquoddy region.

A Joint Engineering and Fisheries Committee of the Engineering and Fisheries Boards was set up in accordance with directions from the International Joint Commission dated October 4, 1957. That Committee established an appropriate and practicable line of demarcation between the work of the two boards and outlined the methods of measuring benefits and damages in matters of common interest to the fisheries and engineering investigations.

Referral of Reports of the Engineering Board and Fisheries Board to Interested Parties for Review and Comment

On November 13, 1959, the International Joint Commission issued a public notice stating that the comprehensive technical investigations and studies necessary for the preparation of the Commission's report were completed, and that the final reports of the two boards had been formally presented to the Commission. In order to obtain the views of interested parties prior to formulation of the Commission's report and recommendations to the two Governments, the Commission made the reports of the Boards available for examination at convenient places in both countries. In addition, copies of the report were sent to the Maine delegation in the United States Congress; the New Brunswick members of the Canadian Parliament; interested agencies of each Government; State, Provincial, and local governments and officials concerned; and others.

In response to the Commission's public notice inviting comments on the reports of the Boards, numerous communications were received. Most of these communications favoured the tidal power project in principle but dealt only in very general terms with the details of the Board's reports.

Commission Hearing on Findings of Engineering and Fisheries Boards Reports

On April 22, 1960, the International Joint Commission conducted a public hearing in the Calais Memorial High School, Calais, Maine, for the purpose of receiving testimony and evidence bearing on the findings and conclusions set forth in the reports of the International Passamaquoddy Engineering Board and the International Passamaquoddy Fisheries Board.

The Calais hearing was attended by a total of about 200 persons from the United States and Canada, including a representative of the United States Congress, the Governor of the State of Maine, representatives of Federal, State, Provincial, County, and Municipal agencies, local civic groups, and other interested individuals. Twenty-nine persons presented briefs or oral testimony at the hearing. About two-thirds of these were favourably inclined toward the tidal power project. In addition to the testimony presented at the hearing, several communications commenting on the tidal power project were received by the Commission and included in the record of the hearing. These communications, for the most part, were favourable to the tidal power project. The views expressed at the hearing are covered more fully in the section dealing with the public hearing.

REPORT OF THE ENGINEERING BOARD

Scope of the Survey

The report of the International Passamaquoddy Engineering Board sets forth the results of a comprehensive survey to determine the engineering and economic feasibility of developing the international tidal power potential of Passamaquoddy Bay in Maine and New Brunswick and the effects which such a project might have on the local and national economies in the United States and Canada. It includes within its scope the results of investigations of the following subjects: the engineering and economic aspects of the tidal project by itself; the engineering and economic aspects of the tidal project combined with an auxiliary source of power supply to supplement the varying output of the tidal power plant; the market for and value of the power from the tidal power project with and without an auxiliary; and the possible beneficial and damaging effects that construction of the tidal project may have on the regional and national economies.

Field Investigations

In order to formulate the best plan of development for the tidal power project, it was necessary for the Engineering Board to conduct a series of field investigations and studies of site conditions in the Passamaquoddy-Cobscook Bay area. These investigations included aerial mapping, deep and shallow water drilling, land drilling, underwater mapping, analysis of soils, and tide gauging. Core drilling in great water depths and high tidal velocities and underwater mapping by newly developed sonic equipment constituted two of the most costly and difficult undertakings of the survey. Highly specialized sonic equipment was utilized to chart the bottoms of the bays and determine depths of overburden.

The Selected Tidal Power Project

In order to determine the most efficient arrangement of works for the tidal power project, estimates were made by the Engineering Board to determine the average annual energy available and the construction cost of a considerable number of alternative arrangements. Since the time required for manual computation of the annual energy output of each of the numerous possible project arrangements was prohibitive, these computations were performed electronically by digital computer. In this way, annual energy generation could be determined for any project arrangement, once its pool areas, number of generating units, and number of filling and emptying gates were established. The project arrangement that revealed the best relationship of power output to cost was selected for detailed design.

The project arrangement thus selected for design includes the 101 square miles of Passamaquoddy Bay as the high pool and the 41 square miles of Cobscook Bay as the low pool, with a powerhouse located at Carryingplace Cove. The location of the tidal power project is shown on Plate 1 and the general arrangement of the selected plan of development is shown on Plate 2.

The selected plan would provide an installed generating capacity of 300,000 kilowatts, a dependable capacity of 95,000 kilowatts, and an average annual generation of about 1,843 million kilowatt-hours.

Components of the Project Selected for Detailed Design

With the major aspects of the project layout determined, design studies were undertaken by the Engineering Board of each component of the selected plan - tidal dams and cofferdams, filling and emptying gates, navigation locks, powerhouse, turbines, and generators - in sufficient detail to permit reliable cost estimates.

The 35,700 linear feet of tidal dams are located as far as practicable on foundations of bedrock or granular material to avoid clay overburden. The tidal dams, composed of clay core supported by flanking dumped-rock fills, are designed to permit greatest possible use of materials excavated for the gate structures, navigation locks and the powerhouse.

Cofferdams of several different types, depending on the depths to be unwatered, would be used to excavate for the foundations of the powerhouse, filling and emptying gates, and navigation locks. Cofferdam designs include embankments, log cribs with timber sheathing, and steel sheet piling of both circular and cloverleaf design.

The selected plan calls for 90 filling gates, 40 in Letite Passage and 50 between Western Passage and Indian River. In the reach between Pope and Green Islets 70 emptying gates, similar to the filling gates but set at a lower elevation, would empty the lower pool. Comprehensive study of all types of gates led to selection of a 30' x 30' vertical lift gate set in a venturi throat. The venturi throat permits maximum discharge for a given gate area.

Four navigation locks are planned for the selected tidal project. Two locks, one at Little Letite Passage and one at Quoddy Roads, would have clear dimensions of 95' x 25' x 12' to pass fishing vessels. Two locks, one at Head Harbour Passage immediately east of the emptying gates and one at Western Passage north of Eastport, would have clear dimensions of 415' x 60' x 21' to pass vessels somewhat larger than the present traffic.

The powerhouse would be of the outdoor type and would contain 30 generating units of 10,000 kilowatts rated capacity each with an overload of 15 percent. The turbines selected for the project are the fixed-blade propeller type with a maximum diameter of 320 inches and a speed of 40 revolutions per minute. The generators would be connected in banks of 7 and 8 to four 90,000 kilovolt-ampere transformers located on the upstream side of the powerhouse and connected to the switchyard by oil-filled high voltage cables. Two transformers would operate at 230 kilovolts for supply to the United States and two at 138 kilovolts for Canada.

A comparison of the performance of fixed-blade and Kaplan turbines indicated that the greater efficiency of the Kaplan turbine over a wide range of heads was offset by its greater cost. A new type of horizontal-axis, bulb-type turbine-generator unit recently developed in Europe and adopted for use in the single-pool tidal project in LaRance Estuary on the northwest coast of France was also studied by the Engineering Board for possible use in the Passamaquoddy project. This unit can be used as a turbine, pump, or sluiceway, with flow in either direction. Studies by the Board showed that the bulb-type turbine-generator develops approximately as much power as the Kaplan, and structural studies indicated that the powerhouse structure would cost about $300,000 less per unit than with conventional units. This saving, however, was off-set by the greater cost of the bulb-type turbine-generator set and the need to compensate for low rotative inertia. For these reasons, and because of unresolved maintenance problems, the Board adopted the conventional fixed-blade type unit for cost estimates of the Passamaquoddy project.

Auxiliary Power Sources Considered

In order to supplement the varying output of the tidal power project, the Engineering Board considered several different types of auxiliary power sources to determine the type best suited for meeting the power loads of the region. These studies included river hydroelectric plants, pumped-storage plants, and steam-electric auxiliaries.

Among a number of river hydroelectric sites examined, Rankin Rapids on the upper Saint John River in Maine, was selected by the Board as the best source of auxiliary power. The Rankin Rapids project would provide 2.8 million acre-feet of usable storage capacity. Operated in conjunction with the tidal plant, the combined project would provide 555,000 kilowatts of dependable capacity and 3,063 million kilowatt-hours of average annual generation.

As a possible alternative plan of development, Rankin Rapids could be constructed, initially, to carry part of the load in Maine, with provision for later installation of additional generating capacity which could be used as an auxiliary power supply for the tidal project. Energy thus borrowed from the Rankin Rapids project when using the "incremental capacity" would be repaid when tidal output is greater than the load. This combination would provide 355,000 kilowatts of

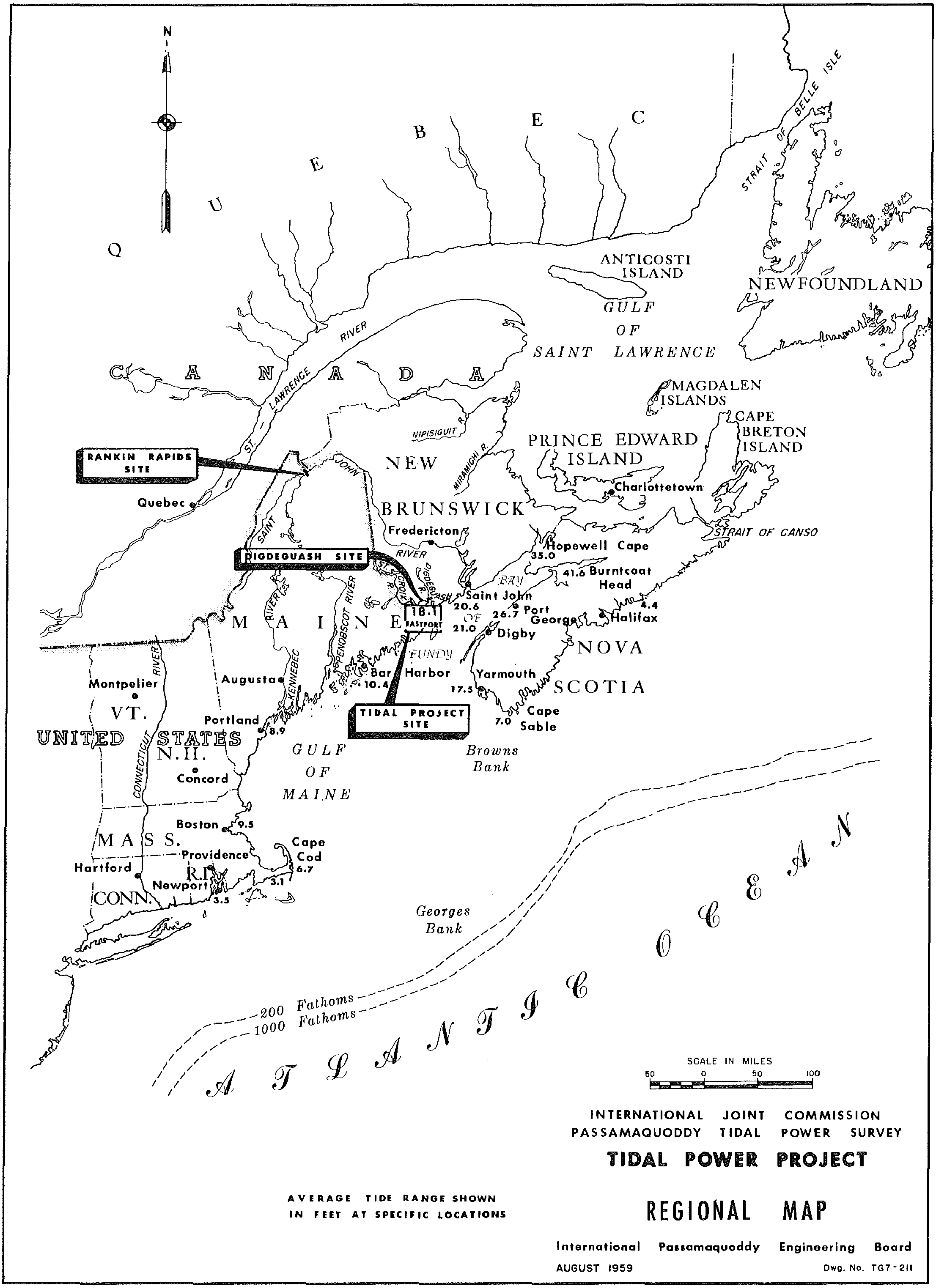

N
Q U E B E C
C A N A D A
ST. LAWRENCE RIVER
ANTICOSTI ISLAND
NEWFOUNDLAND
STRAIT OF BELLE ISLE
GULF OF SAINT LAWRENCE
MAGDALEN ISLANDS
CAPE BRETON ISLAND
PRINCE EDWARD ISLAND
Charlottetown
RANKIN RAPIDS SITE
Quebec
NIPISIGUIT R.
MIRAMICHI R.
NEW BRUNSWICK
Fredericton
SAINT JOHN RIVER
DIGDEGUASH SITE
ST. CROIX R.
DIGDEGUASH R.
STRAIT OF CANSO
Hopewell Cape 35.0
41.6 Burntcoat Head
Saint John
20.6
26.7
21.0
Port George
4.4 Halifax
Digby
18.1 EASTPORT
BAY OF FUNDY
NOVA SCOTIA
M A I N E
PENOBSCOT RIVER
KENNEBEC RIVER
Bar Harbor 10.4
Yarmouth
17.5
Cape Sable 7.0
TIDAL PROJECT SITE
Augusta
Montpelier
VT.
CONNECTICUT RIVER
Portland 8.9
UNITED STATES
N.H.
Concord
GULF OF MAINE
Browns Bank
Boston 9.5
MASS.
Providence
Cape Cod 6.7
Hartford
R.I.
Newport 3.5
3.1
CONN.
Georges Bank
200 Fathoms
1000 Fathoms
ATLANTIC OCEAN
SCALE IN MILES
50 0 50 100
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
REGIONAL MAP
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-211
AVERAGE TIDE RANGE SHOWN IN FEET AT SPECIFIC LOCATIONS

PLATE 1

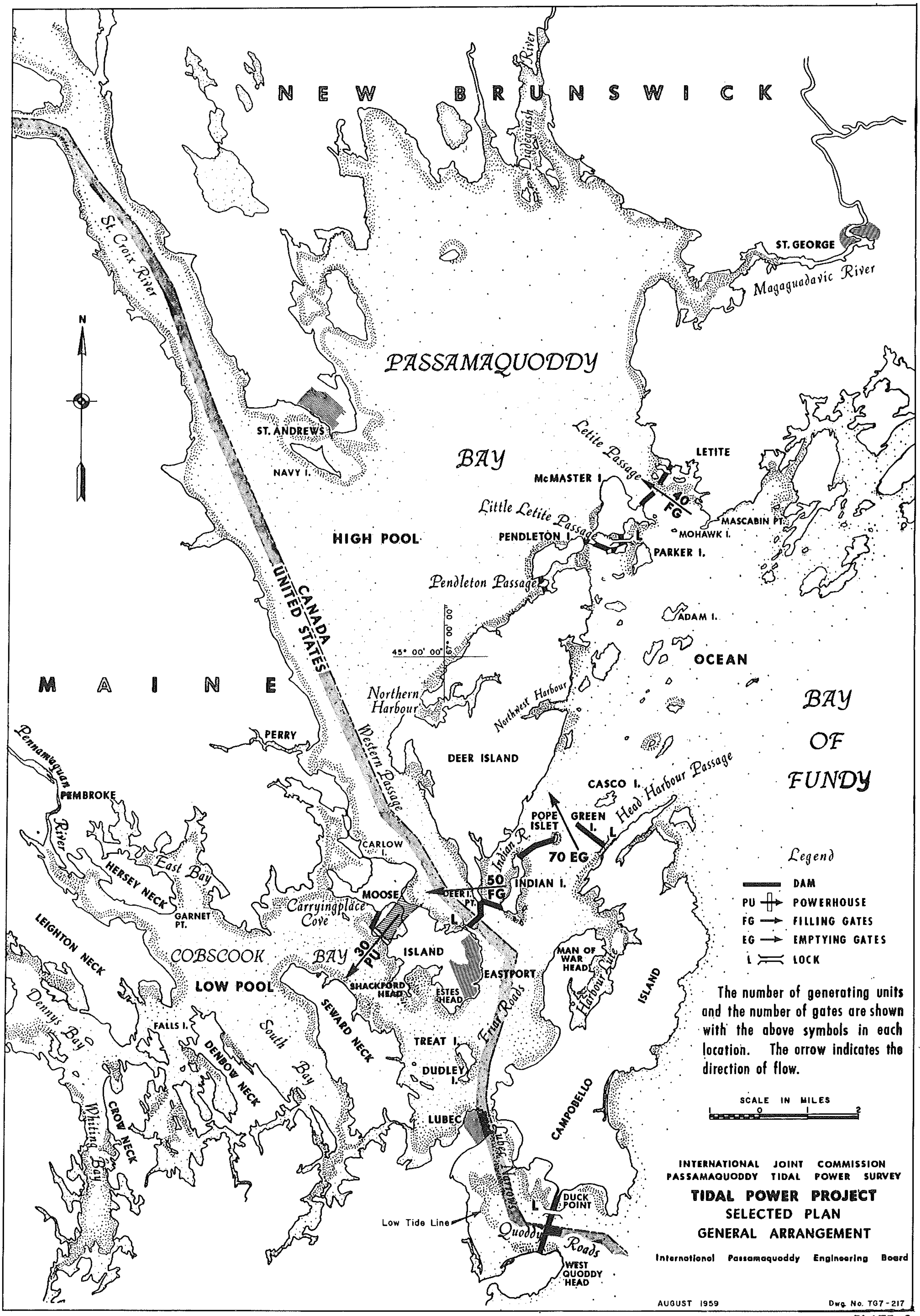

NEW BRUNSWICK
MAINE
PASSAMAQUODDY
BAY
HIGH POOL
LOW POOL
COBSCOOK BAY
BAY OF FUNDY
OCEAN
St. Croix River
Digdeguash River
Magaguadavic River
ST. GEORGE
ST. ANDREWS
NAVY I.
LETITE
Letite Passage
McMASTER I.
40 FG
Little Letite Passage
PENDLETON I.
MASCABIN PT.
MOHAWK I.
PARKER I.
Pendleton Passage
ADAM I.
45° 00' 00"
67° 00' 00"
CANADA
UNITED STATES
Northern Harbour
Northwest Harbour
Western Passage
DEER ISLAND
PERRY
Pennamaquan River
PEMBROKE
CASCO I.
Head Harbour Passage
POPE ISLET
GREEN I.
70 EG
Indian R.
INDIAN I.
50 FG
DEER I. PT.
CARLOW I.
MOOSE
ISLAND
30 PU
East Bay
HERSEY NECK
GARNET PT.
Carryingplace Cove
LEIGHTON NECK
EASTPORT
MAN OF WAR HEAD
Harbour Cove
ISLAND
SHACKFORD HEAD
ESTES HEAD
SEWARD NECK
Friar Roads
Dennys Bay
FALLS I.
DENBOW NECK
South Bay
TREAT I.
DUDLEY I.
CROW NECK
Whiting Bay
LUBEC
Lubec Narrows
CAMPOBELLO
DUCK POINT
Low Tide Line
Quoddy Roads
WEST QUODDY HEAD
N
Legend
DAM
PU POWERHOUSE
FG FILLING GATES
EG EMPTYING GATES
L LOCK
The number of generating units and the number of gates are shown with the above symbols in each location. The orrow indicates the direction of flow.
SCALE IN MILES
1 0 1 2
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
SELECTED PLAN
GENERAL ARRANGEMENT
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-217

PLATE 2

dependable capacity and 1,843 million kilowatt-hours of average annual generation without a serious effect on the basic Rankin Rapids project (200,000 KW and 1,220 million KWHrs).

Tidal power also could be supplemented by means of a pumped-storage plant. Using power from the tidal plant at times when it is not required to meet load demands, water could be pumped to a higher storage basin and released through turbines as required to meet the load. Since the output of the tidal plant alone would vary from 95,000 to 345,000 kilowatts, a pumped-storage plant with 260,000 kilowatts of installed capacity would provide a dependable capacity of 323,000 kilowatts from the combined project. The average annual generation would be 1,759 million kilowatt-hours. A pumped-storage site on the Digdeguash River near its outlet into Passamaquoddy Bay east of St. Andrews was adopted by the Engineering Board for detailed study.

A steam-electric plant also could be used to firm the potential power output of the tidal plant up to its rated capacity of 300,000 kilowatts. Since the tidal plant would have a dependable capacity of 95,000 kilowatts, a steam-electric plant would need to supply a maximum of 205,000 kilowatts. This combination would provide about 2,143 million kilowatt-hours of electric energy annually. Since a steam-electric plant was found to be economically the least favourable type of auxiliary for the tidal power project, this combination was not considered further by the Engineering Board.

In summary, four project combinations were selected by the Engineering Board for evaluation of costs and benefits. These are: (1) the Passamaquoddy tidal project alone; (2) the tidal project operated in combination with all the Rankin Rapids project; (3) the tidal project supplemented by incremental capacity only at Rankin Rapids; and (4) the tidal project supplemented by the Digdequash pumped-storage auxiliary. Pertinent data for these four project combinations, as determined by the Board, are summarized as follows:

Project Combination	Installed Capacity (1000 KW)	Dependable Capacity (1000 KW)	Average Annual Generation (Billion KWH)	Capital Investment (At Site) (Millions of Dollars)	Capital Investment (Including Transmission To Market) (Millions of Dollars)
(1) Tidal Project Alone	300	95	1.843	532.1	546.8
(2) Tidal Project and All of Rankin Rapids	700	555	3.063	687.7	732.1
(3) Tidal Project and Incremental Capacity only at Rankin Rapids	526	355	1.843	565.7	600.0
(4) Tidal Project and Digdeguash Pumped-Storage Storage Project	560	323	1.759	568.9	586.4

The Board concluded that the second of the above combinations, the tidal project and all of Rankin Rapids, would provide the most favourable project.

Conclusions of the Engineering Board

On the basis of its comprehensive studies, the International Passamaquoddy Engineering Board reached the following conclusions:

(1) A tidal power project using the waters of Passamaquoddy and Cobscook Bays can be built and operated. The two-pool type of project is best suited for the site conditions in the area and the power markets it would serve. The tidal project arrangement selected makes best use of the site conditions.

(2) The first cost (construction cost) of the tidal power project by itself would be $484 million. With interest during construction, the investment would be $532. 1 million. The tidal power project would have an installed capacity of 300,000 kilowatts and a dependable capacity of 95,000 kilowatts. Average annual energy would be 1,843 million kilowatt-hours. However, for maximum power benefits, the tidal power project would have to be combined with an auxiliary power source.

(3) The most favorable project combination is the tidal power project operated in conjunction with a river hydroelectric auxiliary built at the Rankin Rapids site on the upper Saint John River in Maine. The combined cost of the tidal project and the Rankin Rapids auxiliary is $630 million. With interest during construction, the investment would be $687. 7 million. The dependable capacity of this combination would be 555,000 kilowatts, and average annual generation would be 3,063 million kilowatt-hours.

(4) Construction of the tidal project - Rankin Rapids combination would increase low flows in the lower Saint John River by a considerable amount, thus increasing substantially the usefulness of the river for downstream generation of power. Downstream benefits accruing to existing power plants were included in the economic evaluation.

(5) The combination of the tidal power project and the installation and use of 260,000 kilowatts of capacity only at Rankin Rapids for firming up the output of the tidal power project would cost $515. 5 million. With interest during construction, the investment would be $565. 7 million. This combination would provide a total dependable capacity of 355,000 kilowatts and an average annual generation of 1,843 million kilowatt-hours.

(6) The tidal power project and the Digdeguash pumped-storage auxiliary would cost $518. 5 million. With interest during construction, the investment would be $568. 9 million. The dependable capacity would be 323,000 kilowatts, and average annual generation would be 1,759 million kilowatt-hours.

(7) The total output from the tidal power project and Rankin Rapids hydroelectric plant can be absorbed readily by the growing utility markets of Maine and New Brunswick.

(8) Because of differences in interest rates prevailing in the two countries, and because of different values of alternative power, it was necessary to compute separate benefit-cost ratios for United States and Canada. Economic evaluations, assuming 50-year and 75-year amortization periods, and assuming that power output and project first cost would be equally divided between the United States and Canada, are tabulated below:

	50-Year Amortization		75-Year Amortization	
	Benefit Cost Ratio	Cost per KW. -Hr., (Mills)	Benefit Cost Ratio	Cost per KW-Hr., (Mills)
Tidal Project Alone				
United States	0.60	10.8	0.70	9.3
Canada	0.34	14.9	0.37	13.7
Tidal Project and All of Rankin Rapids				
United States	1.31	8.4	1.53	7.2
Canada	0.58	11.5	0.63	10.6
Tidal Project and Incremental Capacity only at Rankin Rapids				
United States	0.93	11.5	1.08	9.9
Canada	0.42	15.8	0.45	14.5
Tidal Project and Digdeguash Pumped-Storage Auxiliary				
United States	0.91	12.2	1.06	10.5
Canada	0.42	16.8	0.46	15.4

(9) The inclusion of taxes foregone with project costs is not the practice in the economic justification of public projects in Canada, and due to the international nature of the project, such taxes have not been applied to United States' costs. However, if they were included in the United States' costs, the benefit to cost ratio of the most favourable project combination would be reduced to 1.10 for the 50-year amortization period and to 1.25 for the 75-year period.

(10) By including appropriate remedial measures in the design of the tidal power structures, the construction, maintenance and operation of the tidal power project would have only a minor residual effect on the fisheries of the region.

(11) Considerable annual recreation benefits would grow out of the construction and operation of the tidal power project. However, the monetary value of these benefits was not included in the economic evaluation.

(12) Assuming an equal division of power output and of first costs between United States and Canada, construction of the tidal power project with all of Rankin Rapids as auxiliary is not an economically justified project for Canada.

(13) The Passamaquoddy tidal project and Rankin Rapids combination, if built entirely by the United States at an interest rate of 2-1/2 percent, is economically justified.

REPORT OF THE FISHERIES BOARD

Scope of the Fisheries Investigation

The investigations of the Fisheries Board were directed primarily toward determination of the effect the tidal power project might have on the fisheries of the area. Consideration was given not only to the sardine industry which accounts for most of the landings in the area, but also to the fisheries for cod, haddock, flounder, redfish, hake, pollock, salmon, alewives, clam, smelt, scallops, and lobsters. The Board's report presents results of: studies of the present oceanographic, biologic, and economic features of the area; investigations pertaining to temperature, salinity, tides and tidal currents in the Bays, in the approaches, and outside the Bays; and biological studies of fish populations, breeding grounds, nursery areas, food and feeding habits and interrelationship of fish and their environment.

Conclusions of the Fisheries Board

On the basis of its studies, the Fisheries Board reached the following conclusions:

1. The construction of dams in the tidal passages will change the oceanographic features of the Quoddy Region. Major changes are anticipated inside Passamaquoddy and Cobscook Bays and immediately outside the dams. Effects outside the Head Harbour-Bliss Island line will likely be insignificant.

2. The mean water level of Passamaquoddy Bay will be raised about 6 feet while the mean level of Cobscook Bay will be lowered about 5 feet. The mean "tidal" range in the high pool and low pool will be reduced to approximately 4 feet and 8 feet respectively. The tidal range of the Bay of Fundy may increase approximately one percent with a maximum increase at the head of this Bay of less than one foot.

3. Current patterns in Passamaquoddy and Cobscook Bays and in the approaches will be altered markedly since the emptying and filling gates will be closed for about 9 and 9-1/2 hours respectively during each tidal cycle of 12-1/2 hours. When the gates are open, velocities in most areas should be only slightly lower than at present. The residual counterclockwise circulation in Passamaquoddy Bay will likely be more pronounced. Tidal streams in the outer Quoddy Region will probably be altered by not more than 20 percent. No change in non-tidal circulation is anticipated for the Bay of Fundy.

4. Reduced velocities in Passamaquoddy and Cobscook Bays will result in decreased vertical mixing, giving rise to increased stratification and hence to greater seasonal variations in surface water temperature. The summer maximum is likely to be in the vicinity of 68 degrees Fahrenheit while in winter an ice cover is expected over part of the Bays. Outside, little change is expected adjacent to the emptying and filling gates where there will be a slightly greater seasonal variation.

5. Mean surface salinities for both pools will be lowered but bottom salinities are likely to be altered only slightly. It is doubtful if fresh water will penetrate below 30 to 50 feet. Flushing time is expected to increase substantially. Outside, no significant change is expected except near the emptying gates where there will be a slight reduction in salinity.

6. Oxygen concentrations of the deep water inside the dams may be lowered somewhat, especially during periods of maximum fresh water discharge. However, it is unlikely to fall below 50 percent saturation.

7. The herring population is produced outside the Quoddy Region, probably off southwest Nova Scotia. The general abundance of herring in the Bay of Fundy and the Gulf of Maine is unlikely to be affected.

8. Echo-sounder records show that a large proportion of herring are in the open waters of Passamaquoddy Bay where no fishing takes place. Tagging experiments show that herring move freely throughout the Quoddy Region during the fishing season.

9 Since there are unlikely to be any significant changes in oceanographic conditions outside the dams, herring should arrive in this area as before. Little change is expected in current velocities in the approaches to the filling gates when open. Since velocities are well above the maximum sustained swimming speed of herring, the fish will be carried through the filling gates. Since the filling gates are open for about 6 hours each day, movement of herring into Passamaquoddy Bay is expected to be delayed. This is also true for Cobscook Bay where entry will be chiefly through turbines. Although the rate at which herring accumulate will be slower, there should be no reduction in over-all abundance inside the Bays.

10. Predicted changes in temperatures and salinities are expected to make the areas inside the dams no less favourable for herring except in isolated areas where high temperatures and low salinities may cause some mortality. Predicted pressures and rates of pressure change between the turbine intakes and exits are within limits which herring can withstand.

11. No relationship between herring landings and various meteorological and oceanographic conditions including surface drift, river discharge, wind speed and direction, zooplankton, temperatures, and salinities is apparent.

12. Long-term statistics of herring landings show year-to-year variations in individual weir catches and in total catches in various parts of the Quoddy Region. These are of far greater magnitude than the changes that can be forecast as resulting from the dams.

13. No measurable change in groundfish landings in the Quoddy Region is anticipated, but a change in species composition of the fraction of the catch taken inside the dams is expected. Inside the dams, winter flounder fisheries may increase while haddock and pollock fisheries will be greatly reduced. Clam fisheries will be greatly reduced for a period of ten years and then may become reestablished at a lower level of production. Scallop stocks should increase substantially. Inside the dams, a modest increase in production of lobsters is anticipated. Conditions for anadromous species such as Atlantic salmon and alewives may be improved. Smelt, shad, and sea-run trout stocks should increase. Striped bass and tom cod thrive in areas where conditions of temperature and salinity are similar to those predicted for Passamaquoddy and Cobscook Bays. Some reduction is expected in the availability of marine worms and rockweed.

14. Six existing herring weir sites will be eliminated by the construction of dams. Other weirs must be relocated or altered to suit the new oceanographic environment. Weir stakes and nets will have to be increased in size to suit new water levels. The resultant fixed costs are estimated at $129,000. Wood borer activity is expected to increase. Ice will cause some damage to weir materials during the winter. The annual cost of weir operations will rise approximately $10,000. It is conceivable that weir owners may discontinue their investments in weirs inside the dams. A shift to alternative methods of fishing could be expected to maintain the fishery, at least at its present level.

15. Lobster fishermen are not expected to be adversely affected, but physical damages due to relocation of lobster pounds, refrigeration of water, or extension of intake pipes are expected to cost $450,000. Changes in the clam fishery may result in a loss of capital investment in plants valued at $100,000 and an annual loss in primary production of $104,000 for 10 years. The disappearance of some groundfish from inside the dams will result in an annual loss of approximately $3,000.

16. Fish passage facilities for anadromous species were estimated by fisheries engineers to cost $3.0 million.

On completion of the preliminary engineering design, which complied with the criteria set down by the Fisheries Board, the Engineering Board determined that incorporation of the fish passage facilities in the initial design and construction would increase the project costs by only $919,100.

PUBLIC HEARING

Public Hearing at Calais, Maine

On April 22, 1960, the International Joint Commission conducted a public hearing in Calais, Maine, for the purpose of obtaining the views of all parties concerned with the international Passamaquoddy tidal power project.

Many of the witnesses at the hearing urged construction of the Passamaquoddy tidal power project with the Rankin Rapids project as an auxiliary. They stressed that this combination project could be expected to have a favourable impact upon the efforts of Maine and New Brunswick to expand industrially, and that construction and operation of the project would greatly enhance the economy of the region. They asserted that the Rankin Rapids project is the logical source of power for firming the power output of the tidal plant, and that construction of the project would not destroy the Allagash wilderness area in Maine as some alleged. Some proponents expressed the view that recreational patronage accorded the Allagash area in recent years was slim and unprofitable, and that over-all recreational use of the area could be expected to increase with construction of the Rankin Rapids project. Members of the State of Maine's Delegation in the Congress, the Governor of Maine, the Maine Governor's Committee on Passamaquoddy Bay, and representatives of local governments in the region went on record in support of the combination Passamaquoddy-Rankin Rapids project presented in the report of the Passamaquoddy Engineering Board.

On the other hand, several witnesses raised objections to the tidal power project alone and to the tidal project combined with the Rankin Rapids project. A spokesman for privately-owned electric utility companies in New England argued that neither the tidal plant alone nor the tidal plant with an auxiliary is economically feasible. A similar view was expressed by a representative of a Special Committee of Maine Engineers. This Committee included representatives of the Maine section of the American Society of Civil Engineers, the Maine Section of the American Institute of Electrical Engineers* and the Maine Association of Engineers. A spokesman for the New Brunswick Electric Power Commission expressed the view that the tidal power project with or without an auxiliary was not economically justified insofar as Canada is concerned.

Several witnesses from Canada urged further consideration of the Cumberland Basin-Shepody Bay tidal power scheme and of potential developments in the Saint John and Hamilton Rivers with the suggestion that these possibilities should be considered in evaluating future sources of power supply for the region.

Conservationists raised objections to the Rankin Rapids project because of inundation of the Allagash wilderness area. They advocated the alternative Big Rapids-Lincoln School development if this reach of the Saint John River is to be utilized as a source of firming power for the tidal project. This alternative was favoured by the Maine Department of Inland Fisheries, the United States Bureau of Sports Fisheries of the Department of the Interior, and numerous organizations interested in conservation.

Representatives of fishery interests in the Passamaquoddy Bay region expressed concern that their sources of sardine supply might be damaged by construction of the tidal project. They asserted that the risk to the fishery inherent in the development of the tidal power project is so great as to outweigh any indicated benefits to the region. They expressed the hope that the fishing industry would be compensated for any damages that might result from construction of the tidal power project.

---

* - The Acting Secretary-Treasurer of the Maine Section of the American Institute of Electrical Engineers informed the Commission by letter dated May 16, 1960, that the findings of the Special Committee of Maine Engineers do not necessarily represent the opinions of all members of that Section.

PROBLEMS OF PROJECT FORMULATION AND ECONOMIC EVALUATION

The Problem of Tidal Power Production

As indicated previously, tidal power can be produced by passing water from a higher to a lower elevation through hydraulic turbines. Unaffected by droughts, floods, or ice jams, the tides provide a dependable source of power and can be predicted with accuracy. One of the principal disadvantages of tidal power production is that four times a day the tides reverse direction, thus causing variations in available power. Development of a workable method of producing continuous power from such a varying flow constitutes one of the principal problems of formulation of a tidal power project.

The generation of large amounts of tidal power requires one or more storage pools. A single pool has the serious disadvantage of producing varying and intermittent power, because no power can be generated when there is insufficient difference between the level of the storage pool and the level of the ocean. Thus no generation is possible until the ocean has receded sufficiently to obtain this difference in water levels, or the power head; nor is generation possible on the rising tide after the level of the ocean becomes too high to provide this necessary minimum head. This disadvantage is reduced in the two-pool plan adopted by the Engineering Board, which generates varying power but a certain minimum amount of continuous power.

Need for an Auxiliary Source of Power to Supplement the Variable Output of the Tidal Project

Another disadvantage of the tides as a source of power is that the tides, following the gravitational pull of the moon as it passes overhead every 24 hours and 50 minutes, are out of phase with the 24-hour solar day. This 50-minute daily lag is fundamental to the economics of tidal power for, since power output varies with the tides, tidal power is out of step with the normal pattern of power demands. Therefore, unless the tidal plant is supplemented by an auxiliary power plant, such varying power would be of limited value. The different types of auxiliary power sources studied by the Engineering Board to determine the type best suited for making the combined power output of the tidal project and its auxiliary match the characteristic load pattern are discussed on Page 8 of this report.

The Rankin Rapids-Allagash Problem

The Rankin Rapids site is located in Maine downstream from the junction of the Allagash River and the main stem of the Saint John River. Development of this site would flood a series of rapids in the lower reaches of the Allagash River. These rapids are esteemed by many sportsmen for the trout fishing and the white water canoeing they afford although the number of visitors has not been great in recent years. Their flooding by construction of the Rankin Rapids reservoir is strongly opposed by associations and agencies concerned with preservation of recreation and wildlife resources.

An alternative to the Rankin Rapids project was considered by the Engineering Board in order to determine the best means of comprehensive development of the upper St. John River with due consideration to all the uses of the water resources. The alternative would consist of a two-dam project, with a high dam at the Big Rapids site, upstream from the mouth of the Allagash River, and a low dam at the Lincoln School site, a short distance downstream from the Rankin Rapids site. The two-dam plan would greatly reduce the extent of inundation of the lower Allagash River and also mitigate possible losses to fish and wildlife.

The Engineering Board estimated that the Rankin Rapids project would produce 68,000 kilowatts of capacity and 215 million kilowatt-hours a year more than the Big Rapids-Lincoln School project. The Board also estimated that the unit cost of power would be 20 percent more at the Big Rapids-Lincoln School project than at Rankin Rapids. Because of the greater drainage area, usable storage capacity, and regulated outflow, Rankin Rapids would improve conditions for further power development on the downstream Saint John River to a greater extent than the alternative Big Rapids-Lincoln School project. Moreover, the larger installed generating capacity at Rankin Rapids permits greater utilization of the tidal power potential. In view of these findings, the Engineering Board selected the Rankin Rapids project as the river hydro auxiliary for the tidal power project.

Because of the opposition of certain groups in the United States to the development of the Rankin Rapids site, the Engineering Board undertook to secure the views of the Bureau of Sports Fisheries and Wildlife, Fish and Wildlife Service of the United States Department of the Interior. The Bureau stated that the Rankin Rapids project would injure the fish and wildlife assets of the area more than the Big Rapids-Lincoln School combination. It recommended a series of measures for the protection of the fish and wildlife resources of the area regardless of the auxiliary project selected. The measures recommended by the Bureau are as follows:

(1) Establishment of a framework for management of fish and wildlife resources.

(2) Provision of public access.

(3) Purchase of additional lands for wildlife management purposes.

(4) Modification of land clearing plans.

(5) Construction of barrier dams.

(6) Provision for minimum flows as required to benefit downstream fisheries.

(7) Provision for a fish hatchery and rearing facilities.

(8) Management of tributary streams.

(9) Sub-impoundments for waterfowl within reservoir maximum flow line.

(10) Control of reservoir pool elevations and provisions for spawning beds.

(11) Control of release temperatures.

Consideration should be given to all the measures listed above if construction of either the Rankin Rapids or Big Rapids-Lincoln School auxiliary is undertaken.

Disparity of Interest Rates and Other Economic Factors Between the United States and Canada

For the purpose of selecting the most favourable tidal project plan, the Engineering Board compared the ratios of construction cost to average annual generation for the various possible plans considered. Estimates of the capital costs of the tidal project combinations made by the Engineering Board were based on United States currency and January 1958 price levels.

In computing the annual costs of project plans, it was found that there are differences between the two countries in interest rates and other economic factors. In the United States, projects such as this are assumed to be financed by the federal government. Thus, the Engineering Board computed interest during construction and annual power costs for the United States portion of development using interest at 2-1/2 percent, since that was the rate recommended, at the time of the survey, by the United States Bureau of the Budget for use by federal agencies in evaluating water resource development projects. 1/ For the Canadian share of development, which was assumed to be financed by an agency of the Province of New Brunswick, an interest rate of 4-1/8 percent was used, because that was the rate used in January 1958 by the federal government of Canada on loans to crown corporations and provincial governments. No amount for taxes was included in the annual project costs applicable to either country.

The annual power benefits of the tidal project combinations were measured by the Engineering Board on the basis of the cost of power from modern steam-electric plants in Maine and New Brunswick. In view of the present ownership and predominant type of generating plants of the respective electric

---

1/ On July 26, 1960, the Bureau of the Budget recommended that this rate be increased to 2-5/8 percent.

power systems, it was deemed appropriate to assume that the most likely alternative power supply, in the absence of the tidal project, would be privately-financed steam-electric plants in Maine and publicly-financed plants in New Brunswick. In computing the annual costs of the steam-electric plants in Maine, the Engineering Board used 6.00 percent as the cost of money and included an amount for taxes equal to 4.44 percent of the capital investment. Annual costs of steam-electric plants in New Brunswick were based on an interest rate of 4-1/8 percent and on including no amount for taxes since the public power agency of the Province does not pay taxes.

In view of these disparities in practices, the Engineering Board prepared separate economic analyses showing ratios of benefits-to-costs applicable to each country's share of the development. These analyses assumed that the capital costs and project power would be divided equally between the two countries. In addition to comparing the United States' share of project costs, using interest at 2-1/2 percent and excluding taxes, with the cost of providing equivalent power by steam-electric plants, using cost of money at 6.00 percent and including taxes, the Engineering Board showed benefit-cost ratios for the United States' share with an item of "taxes foregone," amounting to about $9 per kilowatt of dependable capacity, included as an economic cost of the project.

Economic Impact of the Tidal Power Project on the Region

An evaluation was made by the Engineering Board of all possible beneficial and damaging effects that construction of the tidal project, with and without an auxiliary source of power, may have on the regional and national economies. The Board concluded from these studies that the tidal project and its auxiliary would have a favourable impact on all segments of the economy of Maine; and that the effect on the general economy of New Brunswick would be the same as that of any other block of power of equal size and cost developed to satisfy the growing power demand. Power market studies by the Engineering Board indicate that the anticipated load growth in the region will be sufficient to absorb a block of power equal to the output of the tidal plant and its auxiliary by 1980 or earlier.

Construction of the tidal power project would produce an important short-term economic impact on the economy of Maine and New Brunswick. Estimates by the Engineering Board indicate that during the six-year construction period of the tidal project alone, total investment outlays in Maine and New Brunswick would amount to about $200 million. The spending of this money would probably stimulate an additional $200 million expenditure which would have a beneficial effect on the region's wholesale and retail trade.

The Passamaquoddy tidal power project would attract a great many visitors. The Engineering Board estimates that had the tidal project been in existence in 1957, about 800,000 visitors from the United States and Canada would have been attracted to the area. In accordance with a practice that has been followed in some cases by the United States Army Corps of Engineers water resources projects might be credited with recreational benefits ranging from $0.50 to $1.50 per visitor day. Using a median value of $1.00 per day, and assuming that each visitor spends one day at the project, the recreation benefits would be at least $800,000 per year. In addition to recreation benefits, other benefits undoubtedly would result from the increased local economic activities due to a greater number of visitors.

The Passamaquoddy tidal project would require no fuel. On the basis of estimates by the Engineering Board, the tidal project in combination with the Rankin Rapids hydroelectric plant would produce power equivalent to that from 1,280,000 tons of coal, or approximately 5,700,000 barrels of oil a year.

Construction of the dams, locks, and gates would provide foundations on which 7 miles of public highways could be built to connect the Canadian coastal highway in New Brunswick with the United States coastal highway in Maine. Although the desirability of such a new link in the highway systems of the two countries is evident, the monetary benefits have not been estimated. Other benefits stemming from construction of the highway would be the increased recreational use of Campobello and Deer Islands that should follow the provision of a ready access to these attractive areas.

The Passamaquoddy tidal project, the Rankin Rapids project, and the Digdeguash pumped-storage project each would affect the fisheries in the waters they would control. The Fisheries Board studied the effects that the tidal project would have on the fisheries in the Bay of Fundy and within the tidal project in Passamaquoddy and Cobscook Bays. The Board found that the tidal project would have very little effect on the important sardine industry in the region, and only a minor effect on other fisheries. It should be noted that the estimated cost of the tidal project includes approximately $450,000 for modifications in or relocation of the lobster pounds at St. Andrews. The Rankin Rapids project would flood substantial reaches of the Allagash and Saint John Rivers in Maine which now support an important trout fishery, particularly on the Allagash River. Changing portions of the Saint John or Allagash Rivers from fast-water streams to deep hydroelectric project reservoirs would change the type of fish and fishing which would prevail. Other wildlife habitat would also be affected. As indicated previously, the Bureau of Fisheries and Wildlife of the United States Department of the Interior considered the problem and recommended that remedial measures be taken if the project is built. The Digdeguash River now supports a small run of Atlantic salmon which would be destroyed by construction of the pumped-storage auxiliary. Methods of restoring this run were not determined.

The firm of Arthur D. Little, Inc. of Cambridge, Massachusetts, was engaged by the Engineering Board to make an economic survey of Maine to determine all possible potential uses for the power from the Passamaquoddy project. One of the principal aims of this survey was to identify industries that might be attracted to the area by the availability of a new source of dependable power at a price they would be willing to pay. These studies indicated that the economic impact of the availability of the project's power would not be significant unless power were made available to industry at a cost considerably less than the current estimate of the cost of power from the project. The firm of Arthur D. Little, Inc. concluded that the course of economic development in the State of Maine as a whole would not be significantly affected by construction of the tidal project.

A similar economic survey of New Brunswick was made by Professor Eugene Grasberg and Professor H. J. Whalen of the Department of Economics of the University of New Brunswick. This survey indicated that the mere availability of electric power from the Passamaquoddy project cannot be expected to spark and propel economic growth in New Brunswick.

FEASIBILITY OF THE PASSAMAQUODDY TIDAL POWER PROJECT AS VIEWED BY THE COMMISSION

The Commission has carefully reviewed the conclusions of the Engineering Board with respect to the engineering and economic feasibility of developing the international tidal power potential of Passamaquoddy Bay and the findings on which these conclusions are based. The Commission is in general agreement with the engineering findings of the Engineering Board. However, as regards the economic analysis, the Commission considers it appropriate to modify certain of the Board's assumptions in considering the tidal project alone and in conjunction with auxiliary power sources in the area.

The feasibility of the Passamaquoddy tidal power project as viewed by the Commission in the light of the findings of the Engineering Board will be discussed in this section, first from the standpoint of its engineering feasibility and secondly its economic feasibility. The economic analysis of the tidal power project alone and of each of the project combinations studied by the Board will be discussed separately with particular attention given to points on which the Commission differs from the Board in the determination of benefit-cost ratios. The unit cost of power also will be developed to show the relative cost of Passamaquoddy power either alone or with an auxiliary source compared with the cost of power from alternative steam-electric plants that are likely to be constructed in the absence of the project.

To assist the two Governments in appraising certain public values of the tidal project beyond those normally considered in determination of benefit-cost ratios for proposed hydroelectric developments, the Commission will, in concluding its feasibility analysis, discuss the effect that consideration of these values might have on the economics of the project.

Engineering Feasibility

The tidal project plan selected by the Engineering Board poses difficult engineering problems which, although challenging, are not insurmountable. Small portions of the tidal dams are in water depths ranging from 125 to 300 feet. The difficulties of closing these dams in the face of restricted and greatly increased velocity heads pose engineering and design problems without precedent. In view of these problems, several outstanding experts in the fields of hydraulic engineering and soil mechanics were consulted by the Engineering Board and model studies were made of deep tidal dams to determine the best and most economical design and methods of construction. The Board concluded from these studies that tidal dams could be built in the deep water passages by use of a granular core placed by special bottom-dump buckets, and that all other tidal dams could be built with conventional land and marine equipment. To overcome the increased tidal velocities during construction, the progress of work on the dams could be scheduled so that the filling and emptying gates would handle part of the tidal ebb and flood.

The cofferdams required for construction of the filling and emptying gates, as well as for navigation locks and the powerhouse, would be subjected to heads as high as 60 feet, whereas the heads on the completed structures would not exceed 26 feet. Construction of cofferdams of this magnitude constitutes one of the major engineering and construction tasks of the Passamaquoddy tidal power project. While they will be expensive, there appear to be no grounds for apprehension that these cofferdams cannot be built.

Based on its review of the studies by its Engineering Board, the Commission is of the opinion that a tidal power project using the waters of Passamaquoddy and Cobscook Bays could be built and operated.

Economic Analysis

Determination of the economic feasibility of a proposed hydroelectric development, whether in a conventional river project or a tidal project, involves a comparison of the value of the power, or power benefits, with the power costs. Normally, a proposed power development is not considered to be economically feasible if the benefit-cost ratio is less than 1.0.

Power benefits are usually measured by or limited in value by the cost of power from the most likely alternative source in the market area, giving due consideration to any differences in transmission costs and losses and in operating characteristics between the alternative plant and the proposed hydroelectric project. In the Maine and New Brunswick area, as well as in many other areas of the United States and Canada, the alternative power source is considered to be a modern steam-electric plant. It is considered also that such an alternative plant in Maine would be privately financed, and in New Brunswick publicly financed, consistent with the present and expected future practice in these two areas.

In analyzing the economic feasibility of the several tidal project combinations considered by the Engineering Board, the Commission has assumed that the capital costs and the project power would be divided equally between the two countries.

The annual cost of power assigned to the United States is determined on the basis of federal financing, assuming an interest rate of 2-1/2 percent and an amortization period of 50 years. "Taxes foregone", defined as the amount of taxes which would not be collected as a result of a federal power development rather than the most likely alternative development, are included in the hydroelectric power costs in an amount approximately equal to the taxes included in the estimated steam-electric power costs used in deriving power benefits. Such inclusion places the United States costs of the tidal project combinations and of alternative steam-electric plants on a comparable basis for purposes of economic analysis. The above criteria are in accord with those used by federal agencies in the United States concerned with water resource development.

The annual cost of power assigned to Canada is determined on the basis of non-federal public financing, assuming an interest rate of 4-1/8 percent and an amortization period of 50 years. No tax item is included in the hydroelectric power costs since none would be paid on alternative steam-electric plants. These criteria are in accord with the practice in New Brunswick.

As indicated in the foregoing, there are differences between United States and Canadian practices in deriving both the annual power values and annual power costs. For this reason, it is necessary to compute separate benefit-cost ratios for the two countries, each applicable to that country's share of the project power. The over-all economic feasibility of the tidal project combinations, United States and Canada, may be determined by comparing the total benefits and costs of the combinations.

Under the conditions and criteria discussed above, and on the basis of information in the Engineering Board's report, the Commission has considered the economic feasibility of the tidal project alone and in combination with the several sources of firming power studied by the Board. The results of this economic analysis are discussed in the following paragraphs and summarized in Table 1.

Tidal Project Alone

This project would have an installed capacity of 300,000 kilowatts, of which 95,000 kilowatts would be dependable. Average annual generation would amount to 1,843 million kilowatt-hours. The project investment, including transmission, would be $546,800,000.

For the United States, the annual power benefits would amount to $5,977,000 and the annual power costs $10,343,000, resulting in a benefit-cost ratio of 0.58. For Canada, the annual power benefits would be $4,663,000, the annual power costs $13,665,000, and the benefit-cost ratio 0.34. For the entire project, United States and Canada, the benefit cost ratio would be 0.44.

Studies by the Engineering Board, based on somewhat different economic assumptions, also failed to provide a ratio of unity.

TABLE 1

POWER AND ECONOMIC DATA AS DERIVED BY THE INTERNATIONAL JOINT COMMISSION

		Tidal Project Alone	Tidal Project and Steam-Electric Plant	Tidal Project and Digdeguash Pumped-Storage	Tidal Project and Incremental Capacity only at Rankin Rapids	Tidal Project and all of Rankin Rapids
Power Data (Entire Project)						
Installed Capacity						
Tidal Project	1,000 KW	300	300	300	300	300
Auxiliary	1,000 KW	---	220	260	226	400
Dependable Capacity	1,000 KW	95	300	323	355	555
Avg. Annual Generation,	Million Kwh	1,843	2,143	1,759	1,843	3,063
Economic Data (United States Half of Project)						
Capital Investment	Million Dollars	271.6	297.5	292.6	300.5	367.6
Annual Power Benefits	" "	5.977	10.365	9.719	9.779	16.782
Annual Power Costs	" "	10.343	13.615	12.134	12.154	15.302
Benefit-Cost Ratio		0.58	0.76	0.80	0.80	1.10
Economic Data (Canadian Half of Project)						
Capital Investment	Million Dollars	275.2	297.6	293.8	299.5	364.5
Annual Power Benefits	" "	4.663	6.900	6.177	6.043	10.235
Annual Power Costs	" "	13.665	16.014	14.669	14.527	17.610
Benefit-Cost Ratio		0.34	0.42	0.42	0.42	0.58
Economic Data (Entire Project)						
Capital Investment	Million Dollars	546.8	595.1	586.4	600.0	732.1
Annual Power Benefits	" "	10.640	17.265	15.896	15.822	27.017
Annual Power Costs	" "	24.008	29.629	26.803	26.681	32.912
Benefit-Cost Ratio		0.44	0.58	0.59	0.59	0.82

Notes: Capital investment includes cost of transmission lines.
Benefit-cost ratios are determined at the project sites, with appropriate allowance for transmission costs.

It is evident that construction of the tidal power project by itself is economically infeasible by a wide margin.

Tidal Project Combined with Steam-Electric Capacity

Under this plan, the 300,000 kilowatts installed capacity at the tidal project is assumed to be combined with 220,000 kilowatts of steam-electric capacity to provide a total dependable capacity of 300,000 kilowatts. The average annual generation would amount to about 2,143 million kilowatt-hours. The project investment would be $595,100,000.

For the United States, the annual benefits would amount to $10,365,000, the annual costs $13,615,000, and the benefit-cost ratio 0.76. For Canada, the annual benefits and costs would amount to $6,900,000 and $16,014,000 respectively, and the benefit-cost ratio 0.42. For the entire project, United States and Canada, the benefit-cost ratio would be 0.58. None of the studies using less rigorous criteria resulted in a ratio as high as unity.

Tidal Project Combined with Digdeguash Pumped-Storage Project

The installed capacity of this combination project would be 560,000 kilowatts, of which 323,000 kilowatts would be dependable. Average annual generation would amount to 1,759 million kilowatt-hours. The total project investment, including transmission, would be $586,400,000.

For the United States, the annual power benefits would total $9,719,000 and the annual power costs $12,134,000, giving a benefit-cost ratio of 0.80. For Canada, the annual power benefits and costs would amount to $6,177,000 and $14,669,000, respectively, and the benefit-cost ratio 0.42. For the entire project, United States and Canada, the benefit-cost ratio would be 0.59.

The only favourable benefit-cost ratio (1.06) derived in the Engineering Board's studies in this combination was for the United States' share of the power, assuming a 75-year amortization period and excluding taxes foregone from project costs.

The Commission is of the opinion that the Digdeguash pumped-storage project could be used as a realistic auxiliary to the tidal power project, and that the combination of the two in a single economic analysis is sound in principle. Combined with the tidal project, the Digdeguash pumped-storage project could utilize off-peak power from the tidal plant to pump water from Passamaquoddy Bay to the reservoir. However, power from the tidal project combined with the Digdeguash pumped-storage project would be more costly than power from available alternative sources.

Tidal Project Combined with Incremental Capacity at Rankin Rapids

The concept of using incremental capacity only at Rankin Rapids as an auxiliary to the tidal project assumes that the Rankin Rapids site would be developed first with 200,000 kilowatts of dependable capacity to serve loads wholly in the State of Maine. An additional 260,000 kilowatts of dependable capacity (226,000 kilowatts installed) would be provided at this site specifically for firming the tidal project output. The combined dependable capacity of this combination (the tidal project plus 260,000-kilowatt incremental capacity at Rankin Rapids) would be 355,000 kilowatts, capable of generating 1,843 million kilowatt-hours of electric energy annually. Under this combination, when the tidal plant output drops below the load to be carried, the energy deficiency would be borrowed from the basic Rankin Rapids project, using the 260,000-kilowatt incremental dependable capacity provided for this purpose, and repaid when tidal energy exceeds load. Thus, there would be no net energy withdrawal from the basic Rankin Rapids project (200,000 kilowatts and 1,220 million kilowatt-hours). In this way, Rankin Rapids and the tidal project could provide 355,000 kilowatts of dependable power for the load at a 60 percent annual load factor. Accordingly, the Commission believes that "incremental capacity" at Rankin Rapids constitutes a realistic auxiliary to the tidal project, and that the treatment of the combination in a single economic analysis is valid. The project investment, including transmission, would be $600,000,000. Only the incremental cost of the additional (260,000 kilowatts) capacity installation at Rankin Rapids is charged against the combination project.

For the United States, the annual power benefits would amount to $9,779,000, the annual power costs $12,154,000, and the benefit-cost ratio is 0.80. For Canada, the annual power benefits would be $6,043,000, the annual power costs $14,527,000, and the benefit-cost ratio 0.42. For the entire project, United States and Canada, the benefit-cost ratio would be 0.59.

As in the case of the combination with the Digdeguash pumped-storage project, the only favourable benefit-cost ratio for this combination (1.08) in the Engineering Board's studies was that for the United States' share of the power, assuming a 75-year amortization period and excluding taxes foregone from project costs.

Tidal Project Combined with all Rankin Rapids

In this plan, as proposed by the Engineering Board, 300,000 kilowatts installed capacity at the tidal project would be combined with all of the capacity and energy available at Rankin Rapids (400,000 kilowatts installed, 460,000 kilowatts dependable, and 1.22 billion kilowatt-hours) to provide a total dependable capacity of 555,000 kilowatts and an average annual generation of 3,063 million kilowatt-hours. The project investment would be $732,100,000.

For the United States, the annual power benefits would be $16,782,000, the annual power costs $15,302,000, and the benefit-cost ratio 1.10. For Canada, the annual benefits would be $10,235,000, the annual costs $17,610,000, and the benefit-cost ratio 0.58. For the entire project, United States and Canada, the benefit-cost ratio would be 0.82. Downstream benefits estimated to be $953,000 annually were assumed in deriving these ratios.

Although the criteria used in certain studies by the Engineering Board resulted in a higher benefit-cost ratio for the United States' share of the power from this combination, no studies made by the Board gave a favourable benefit-cost ratio for the Canadian share.

The Engineering Board found that, with a 50-year amortization period, the benefit-cost ratio for the tidal project combined with all of Rankin Rapids would be greater than unity (1.31), and concluded that this combination, if built entirely by the United States at an interest rate of 2-1/2 percent, would be economically justified. However, the Commission believes there is an economic fallacy in the concept of such a combination project.

The facts presented in the Engineering Board's report and in this report show that, when considered alone, the tidal project is clearly uneconomic. Its benefit-cost ratio with a 50-year amortization period is considerably less than unity both for the United States and Canadian shares of the project power. On the other hand, the Rankin Rapids project with 200,000 kilowatts installed when considered alone has a benefit-cost ratio somewhat in excess of unity; i.e., 2.0 for United States federal development. In the Board's economic analysis, the costs and benefits of the uneconomic tidal project are added to those of the economically feasible Rankin Rapids project to determine the benefit-cost ratio of this possible combination project. The Commission is of the opinion that a benefit-cost ratio determined on this basis is not a valid representation of the economic worth of the tidal project, and the ratio of 1.31 determined by the Engineering Board for the combination project cannot be construed as indicating economic feasibility for the tidal power project. Hence, the findings of the Commission do not include consideration of this combination project.

Unit Cost of Power

While the benefit-cost ratios summarized in Table 1 for the Tidal project alone and the proposed project combinations provide a ready comparison of their relative economic value, they do not reveal the relative unit costs of power. Energy cost per kilowatt-hour furnishes a more direct basis for comparison of the cost of tidal power with other sources of power in the area. Unit costs of energy from tidal project combinations are summarized below. The cost of energy from alternative steam-electric plants is shown for comparison since such plants are the most likely alternative source of a comparable block of power for Maine and New Brunswick in the absence of the tidal project. In accordance with present practice, alternative

COMPARISON OF UNIT COST OF POWER FROM TIDAL PROJECT AND FROM ALTERNATIVE STEAM-ELECTRIC PLANTS

Power Source	Unit Cost of Energy - Mills per Kwh			
	At-Site		At-Market 1/	
	United States	Canada	United States	Canada
1. Tidal Project Alone	26.2	42.8	28.9	43.8
2. Tidal Project and Steam-Electric Capacity	13.5	18.6	15.0	19.6
3. Tidal Project and Digdeguash Pumped-Storage Project	12.2	16.8	13.5	17.4
4. Tidal Project and Incremental Capacity at Rankin Rapids	11.5	15.8	13.4	17.3
5. Alternative Steam-Electric Plants	10.6	7.3	11.6	7.4

1/ Includes cost of Transmission of Power from Project Site to the Market.

steam-electric plants in Maine are assumed to be privately financed and in New Brunswick, publicly financed.

For the purpose of this comparison, "taxes foregone" are not included in the United States' share of the Tidal project costs (as was done in the economic analyses summarized in Table 1) because rates for the sale of power from federally-financed projects are customarily established on the basis of returning only the power costs actually incurred. Unit energy costs for both the Tidal project and the alternative steam-electric plants are calculated on the basis of about 60 percent load factor, to present them on a uniform basis. This is the approximate present annual load factor of the utility systems in the area.

It will be noted that the unit costs of energy for the Tidal project alone are considerably higher than the 10.8 mills and 14.9 mills shown in the Engineering Board's report for the United States and Canadian shares of the power. Since the Board's figures were determined without regard to the 60 percent load factor limitation placed on the combination projects, they do not provide a proper basis for comparison of unit costs. The Commission has, therefore, adjusted the Board's figures to a 60 percent load factor basis, and credited to the project costs (at a steam-energy replacement value of 5.0 mills per kilowatt-hour in the United States and 4.4 mills in Canada as derived by the Engineering Board) all energy that could be produced in excess of a 60 percent load factor. This adjustment results in unit at-site costs of 26.2 mills for the United States' share and 42.8 mills for the Canadian share of the Tidal project power. It may be expected, however, that in actual operation, the dependable capacity (95,000 kilowatts) of the Tidal project would be used at about 100 percent load factor. Under such operation, the unit cost of energy would be 18.2 and 27.5 mills in Maine and New Brunswick, respectively.

It will be observed from the preceding tabulation that alternative steam-electric plants in Maine and New Brunswick, financed in accordance with present practices, could produce power at a lower cost than either the Tidal project alone or any of the project combinations. It may be noted that this tabulation does not include the combination of the Tidal project and all of Rankin Rapids for the reasons indicated on page 27. In comparing the United States' costs, it should be noted that the Tidal project and the project combinations are assumed to be federally financed, while the alternative steam-electric plants are assumed to be privately financed, as previously pointed out.

In the discussion of the combination of the Tidal projects with all of Rankin Rapids as proposed by the Engineering Board, the Commission points out that, if constructed alone to serve power loads in the State of Maine, the Rankin Rapids project could provide 200,000 kilowatts of dependable capacity and 1,220 million kilowatt-hours average annual energy. If this project were constructed with private financing, power could be produced at a unit cost of about 11.0 mills per kilowatt-hour at the dam-site and 13.0 mills per kilowatt-hours delivered to the market. On the basis of federal financing at the 2-1/2 percent interest rate used in this report and 50-year amortization of the investment, the unit cost would be about 3.8 mills at site and 5.3 mills at market. In addition to supplying a large block of relatively low cost power for the State of Maine, the Rankin Rapids project would provide substantial benefits to downstream hydroelectric plants in New Brunswick.

Economic Feasibility

On the basis of the foregoing economic analyses, the Commission finds that the tidal project alone is not economically feasible and could not provide firm power at a unit cost as low as the cost of power from new alternative steam-electric plants that could be built in the area to meet its future power requirements. None of the proposed combination projects considered by the Commission to be valid would provide an economic development for either the United States or Canada if they are evaluated on the basis of the usual practices followed in the two countries in determining the economic feasibility of proposed hydroelectric projects.

The Commission notes, however, that the tidal project could provide certain public benefits in addition to those which have been evaluated in monetary terms in determining benefit-cost ratios as previously described. Important among such benefits would be the recreation value of the project. It is believed that the uniqueness of the tidal project would make a substantial contribution to the large recreation industry of the area by attracting many visitors. The Engineering Board points out that on the basis of evaluation procedures currently used by the Corps of Engineers, the potential recreation benefits of the project would be at least $800,000 per year. Inclusion of these benefits in the foregoing analyses would improve slightly the benefit-cost ratio but would not alter the indicated conclusions as to economic feasibility of the project.

Other potential project benefits not evaluated in the benefit-cost analyses include those to navigation and to the highway systems of Maine and New Brunswick. The cost estimates prepared by the Engineering Board include navigation locks adequate for the volume of current traffic and for a moderate increase in vessel size. While the Board made no attempt to determine the future ship traffic in the project area, the Commission recognizes that the availability of an upper pool having considerably less range in its levels than now occurs with normal ebb and flood of the tides might stimulate greater traffic to shipping points on Passamaquoddy Bay. These possibilities may justify further study of navigation values in the future.

A highway system built on the approximately 7 miles of tidal dams could replace the present ferries serving the Passamaquoddy Bay area and provide a connecting link between United States and Canadian coastal highways that would shorten the highway distance between Whiting, Maine, and St. George, New Brunswick by about 40 miles. Ready access would also be provided to Campobello and Deer Islands thereby increasing their recreational value. Neither the Engineering Board nor the Commission has attempted to estimate in monetary terms the potential highway value of the tidal dams.

Other factors, largely subject to policy determination, that could have an effect on the economics of the tidal project are: possible changes in interest rates, allowance of a longer amortization period, and exclusion of taxes foregone from the United States costs. In addition, it may be noted that any increase in fuel costs in the project area would have a favourable affect on the benefit-cost ratio by increasing the value of the tidal project power.

Table 2 illustrates the cumulative effect on the project's benefit-cost ratios of assumed variations from the project benefits and costs determined by the International Joint Commission. The cumulative effects are shown in relation to the Commission's basic analyses presented in Table 1 using conventional evaluation practices in the United States and Canada. The assumed variations from the basic assumptions are as follows: (1) a uniform interest rate of 3 percent for both the United States and Canada; (2) amortization of the project investment in 75 years instead of 50 years; (3) allowance of $800,000 for annual recreational benefits (one-half to each country); and (4) taxes foregone eliminated from United States costs.

It may be seen from Table 2 that none of the assumed variations from the basic evaluation made by the Commission would result in a benefit-cost ratio of unity for the tidal project alone or in combination with either incremental capacity at Rankin Rapids or the Digdeguash pumped-storage project. An increase as great as 25 percent in fuel costs would still not provide a benefit-cost ratio of unity for the Canadian share or for the entire project.

As to other possible effects of future trends on the economics of the project, the Commission notes that improvements in equipment design and construction methods may result in some saving in project costs. It is possible, for example, that further experience with bulb-type generating units may lead to savings through their adoption and use in the tidal project.

The Commission recognizes the existence of other tidal power potentials in the area and that their construction might provide sufficient diversity of power production to enhance the marketability of power from the International project considered for Passamaquoddy Bay.

The Commission also recognizes that factors other than strict economic feasibility based on tangible benefits and costs, and which were not taken into account by the Commission, may be of importance to the two Governments in arriving at decisions to undertake resource development projects such as this. Such factors might include the development of new and unique sources of power, the conservation of fossil fuel resources, and the provision of employment opportunities in economically depressed areas.

Table 2

EFFECT ON BENEFIT-COST RATIO OF ASSUMED VARIATIONS FROM THE PROJECT BENEFITS AND COSTS DETERMINED BY THE INTERNATIONAL JOINT COMMISSION

Assumptions for Determination of Benefit-cost Ratios	Tidal Project Alone			Tidal Project and Incremental Capacity only at Rankin Rapids[1]		
	United States	Canada	United States and Canada	United States	Canada	United States and Canada
Basic Analysis using Conventional Evaluation Practices in United States and Canada. (From Table 1)	0.58	0.34	0.44	0.80	0.42	0.59
Cumulative Effect of Successive Variations from Basic Analysis:						
1. Annual costs based on uniform interest rate of 3% for both countries	0.52	0.42	0.47	0.72	0.52	0.63
2. Amortization of Capital investment in 75 years.	0.60	0.49	0.54	0.83	0.59	0.72
3. Allowance of $800,000 annual recreation benefits. ($400,000 to each country)	0.64	0.53	0.58	0.86	0.63	0.75
4. With taxes foregone eliminated from United States costs.	0.66	0.53	0.60	0.99	0.63	0.81

(1) This combination project is shown in the Table for illustrative purposes. The combination with Digdeguash pumped-storage would give approximately the same results.

FINDINGS OF THE INTERNATIONAL JOINT COMMISSION ON SPECIFIC POINTS OF THE REFERENCE

The reference to the International Joint Commission by the Governments of Canada and the United States requested findings on certain specific points with respect to development of the international tidal power potential of Passamaquoddy Bay in the State of Maine and the Province of New Brunswick. These findings follow:

(a) The estimated cost of developing the international tidal power potential of Passamaquoddy Bay

On the basis of the detailed studies of the Engineering Board, the Commission finds the estimated costs, using United States currency and January 1958 price levels, of the tidal project alone and in combination with several possible sources of firming power to be as follows:

Project	Generating Capacity (1000 KW) Installed	Generating Capacity (1000 KW) Dependable	Avg. Ann. Energy (Million KWH)	Capital Investments, including Transmission to Market (Million Dollars)
1. Tidal Project alone	300	95	1,843	546.8
2. Tidal Project and Steam-Electric Capacity	520	300	2,143	595.1
3. Tidal Project and Digdeguash Pumped-Storage	560	323	1,759	586.4
4. Tidal Project and Incremental Capacity at Rankin Rapids	526	355	1,843	600.0

The at-site unit costs per kilowatt hour of producing electric energy from the Tidal project alone is estimated to be 26.2 mills for the United States' share of the power and 42.8 mills for Canada's share based on a 60 percent annual load factor. Based on a 100 percent load factor the unit costs would be 18.2 mills and 27.5 mills for the United States and Canada, respectively.

The unit costs per kilowatt hour of energy of power from a combination of the tidal project with either incremental generating capacity at the Rankin Rapids reservoir site in Maine or the Digdeguash pumped-storage site in New Brunswick would be approximately 12 mills for the United States' share of the power and 16 mills for Canada's share. The Rankin Rapids and Digdeguash sites are considered the lowest cost means available of supplying auxiliary power for the tidal project.

(b) Whether such costs will allow hydroelectric power to be produced at a price which is economically feasible

The Commission finds that the tidal project either alone or in combination with auxiliary power sources is not economically feasible if it is evaluated in accordance with the conventional methods of economic analysis of hydroelectric projects in the United States and Canada. On the basis of such evaluation standards, the benefit-cost ratios for the tidal project alone would be 0.58 for the United States and 0.34 for Canada. For the project as a whole, the benefit-cost ratio would be about 0.44. Using either the Digdeguash pumped-storage auxiliary in Canada or incremental generating capacity at the Rankin Rapids project in the United States, the benefit-cost ratio for each combination project would be 0.80 for the United States and 0.42 for Canada. The over-all benefit-cost ratio for each of these combinations would be about 0.59.

If, as a matter of policy applicable to this international project, the Governments of the United States and Canada wish to adopt criteria different from the conventional concepts of economic analysis with respect to such factors as interest rates, amortization period, taxes foregone, and allowance of recreation benefits, the benefit-cost ratios for the combination project (Tidal project and Digdeguash or Tidal project and incremental capacity at Rankin Rapids) would, as shown in Table 2, become 0.99 for the United States, 0.63 for Canada, and 0.81 for the two countries combined.

Construction of the Rankin Rapids dam and reservoir on the Upper Saint John River in the State of Maine would be prerequisite to its use to supply incremental firming capacity for the tidal project. The Rankin Rapids project could be constructed initially with an installed generating capacity of 200,000 kilowatts to supply economic hydroelectric power to the State of Maine and downstream benefits to hydroelectric plants on the Saint John River in New Brunswick. Such a plan of development would not preclude later use of Rankin Rapids as a source of firming power by construction of 260,000 kilowatts of additional dependable capacity at the site to be operated in coordination with and as an auxiliary to the tidal project. The Commission is of the opinion, however, that it would not be consistent with sound practices of economic analysis of hydroelectric projects to combine the basic Rankin Rapids project (200,000 kilowatts and 1,220 million kilowatt-hours) with the tidal project to determine the economic worth of the tidal project.

In short, the Commission finds that the tidal project, either alone or in combination with auxiliary power sources will not permit power to be produced at a price which is competitive with the price of power from alternative available sources.

(c) The effects, beneficial or otherwise, which such a power project might have on the local and national economies in the United States and Canada

Because of the relatively high cost of development of the tidal power potential, the Commission finds that construction of the tidal project would not appreciably affect industrial development in the project area.

Construction of the project would have substantial, although short-term, beneficial effect on the economies of Maine and New Brunswick during the six-year construction period resulting from expenditures of over $200,000,000 for goods and services.

The uniqueness of the tidal project and the creation of two large salt water lakes in an area where recreation is already an important industry would result in the provision of additional recreation benefits.

Since the tidal project would raise the level of the Passamaquoddy Bay high pool and decrease the tidal range, navigation conditions would be improved in the Saint Croix River estuary and at Saint Andrews and other ports on Passamaquoddy Bay. In the low pool, on the other hand, the beneficial effects of decreasing the tidal range would be partially offset by lowering the maximum level of Cobscook Bay to a point below the level of normal high tide. Navigation conditions in the lower pool in the Falls Island and Lubec area, which rapid tidal currents now occur, would be improved during a considerable portion of the tidal cycle. In general, tidal velocities in the project area would be reduced, except in areas immediately adjacent to the gates when open.

Construction of the tidal dams, locks and gates would provide foundations on which an international highway could be built connecting the present coastal highways in Maine and New Brunswick, reducing the travel distance from Whiting, Maine to St. George, New Brunswick by about 40 miles. Ready access to the recreational advantages of the large islands in Passamaquoddy Bay also would be provided by this highway.

(d) Specifically, the effects which the construction, maintenance, and operation of the tidal power project might have upon the fisheries in the area.

On the basis of the extensive studies of the Fisheries Board, the Commission finds that by providing for relocation and modification of existing fisheries facilities and by including appropriate remedial measures in the design of the tidal power structures, construction and operation of the tidal power project would have very little effect on the important sardine industry in the region and only a minor effect on other fisheries.

The Rankin Rapids project would flood substantial reaches of the Allagash and Saint John Rivers in Maine which now support an important trout fishery. Construction of this project would change the type of fishing which now prevails. Other wildlife habitat would also be affected.

The Digdeguash River now supports a small run of Atlantic salmon which would be destroyed by construction of the pumped-storage auxiliary. Methods of restoring this run were not determined.

RECOMMENDATIONS

In view of the finding that the Passamaquoddy tidal power project is not economically feasible under present conditions, the Commission recommends that development of the project be viewed as a long-range possibility having better prospects of realization when other less costly energy resources available to the area are exhausted. In making this recommendation, the Commission wishes to point out that the economic feasibility of the project may be affected by future changes in the costs and benefits considered in the present evaluation of the project. The two Governments may wish to give consideration to the desirability of crediting the tidal project with certain public benefits that have not been included in the economic feasibility determination presented in this report.

The Commission recommends, further, that this report with the accompanying reports of the Engineering and Fisheries Boards be made available to all interested parties as a valuable source of relevant engineering and economic data for use in any future study of the possibilities for development of the international tidal power potential of Passamaquoddy Bay.

Signed at Washington this 4th day of April 1961.

Edward A. Bacon

A. G. L. McNaughton

Eugene W. Weber

J. Lucien Dansereau

Francis L. Adams

D. M. Stephens

PASSAMAQUODDY ENGINEERING INVESTIGATIONS

INTERNATIONAL PASSAMAQUODDY ENGINEERING BOARD

Report to

INTERNATIONAL JOINT COMMISSION

October 1959

International Passamaquoddy Engineering Board

Ottawa, Ontario
Washington, D. C.

October 1, 1959.

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

Gentlemen:

In accordance with the assignment given this Board on its appointment by the Commission on October 3, 1956, the Report "Investigation of International Passamaquoddy Tidal Power Project" is submitted herewith.

Under the terms of the instructions from the Commission, the Engineering Board was requested to carry out all the engineering investigations and studies necessary to enable the Commission to prepare and submit to the Governments of the United States and Canada, a comprehensive report on the proposed Passamaquoddy Tidal Power Project.

In view of the different conditions existing in Canada and the United States pertaining to interest rates and power values, it was necessary to carry out two series of benefit/cost analyses — one for Canada and one for the United States. This has resulted in the unusual conclusion that although the project would have a favourable benefit/cost ratio in the United States, the Canadian ratio is unfavourable.

The details of the studies and investigations carried out by the Board are being included in nineteen appendices to the main report. These appendices have been approved, and the Board expects to forward these appendices to the Commission prior to the end of the calendar year.

Respectfully submitted,

Gerald Millar

Gerald Millar,
Chairman, Canadian Section

S D Sturgis

S.D. Sturgis,
Chairman, United States Section

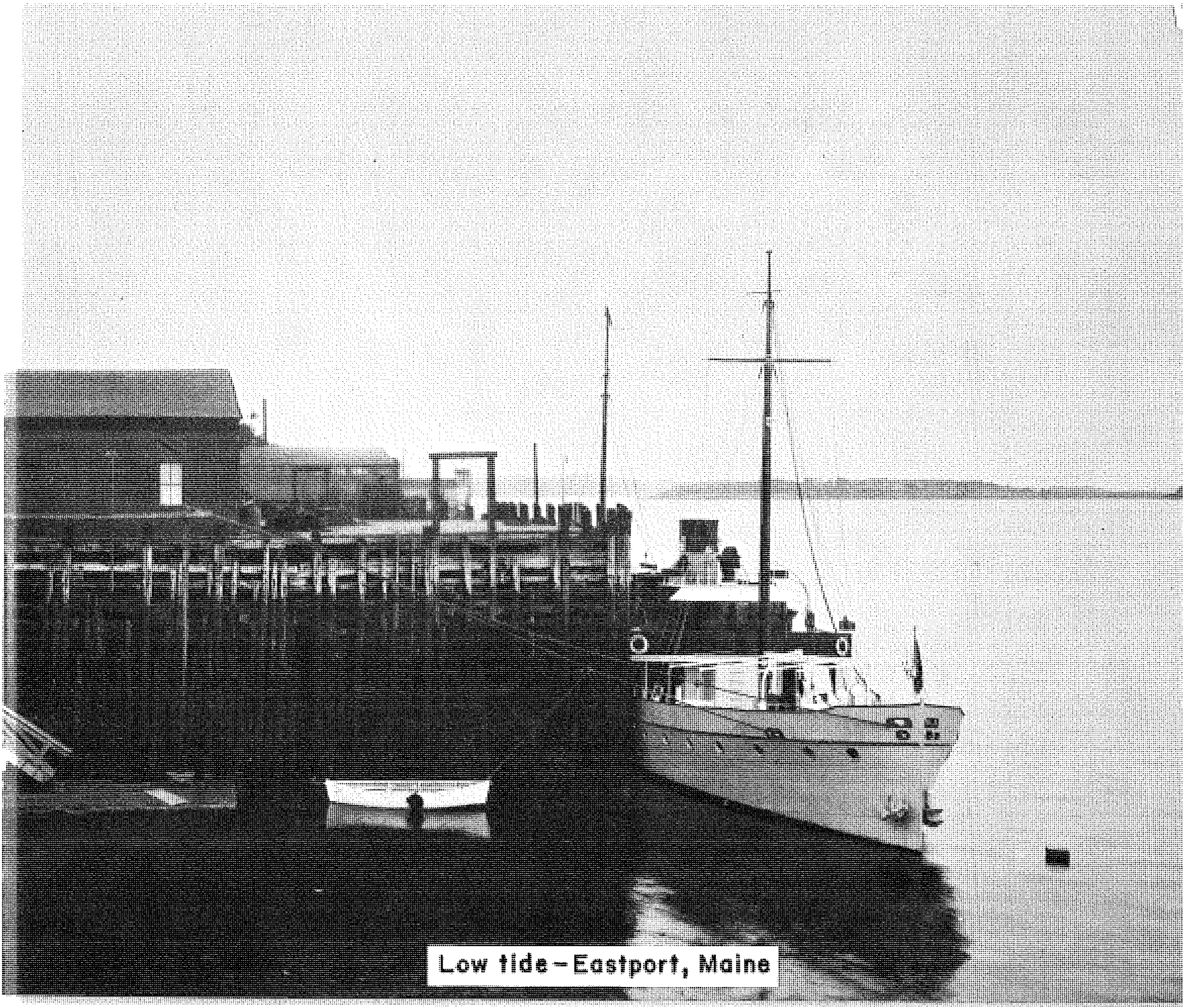
H B Rosenberg

H.B. Rosenberg,
Member, Canadian Section

Frank L. Weaver

Frank L. Weaver,
Member, United States Section

INVESTIGATION OF THE INTERNATIONAL PASSAMAQUODDY TIDAL POWER PROJECT



Low tide—Eastport, Maine

High tide — Eastport, Maine

REPORT TO THE INTERNATIONAL JOINT COMMISSION BY THE INTERNATIONAL PASSAMAQUODDY ENGINEERING BOARD

October 1959

CONTENTS

CHAPTER IV

TIDAL PROJECT DESIGN

CHAPTER V

AUXILIARY POWER PROJECT DESIGNS

CHAPTER VI

DEVELOPMENT OF COSTS

CHAPTER VII

ECONOMIC EFFECTS OF PROJECT

CHAPTER VIII

POWER UTILIZATION

PLATES

APPENDICES

(separately bound)

SYLLABUS

In accordance with United States Public Law 401, 84th Congress, 2nd Session, and the Boundary Waters Treaty of 1909, the Governments of Canada and the United States in August 1956 directed the International Joint Commission to investigate the engineering and economic feasibility of harnessing the tides of Passamaquoddy and Cobscook Bays in the Province of New Brunswick and the State of Maine for production of hydroelectric power. The investigation, completed in October 1959 well within the appropriations authorized by both countries, established the type and cost of the most economical project to generate electricity from the tides, and determined whether tidal power could be generated at a price competitive with the most economical alternative source of power.

To carry out the investigation of the tidal power project and its effect on the economies of the United States and Canada, including the fisheries of the area, the Commission established two separate boards, the International Passamaquoddy Engineering Board and the International Passamaquoddy Fisheries Board. Composed of two representatives each from Canada and the United States, the boards were directed to coordinate their studies and to submit separate reports to the Commission. The Engineering Board in turn established an Engineering Committee to supervise the detailed investigations. These investigations were carried out primarily by the U.S. Army Engineer Division, New England, Corps of Engineers, and the Regional Office of the United States Federal Power Commission, New York. Canadian aspects of the survey were conducted by the Department of Public Works, the Department of Northern Affairs and National Resources, and other agencies of the Federal and Provincial Governments of Canada . This syllabus presents a brief summary of the report of the International Passamaquoddy Engineering Board, including the Board's conclusions on engineering and economic feasibility.

HARNESSING THE TIDES

Man has for centuries devised methods of putting the ocean tides to work. As early as the eleventh century tides were harnessed in a small way in England and other Western European countries when small tide mills were used to grind corn. In Chelsea, Massachusetts, in 1734 "Slade's Mill" was built to grind spices. This mill developed about 50 horsepower from four water wheels driven by the head created by damming a small estuary to trap water at high tide. Since the advent of hydroelectric power, numerous tidal power sites throughout the world have been investigated. In addition to the Passamaquoddy Bay area, a few of the locations recently studied for large tidal power plants include the tidal estuary of the River Severn in England, the Bay of L'Aber Vrach on the northwest coast of Brittany, Mont St. Michel in northwest France near St. Malo, and the Gulf of San José in Argentina. Components of what may be the world's first large-scale tidal power plant are now being tested to harness the La Rance River estuary on the Brittany coast.

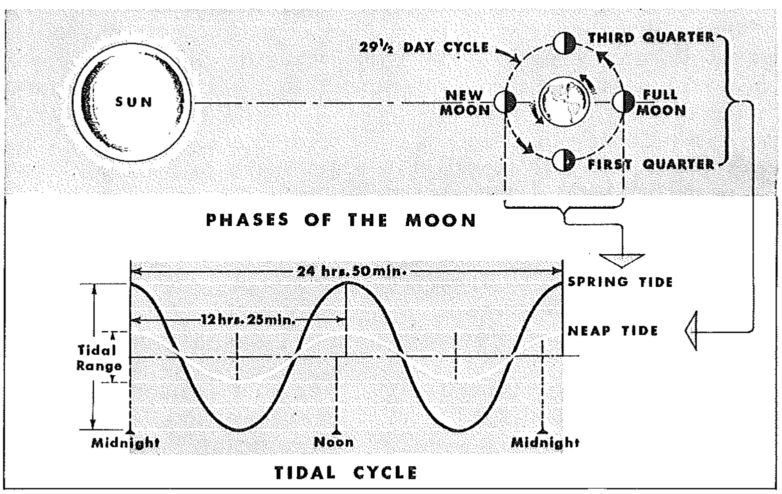
Tidal hydroelectric power, similar to river hydro power, can be produced by a flow of water from a higher to a lower level through hydraulic turbines. A single pool equipped with gates may be built to trap water at high tide and discharge through turbines to the ocean at low tide, or the pool may be emptied at low tide to receive turbine discharge from the ocean at high tide. Two separate pools equipped with emptying and filling gates may be used, one pool filled at high tide and the other emptied at low tide, with the high pool discharging through the turbines into the low pool.

A single high pool has the serious disadvantage of producing discontinuous power, because no power can be generated without a sufficient difference between the level of the pool and the level of the ocean. Thus no generation is possible until the ocean has receded sufficiently to obtain this difference in water levels, or power head; nor is generation possible on the rising tide after the level of the ocean becomes too high to provide this minimum necessary head. For similar reasons, a single low pool also produces interrupted power. This disadvantage is avoided in the two-pool plan, the plan adopted for the project described in this report, which generates varying but continuous amounts of power. This continuous power is achieved in the two-pool plan by operating emptying and filling gates so that the level of one pool is always sufficiently higher than the other.

The advantages of a tidal power plant are that the tides, which can be predicted with accuracy for many years in the future, can produce power unaffected by droughts, floods, ice jams, or silting -- adverse factors which decrease the output and limit the life of river hydroelectric plants. An inherent disadvantage of the tides as a source of power is that the tides, following the gravitational pull of the moon as it passes overhead every 24 hours and 50 minutes, are out of phase with the 24-hour solar day. This 50 minute daily lag is fundamental to the economics of tidal power for, since power output varies with the tides, tidal power is completely out of step with the normal patterns of daily use of electricity. Therefore, unless the tidal plant is supplemented by an auxiliary power plant, such varying power would be of little value.

Tidal ranges, the height between high and low tides, determines the available head and thus governs the amount of power generated. Tides are caused by the changing relationship of the sun, earth and moon with respect to each other, and tidal range, which is affected primarily by the phases of the moon, also varies from day to day. As shown in the simplified illustration, the sun and moon appear on the same side of the earth approximately every four weeks, at the time of new moon. Two weeks later, at the time of full moon, the sun and moon appear on opposite sides of the earth. When either of these conditions occurs, gravitational attraction of the sun and moon reinforce each other and cause maximum or spring tides. When the moon is at either quarter phase, the gravitational attraction of the sun and moon are approximately at right angles with respect to the earth, causing minimum or neap tides. When the moon is new or full and simultaneously in perigee -- the point in the moon's orbit closest to earth -- the spring tide is particularly great.

The height the tide will reach is also affected, sometimes to a high degree, by the coastline. On open, exposed headlands tides may range from 4 to 5 feet, while in nearly landlocked embayments, like the Mediterranean, tides are negligible. In the Gulf of Maine, however, which opens toward the deep areas of the Atlantic Ocean as the continental shelf drops off beyond Georges and Browns banks, the tides are greatly amplified by the size and configuration of the shore and bottom. As shown on plate 1, the mean tidal ranges become progressively greater as the tides move into the Gulf of Maine toward the mouth of the Bay of Fundy. The funnel-shaped Bay of Fundy again amplifies the tidal range, producing the highest tides in the world at the head of the bay. To devise a workable and feasible scheme to harness these tides for the economical production of uninterrupted power constitutes the essence of tidal power engineering.




QUEBEC
CANADA
NEWFOUNDLAND
ANTICOSTI ISLAND
GULF OF SAINT LAWRENCE
STRAIT OF BELLE ISLE
MAGDALEN ISLANDS
CAPE BRETON ISLAND
PRINCE EDWARD ISLAND
Charlottetown
NEW BRUNSWICK
ST. LAWRENCE RIVER
RANKIN RAPIDS SITE
DIGDEQUASH SITE
TIDAL PROJECT SITE
Quebec
Fredericton
SAINT JOHN RIVER
STRAIT OF CANSO
Hopewell Cape 35.0
41.6 Burntcoat Head
Saint John
20.6
26.7 Port George
4.4 Halifax
21.0 Digby
18.1
EASTPORT
BAY OF FUNDY
NOVA SCOTIA
Yarmouth
17.5
Cape Sable 7.0
MAINE
PENOBSCOT RIVER
KENNEBEC RIVER
Bar Harbor 10.4
Augusta
Montpelier
VT.
UNITED STATES
Portland 8.9
N.H.
Concord
CONNECTICUT RIVER
GULF OF MAINE
Browns Bank
Boston 9.5
MASS.
Providence
Cape Cod 6.7
3.1
Hartford
R.I.
Newport
3.5
CONN.
Georges Bank
200 Fathoms
1000 Fathoms
ATLANTIC OCEAN
SCALE IN MILES
50 0 50 100
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
REGIONAL MAP
AVERAGE TIDE RANGE SHOWN IN FEET AT SPECIFIC LOCATIONS
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-211

PLATE 1

Generation of hydroelectric power from the tides within the Bay of Fundy has intrigued engineers in Canada and the United States for over forty years. At Burntcoat Head in the Minas Basin at the head of the Bay of Fundy in Canada, the spring tides reach an extreme range of over 50 feet. The range of the tides in Passamaquoddy and Cobscook Bays near the mouth of the Bay of Fundy, the site of the tidal project described in this report, varies from a minimum of 11.3 feet at neap tide to a maximum of 25.7 feet at spring tide, averaging 18.1 feet. During each tidal cycle, an average volume of approximately 70 billion cubic feet of water regularly enters and leaves Passamaquoddy and Cobscook Bays.

As early as 1919, W. R. Turnbull of Saint John, New Brunswick, suggested production of hydroelectric power from the great tides at the head of the Bay of Fundy in the Petitcodiac and Memramcook estuaries. In 1945 this site was again investigated by Canadian engineers but the proposed tidal project proved uneconomical.

Dexter P. Cooper made the first large-scale study of potential power production in Passamaquoddy and Cobscook Bays in the early 1920's. The most extensive of the many plans Cooper studied was an international project using both Passamaquoddy and Cobscook Bays. Each bay was to be closed by a series of dams, together with regulating gates and navigation locks, to form a two-pool tidal project. Power was to be generated by discharging water from the high pool in Passamaquoddy Bay to the low pool in Cobscook Bay through turbines in a powerhouse located between the two pools. Cooper also planned an auxiliary pumped-storage plant to supplement the fluctuating tidal power. Cooper, however, lost support during the financial crisis of 1929 and his plans were never realized.

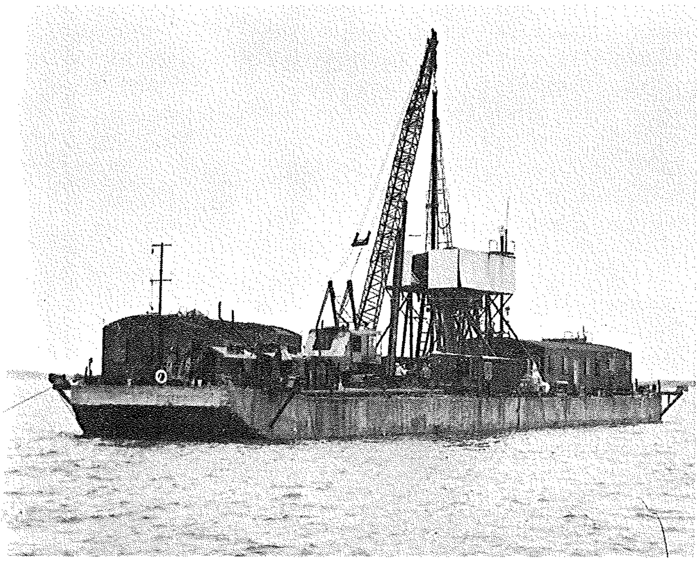
In 1935 the Government of the United States undertook development of a single-pool project using only the waters of Cobscook Bay on the United States side of the international boundary. Although this work was suspended in 1937 when no further funds were made available, the surveys, investigations, and construction of three small dams completed by the Corps of Engineers proved of great value to the present investigation.

The major differences between the 1935-37 project and the project which is the subject of this report are that (1) the project proposed in this report is an international two-pool project which permits production of continuous power; and (2) that a river hydroelectric auxiliary plant is used to firm the tidal plant output. Compared to the single-pool project planned in 1935-37, these differences are highly advantageous.

As the result of continued interest in the Passamaquoddy tidal power project on the part of the people of Maine and New Brunswick, supported by an increasing awareness of the need to exploit all possible sources of energy, the International Joint Commission was requested in 1948 by both governments to review all previous reports and to estimate the cost of carrying out a complete study in order to decide conclusively the engineering and economic feasibility of a large-scale international tidal power project in Passamaquoddy and Cobscook Bays. This report, completed in 1950, led directly to the present 1956-59 survey. The present study is the first investigation sufficiently comprehensive to permit the Governments of Canada and the United States to determine the economic justification and advisability of developing an international tidal power project in Passamaquoddy and Cobscook Bays.

FIELD INVESTIGATIONS

In order to determine the best layout of an international tidal power project, it was first necessary to conduct a series of field investigations and studies of site conditions in the Passamaquoddy-Cobscook area. Full use was made of all data gathered in previous studies, particularly those made by the U.S. Army Corps of Engineers in 1935-37. A field office and soils laboratory were established in Eastport, Maine, to gather and analyze new basic data. Aerial topographic surveys, tidal observations, hydrographic surveys, and subsurface explorations by deep-water core drilling and sonic methods were made in areas not investigated during any of the several earlier studies of the project area. Underwater mapping and exploration using recently developed sonic equipment furnished bottom contours and valuable foundation data.



Deep-water core drilling in Friar Roads

Core drilling in great water depths and high tidal velocities to determine the design and location of deep rock-filled dams and emptying and filling gates was the largest and most costly phase of the field investigations. To accomplish the difficult task of core drilling in waters up to 300 feet deep swept by reversing tidal currents reaching velocities of 6 to 10 feet per second, a 240-foot barge equipped with a special drilling assembly was brought from the Gulf of Mexico specifically for this task. With this equipment, samples of undisturbed overburden and bedrock were successfully taken for analysis from 15 carefully selected borings. Properties of these samples were analyzed in the laboratory of the Eastport field office. As the field investigations progressed, all new information was used to determine the best project arrangement -- the location of dams, gates, locks, powerhouse, and other components of the tidal project.

THE PROJECT SELECTED FOR DESIGN

From comparative analyses of a number of single-pool and double-pool schemes, it became evident that conditions at Passamaquoddy are particularly well suited to a two-pool tidal power project.

The topography of the Passamaquoddy-Cobscook areas permits many different arrangements of the components of a large-scale, two-pool project. Before the best arrangement could be selected, preliminary estimates were made to determine the power output and cost of numerous different project arrangements. Five of the most promising arrangements were then studied in greater detail. To avoid time-consuming and costly computations of energy output, this work was done by an electronic computer. In this way annual energy generation could be determined rapidly for any project arrangement once its pool areas and the optimum number of its generating units were established. The project arrangement that revealed the best relationship of installed capacity and energy output to construction cost was then selected for design.

The project arrangement thus selected for specific design and cost estimates includes the 101 square miles of Passamaquoddy Bay as the high pool and the 41 square miles of Cobscook Bay as the low pool, with a 30-unit powerhouse located at Carryingplace Cove, as shown on plate 2. With 30 generating units rated at 10,000 kilowatts each, operated at 15 percent above rated capacity for short periods during spring tides, the output of the tidal power plant would range from 95,000 to 345,000 kilowatts. Average energy generation would be 1,843 million kilowatt-hours a year.

With the major aspects of the best project layout determined, specific design studies were undertaken of each component of the selected plan -- tidal dams and cofferdams, filling and emptying gates, navigation locks, the powerhouse, turbines and generators -- to a point that would permit reliable cost estimates.

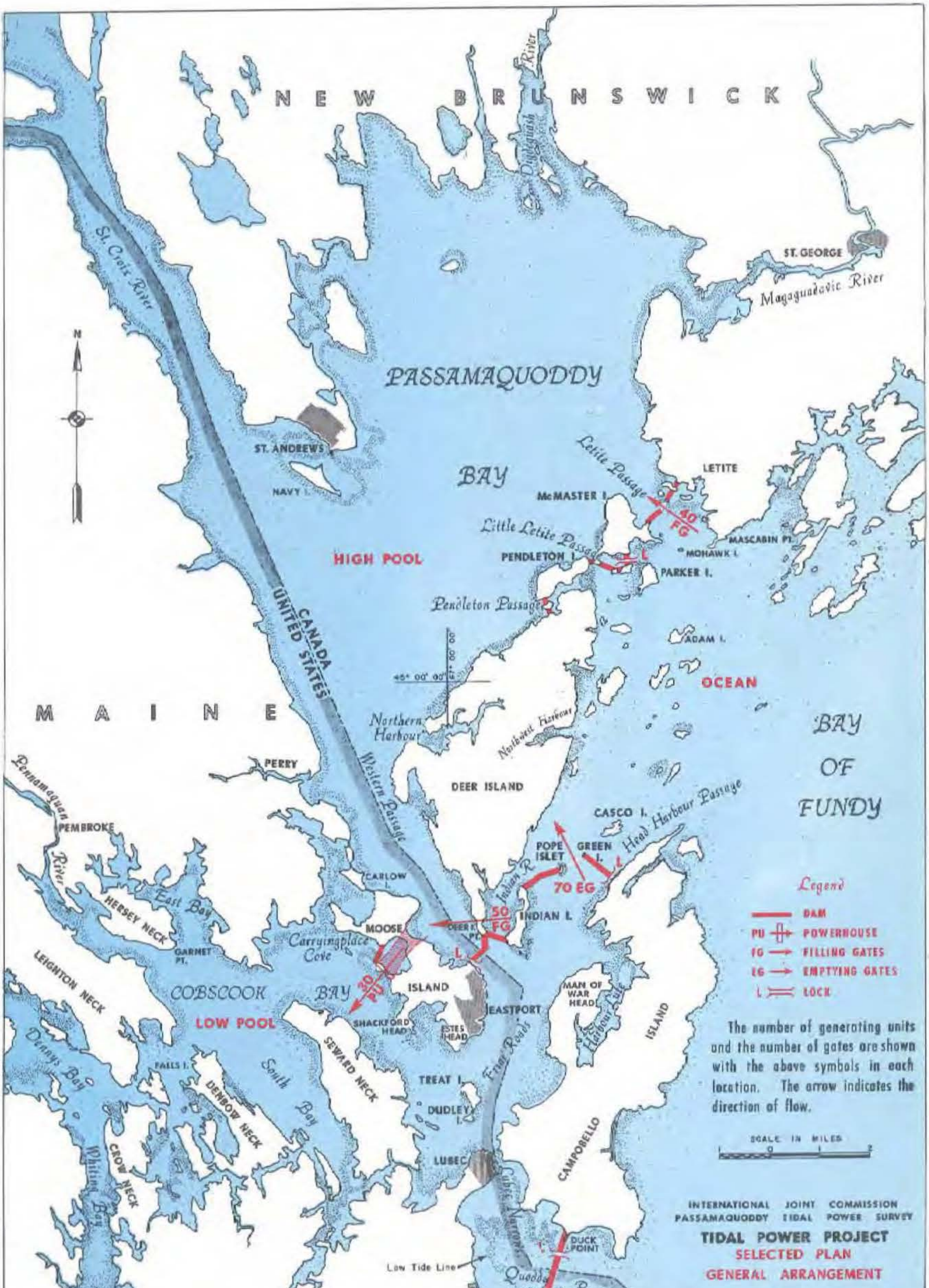

NEW BRUNSWICK
MAINE
PASSAMAQUODDY
BAY
HIGH POOL
LOW POOL
OCEAN
BAY OF FUNDY
St. Croix River
Digdeguash River
ST. GEORGE
Magaguadavic River
ST. ANDREWS
NAVY I.
Letite Passage
LETITE
McMASTER I.
40 FG
Little Letite Passage
MASCABIN PT.
PENDLETON I.
MOHAWK I.
PARKER I.
Pendleton Passage
ADAM I.
CANADA
UNITED STATES
45° 00' 00"
67° 00' 00"
Northern Harbour
Northwest Harbour
PERRY
Western Passage
DEER ISLAND
Head Harbour Passage
CASCO I.
Pennamaquan River
PEMBROKE
POPE ISLET
GREEN I.
Indian R.
70 EG
CARLOW I.
East Bay
HERSEY NECK
MOOSE
50 FG
INDIAN I.
DEER I. PT.
Carryingplace Cove
GARNET PT.
LEIGHTON NECK
COBSCOOK
BAY
30 PU
ISLAND
EASTPORT
MAN OF WAR HEAD
Harbour de Lute
ISLAND
SHACKFORD HEAD
ESTES HEAD
SEWARD NECK
South Bay
Friar Roads
Dennys Bay
FALLS I.
DENBOW NECK
TREAT I.
DUDLEY I.
CROW NECK
Whiting Bay
LUBEC
CAMPOBELLO
Lubec Narrows
DUCK POINT
Low Tide Line
Quoddy Roads
WEST QUODDY HEAD
Legend
DAM
PU POWERHOUSE
FG FILLING GATES
EG EMPTYING GATES
L LOCK
The number of generating units and the number of gates are shown with the above symbols in each location. The arrow indicates the direction of flow.
SCALE IN MILES
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
SELECTED PLAN
GENERAL ARRANGEMENT
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. 707-217

PLATE 2

DAMS AND COFFERDAMS

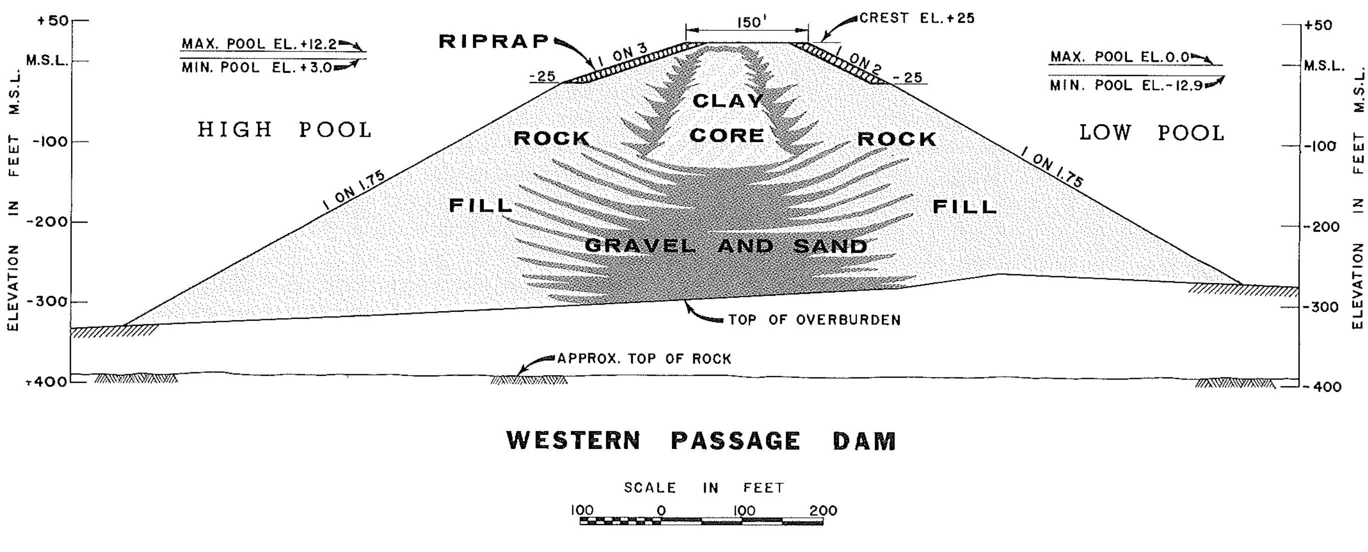
The selected project would require construction of nearly seven miles of rock-filled dams. With tidal velocities as high as 10 feet per second during the 26-foot high tide, the difficulties of constructing sufficiently watertight tidal dams, small portions of them in depths ranging from 125 to 300 feet, and closing these dams in the face of restricted and greatly increased tidal velocities up to 20 feet per second, posed engineering and design problems without precedent. In view of these problems, several outstanding specialists in the fields of hydraulic engineering and soils mechanics were consulted, and model studies were made of the hydraulic characteristics of deep tidal dams to determine the best and most economical design and methods of construction.

Bottom conditions in Passamaquoddy and Cobscook Bays vary widely from areas of exposed bedrock to clay overburden more than 100 feet thick. The 35,700 linear feet of tidal dams are located as far as practicable on foundations of bedrock or granular material to avoid clay overburden. The tidal dams, composed of a clay core supported by flanking dumped-rock fills, are designed to permit greatest possible use of materials excavated for the gate structures, navigation locks and the powerhouse.

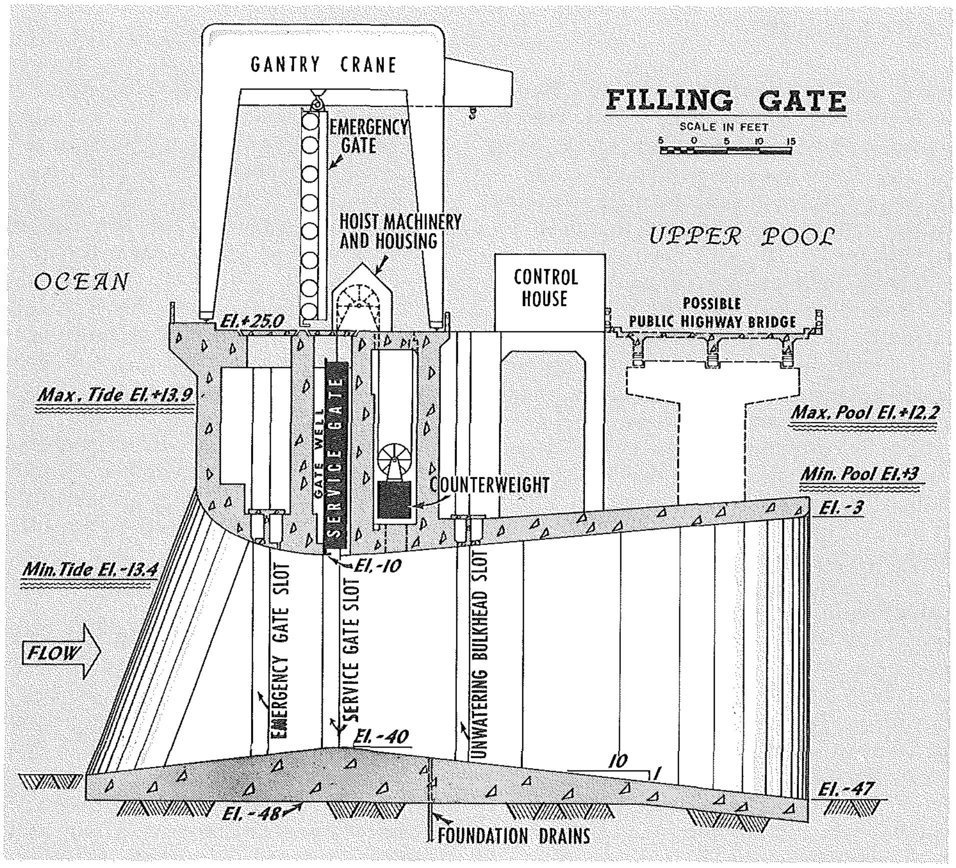
Of some 17 million cubic yards of clay which must be excavated from Carryingplace Cove for the powerhouse, the greater portion would be used in the clay cores of the dams to depths of 125 feet. About 2,900 linear feet of dams, or 8 percent of the total length of tidal dams in the project, would be located in water depths varying from 125 feet to about 300 feet below mean sea level. At these greater depths a granular core would be placed by special bottom-dump buckets. With the exception of these deep, granular core sections, the tidal dams can all be built with conventional land and marine equipment.

Construction of the dams would be scheduled to permit direct placement of material excavated for the powerhouse, gates, and navigation locks without costly stockpiling and rehandling. To overcome the problem of greatly increased tidal currents during closure of the dams, the 160 emptying and filling gates would be constructed first and operated to handle part of the tidal ebb and flood, thus reducing the quantity of water passing through the closure sections.

Cofferdams of several different types, depending upon the depths to be unwatered, would be used to excavate for the foundations of the powerhouse, filling and emptying gates, and navigation locks. Cofferdam designs include embankments, log cribs with timber sheathing, and steel sheet piling of both circular and cloverleaf design. Construction of the emptying gates in Head Harbour Passage would entail an embankment cofferdam 120 feet below mean sea level under a head of 75 feet when pumped out. Construction of cofferdams of this magnitude, built to withstand water pressures far greater than those on the tidal dams themselves, constitutes one of the major engineering and construction tasks of the Passamaquoddy tidal project.



WESTERN PASSAGE DAM



FILLING AND EMPTYING GATES

The project plan includes 90 filling gates, 40 in Letite Passage and 50 between Western Passage and Indian River, as shown on plate 2. In the reach between Pope and Green Islets 70 emptying gates, similar to the filling gates but set at a lower elevation, would empty the lower pool. Comprehensive study of all types of gates, and detailed examination of nine of the most feasible, led to the selection of a 30' x 30' vertical-lift steel gate set in a venturi throat. Early in the study a crest gate with a vertical-lift leaf appeared to promise economy because of high flow capacity, but the costs of auxiliary structures and maintenance to prevent icing more than offset its lower construction cost and superior hydraulic capacity. The venturi throat was selected because, among other important advantages, it permits maximum discharge for a given gate area.

NAVIGATION LOCKS

The project would have four navigation locks. The dimensions and locations of the navigation locks were selected to accommodate present traffic in Passamaquoddy and Cobscook Bays, with an allowance for a modest increase in the size of ships using the area. Two locks, one at Little Letite Passage and one at Quoddy Roads, would have clear dimensions of 95' x 25' x 12' to pass fishing vessels. Two locks, one at Head Harbour Passage immediately east of the emptying gates and one at Western Passage north of Eastport, would have clear dimensions of 415' x 60' x 21' to pass vessels somewhat larger than the present traffic. The reversing head on the locks ruled out the use of miter gates in favor of sector gates, which have proved successful under similar conditions at numerous locks on the Intracoastal Waterway in the Gulf of Mexico and on the Sacramento River.

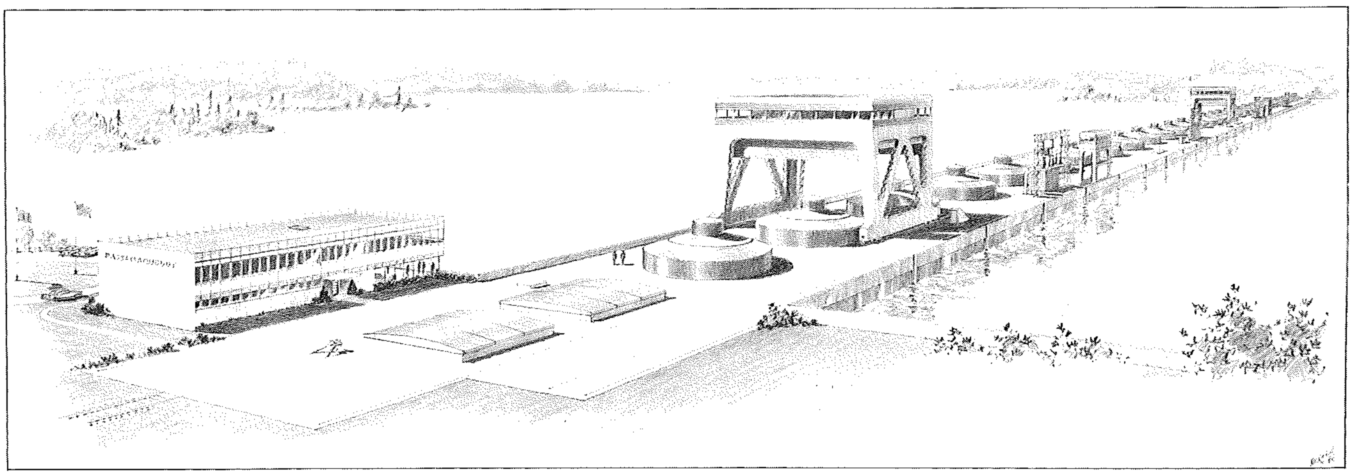
POWERHOUSE

Located northwest of Eastport in Carryingplace Cove, the powerhouse would contain 30 turbine-generator units, each placed in a concrete monolith 78 feet wide and 176 feet long in the direction of flow, with the bottom of the draft tube 110 feet below the powerhouse deck. The outdoor powerhouse shown in the architect's rendering proved more economical than partially or fully-housed types. The generators would be protected by weatherproof housings on the powerhouse deck and serviced by two large travelling gantry cranes equipped with moveable doors to enclose and protect the generators while being serviced. All control equipment would be located on the turbine room floor under the top deck of the powerhouse. All metal parts of the powerhouse and of all other components of the tidal project exposed to salt water would be protected from corrosion by use of corrosion-resistant alloys, protective coatings, and cathodic protection.

Design of an economical 30-unit powerhouse of minimum length to fit the available site, and capable of handling a tremendous volume of discharge, indicated use of turbines as large as possible. The turbines selected for the project are the fixed-blade propeller type with a throat diameter of 320 inches and a speed of 40 r.p.m. Due to the low average power head of 11 feet, the large turbines would be directly connected to generators with a relatively low rating of 10,000 kilowatts.

A comparison of the performance of fixed-blade and Kaplan turbines, based on data furnished by United States and Canadian manufacturers, indicated that the greater efficiency of the Kaplan turbine over a wide range of heads was offset by its greater cost. A new type of horizontal-axis turbine-generator unit recently developed in Europe and adopted for use in the single-pool project at La Rance on the northwest coast of France was also studied for possible use in the Passamaquoddy project. The European manufacturer recommended this unit, which can be used as a turbine, pump, or sluiceway, with flow in either direction, as more efficient than conventional units. Power studies showed that the European bulb-type turbine generator develops approximately as much power as the Kaplan, and structural studies indicated a possible saving of $300,000 per powerhouse unit. This saving, however, was offset by the greater cost of the bulb-type turbine-generator set and the need to compensate for low rotative inertia. For these reasons, and because of unresolved maintenance problems, the bulb-type unit was abandoned in favor of the conventional fixed-blade type for the purpose of evaluating the Passamaquoddy project.

The 30 generators would be connected in banks of 7 and 8 to four 90,000 kilovolt-ampere transformers located on the upstream side of the powerhouse and connected to the switchyard by oil-filled high-voltage cables. Two transformers would operate at 230 kilovolts for supply to the United States and two at 138 kilovolts for Canada.



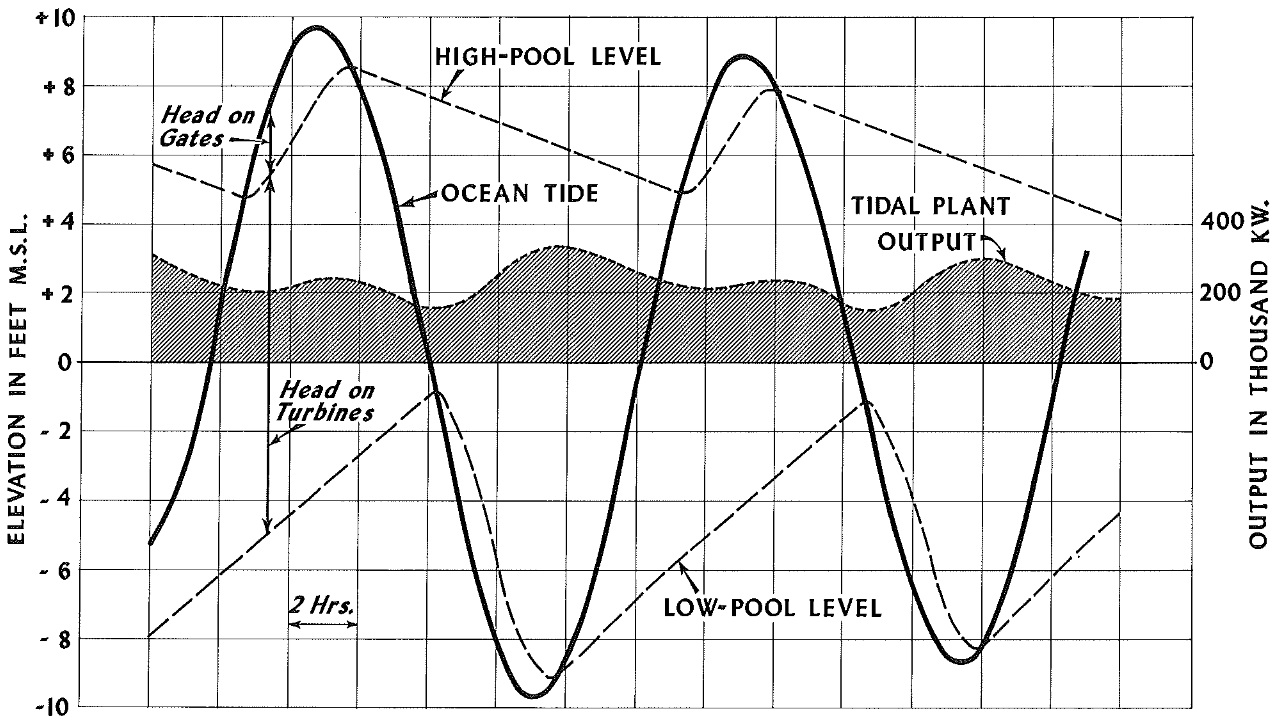
Operation of the powerhouse would be fully automatic. The wicket gate setting of each turbine would be automatically controlled at a pre-determined opening, depending on the gross head on the plant. Synchronizing, loading, and the stopping and starting sequences of each power unit would be controlled automatically by computer punch cards or tapes based on tide predictions. A central control board permitting fully automatic or manual control of all units, as well as the auxiliary power plant, would be located at the center of the powerhouse.

AUXILIARY POWER SOURCES

Each tide would fill the high pool of the tidal power project regardless of the amount of water used to generate energy in the previous cycle. Water left unused would be wasted. Somewhat similar in this respect to a "run-of-the-river" hydroelectric plant where no storage is available, energy generated by a two-pool tidal plant must take full advantage of the ebb and flood of the tides. Because tidal energy must be generated as the tides occur, rather than when the power market requires it, modifying this fluctuating output to meet the demand is essential to the operation of a tidal power plant.

As illustrated in the typical cycle of tidal plant operation, the output of the selected two-pool project would vary with the ebb and flood of the tides. Coupled with the additional variations in tidal range from spring tide to neap tide and the 50-minute difference between the lunar and solar days, this variable output contrasts sharply with the normal pattern of power demand. Hourly, weekly and seasonal variations in the demand for electricity reflect the pattern of activity and life habits of people. Therefore, daily variations in demand, or load patterns, follow the solar cycle which, as previously described, is out of step with the lunar cycle of the tides. At times, therefore, the peak demand for power may coincide with minimum output from the tidal power plant.

For load-carrying purposes, power from the tidal project is limited to the capacity it can furnish under the most adverse conditions. All output in excess of this capacity is not dependable for serving loads. All excess generation would have value only as non-firm or secondary energy. Therefore, to make the maximum output of the tidal power plant dependable, this output must be firmed by an auxiliary source of power.



TYPICAL TIDAL PLANT OPERATION

Several different types of auxiliary power sources were studied to determine the type best suited for making the combined output of the tidal project and its auxiliary match the characteristic load pattern. These studies included river hydroelectric plants, pumped-storage plants, and steam-electric auxiliaries.

Among a number of river hydroelectric sites examined, Rankin Rapids on the upper Saint John River in Maine, about 175 air miles from the tidal project, was selected to provide the best river hydro and tidal power project combination. The Rankin Rapids project, with an embankment 7,400 feet long and 333 feet high, would impound 8.23 million acre-feet, of which 2.80 million acre-feet would be useable storage. With a powerhouse of 8 units, the dependable capacity would be 460,000 kilowatts, and the plant would generate 1,220 million kilowatt-hours annually. Operated in conjunction with the tidal plant, the combined project would have a total dependable capacity of 555,000 kilowatts and would generate 3,063 million kilowatt-hours of energy annually.

As a possible alternative method of operation, Rankin Rapids could be built to carry part of the load in Maine, and to include additional capacity which could be used as needed to supplement the varying tidal project capacity. Energy thus borrowed from Rankin Rapids when using incremental capacity would be repaid when tidal output is greater than the load.

The Rankin Rapids project, with 2.8 million acre-feet of useable storage, would regulate the flow of the Saint John River and would benefit existing and potential hydroelectric plants downstream in New Brunswick. Although regulation by Rankin Rapids would assist in justifying installation of a great amount of additional capacity on the Saint John River, the work of designing and estimating the cost of these potential projects was beyond the scope of the Passamaquoddy tidal power survey. For this reason, only those benefits accruing to the existing installations at Beechwood and Grand Falls, consisting of an additional 180 million kilowatt-hours a year and a small increase in dependable capacity, were credited to the Rankin Rapids-tidal project combination.

Tidal power can also be supplemented by means of a pumped-storage plant. Using power from the tidal plant at times when it is not required to meet load demands, water can be pumped to a higher storage basin and released through turbines as required to meet the load. Since the output of the tidal plant alone would vary from 95,000 to 345,000 kilowatts, a pumped-storage plant with 228,000 kilowatts of installed capacity would provide a dependable capacity of 323,000 kilowatts from the combined project.

The three most favorable pumped-storage sites were investigated, and a site on the Digdeguash River near its outlet to Passamaquoddy Bay east of St. Andrews, New Brunswick, was adopted for design. Useable storage would amount to 204,000 acre-feet, equivalent to an output of 28 million kilowatt-hours. A loss of about 114 million kilowatt-hours of tidal energy a year in the pumping and generating cycles would be partially offset by 30 million kilowatt-hours a year of fresh-water inflow from the Digdeguash River drainage area. Using 400 million kilowatt-hours of energy from the tidal plant for the pumping cycle, the annual energy generation of the Passamaquoddy tidal plant-Digdeguash combination would be 1,759 million kilowatt-hours.

Supplementing tidal power with a steam-electric plant was studied and found to be the least favorable type of auxiliary. Although construction of a steam-electric plant would cost approximately the same as the Digdeguash pumped-storage plant, the added cost of fuel and operation at a low load factor greatly increased the annual cost and precluded further consideration of a steam-electric plant as an auxiliary to the tidal power project.

In summary, four project combinations were selected for evaluation of costs and benefits:

(1) The Passamaquoddy tidal project operated without an auxiliary: Operating alone, the tidal project output would vary from a dependable capacity of 95,000 to a peak of 345,000 kilowatts. Average annual energy generation would be 1,843 million kilowatt-hours.

(2) The tidal project operated in combination with all the power of the Rankin Rapids hydroelectric project: Using the 460,000 kilowatts of dependable capacity and the annual generation of 1,220 million kilowatt-hours from Rankin Rapids, this combination would have a total dependable capacity of 555,000 kilowatts and generate annually 3,063 million kilowatt-hours.

(3) The tidal project supplemented by capacity alone at Rankin Rapids: Assuming that Rankin Rapids were built primarily to serve the utility load in Maine, 260,000 kilowatts of additional capacity could be installed at Rankin Rapids to firm the varying tidal project output. This combination would have a dependable capacity of 355,000 kilowatts, with an annual generation of 1,843 million kilowatt-hours.

(4) The tidal project supplemented by the Digdeguash pumped-storage auxiliary: Using the dependable capacity of 228,000 kilowatts of the pumped-storage auxiliary, this combination would have a total dependable capacity of 323,000 kilowatts with a net annual generation of 1,759 million kilowatt-hours.

The second of these project combinations, the tidal plant operated in combination with all the power of the Rankin Rapids hydroelectric auxiliary, proved to be the most economical. Engineering and economic data on each of the four project combinations analyzed are presented at the end of this syllabus.

POWER MARKETS

Detailed studies were made to determine whether present and potential power markets in Maine and New Brunswick could absorb the project power. Since a power project will have value only to the extent that a demand for power exists, power market surveys were conducted in the Maine-New Brunswick area. The New Brunswick markets were surveyed by The New Brunswick Electric Power Commission, which serves over 90 percent of the people in the Province, and the power markets of Maine were studied by the United States Federal Power Commission.

Power markets consist of rural, urban, residential, commercial, industrial and other electric energy consumers served by utility systems. Requirements for utility-furnished energy are influenced directly by population growth, greater use of energy per customer, expansion of industrial, trade and service activities, and introduction of new uses of electric energy. The aggregate effect is a sustained growth in demand for electric power and a continuing need for adding to the power supply of the utility systems. Thus consumers who could use power from the tidal power project in a definite and predictable way are those now served by public and private utility systems.

In 1957 Maine utilities supplied 2,682 million kilowatt-hours to their customers, with a combined peak demand of 493,000 kilowatts. Power market studies show that energy requirements will reach an estimated total of 4,020 million kilowatt-hours by 1965 and will grow to 7,630 million kilowatt-hours with a peak demand of 1,390,000 kilowatts by 1980.

In 1957 New Brunswick utility requirements amounted to 680 million kilowatt-hours, with an annual peak demand of 152,000 kilowatts. The record of past energy requirements in the Province, however, is one of spectacular growth, particularly in the years following World War II. Between 1940 and 1957 the utility market increased some 450 percent. Further growth can be expected as uses of electricity find wider application with greater industrialization in the Province and exploitation of its mineral resources. According to estimates prepared by The New Brunswick Electric Power Commission, requirements will continue to increase to 1,220 million kilowatt-hours in 1965 and to 3,040 million kilowatt-hours in 1980.

From 1940 to 1957 the energy requirements of the combined markets increased from 1,228 to 3,362 million kilowatt-hours, for an over-all increase of 174 percent. In the same period of time the peak demand increased from 238,000 to 645,000 kilowatts, for a gain of 171 percent. Energy requirements of the combined market will increase to an estimated 8,450 million kilowatt-hours in 1975, and to 10,670 million in 1980, an average annual growth during this five-year period of 440 million kilowatt-hours. Peak demand is expected to increase to 1,590,000 kilowatts in 1975 and to 1,990,000 kilowatts in 1980, an average annual increment of 80,000 kilowatts during this five-year interval.

Total kilowatts of capacity required in addition to that scheduled for installation in the near future to meet the growing utility loads in Maine and New Brunswick, considering reserves and retirements, is shown in the following table.

Year	Maine	New Brunswick	Total
1965	200,000	28,000	228,000
1970	405,000	135,000	540,000
1975	650,000	258,000	908,000
1980	955,000	427,000	1,382,000

Thus, the power market surveys revealed that the need for additional capacity to meet future demands in both Maine and New Brunswick could readily absorb by 1980 the 555,000 kilowatts of dependable capacity from the Passamaquoddy tidal plant and the Rankin Rapids hydroelectric plant on the Saint John River, the largest project combination studied.

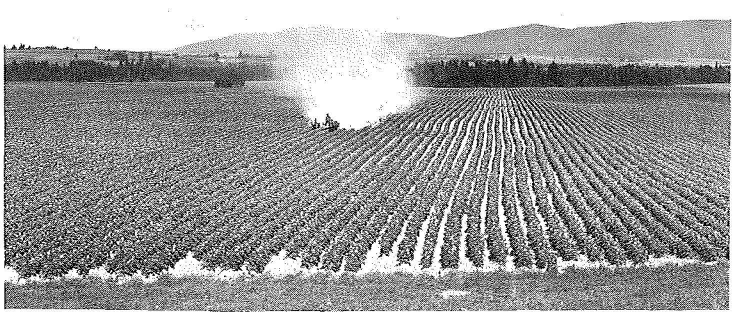
ECONOMIC EFFECTS

In consonance with the objectives of the comprehensive survey, and for purposes of economic analysis of the project, an evaluation was made of all possible beneficial and damaging effects that construction of the tidal project, with and without an auxiliary power plant, may have on the regional and national economies. These studies encompassed all aspects of the general economies, including power markets, manufacturing and industrial growth, the lumber, pulp and paper industries, agriculture, fisheries, recreation, transportation systems and consideration of national defense.

In the State of Maine, the largest income-producing and power-consuming segment of the economy is manufacturing, which includes lumber, pulp and paper production, fish processing, textiles and apparel, leather and leather goods, and food processing. The next largest employed group is engaged in wholesale and retail trade, followed by agriculture, fisheries, recreation, and professional and related services. With the exception of the textile industry, almost all segments of the Maine economy have shown continuous growth. Extensive efforts are being made to attract new and diversified industries into the state.

With 86 percent of the land area of the state in forest, the forest products industry is the most important single element in the state's economy, and the long-time prospects of forest-based industries are favorable, particularly the pulp and paper industry. Agriculture has long been dominated by the potato crop of Aroostook County. Despite rising output in other parts of the country, Maine has maintained its position as the leading potato-producing state by attaining greatly increased yields on a reduced acreage. An important recent development in Maine agriculture is that the growth of poultry production has surpassed the potato crop as the leading source of farm income. The long-established fishing and fish processing industry has produced higher personal income in recent years due to the growth in demand for more expensive fish, particularly the valuable lobster catch.

Important future growth is also expected in the recreation industry of Maine, which in 1959 ranks as the second largest income-producing activity in New England as a whole. The value of the recreation industry in Maine rose from $135 million in 1950 to $272 million in 1957. The Passamaquoddy tidal power project, which would be the first large-scale tidal power plant in the western hemisphere, and perhaps the first in the world, would attract a great number of visitors. Had the tidal project been in existence in 1957, an estimated 800,000 visitors from the United States and Canada would have been attracted to the area.



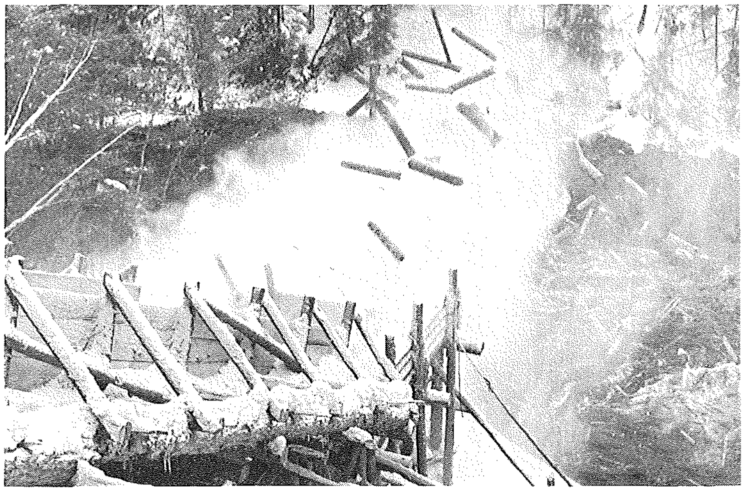
Spraying a potato field

In addition to the fact that the growing power markets of Maine can readily absorb all project power by 1980, other important advantages in Maine should encourage more rapid economic growth. The State has a large labor force of high quality. In 1956 non-agricultural employment amounted to 281,700, of which nearly 39 percent were engaged in manufacturing -- a considerably higher percentage than the United States average. Native ingenuity, versatility, sense of responsibility, and productivity, as well as a higher than average educational level, make this labor force readily adaptable to new employment opportunities.

At present, rail and commercial air transport are adequate and stimulating to economic communication among all parts of the State. The highway system is not only adequate and modern, but is keeping well ahead of requirements. In the field of coastal and overseas transport, Maine has many superb harbors which were the basis of her prosperous economy during the nineteenth century and which, today, because of relative proximity to Europe, the St. Lawrence Seaway, and leading eastern ports, constitute a great economic potential.

Other advantages in Maine attractive to new enterprises are the availability of suitable industrial sites; abundant supplies of fresh water; access to overseas raw materials; favorable and cooperative local governments and business organizations; and proximity to leading academic, professional, and research centers throughout New England.

Construction of the tidal power project and its auxiliary power plant would have a favorable impact on all segments of the economy of Maine. As well as assisting to supply the needs of the growing power markets in the state., construction and operation of the tidal project and its auxiliary would serve to regenerate the economy of Maine, particularly in Washington County. In addition to long-term beneficial effects, construction of the tidal power project alone would also produce an important short-term impact on the economy of Maine resulting from an investment of $100 million or more. The economy of Washington County would be transformed during the six-year construction period of the project by the influx of several thousand workers and the generation of substantial new income from wages alone.



Pulpwood chute

As reflected in the power market and economic surveys, considerable growth is expected in the economy of New Brunswick. Manufacturing, the leading economic activity of the Province, is based on pulp and paper, the lumber and wood-using industries, minerals, and fishing and fish processing. Other major segments of the economy are agriculture, construction, secondary manufacturing, food processing, the recreation industry and professional and other services.

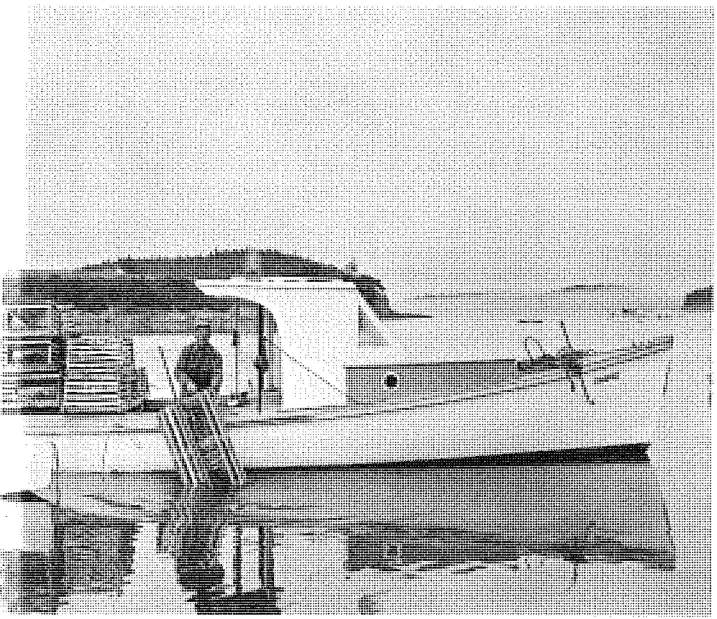
Rapid growth is expected in almost all segments of the Provincial economy. Long-term economic growth, however, is expected to be most pronounced in resource-based industries that manufacture for export. Pulpwood and paper production, based on the vast timber resources of the Province, is economically the most important industry and is expected to double by 1980. Canada's domestic market for pulp and paper products is growing rapidly, and market prospects in the United Kingdom and Western Europe appear equally favorable.

Exploitation of the recently discovered deposits of base metals in the Bathurst-Newcastle area is also expected to stimulate the economy. The discovery of lead, zinc, copper, and silver is of major economic importance, and by 1980 mineral production is expected to be second only to the pulp and paper industry as an employer and in value of product. Large deposits of high-grade ores, suitably located near tidewater, have already brought about a sizeable investment of external capital, and one 1,500-ton per day concentrating mill has been put into operation.

Important growth is also expected in the fishing and fish processing industries. Shellfish, particularly lobsters, constitute a substantial part of the total .market value. Sharply increased ouput through mechanization and the growth of by-product use is expected to stimulate the future growth of the fishing industry.

Because manufacturing in areas other than mineral, forest, and fish processing is not highly developed in New Brunswick, the efforts of the Maritime Provincial Governments and the Maritime Boards of Trade to attract new industries to New Brunswick have led to the formation of the Atlantic Provinces Economic Council. With well-developed transportation systems, port facilities, a growing and dependable labor force and other assets, the future development of secondary industries in the Province can be expected.

The tourist industry is recognized as a growing segment of New Brunswick's economy, income from which is estimated to be from 30 to 40 million dollars annually. A total of 1,370,000 people visited the Province in 1958. Construction of the Passamaquoddy tidal power plant, by attracting an estimated 800,000 or more visitors each year from the United States and Canada, would further increase the recreation industry.



Lobster fishing

The economic effect of the tidal project in New Brunswick resulting from the addition of a large block of power from the tidal project and its auxiliary would be similar to that of any other block of power of equal size and cost developed to satisfy the growing load demand. The short-term economic benefits to the economy of Charlotte County would be substantial. Construction of the project, with attendant expenditures of $100 million or more to purchase materials and equipment, would have a stimulating effect on the provincial economy. Substantial new income could be expected to stimulate retail trade, and construction of the project would improve the lumber industry in the county.

Inherent in the name "Passamaquoddy," derived from the Indian word "Peskutumaquahdik," meaning "place where the fish are," or "place of the pollock," is the importance of the fisheries in the waters within the tidal project area. On the recommendations of the International Passamaquoddy Fisheries Board, two fishways to pass anadromous fish from the ocean into Passamaquoddy and Cobscook Bays, and the relocation, if necessary, of two lobster pounds in the upper pool, were included in the tidal project. By including these remedial measures, the tidal project would have only a minor residual effect on the fisheries of the region.

Since the tidal project would raise the level of the Passamaquoddy Bay high pool and decrease the tidal range, navigation conditions would be improved in the St. Croix River estuary and at St. Andrews and other ports on Passamaquoddy Bay. In the low pool in Cobscook Bay, on the other hand, the beneficial effects of decreasing the tidal range would be partially offset by lowering the maximum level of the low pool to a point below the level of normal high tide. Navigation in the lower pool in the Falls Island and Lubec area, where rapid tidal currents occur, would be improved during a considerable portion of the tide cycle. While the lower pool is being emptied, however, tidal velocities would occur equal to those under present conditions. In general, tidal velocities in the project area would be reduced, except in areas immediately adjacent to the gates when open.

Construction of the tidal power project would require relocation of part of State Highway 190, one track of the Maine Central

Railroad, and water lines and other utilities coming from the north to Eastport, Maine. These utilities would be cut by the powerhouse forebay channel excavated through the narrow neck of Moose Island. The cost of these relocations, which would require construction of a highway and railroad bridge across the powerhouse forebay, would be charged to the power project.

Construction of the dams, locks and gates would provide foundations on which a system of public highways could be built to serve both the United States and Canada.

The defense agencies of both United States and Canada concluded that construction of the tidal power project would have no effect on defense planning. It is estimated, however, that the annual energy of 3,063 million kilowatt hours generated by the Passamaquoddy tidal plant in combination with the Rankin Rapids hydroelectric plant would save 1,280,000 tons of coal, or approximately 5,700,000 barrels of oil, during each year of operation. This would preserve 64 million tons of coal, or 585 million barrels of oil, over a 50-year period.

PROJECT EVALUATION

The benefits of the tidal power project must exceed the cost to the taxpayer if it is to be economically sound. Accordingly, the economic justification of the project depends upon whether its power can be produced more economically than the least costly alternative method of developing an equivalent amount of power.

Estimates of the cost of the tidal project and its auxiliaries are based on United States currency at price levels of January 1958. Estimated project costs were derived from the basic costs of labor, equipment, material and supplies as applied to the pre-determined construction method planned for each major feature of the project. Equipment costs, based on manufacturers' quotations in both countries, are taken to be duty free, although appropriate import duties were used for comparison with equipment costs from foreign sources. The first cost, or construction cost, includes an allowance for 10 percent profit, 15 percent for contingencies, and 9 percent for engineering, supervision and overhead. The cost of transmission lines were not included in the first costs, but have been accounted for in the evaluation of the project. On this basis, the first cost of each of the four project combinations, not including interest during construction, is as follows:

(1) Passamaquoddy tidal project alone — $484,000,000

(2) Tidal project with all of Rankin Rapids as auxiliary — $630,000,000

(3) Tidal project with auxiliary capacity only at Rankin Rapids — $515,500,000

(4) Tidal project with Digdeguash pumped-storage auxiliary — $518,500,000

It is assumed that the financing of each project would be an undertaking of the two governments, and that the first cost of the project would be shared equally between the United States and Canada, just as the power is equally shared. The degree of economic justification is measured by the ratio of annual benefits to annual costs. Annual costs of the tidal project and its auxiliary include interest and amortization of the initial investment and the annual cost of operation and maintenance.

In accordance with the current Federal practice in evaluating water resource projects, the interest rate used for economic analysis in the United States is 2 1/2 percent. In Canada the interest rate is 4 1/8 percent, which was the rate used in January 1958 by the Federal Government of Canada. Therefore, differences in interest rates and power values between the two countries led to computation of separate benefit-cost ratios for each country. The investment is amortized over two periods, 50 years and 75 years, with allowances made for periodic major replacement and self insurance.

Power benefits, the value of power produced by the tidal project and its auxiliary, are taken as equal to the cost of power generated by a steam-electric plant, with allowances for transmission lines and annual transmission costs. Alternative steam-electric plants were assumed privately financed in the United States, and financed by The New Brunswick Electric Power Commission in Canada.

Thus the ratio of benefit to cost for each of the four project combinations was computed by dividing the total annual benefits by the annual costs.

CONCLUSIONS

(1) A tidal power project using the waters of Passamaquoddy and Cobscook Bays can be built and operated. The two-pool type of project is best suited for the site conditions in the area and the power markets it would serve. The tidal project arrangement selected makes best use of the site conditions.

(2) The first cost (construction cost) of the tidal power project by itself would be $484 million. With interest during construction, the investment would be $532.1 million. The tidal power project would have an installed capacity of 300,000 kilowatts and a dependable capacity of 95,000 kilowatts. Average annual energy would be 1,843 million kilowatt-hours. However, for maximum power benefits, the tidal power project would have to be combined with an auxiliary power source.

(3) The most favorable project combination is the tidal power project operated in conjunction with a river hydroelectric auxiliary built at the Rankin Rapids site on the upper Saint John River in Maine. The combined cost of the tidal project and the Rankin Rapids auxiliary is $630 million. With interest during construction, the investment would be $687.7 million. The dependable capacity of this combination would be 555,000 kilowatts, and average annual generation would be 3,063 million kilowatt-hours.

(4) Construction of the tidal project - Rankin Rapids combination would increase low flows in the lower Saint John River by a considerable amount, thus increasing substantially the usefulness of the river for downstream generation of power. Downstream benefits accruing to existing power plants were included in the economic evaluation.

(5) The combination of the tidal power project and the installation and use of 260,000 kilowatts of capacity only at Rankin Rapids for firming up the output of the tidal power project would cost $515.5 million. With interest during construction, the investment would be $565.7 million. This combination would provide a total dependable capacity of 355,000 kilowatts and an average annual generation of 1,843 million kilowatt-hours.

(6) The tidal power project and the Digdeguash pumped-storage auxiliary would cost $518.5 million. With interest during construction, the investment would be $568.9 million. The dependable capacity would be 323,000 kilowatts, and average annual generation would be 1,759 million kilowatt-hours.

(7) The total output from the tidal power project and Rankin Rapids hydroelectric plant can be absorbed readily by the growing utility markets of Maine and New Brunswick.

(8) Because of differences in interest rates prevailing in the two countries, and because of different values of alternative power, it was necessary to compute separate benefit-cost ratios for United States and Canada. Economic evaluations, assuming 50-year and 75-year amortization periods, and assuming that power output and project first cost would be equally divided between the United States and Canada, are tabulated below:

	50-year amortization		75-year amortization	
	Benefit cost ratio	Cost per kw.-hr., (mills)	Benefit cost ratio	Cost per kw.-hr., (mills)
Tidal project alone				
United States	0.60	10.8	0.70	9.3
Canada	0.34	14.9	0.37	13.7
Tidal project and all of Rankin Rapids				
United States	1.31	8.4	1.53	7.2
Canada	0.58	11.5	0.63	10.6
Tidal project and incremental capacity only at Rankin Rapids				
United States	0.93	11.5	1.08	9.9
Canada	0.42	15.8	0.45	14.5
Tidal project and Digdeguash pumped-storage auxiliary				
United States	0.91	12.2	1.06	10.5
Canada	0.42	16.8	0.46	15.4

(9) The inclusion of taxes foregone with project costs is not the practice in the economic justification of public projects in Canada, and due to the international nature of the project, such taxes have not been applied to United States' costs. However, if they were included in United States' costs, the benefit to cost ratio of the most favorable project combination would be reduced to 1.10 for the 50-year amortization period and to 1.25 for the 75-year period.

(10) By including appropriate remedial measures in the design of the tidal power structures, the construction, maintenance and operation of the tidal power project would have only a minor residual effect on the fisheries of the region.

(11) Considerable annual recreation benefits would grow out of the construction and operation of the tidal power project. However, the monetary value of these benefits was not included in the economic evaluation.

(12) Assuming an equal division of power output and of first costs between United States and Canada, construction of the tidal power project with all of Rankin Rapids as auxiliary is not an economically justified project for Canada.

(13) The Passamaquoddy tidal project and Rankin Rapids combination, if built entirely by the United States at an interest rate of 2 1/2 percent, is economically justified.

PERTINENT DATA

PASSAMAQUODDY TIDAL POWER PROJECT

Location

Passamaquoddy Bay and Cobscook Bay, in Maine and New Brunswick.

High Pool

Passamaquoddy Bay, Maine, and New Brunswick.

Area, sq. mi.	101
Max. operating level, ft., m.s.l.	12.2
Min. operating level, ft., m.s.l.	3.0

Low Pool

Cobscook Bay, Maine, and Friar Roads, New Brunswick.

Area, sq. mi.	41
Max. operating level, ft., m.s.l.	0.0
Min. operating level, ft., m.s.l.	-12.9

Powerhouse

Outdoor type; two 220-ton gantry cranes; thirty 320-inch diameter fixed-blade, propeller type, vertical-axis turbines direct connected to 10,000-kw., 13,800-volt, 3-phase, 60-cycle generators turning at 40 r.p.m.; average power head 11 feet.

Dams

Earth and rockfill type

Total length, ft.	35,700
Max. height, ft.	315
Crest elevation, ft., m.s.l.	25

Filling and Emptying Gates

Ninety 30- x 30-foot vertical-lift, submerged venturi filling gates. Seventy 30- x 30-foot vertical-lift submerged venturi emptying gates.

Navigation Locks

Head Harbour Passage, ft.	415 x 60 x 21
Western Passage, ft.	415 x 60 x 21
Little Letite, ft.	95 x 25 x 12
Quoddy Roads, ft.	95 x 25 x 12

Principal Quantities

Rock and earthwork	
Dams, cu. yd.	53,000,000
Cofferdams, cu. yd.	12,000,000
Misc. fill, cu. yd.	1,000,000
Waste, cu. yd.	9,000,000
Concrete, cu. yd.	1,473,000
Steel, tons	182,000

RANKIN RAPIDS HYDRO AUXILIARY

Location

Saint John River, Maine, 291 miles above mouth.

Streamflow

Ave. annual runoff, ac.-ft.	4,950,000
Max. discharge, c.f.s.	90,400
Min. discharge, c.f.s.	373
Ave. discharge, c.f.s.	6,780

Reservoir

Drainage area, sq. mi.	4,060
Max. operating level, ft., m.s.l.	860
Limit of drawdown, ft., m.s.l.	823
Useable storage, ac.-ft.	2,800,000
Total storage, ac.-ft.	8,230,000
Area, max. operating level, ac.	93,300

Main Embankment

Crest length, ft.	7,400
Max. height, ft.	333
Crest elevation, ft., m.s.l.	875

Spillway

Six 30- x 40-foot taintor gates

Crest elevation, ft., m.s.l.	830
Design discharge, c.f.s.	167,000

Low Level Outlets

Two 24-foot diameter tunnels controlled by four 90-inch fixed-cone dispersion valves.

Powerhouse

Indoor type, concrete. Eight Francis-type, vertical-axis turbines, ave. head 284 ft., direct connected to 50,000-kw., 13,800-volt, 3-phase, 60-cycle generators turning at 164 r.p.m.

Principal Quantities

Rock and earthwork	
Dams, cu. yd.	33,000,000
Miscellaneous, cu. yd.	1,500,000
Concrete, cu. yd.	400,000
Structural steel, tons	19,000
Reinforcing steel, tons	12,000

DIGDEGUASH PUMPED-STORAGE AUXILIARY

Location

Mouth of Digdeguash River, New Brunswick.

Streamflow

Ave. annual runoff, ac.-ft.	265,000

Reservoir

Drainage area, sq. mi.	176
Max. operating level, ft., m.s.l.	180
Min. operating level, ft., m.s.l.	140
Useable storage, ac.-ft.	204,000
Total storage, ac.-ft.	308,500

Embankments

Impervious core, rock-shell.

Total length, ft.	5,500
Max. height, ft.	190

Powerhouse

Indoor type, concrete. Four adjustable feathering-blade pump-turbines; mean pumping head 158 ft.; mean generating head 154 ft. Four motor-generators, 100 r.p.m., rated at 84,300 h.p., 13.8 kv., as motors; 68,300 kv.-a., 13.8 kv., 0.95 P.F., as generators.

Spillway

Three 25- x 40-foot taintor gates

Crest elevation, ft., m.s.l.	155
Design discharge, c.f.s.	75,000

Principal Quantities

Rock and earthwork	
Dams, cu. yd.	1,881,000
Miscellaneous, cu. yd.	269,000
Concrete, cu. yd.	130,000
Structural steel, tons	3,000
Reinforcing steel, tons	2,400

POWER OUTPUT AND CONSTRUCTION COST

In this table it is assumed that power output and project first cost would be shared equally by the United States and Canada. The initial investment includes 2 1/2 percent interest during construction on the United States' share of the first cost and 4 1/8 percent interest on Canada's share of the first cost. Costs are based on price levels of January 1958.

Project Combination	Dependable capacity (kw.)	Average annual generation (millions of kw.-hr.)	Total project first cost (millions of dollars)	Initial investment (millions of dollars) United States	Canada
Tidal project alone	95,000	1,843	484.0	260.2	271.9
Tidal project and all of Rankin Rapids	555,000	3,063	630.0	336.8	350.9
Tidal project and incremental capacity only at Rankin Rapids	355,000	1,843	515.5	276.8	288.9
Tidal project and Digdeguash pumped-storage capacity	323,000	1,759	518.5	278.4	290.5

CHAPTER I

INTRODUCTION

AUTHORITY

United States Public Law 401, 84th Congress, 2nd Session, approved by the President on January 31, 1956, authorized the State Department to request the International Joint Commission, in accordance with the Boundary Waters Treaty of 1909 with Canada, to arrange for a final comprehensive survey of an international Passamaquoddy tidal power project. The Governments of the United States and Canada, on August 2, 1956, transmitted to the International Joint Commission the following Reference:

In accordance with the provisions of Article IX of the Boundary Waters Treaty of January 11, 1909, the Governments of Canada and the United States have agreed to refer and do hereby refer to the International Joint Commission the following matters for joint examination and advisory report, including conclusions and recommendations:

a) It is desired that the Commission determine the estimated cost of developing the international tidal power potential of Passamaquoddy Bay in the State of Maine and the Province of New Brunswick, and determine whether such cost would allow hydroelectric power to be produced at a price which is economically feasible;

b) The Commission is requested to determine the effects, beneficial or otherwise, which such a power project might have on the local and national economies in the United States and Canada, and to this end, to study specifically the effects which the construction, maintenance and operation of the tidal power structures might have upon the fisheries in the area.

In the discharge of its responsibilities under this reference, the Commission is requested to review and, in so far as is practicable, make advantageous use of existing reports and plans such as the Report of March 15, 1950, submitted by the International Passamaquoddy Engineering Board to the Commission and the supplemental report of May 1952 prepared by the United States Army Corps of Engineers on the details of estimate of cost of a comprehensive investigation of the Passamaquoddy tidal power project. Having regard to the foregoing, the Commission should determine the most desirable general project design from the viewpoint of the public interest in United States and Canada respectively – such design to include plans for structure and appurtenant works in sufficient detail to form the basis of dependable cost estimates and considerations of economic feasibility.

In the conduct of its investigations, and otherwise in the performance of its duties under this reference, the Commission may utilize the services of specially qualified engineers and other experts of the technical agencies of the United States and Canada and will, so far as possible, make use of any pertinent data that may be available in such agencies or which may become available during the course of the investigations, thus avoiding duplication of effort and unnecessary expense.

The United States Government is willing, subject to the availability of funds, to incur cost in connection with this survey up to $3 million, and the Canadian Government is willing to incur costs up to $300,000. Each Government has the right to participate at its own expense in all aspects of the survey to an extent appropriate with its interest. In making administrative arrangements for the necessary surveys and studies, the Commission should give suitable effect to these responsibilities.

The costs incurred by the Governments of the United States and Canada respectively under this Reference will be credited against the costs to be borne by each of the Governments in the event that the project should be constructed as a joint undertaking by the two Governments. The decision of the two Governments to refer this study to the

Commission does not imply any commitment regarding the eventual construction of the project.

It is the desire of both Governments that the Commission endeavour to complete its various surveys, investigations, studies and other activities under the Reference within a three-year period. Upon completion, it is requested that the Commission prepare and submit to the Governments of the United States and Canada a comprehensive report covering the subject matter of this Reference. The Commission's report should include the details of the specific design, cost estimates, and an estimate of the benefits to be derived or the losses to result from this project.

The site with which the Reference is concerned lies across the international boundary between the United States and Canada and includes Cobscook Bay, Maine and Passamaquoddy Bay, Maine and New Brunswick. The relation of the site to the New England States and the Maritime Provinces is shown on plate 1 in the syllabus. Plate 3 is a map of the two bays and the adjoining areas.

The International Joint Commission, at its meeting on October 3, 1956, established the International Passamaquoddy Engineering Board and the International Passamaquoddy Fisheries Board to carry out the studies required to fulfill the terms of the Reference to the Commission. At this meeting the Commission issued the following directive to the two Boards:

a) The Engineering Board will carry out all the engineering investigations and studies necessary to enable the Commission to prepare and submit to the Governments of the United States and Canada a comprehensive report on the proposed Passamaquoddy Tidal Power Project, as requested by the two Governments in a Reference to the Commission dated 2 August, 1956.

b) The Fisheries Board will study specifically the effects which the construction, maintenance and operation of the tidal power structures, proposed, might have upon the fisheries in the area.

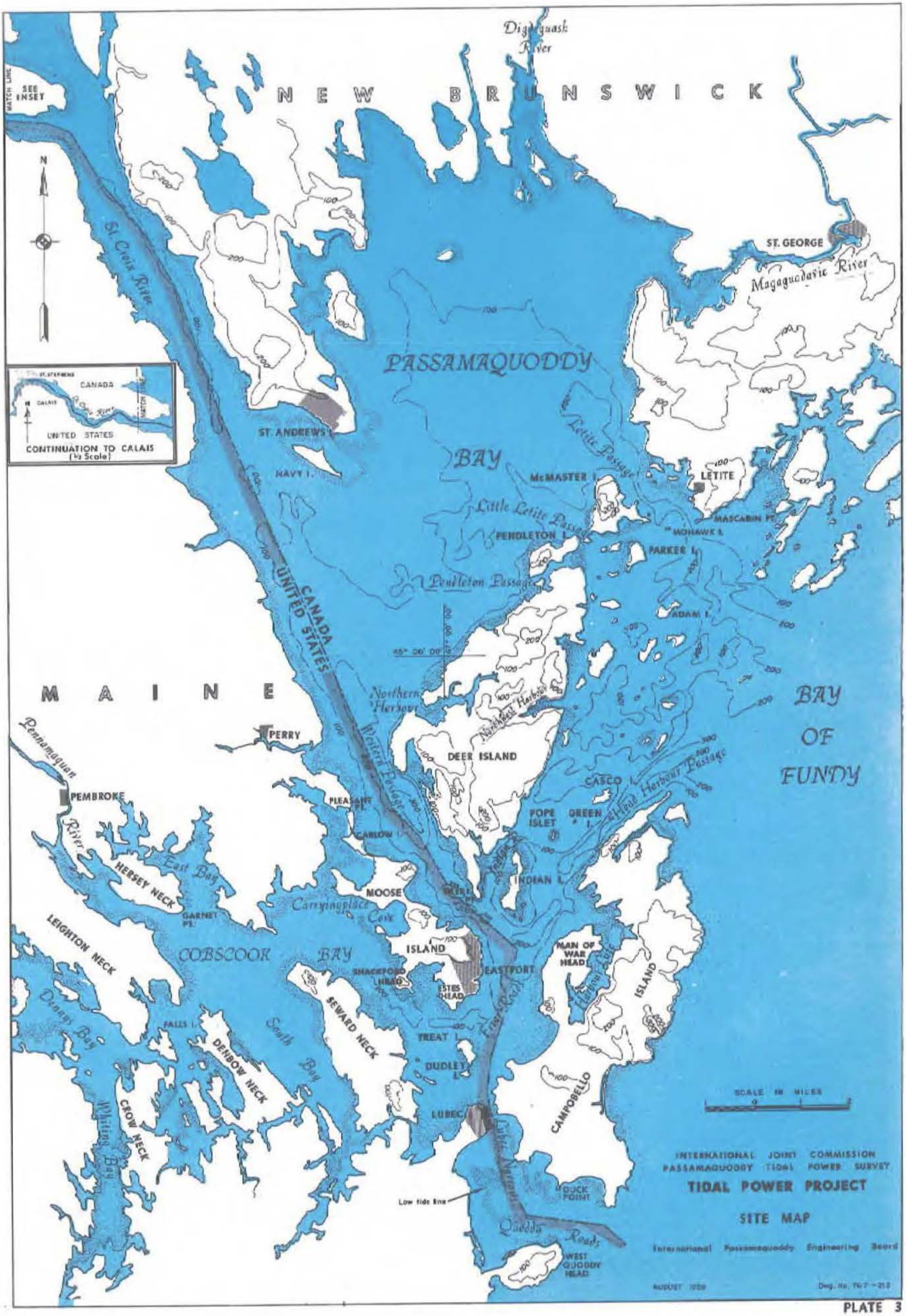
c) In order to enable the Fisheries Board to commence its studies and investigations without delay, the Engineering Board is requested to forward to the Commission as soon as possible, for transmittal to the Fisheries Board, an outline of the various project plans which the Engineering Board proposes to investigate. Pending the submission of this information it is suggested that the Fisheries Board proceed with its studies on the basis of the general plans outlined in the March 15, 1950 Report of the previous International Passamaquoddy Engineering Board.

d) In order that each of the Boards may be fully aware at all times of the progress being made in the investigations and studies carried out by the other Board, each Board is requested to keep the Commission currently informed regarding the investigations and studies it is conducting. The Commission will undertake responsibility for promptly transmitting the information thus received to the other Board, together with such suggestions or instructions as may appear to be appropriate.

e) In accordance with the desire of the two Governments as evidenced by the terms of the Reference the Engineering Board is requested to review and to utilize, insofar as is practicable, existing reports and plans such as the Report of 15 March, 1950, submitted to the Commission by the previous International Passamaquoddy Engineering Board, and the supplemental report of May, 1952 prepared by the Corps of Engineers, United States Department of the Army.

f) Each Board is authorized to establish such committees and working groups as may be required to effectively discharge the Board's responsibilities.

g) In accordance with the desire expressed by the two Governments, the Commission will endeavour to complete its various investigations and studies under the Reference within a three year period and submit a comprehensive report covering the subject matter of the Reference as soon as possible thereafter. In order that this may be done, the Commission would appreciate receiving the final reports of both Boards prior to 1 October, 1959.


NEW BRUNSWICK
MAINE
PASSAMAQUODDY BAY
BAY OF FUNDY
COBSCOOK BAY
DEER ISLAND
CAMPOBELLO ISLAND
MOOSE ISLAND
ST. ANDREWS
ST. GEORGE
Magaguadavic River
LETITE
PERRY
PEMBROKE
EASTPORT
LUBEC
St. Croix River
CANADA
UNITED STATES
SEE INSET
MATCH LINE
CONTINUATION TO CALAIS
(½ Scale)
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
SITE MAP
International Passamaquoddy Engineering Board
SCALE IN MILES
Low tide line

h) Each Board will prepare and submit semiannual progress reports to the Commission on or about 31 March and 30 September of each year and such other reports from time to time as the Commission may direct or as the Board may consider desirable.

BOARD MEMBERSHIP

The International Joint Commission appointed the following members to the International Passamaquoddy Engineering Board:

UNITED STATES SECTION

Samuel D. Sturgis, Jr., Chairman
Lieutenant General, U.S. Army (Ret.)

Francis L. Adams
Chief, Bureau of Power, Federal Power Commission (to August 1958)

Frank L. Weaver
Chief, Division of River Basins, Bureau of Power, Federal Power Commission (from August 1958)

CANADIAN SECTION

Jean P. Carriere, Chairman
Chief Engineer, Department of Public Works (to March 1957)

Gerald Millar, Chairman
Chief Engineer, Department of Public Works (from March 1957)

Charles K. Hurst
Water Resources Branch, Department of Northern Affairs and National Resources (to September 1957)

H. B. Rosenberg
Water Resources Branch, Department of Northern Affairs and National Resources (from September 1957)

Board Secretaries

The Engineering Board appointed the following secretaries to their respective sections:

UNITED STATES SECTION

John W. Roche
U.S. Army Corps of Engineers

CANADIAN SECTION

J. F. Godsell
Department of Public Works (to May 1957)

Charles K. Hurst
Department of Public Works
(from May 1957)

Engineering Committee

The Engineering Board established an Engineering Committee in November 1956 to supervise the detailed investigations of the survey. The following were appointed to the Committee:

UNITED STATES SECTION

Robert J. Fleming, Jr., Chairman
Brigadier General, U.S. Army
Division Engineer, U.S. Army Engineer Division, New England (to April 1957)

Alden K. Sibley, Chairman
Brigadier General, U.S. Army
Division Engineer, U.S. Army Engineer Division, New England (from April 1957)

Richard D. Field, Alternate Chairman
U.S. Army Engineer Division,
New England (to December 1958)

Day J. Wait,
Regional Engineer, New York
Federal Power Commission

CANADIAN SECTION

R. P. Henderson, Chairman
District Engineer, Department of Public Works, Harbours and Rivers Engineering Branch, Saint John, New Brunswick
(to May 1957)

J. F. Godsell, Chairman
District Engineer, Department of Public Works, Harbours and Rivers Engineering Branch, Saint John, New Brunswick
(from May 1957)

J. E. Peters,
District Engineer, Department of Northern Affairs and National Resources,
Halifax, Nova Scotia

The Engineering Committee Secretaries were Mr. George A. Makela, U.S. Army Engineer Division, New England, for the United States Section; and Mr. C. D. McAllister, Assistant District Engineer, Department of Public Works, Saint John, New Brunswick for the Canadian Section. Mr. McAllister died in March 1959, and his duties were assumed temporarily by Mr. Godsell, Chairman of the Canadian Section of the Committee. Mr. L. Harriott, engineer, Department of Public Works, Saint John, New Brunswick, was appointed as the Canadian Secretary in June 1959.

The principal work group, which had the primary responsibility for preparing material for the survey report, was established under the Division Engineer of the U.S. Army Engineer Division, New England, Waltham, Massachusetts. The group was under the direct supervision of Mr. Richard D. Field until December 1958, and under Mr. John Wm. Leslie thereafter. Power marketing and power value studies were conducted in the Regional Office, U.S. Federal Power Commission, New York, N.Y. The Canadian part of the study was carried out by the Harbours and Rivers Engineering Branch, Department of Public Works, and the Water Resources Branch of the Department of Northern Affairs and National Resources.

ACKNOWLEDGMENTS

Grateful acknowledgment is made of the advice and assistance obtained during the current survey from several federal, state, and provincial agencies in Canada and United States. These agencies include the Canadian Hydrographic Service; Geological Survey of Canada; the Saint Lawrence Seaway Authority of Canada; Department of Mines and Technical Surveys; Hydrographic Department, British Admiralty, England; The New Brunswick Electric Power Commission; Department of Lands and Mines, New Brunswick; the Fish and Wildlife Service and the Geological Survey of the U.S. Department of the Interior; the Coast and Geodetic Survey of the U.S. Department of Commerce; and the Maine State Highway Department. Many private individuals, groups and concerns also made valuable contributions to this survey.

REPORT PRESENTATION

This report is made up as follows: the syllabus contains a brief summary of survey investigations and findings; the main body of the text is the complete report of the survey; and nineteen appendices accompanying this report describe in detail the investigations and studies made during the survey. These appendices are listed below:

Appendix No.	Title
1	Topography and Underwater Mapping
2	Geology, Foundations, and Materials
3	Observation and Prediction of Tides
4	Basic Hydrologic Data
5	Selection of Plan of Development
6	Filling and Emptying Gates
7	Navigation Locks
8	Tidal Power Plant and Corrosion Prevention
9	Tidal Dams and Cofferdams
10	Service Facilities and Operating Staff
11	Auxiliary Pumped-Storage Developments
12	Auxiliary River Hydro Developments
13	Project Power
14	Power Markets and Transmission Lines
15	Value of Power
16	Auxiliary Steam-Electric Development
17	Estimates of Cost
18	Annual Benefits and Costs
19	Survey Administration and Coordination

POWER FROM THE TIDES

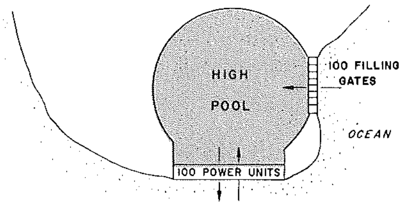
The idea of harnessing the continuous ebb and flood of the tides is not new, nor have proposals for this type of power development been confined to any particular part of the world. Details of early installations are lost, but evidence exists that tidal power was used to grind grain as early as the 11th century. During the 18th and the early part of the 19th century inventors and engineers were busy devising schemes for developing mechanical power from the tides. In general, these schemes fall into four major categories: (1) floats with a rack and pinion arrangement to convert vertical reciprocating motion to rotary motion; (2) air compressed in an open-bottomed tank by the rising tide and used to turn a turbine shaft; (3) wheels turned by tidal currents; (4) tidal pools, emptied or filled at the extremes of the tides, to provide storage for water discharged through turbines at other tide levels. A number of "tide mills" were constructed in England and America during the 18th and 19th centuries, none of which developed more than 100 horsepower. A one-pool project, developing about 50 horsepower from four wheels, was built in 1734 and still exists in Chelsea, Massachusetts. This project, known as "Slade's Mill," was used to grind spices.

With the advent of electricity and the increasing use of electrical energy, investigation of the possibilities of generating large amounts of energy in tidal power projects became world-wide. Nearly all of these studies envisioned pools in which high tides were trapped, or from which low tides were excluded.

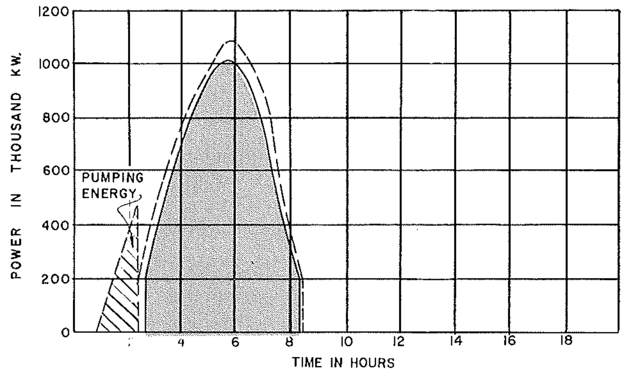
A power project using tidal pools is essentially the same as a river hydroelectric project. The amount of power generated by both methods is proportional to the amount of water flowing and the head through which it drops. Because the head at a tidal power project is considerably less than at most conventional hydroelectric projects, large quantities of water must be used to generate the same amount of power. Dams, channels, gates, and a powerhouse are needed for a tidal project as for a power project on a river. Other factors such as a rapidly varying head and problems of salt water corrosion must also be considered. For use in a tidal project, however, these structures must be built to extract power from a smaller head and greater flow. The components of a tidal project may be arranged in many different ways to generate power. These methods are described in the following paragraphs.

Single-Pool Arrangements

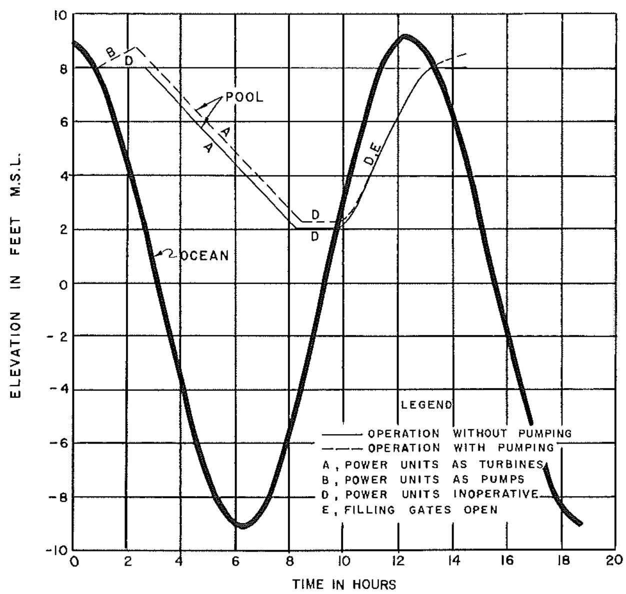
The simplest tidal project arrangement is the single-pool plan. To operate the single high-pool plan, as illustrated, the pool is filled during high tide, after which the filling gates are closed. Power is generated during



SCHEMATIC LAYOUT



POWER OUTPUT



POOL ELEVATIONS

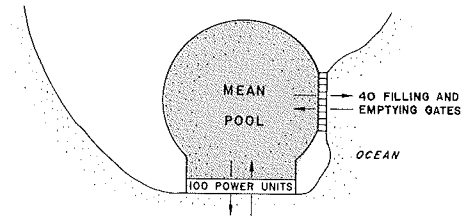
SINGLE-HIGH-POOL PLAN

each tide cycle when the head from the pool to ocean level is large enough. No power is generated during pool filling on the high tide. To operate a low-pool plan the cycle is reversed. The total energy output for the same project is greater for high-pool operation than for low-pool operation because of the larger area which the pool covers at the higher water levels.

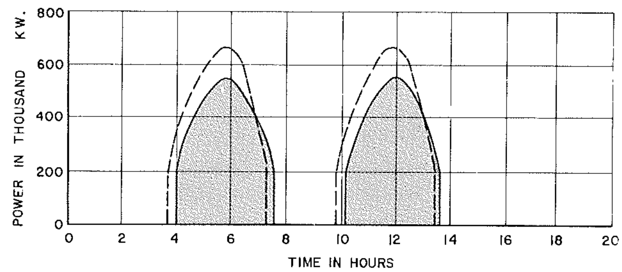
It would be an advantage in both types of single-pool projects to use turbines that also operate as pumps. This would require energy from an outside source. In the high-pool project, for example, the pool level can be raised further by pumping for a short period after the filling gates are closed. The energy used in pumping at a low head increases the pool level, and increases the head during the subsequent generating period. The energy gain in the generating cycle exceeds the energy used in pumping to the benefit of the project. In the single-high-pool illustration, the energy gain is 1.56 times the energy used for pumping.

Using turbines which can generate power from flow in either direction, a single mean pool can be operated as a high pool during low tides, and as a low pool during high tides, as illustrated. This arrangement results in two separate generating periods in each tide cycle. Because the average pool level is about the same as mean sea level, the generating head is considerably less than either the high-pool or low-pool arrangements. Because of the smaller head, total power generation for the mean-pool plan is less than with the other arrangements.

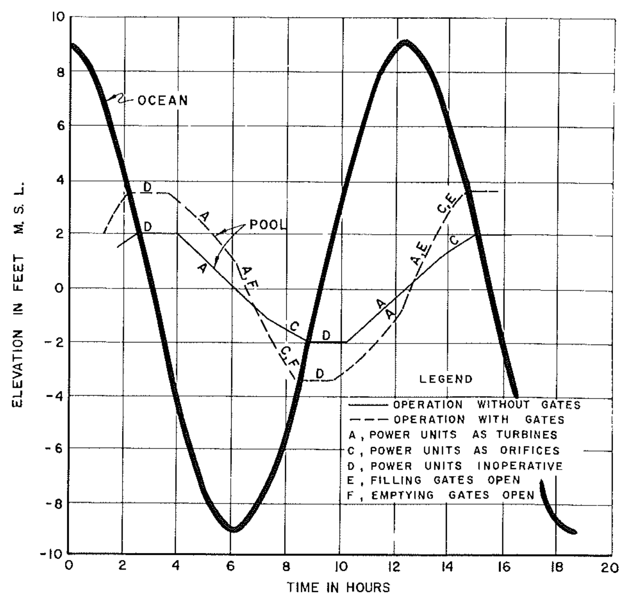
An interesting aspect of the mean-pool arrangement is the possibility of wasting water from the pool to gain energy. This apparent contradiction is diagrammed by the dotted lines on the single-mean-pool illustration. It is accomplished by use of auxiliary



SCHEMATIC LAYOUT



POWER OUTPUT

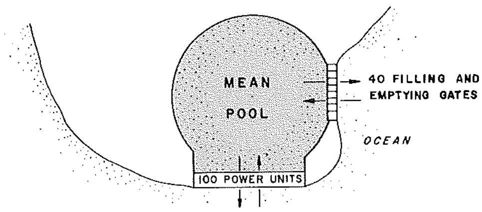


POOL ELEVATIONS

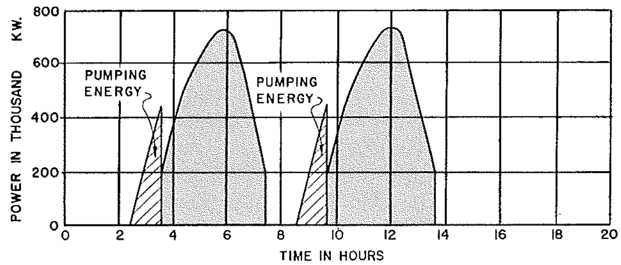
SINGLE-MEAN-POOL PLAN

gates. The gates are opened near the end of a generating period to supplement the flow through the turbines, thus hastening the change in pool level. The change in pool level increases the head and consequently the energy during the following generating period.

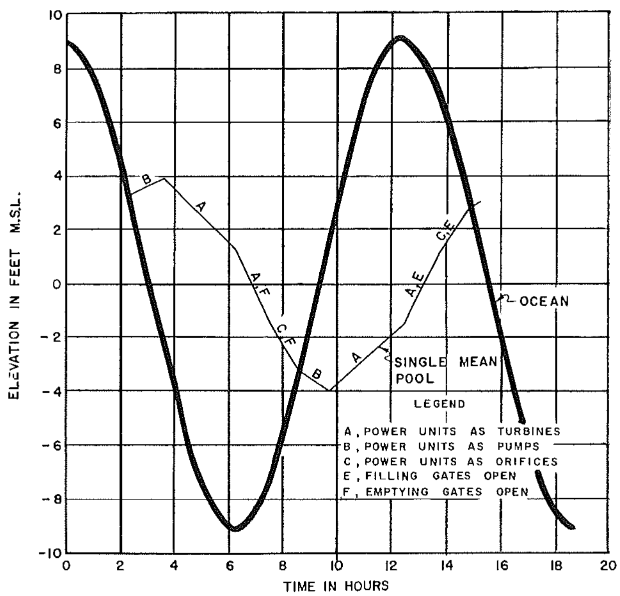
A further modification of the single-mean-pool plan, diagrammed in the next illustration, includes both auxiliary gates and additional pumping at selected periods. For this arrangement the power units are operated as turbines or pumps with flow in both directions through the powerhouse. Even with these auxiliary features, however, power generation with this arrangement remains intermittent.



SCHEMATIC LAYOUT



POWER OUTPUT



POOL ELEVATIONS

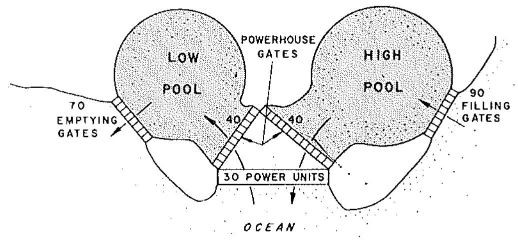
SINGLE-MEAN-POOL PLAN
WITH GATES AND PUMPING

Two-Pool Arrangements

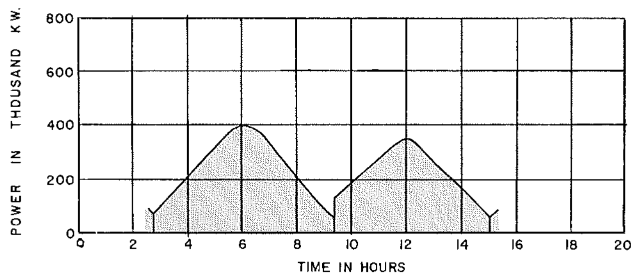
By using two separate pools, power generation can be increased by avoiding the relatively low heads of the single mean pool. A single powerhouse can be used if auxiliary gates are provided at the powerhouse, as illustrated, so that either pool can be used as needed. Since one pool is high and the other low, the turbines must be constructed for generating power from flow in either direction. To change from high-pool to low-pool operation, one set of gates at the powerhouse must be closed, the other set opened, and the direction of rotation of the turbines changed. Therefore, power generation, although greater, remains intermittent as in the single-pool arrangements.

The disadvantage of intermittent generation is overcome by the simple two-pool plan as illustrated. The high pool is filled during high tide through one set of gates, and the low pool emptied during low tide through a separate set of gates. Since one pool is operated at a high level and the other at a low level, conventional turbines which permit flow in only one direction can be used. The two-pool plan produces varying but continuous power.

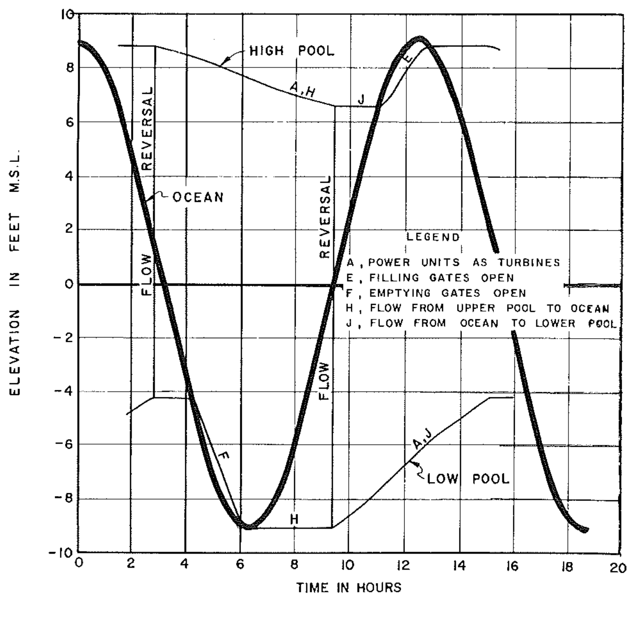
If one of the pools of a two-pool arrangement is substantially smaller than the other, the change in water level in the smaller pool occurs much faster than in the larger. However, this limited storage in a small low pool, for example, can be compensated by generating power as a single high-pool project for a short period of time immediately after low tide by discharge to the ocean. This can be done by adding two sets of gates in the tailrace of the powerhouse, as illustrated in the diagram of the two-pool plan with discharge to ocean. When the low pool reaches its lowest level, the tailrace gates leading to the low pool are closed and those leading to the ocean opened. The powerhouse then discharges to the ocean until the rising tide makes the head too small for generating. At this time, powerhouse flow is again directed to the low pool by changing the settings of the tailrace gates. The consequent saving in storage in the lower pool secured by this maneuver increases the head during the remainder of the low-pool filling period as shown. Net energy generation is therefore increased.



SCHEMATIC LAYOUT

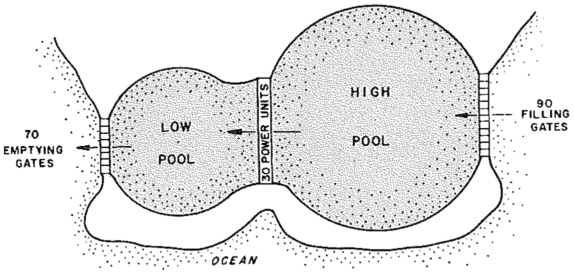


POWER OUTPUT

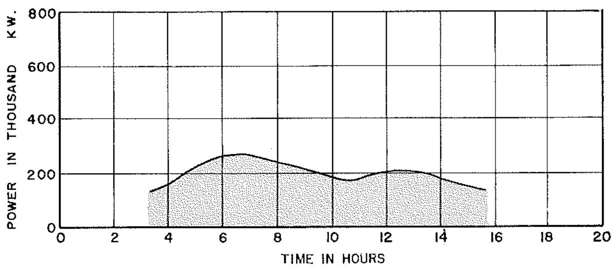


POOL ELEVATIONS

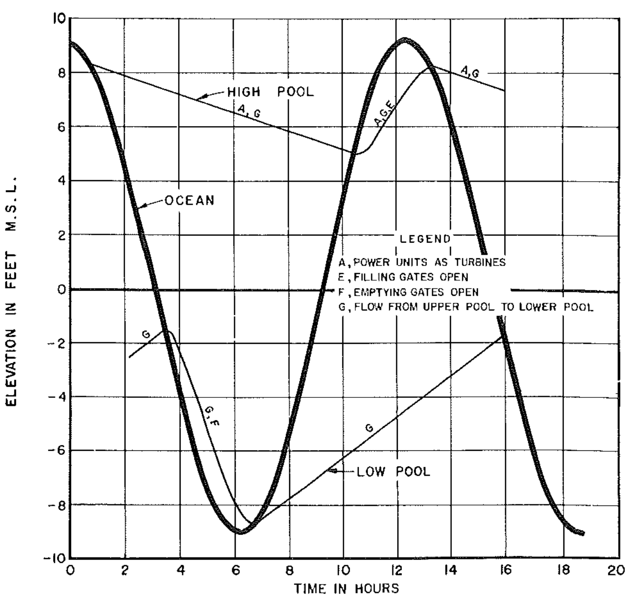
DOUBLE SINGLE-POOL PLAN



SCHEMATIC LAYOUT

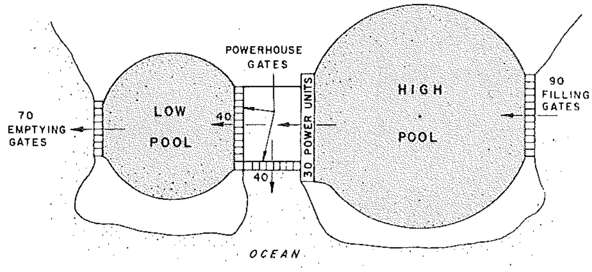


POWER OUTPUT

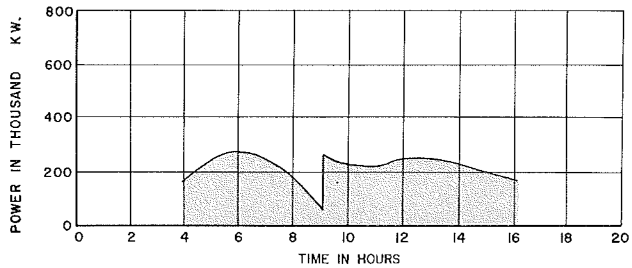


POOL ELEVATIONS

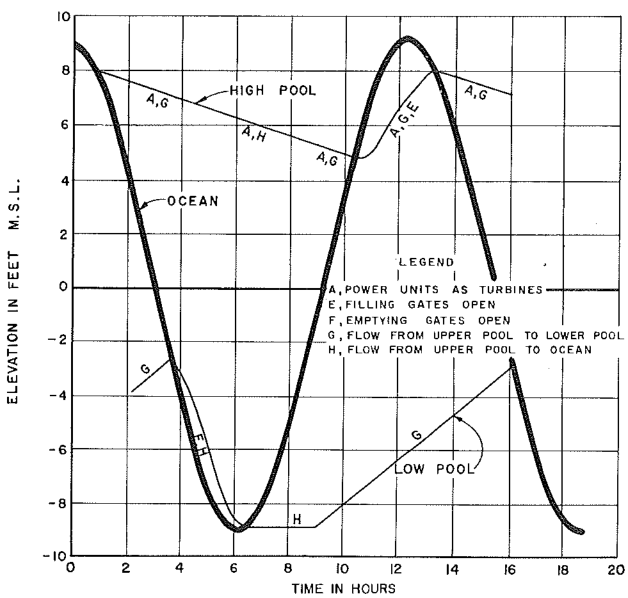
SIMPLE TWO-POOL PLAN



SCHEMATIC LAYOUT



POWER OUTPUT



POOL ELEVATIONS

TWO-POOL PLAN
WITH DISCHARGE TO OCEAN

The simple two-pool plan, which generates varying but continuous power, was adopted as a result of this survey.

SITES FOR TIDAL POWER PROJECTS

A tidal power project requires a location where the tides are high, where one or two pools can be isolated from the ocean at a reasonable cost, and where suitable sites exist for the powerhouse, gates, and other necessary works. Many countries of the world including France, The United Kingdom, Canada, Argentina, Brazil, New Zealand, and Soviet Russia have sites that fill these requirements to varying degrees. The most important of these sites are discussed in the following paragraphs.

La Rance Project, France

Of the many sites studied for tidal power on the north coast of France, such as Aber-Vrach, the Bay of Mont-Saint-Michel and others, the most important is the Rance River estuary in Brittany. To date, an access road, an office building, a concrete laboratory and other buildings have been constructed. Construction on the project proper has been deferred pending further studies to reduce project cost.

The project would use one pool, 8.5 square miles in area, to develop power from the tides which have an average range of 27.8 feet at the site. The project would be operated as a single high, low, or mean pool as required to meet peak loads. These various methods of operation are made possible by use of a recently developed bulb-type power unit which can serve as a turbine, a pump, and a conduit, with flow in either direction. The axis of the turbine is horizontal and the water passages on both sides of the turbine are parallel to the axis. A small-diameter generator is enclosed in a "bulb" immersed in the water passage in line with the turbine runner. Wicket gates are used and the runner blades are adjustable as in a Kaplan turbine. The turbines have a diameter of about 19 feet, and rotate at 88.2 r.p.m. The 32 generating units of the Rance project are rated at 9,000 kw. each, and have a total capacity of 288,000 kw. Sluiceways at one end of the powerhouse supplement the filling and emptying cycle. The average annual generation of 627 million kw.-hr. would be fed into the French power grid.

The bulb-type turbines were considered for the Passamaquoddy site during the current survey and appeared about equal in power output to the best of the conventional turbines. They were not used in the powerhouse design, however, because of their high cost, low rotative inertia, untried design, and meager maintenance experience.

Severn Plan, United Kingdom

A plan for tidal power development at the mouth of the Severn River in England was conceived in 1918 and reconsidered in 1933, 1945, and 1955. Each time the project was found uneconomical. The project plan was a single-high-pool arrangement with an installed capacity of 800,000 kw. About 2,400 million kw.-hr. a year could be generated from the tides, which range from about 22 to 48 feet at the site.

Petitcodiac and Memramcook Estuaries, Canada

The Petitcodiac and Memramcook estuaries are located in New Brunswick, Canada, at the head of the Bay of Fundy, where the tides range from 21 feet at neap (lowest) tide to 52 feet at spring (highest) tide. A 1945 report prepared for the Government of Canada considered a project with a 216,000-kw. powerhouse between two pools. Firm power was estimated to be 55,000 kw., with annual energy of 1,300 million kw.-hr. The project was found uneconomical.

Passamaquoddy Bay, United States and Canada

The Passamaquoddy site is located near the mouth of the Bay of Fundy, as shown on plate 1 in the syllabus. The tidal ranges at the site are considerably less than at the head of the bay. At Eastport, Maine, the average tidal range is 18.1 feet, the minimum neap tide 11.3 feet, and the maximum spring tide 25.7 feet.

Although the tidal ranges at the Passamaquoddy site are much smaller than those in the upper part of the Bay of Fundy, this site offers unique topographical advantages. As shown on plate 3, the site provides the opportunity of closing tidal pools from the ocean in many different ways. It also permits construction of two pools, a feature that does not exist at many potential tidal project sites. The intricate system of islands and passages of the site makes possible a wide variety of project layouts. Numerous shoal areas and narrow necks of land can be developed as sites for the required tidal dams, gates, powerhouses, and navigation locks.

PASSAMAQUODDY BAY INVESTIGATIONS

Prior to 1800, at least two small tide mills operated in Passamaquoddy Bay. They were small, single-pool schemes used for grinding grain. Tidal hydroelectric projects in the same area have been investigated intermittently over the past 40 years. Before the present survey, the two principal investigations were those made by Dexter P. Cooper from 1919 to 1933, and by the U. S. Army Corps of Engineers in 1935-37.

Studies by Dexter P. Cooper, 1919-33

Dexter P. Cooper first became interested in producing electricity from the Passamaquoddy tides in 1919, and in the early 1920's Cooper and the interests he represented started the first large-scale investigation of a Passamaquoddy tidal power project. His first scheme, international in scope, contemplated using Passamaquoddy Bay as a high pool and Cobscook Bay as a low pool. The Federal Power Commission, in 1926, issued a preliminary permit to Dexter P. Cooper, Inc. for the proposed tidal power project. The associated Canadian Dexter P. Cooper Company was chartered by the Canadian Government in 1926, subject to provisions in the interest of navigation and fisheries. The Canadian Biological Board in 1929 reported adversely on the project, after concluding that the project dams would injure the fisheries of the area. Both the United States' preliminary permit and the Canadian charter expired in 1929.

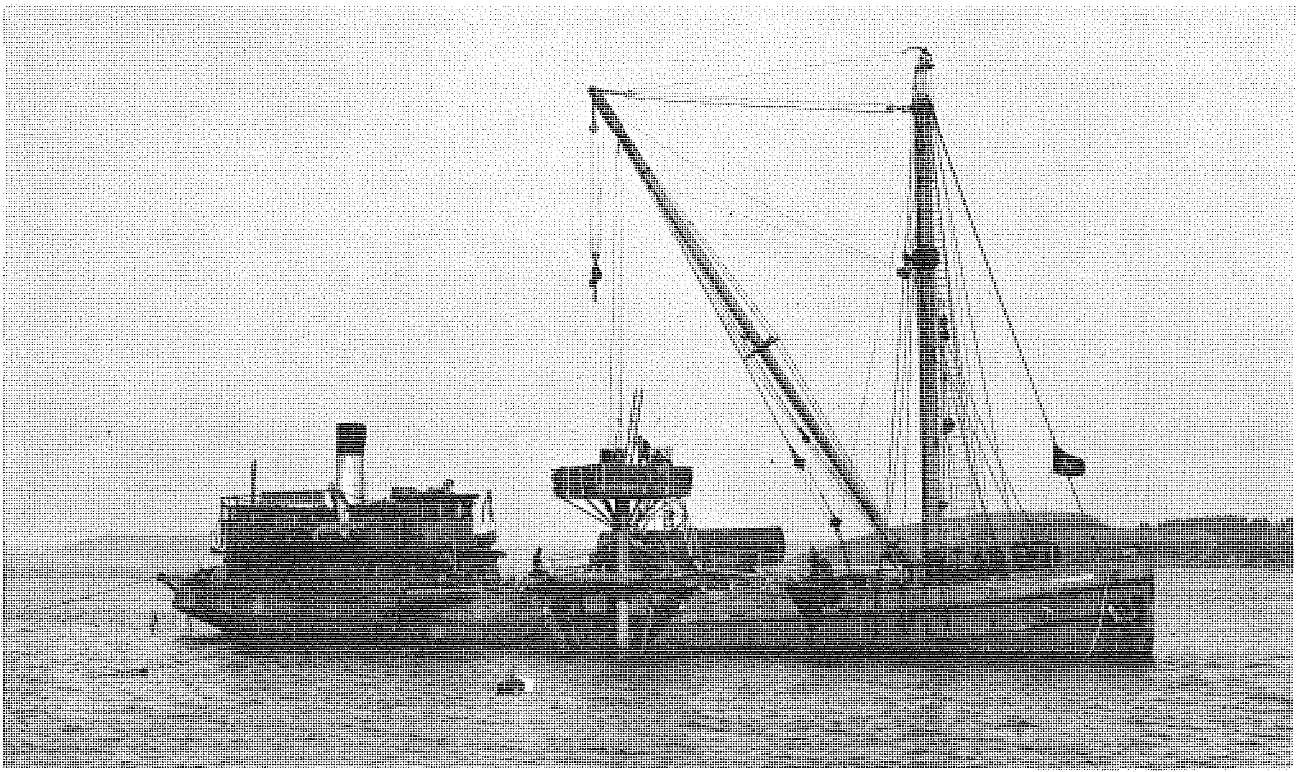
In September 1929, Dexter P. Cooper, Inc. applied for a license from the Federal Power Commission for a two-pool tidal power project and an auxiliary pumped-storage project, both to be located wholly within the United States. In September 1933, a supplementary application was filed with the Federal Power Commission for a larger installation in the United States two-pool project. The Corporation also applied for a loan of $43 million from the Federal Emergency Administration of Public Works to construct the project. The Federal Power Commission reported in January 1934 that it could not recommend approval of the application for loan. The application for loan was not approved and the loan was refused. In September 1935, the Federal Power Commission denied the application for license filed by Dexter P. Cooper, Inc., because the United States Government had undertaken a tidal project in the same area and had acquired the assets of Dexter P. Cooper, Inc.

Other Studies, 1927-35

On April 15, 1927, Murray and Flood, Engineers, of New York, N.Y. reported to Gerard Swope, then president of General Electric Company, on undeveloped water power of four rivers in Maine and the international Passamaquoddy tidal power project proposed by Cooper. The proposed tidal project had an installed capacity of 400,000 kw. with a firm capacity of 122,000 kw. and would deliver 1,594 million kw.-hrs. a year to Woburn, Massachusetts, at an average cost of 8.09 mills per kilowatt-hour. The total estimated cost of the project, at 1926-27 price levels, was $125 million.

In 1930, the International Passamaquoddy Fisheries Commission was created by United States and Canada to investigate the probable effects of the proposed international Passamaquoddy tidal power project on the fisheries of that region. The Commission reported in 1935 that the weir fisheries for young herring inside the bays, which produce 2.5 percent of the total annual catch, would be greatly reduced by the construction of the dams, and that the effect upon the fisheries outside of the dams could not be foretold without further investigation.

In January 1935, the American Passamaquoddy Bay Tidal Power Commission -- a special board of four members appointed by the Administrator of Public Works -- recommended construction of an initial project consisting of a one-pool tidal power project using Cobscook Bay as a low pool, a pumped-storage plant near Haycock Harbor, and a transmission line between the two plants -- all wholly within the United States -- at a cost of about $30 million. These works were to be designed and constructed so that they could be a part of an ultimate international two-pool plan. On May 28, 1935, under authority of the Emergency Relief Appropriation Act of 1935, the recommended initial project was



Deep-water drilling by U.S. Army Corps of Engineers, 1935

approved for construction by the United States Government, and $10 million (later reduced to $7 million) was allotted to the Corps of Engineers, War Department, for the first fiscal year's work on the project.

U. S. Army Corps of Engineers Project, 1935-37

The U. S. Army Corps of Engineers started work on the project in June 1935 and continued full scale work until August 1936, when most of the construction work ceased because Congressional approval was not forthcoming. Repair work on two dams built in this period and damaged by severe storms in October 1936 continued until April 1937.

In December 1935, the Corps of Engineers estimated the first cost of the initial project to be $61,500,000 which was raised to $68,158,000 by a review board. The project planned in 1935 was a single high-pool plan with five power units totalling 62,500 kw., with a 30,000-kw. diesel electric auxiliary plant. The total estimated output was 262 million kw.-hr. a year.

In little over one year of active work, nearly $7 million was spent to acquire the assets of Dexter P. Cooper, Inc., and to make engineering studies, to construct three tidal dams, to acquire lands and rights-of-way, and to construct temporary housing facilities. One dam was built between Treat

Island and Dudley Island, forming a small part of the major tidal dam which would have extended from Eastport to Lubec, Maine. Another dam was built between Pleasant Point on the mainland to Carlow Island, and a third dam was built between Carlow and Moose Islands, replacing the Maine Central Railroad trestles. These two dams were later used by the State of Maine as the base for Maine Highway 190, the principal highway to Eastport.

A comprehensive program of field exploration and laboratory testing was started and partly completed, and many design studies were made before the project was stopped. Most of the data and analyses were preserved and proved of great value to the current survey.

Interim Actions, 1936-56

The Senate of the United States adopted Senate Resolution 62, on February 2, 1939, requesting the Federal Power Commission to review all previous reports and information on the Passamaquoddy tidal power project wholly within the United States. Published on April 7, 1941, in Senate Document No. 41, 77th Congress, 1st Session, their report showed that neither a tidal plant nor a steam-electric plant, when compared with potential river hydroelectric plants in Maine, was desirable to meet the forecasted power requirements of the region. However, it was concluded that the findings of the survey should not preclude thorough exploration of the possibilities of a large, international tidal power project by the Governments of the United States and Canada.

On November 9, 1948, the Governments of of Canada and the United States requested the International Joint Commission to (1) review existing plans for hydroelectric power plants at Passamaquoddy and Cobscook Bays; (2) to determine the scope and cost of an investigation necessary to establish whether these or any other plans are practicable or desirable; and (3) to report its recommendations for apportioning to each country the costs of the investigation. The International Passamaquoddy Engineering Board appointed in April 1949 reported on March 15, 1950 that (1) an international Passamaquoddy tidal power project could be physically engineered, constructed and operated; (2) an investigation to determine the economic feasibility of a tidal power project should be broad enough and exhaustive enough to furnish all the information necessary to decide whether a tidal power plant should be constructed in the foreseeable future; and (3) the investigation costs might be apportioned between the countries when the project is constructed. The investigation was estimated to cost $3,600,000 and to take 18 months to complete. Investigation of the fisheries problem would cost $300,000 and take 3 years.

The U.S. Geological Survey's Water Resources Division and the U.S. Army Engineer Division, New England, made geologic and geophysical studies to test the sonic method of determining the thickness of unconsolidated underwater sediments, and to discover as much as possible about the sediments in Passamaquoddy Bay. The field work was done during June, July, and August of 1951. The preliminary report of the results of this survey was published in December 1952.

In May 1952, the U.S. Army Corps of Engineers reviewed the estimated cost of the comprehensive investigations described in the report of the International Passamaquoddy Engineering Board of March 1950, taking into account the 1951 experience with the sonic method of exploring underwater sediments. The cost of the comprehensive investigation was revised downward to $3,000,000, including $300,000 for a fisheries investigation.

The New England - New York Inter-Agency Committee made a comprehensive survey of the land, water, and related resources of the New England - New York region. The Committee report of 1955 summarizes all information on the Passamaquoddy Bay region available at that time, including an estimate of the cost of a comprehensive survey (same as the 1952 Corps of Engineers' report). The report recommended that the comprehensive survey of an international Passamaquoddy tidal power project be undertaken.

CHAPTER II

COMPARISON AND SELECTION OF PROJECT PLANS

Selection of the best project required comparison of many different tidal power projects and several potential sources of auxiliary power. The studies made to determine the best arrangement for the tidal project and the best combinations of tidal project and auxiliary power source are described below.

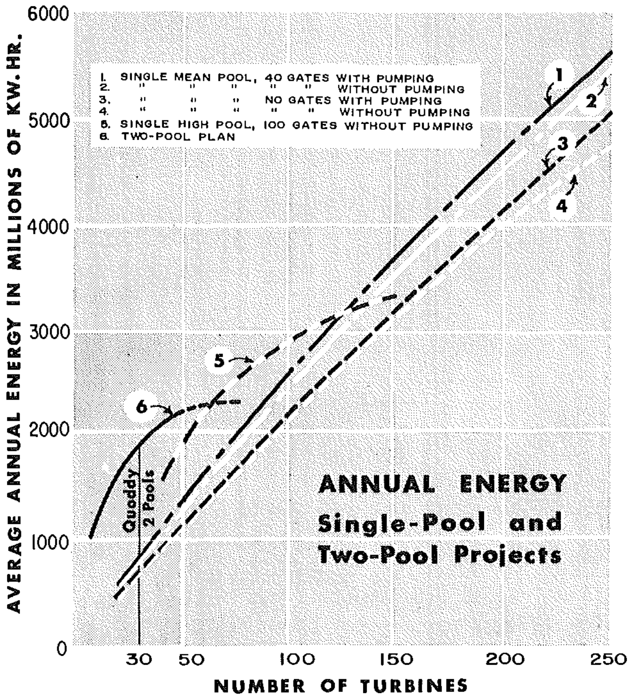
TIDAL POWER PROJECT

Several of the pool arrangements and methods of pool operation described in chapter I could be developed in Passamaquoddy Bay and vicinity. Initial general studies and comparisons of one-pool and two-pool arrangements showed that a two-pool arrangement would be best for the Passamaquoddy site. Comparative studies and cost estimates led to the selection of the two-pool tidal project plan for which specific designs and cost estimates were developed.

Initial General Studies

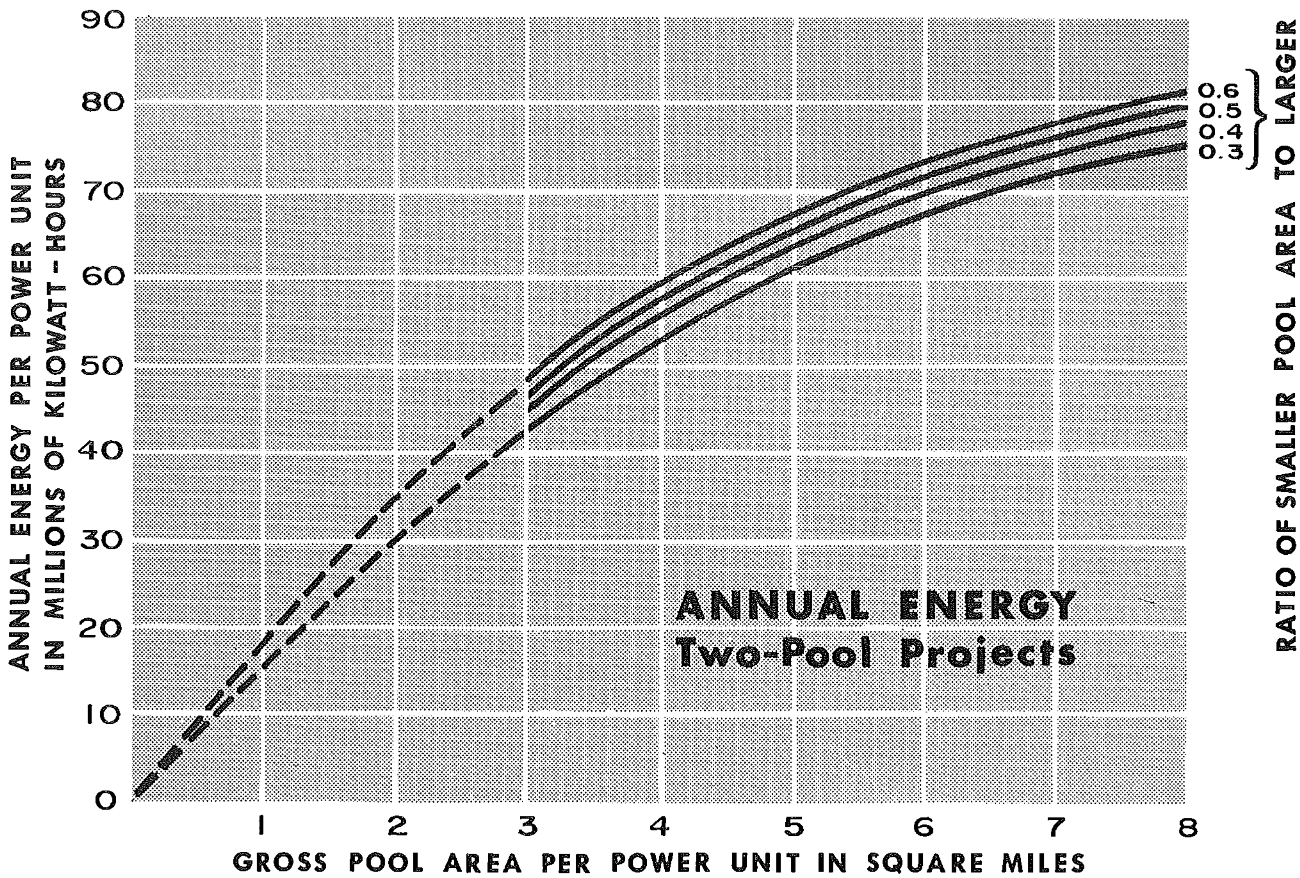
The first phase of the study was to compile all available pertinent data on topography, hydrography, foundation conditions, construction materials, tides, and designs of project components developed during previous investigations. Preliminary studies indicated that the cost of providing generating capacity is one of the major costs of a tidal project and, consequently, the best use of generating capacity results in the least costly power. The Rance project and the one-pool, all-United States tidal project started in 1935, for example, were not promising in this respect, since they would generate power at 25 to 27 percent capacity over a period of a year. A two-pool project, on the other hand, would generate at more than twice this rate.

A further comparison of one-pool and two-pool projects was made by computing the annual energy which each type of project described in chapter I could generate if used at the Passamaquoddy site. The results of these studies are summarized in the illustration showing annual energy for single-pool and two-pool projects. The tide data used in the studies are of the tides occurring at Eastport, Maine, and the pool areas assumed were about 140 square miles, equal to that for the selected plan. Kaplan turbines, with a diameter of 320 inches and rotating at 40 r.p.m., were assumed for this phase of the study.



One-Pool and Two-Pool Arrangements

A two-pool project would generate more energy than any one-pool project with less than 60 turbines. With more than 60 turbines, a single-pool project would produce more energy than a two-pool project. Studies of two-pool projects showed that the cost of power would be least with about 30 generating units. The use of 60 or more generating units in a one-pool project would increase the cost of tidal power over that which can be obtained with a two-pool project.



A two-pool project with about 30 units has the additional advantage of generating as much energy as the best one-pool project with 50 units. Two-pool power with lower peak output could be used to better advantage and could be transmitted at lower cost. Another advantage of the two-pool project is that generation, being continuous, would provide some dependable capacity, while intermittent one-pool operation has no dependable capacity. Varied operation of a single-pool project, as at La Rance, would yield some dependable capacity, but the number of generating units must be increased substantially to secure the same amount of energy. Using the same number of units, a substantial amount of energy must be sacrificed to secure dependable capacity. On the basis of the above considerations, one-pool projects were eliminated from further study.

Many different two-pool arrangements were studied to determine which would be most satisfactory. An important tool in these studies is the plot "Annual Energy, Two-Pool Projects." Once the area of the pools was determined and the number of turbines selected, this plot permitted rapid estimates of the annual energy from a project layout. The number of turbines was easily changed in the computations to determine the effect on annual energy. The plot also shows that more energy per unit is possible as the two pools approach each other in size.

The many two-pool arrangements examined vary in the location of dams separating the pools from the ocean, in dams separating the two pools, in the use of either pool as the high pool, in possible operation of the powerhouse with alternate discharge to the ocean or lower pool, in the location and size of the powerhouse, and in the location and number of filling and emptying gates. An estimate of cost was made for each project arrangement. The ratio of project cost to annual energy output was used as an index in selecting the more favorable layouts. This ratio is called the "comparative index" in the following discussion. The lower this index the more favorable the arrangement.

The studies revealed that five different arrangements have nearly the same comparative index, and these plans were studied further. Each of these plans would use all of Passamaquoddy Bay and all of Cobscook Bay. In some of the plans the Cobscook Bay pool was extended to include all or parts of Quoddy Roads, Friar Roads, and Head Harbour Passage as far as Pope and Green Islets (plate 3). The selected two-pool plan, and other two-pool plans considered, are described below.

Selected Two-Pool Plan

The two-pool arrangement selected for specific design and cost estimates is diagrammed on plate 2 in the syllabus. The arrows show the direction of flow through the filling gates, powerhouse, and emptying gates.

The upper pool would be formed in Passamaquoddy Bay by a dam in Western Passage at Deer Island Point, and by a series of dams extending from the north end of Deer Island to the Canadian mainland across Pendleton Passage, Little Letite Passage, and Letite Passage. The pool would be filled partly through gates in Letite Passage and partly through gates on Deer Island Point. Dividing the flow to the upper pool between Letite Passage and Western Passage reduces the construction cost and hydraulic losses in the filling gates and channels.

The lower pool would include Cobscook Bay and would extend to dams in Quoddy Roads and in Head Harbour Passage at Pope and Green Islets, thus including Quoddy Roads and Friar Roads in the lower pool. The gate structures for emptying the low pool would be located between Pope and Green Islets. The dams would extend from Deer Island Point across Indian River to Indian Island, from Indian Island to Pope Islet, from Green Islet across Head Harbour Passage to Campobello Island, and from Campobello Island across Quoddy Roads to the United States mainland near West Quoddy Head.

A powerhouse with a rated capacity of 300,000 kw. would be located between the two pools in a channel excavated through Moose Island at Carryingplace Cove.

Two navigation locks for vessels moderately larger than those in current traffic would be provided, one in Head Harbour Passage for traffic between the ocean and the lower pool, and one in Western Passage for traffic between the lower pool and the upper pool. Two smaller locks, one at Quoddy Roads and one at Little Letite Passage, would accommodate vessels up to 95 feet long. A possible future ship lock 800 or more feet long can be constructed in Little Letite Passage when justified by future traffic of large vessels.

Location and Features of Principal Structures

The general plan of the selected tidal project, including six general areas, is shown on plates 4 through 9. Each of these areas, and the structures proposed, are discussed below. All elevations in this report are stated in feet above or below mean sea level.

The sites of dams and filling gates in Letite Passage between the Canadian mainland and McMaster Island are shown on plate 4. The south dam, 1,700 feet long, would extend across the main part of Letite Passage from McMaster Island to an abutment with the filling gate structure at Dry Ledge. The bottom of the dam would be at el. -150, the deepest point along the axis, with the toe extending to el. -175. The other abutment of the filling gate structure would be at Thum Cap. From Thum Cap, a shallow dam 2,800 feet long, would extend to the mainland, crossing Mathew Island and the adjacent tidal area. The alignment of the dams and structures was selected to provide a site for rockfill dams of minimum volume, and a site for gate structures with rock foundations at a suitable elevation and with ledge rock at each abutment. Forty filling gates, 30 feet by 30 feet in size, would be located so that hydraulic losses would be held to a minimum. The excavated channel for the filling gates would be about 1,520 feet wide with the bottom at el. -44.5 on the approach side of the gates and at el. -47 on the discharge side.

The sites of the dams and navigation lock in Little Letite Passage and the dam in Pendleton Passage are shown on plate 5. The lock on the north tip of Jameson Island would have clear dimensions of 95 feet by 25 feet in the chamber with sills at el. -21.2, which would provide a 12-foot draft at mean low water. This arrangement provides a site on Jameson Island for a possible future ship lock of large size. The dams would extend from McMaster Island to Jameson Island, thence to New, Pendleton, English, and Deer Islands. The dams in this area would have a combined length of 6,700 feet, with a considerable portion of this length on a foundation above mean sea level. The deepest parts of the dams would extend to about el. -50.

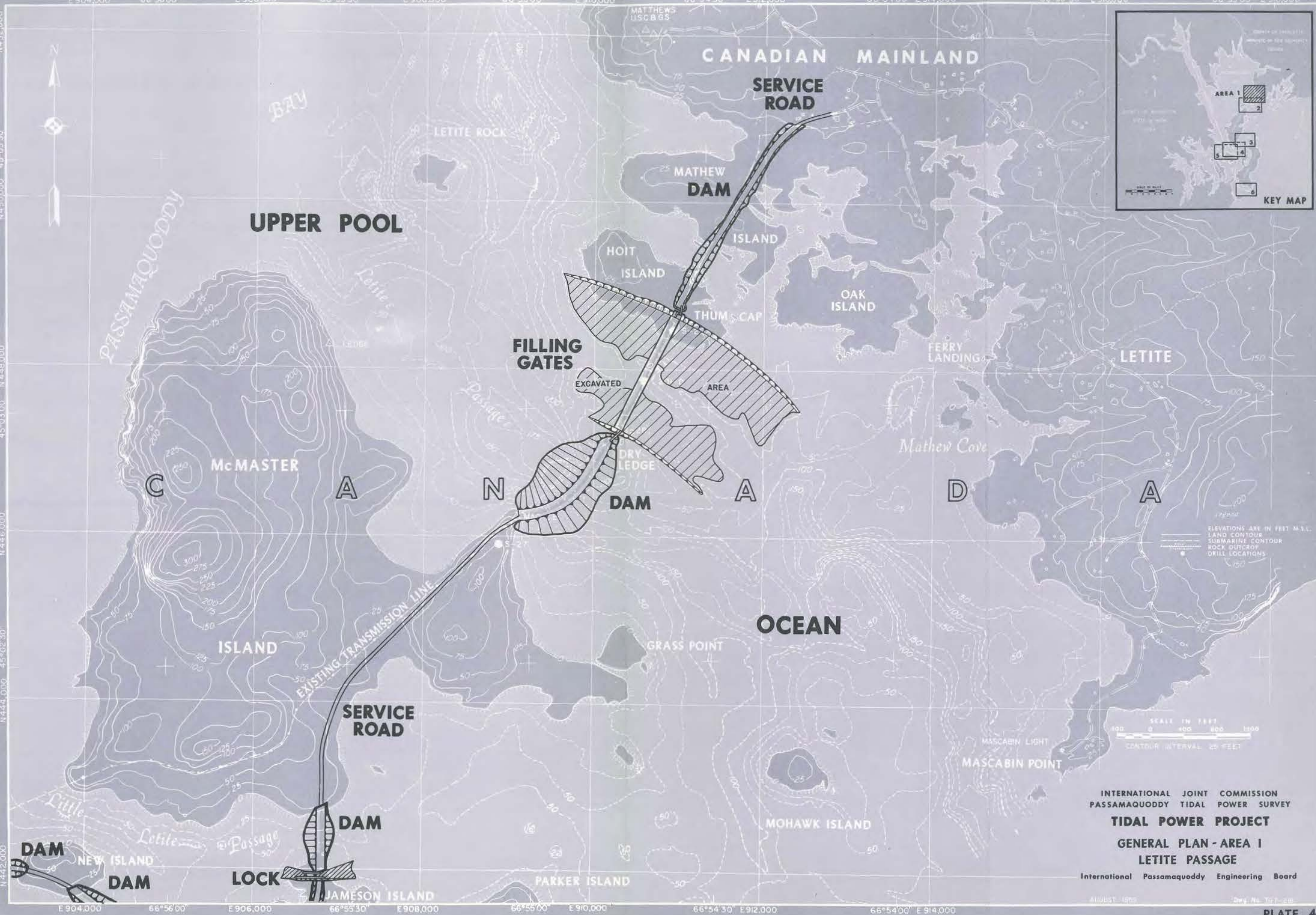
The sites of the dams, emptying gates, and lock in Head Harbour Passage are shown on plate 6. The west dam would extend from Indian Island to Pope Islet and the east dam from Green Islet to Campobello Island. The west dam would be 4,600 feet long with the bottom at el. -150 at the deepest point. The east dam would be 4,400 feet long with the lowest point at about el. -280. The emptying gate structure, including 70 gates, 30 feet by 30 feet in size, would be located between Pope and Green Islets on submerged ridges which provide a rock foundation at a suitable elevation. A fishway would be provided at the Pope Islet end of the gate structure. The channel for the emptying gates would be about 2,730 feet wide with the excavated bottom at el. -59.0 on the approach side and el. -61.5 on the discharge side. The navigation lock on the northwest shore of Campobello Island would provide clear dimensions of 415 feet by 60 feet in the chamber with sills at el. -30.2, providing a 21-foot draft at mean low water.

Looking northeast from Eastport, Maine, across Western Passage and into Head Harbour Passage, with Deer Island at left, Indian Island in center, and Campobello Island at right.

The sites of the dam, navigation lock, and filling gates at Western Passage, and the site of the dam across Indian River, are shown on plate 7. Fifty filling gates, 30 feet by 30 feet in size, would be located on Deer Island Point in a channel excavated through the peninsula between Indian River and Western Passage. The channel would be about 1,900 feet wide with the bottom at el. -44.5 on the approach side of the gates and at el. -47.0 on the discharge side. The dam across Western Passage would be 3,900 feet long and would extend from Deer Island Point to Moose Island, separating the upper and lower pools. The deepest part of the dam, along the axis, would be at el. -275, while the deepest part at the toe would be el. -375. This dam would be intersected near Deer Island by a dam across Indian River from Indian Island, which would separate the ocean from the lower pool. This dam would be 2,300 feet long with a bottom elevation of -160 at the deepest point. The navigation lock on the northeast shore of Moose Island would provide clear dimensions of 415 feet by 60 feet in the chamber with sills at el. -30.2, providing a 21-foot draft at mean low water.

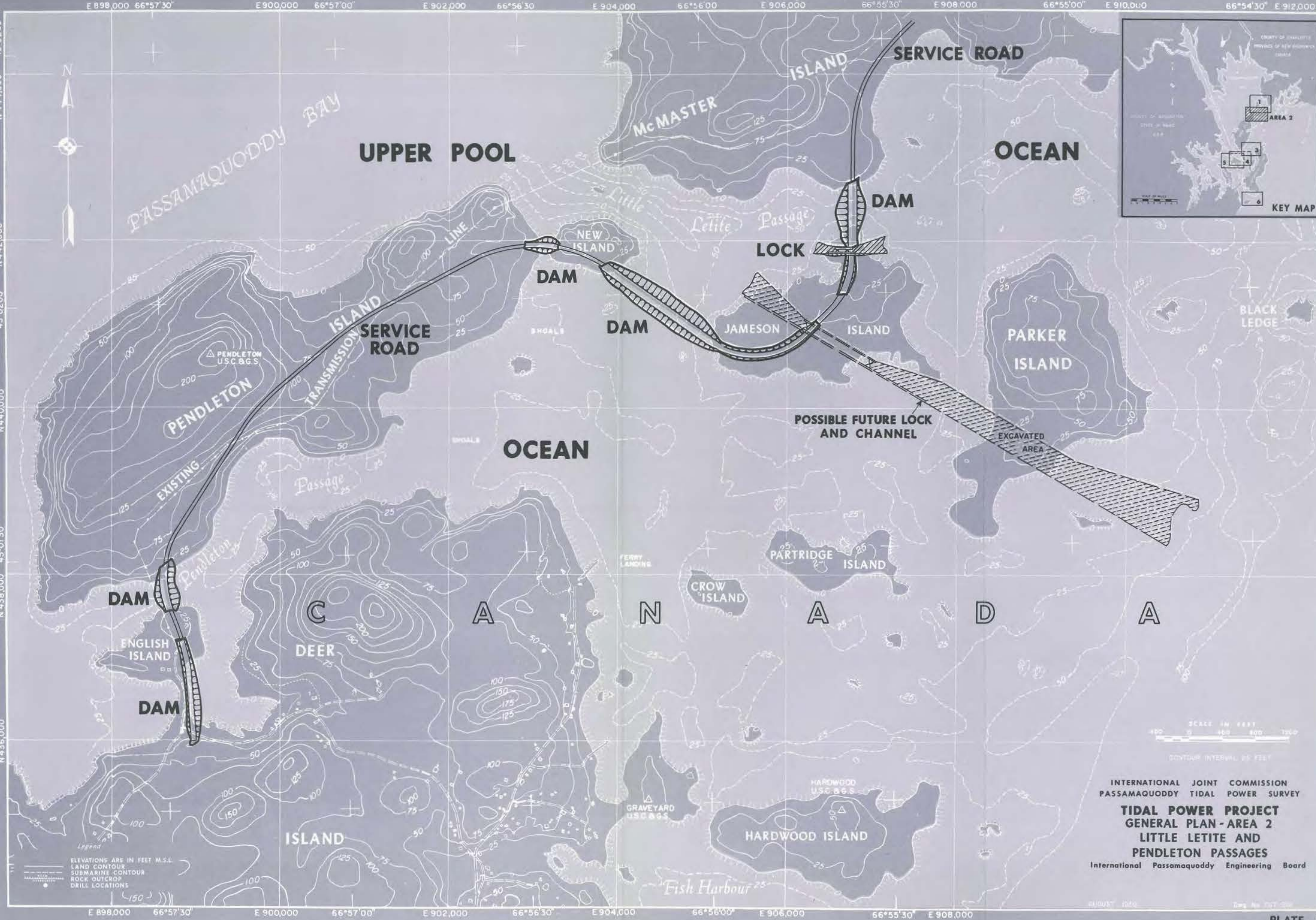
The powerhouse, 2,580 feet long, would be located between the upper and lower pools in a channel excavated through Moose Island and Carryingplace Cove from Western Passage to Cobscook Bay, as shown on plate 8. A fishway would be provided at the northwest end of the structure on Mathews Island. The switchyard, with four outgoing lines, would be located about 200 feet from the northwest end of the powerhouse.

The headrace channel would extend from Johnson Cove in the upper pool through Carryingplace Cove to the powerhouse, a distance of about 6,300 feet. The sections would vary from a width of 1,700 feet with the bottom at el. -50, to a width of 2,340 feet with the bottom at el. -33. A bridge 2,300 feet long would carry the relocated



CANADIAN MAINLAND
SERVICE ROAD
MATHEW
DAM
ISLAND
HOIT ISLAND
THUM CAP
OAK ISLAND
LETITE ROCK
BAY
PASSAMAQUODDY
UPPER POOL
FILLING GATES
EXCAVATED
AREA
FERRY LANDING
LETITE
Mathew Cove
Letite Passage
McMASTER
ISLAND
DRY LEDGE
DAM
C A N A D A
EXISTING TRANSMISSION LINE
OCEAN
GRASS POINT
SERVICE ROAD
MASCABIN POINT
MOHAWK ISLAND
DAM
Little Letite Passage
DAM
NEW ISLAND
DAM
LOCK
JAMESON ISLAND
PARKER ISLAND
KEY MAP
AREA 1
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
GENERAL PLAN - AREA I
LETITE PASSAGE
International Passamaquoddy Engineering Board

PLATE 4


PASSAMAQUODDY BAY
UPPER POOL
OCEAN
OCEAN
SERVICE ROAD
McMASTER
ISLAND
Little
Letite
Passage
DAM
LOCK
NEW ISLAND
DAM
DAM
JAMESON
ISLAND
EXISTING TRANSMISSION LINE
ISLAND
SERVICE ROAD
PENDLETON
PENDLETON U.S.C.&G.S.
Passage
Pendleton
DAM
ENGLISH ISLAND
DAM
DEER
ISLAND
PARKER ISLAND
POSSIBLE FUTURE LOCK AND CHANNEL
EXCAVATED AREA
BLACK LEDGE
PARTRIDGE ISLAND
CROW ISLAND
C A N A D A
GRAVEYARD U.S.C.&G.S.
HARDWOOD U.S.C.&G.S.
HARDWOOD ISLAND
Fish Harbour
SHOALS
FERRY LANDING
KEY MAP
AREA 2
CONTOUR INTERVAL 25 FEET
Legend
ELEVATIONS ARE IN FEET M.S.L.
LAND CONTOUR
SUBMARINE CONTOUR
ROCK OUTCROP
DRILL LOCATIONS
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
GENERAL PLAN - AREA 2
LITTLE LETITE AND
PENDLETON PASSAGES
International Passamaquoddy Engineering Board

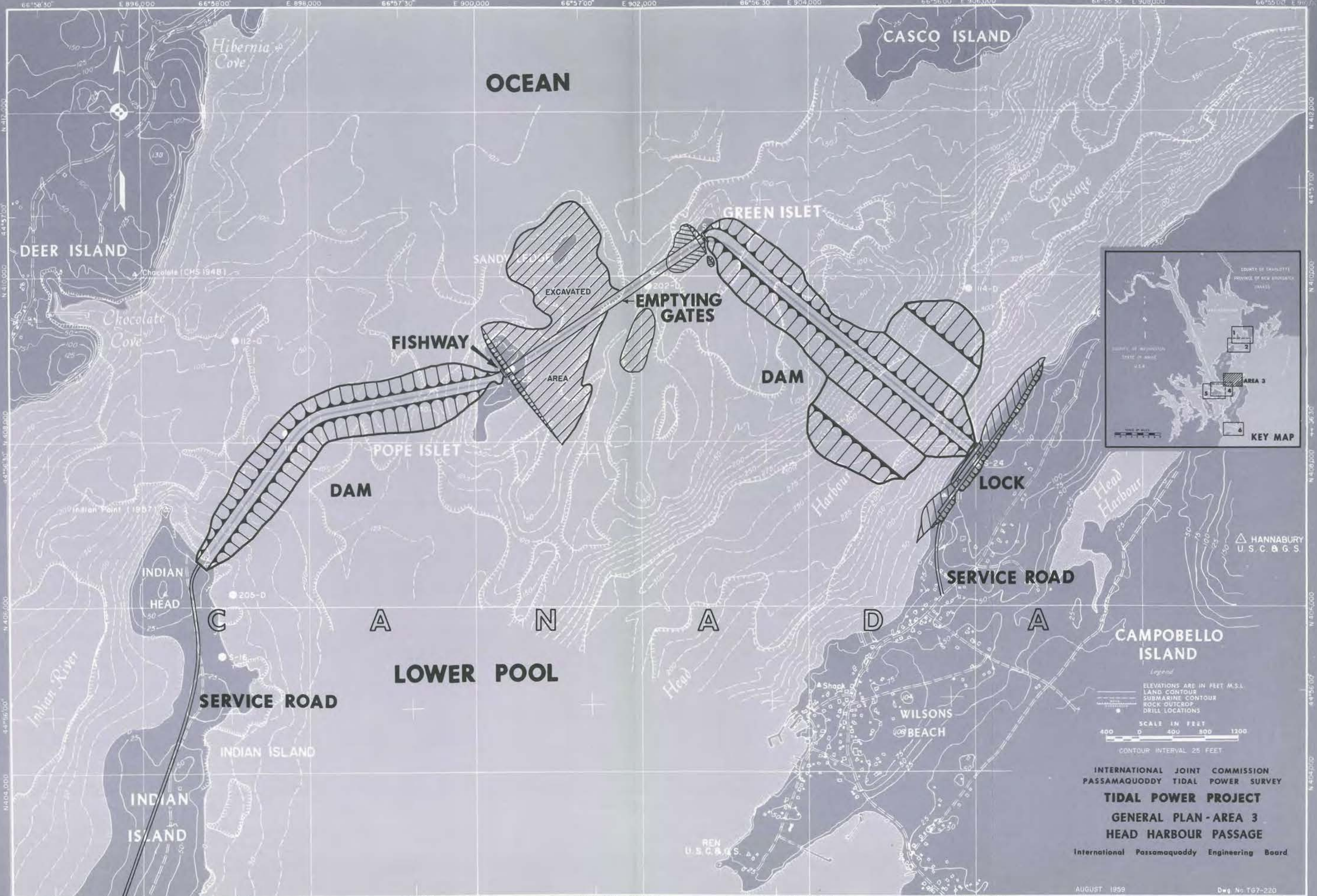

OCEAN
CASCO ISLAND
Hibernia Cove
DEER ISLAND
Chocolate (CHS 1948)
Chocolate Cove
GREEN ISLET
SANDY LEDGE
EXCAVATED
AREA
EMPTYING GATES
FISHWAY
DAM
POPE ISLET
DAM
LOCK
Passage
Head Harbour
Head Harbour
SERVICE ROAD
Indian Point (1957)
INDIAN HEAD
C A N A D A
LOWER POOL
SERVICE ROAD
INDIAN ISLAND
INDIAN ISLAND
Indian River
Head
WILSONS BEACH
Shack
HANNABURY U.S.C.&G.S.
CAMPOBELLO ISLAND
KEY MAP
AREA 3
Legend
ELEVATIONS ARE IN FEET M.S.L.
LAND CONTOUR
SUBMARINE CONTOUR
ROCK OUTCROP
DRILL LOCATIONS
SCALE IN FEET
400 0 400 800 1200
CONTOUR INTERVAL 25 FEET
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
GENERAL PLAN - AREA 3
HEAD HARBOUR PASSAGE
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg No TG7-220

PLATE 6

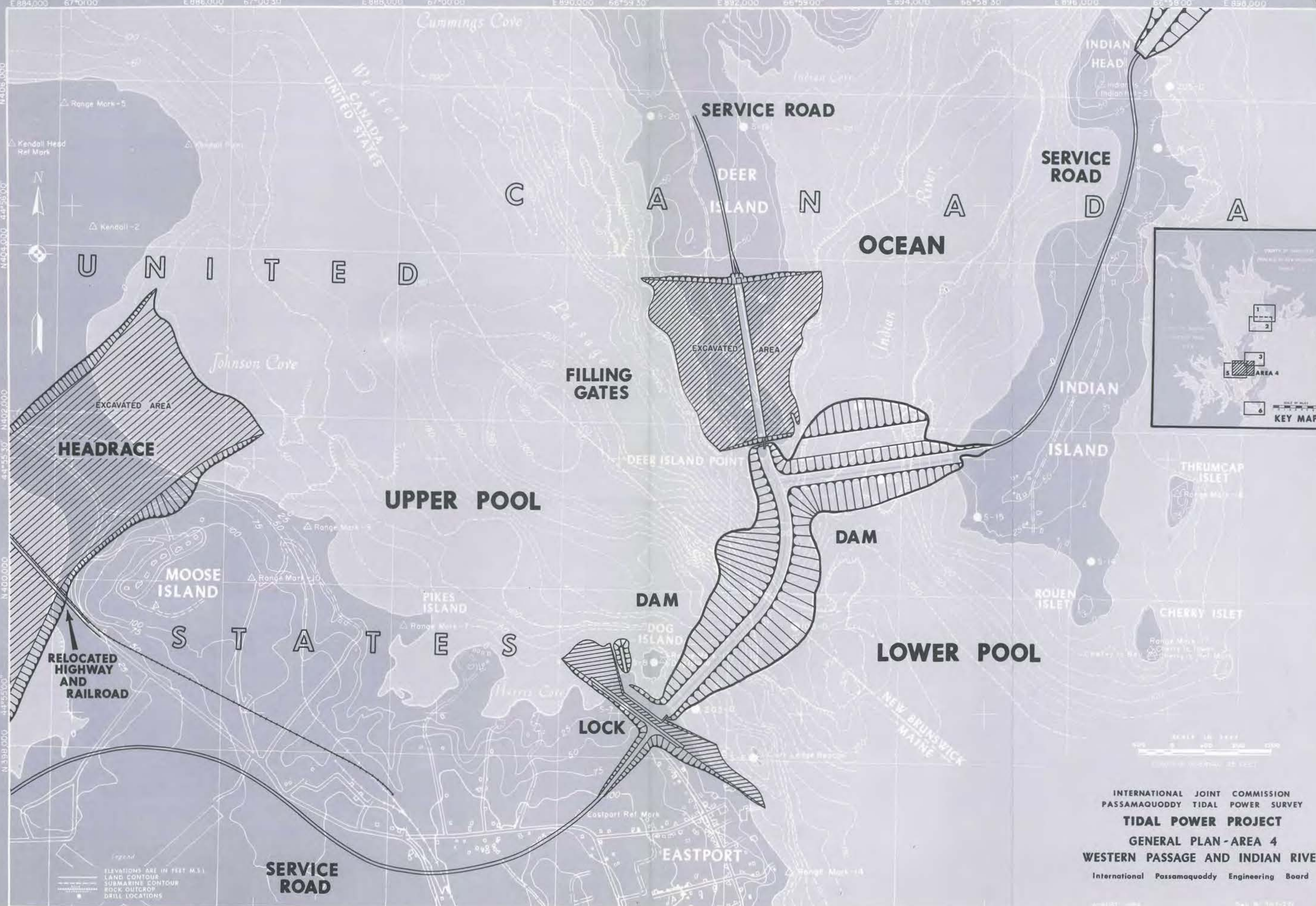

SERVICE ROAD
DEER ISLAND
SERVICE ROAD
INDIAN HEAD
C A N A D A
OCEAN
U N I T E D
S T A T E S
EXCAVATED AREA
FILLING GATES
EXCAVATED AREA
HEADRACE
INDIAN ISLAND
DEER ISLAND POINT
UPPER POOL
DAM
THRUMCAP ISLET
MOOSE ISLAND
PIKES ISLAND
DAM
DOG ISLAND
ROUEN ISLET
CHERRY ISLET
LOWER POOL
RELOCATED HIGHWAY AND RAILROAD
LOCK
NEW BRUNSWICK
MAINE
Johnson Cove
Cummings Cove
Western Passage
Indian River
EASTPORT
SERVICE ROAD
KEY MAP
AREA 4
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
GENERAL PLAN - AREA 4
WESTERN PASSAGE AND INDIAN RIVER
International Passamaquoddy Engineering Board

PLATE 7

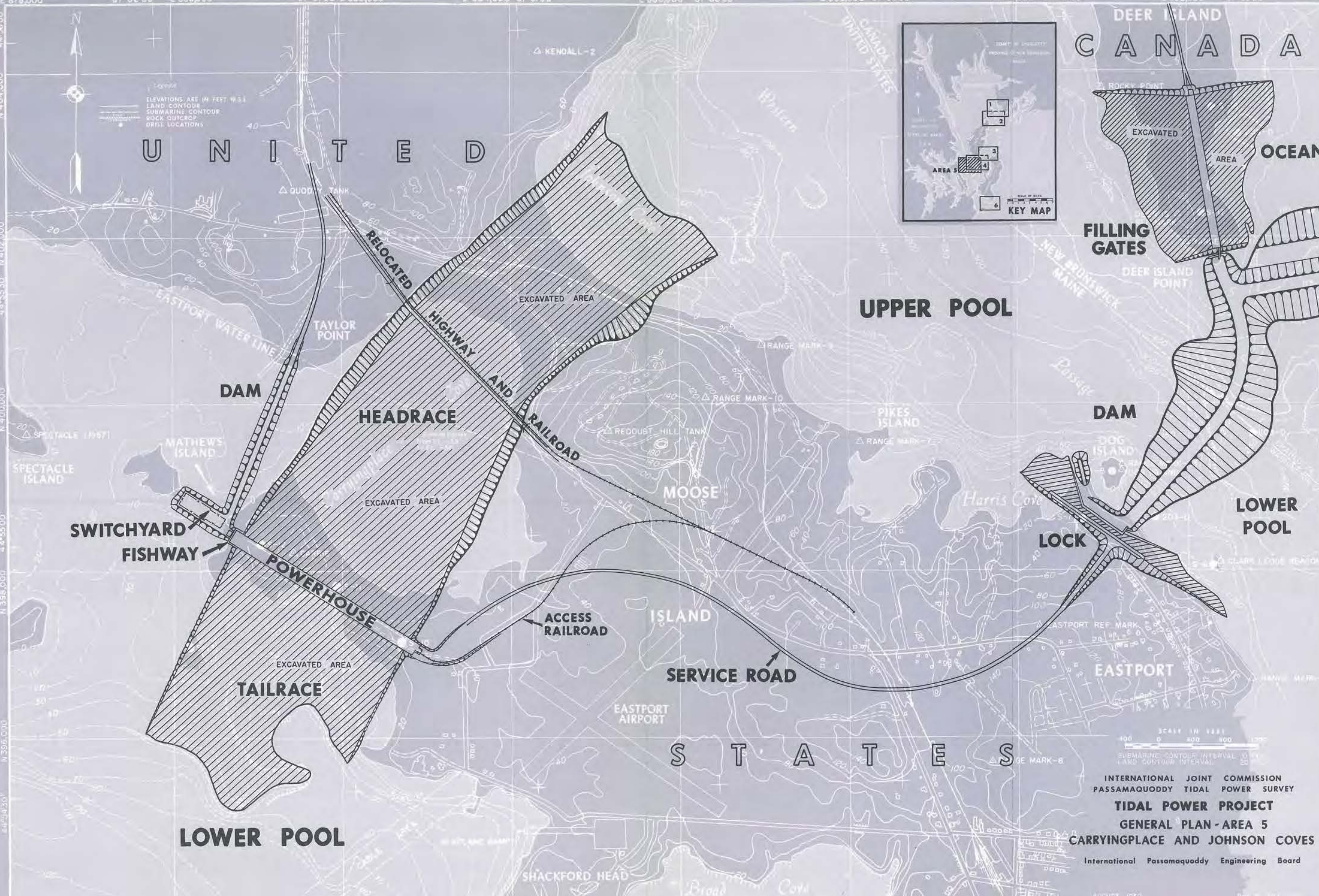
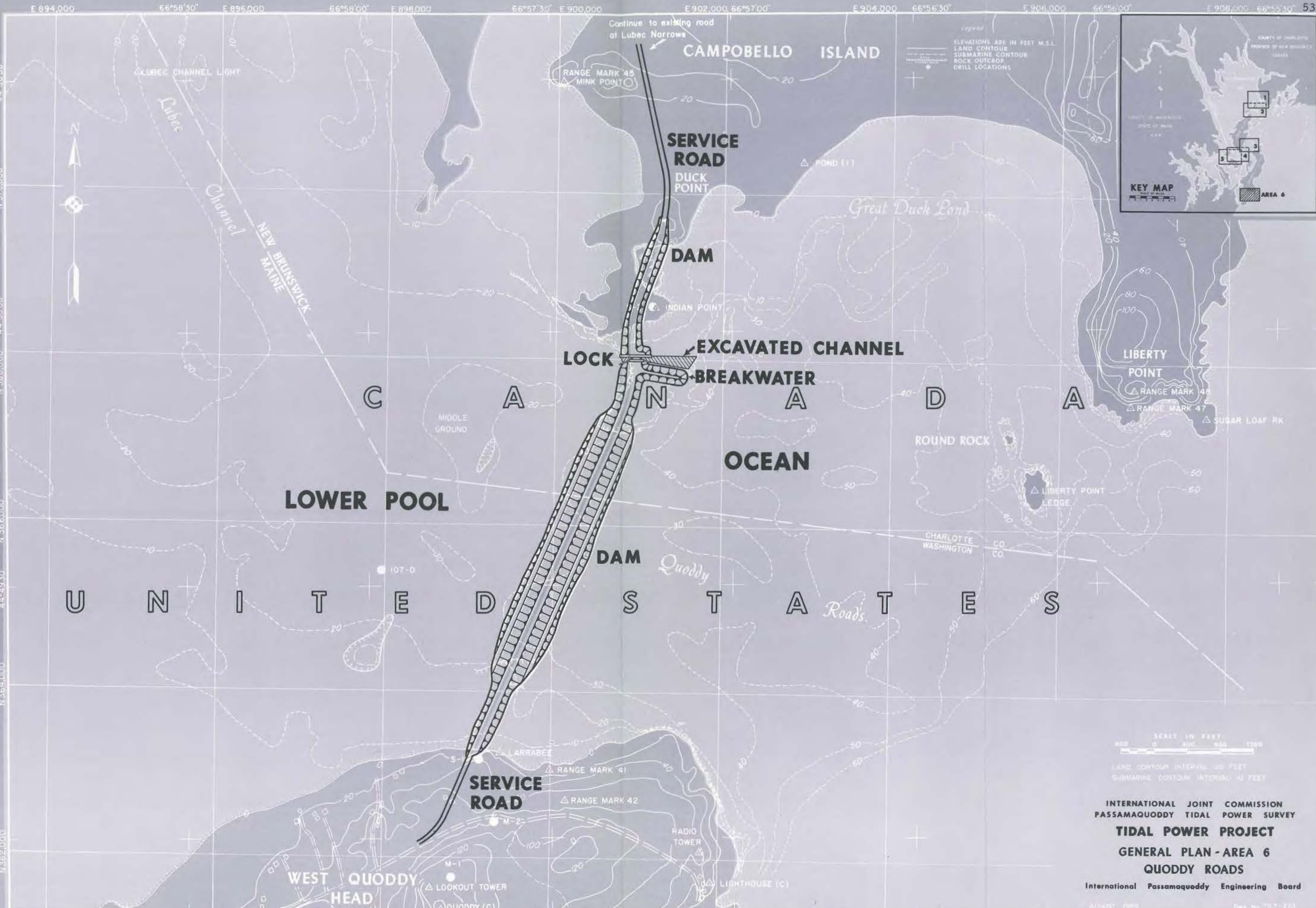

UNITED STATES
CANADA
DEER ISLAND
OCEAN
FILLING GATES
EXCAVATED AREA
UPPER POOL
DAM
LOWER POOL
LOCK
RELOCATED HIGHWAY AND RAILROAD
HEADRACE
EXCAVATED AREA
SWITCHYARD
FISHWAY
POWERHOUSE
ACCESS RAILROAD
SERVICE ROAD
TAILRACE
MOOSE ISLAND
EASTPORT
EASTPORT AIRPORT
TAYLOR POINT
MATHEWS ISLAND
SPECTACLE ISLAND
PIKES ISLAND
DOG ISLAND
DEER ISLAND POINT
SHACKFORD HEAD
KEY MAP
AREA 5
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
GENERAL PLAN - AREA 5
CARRYINGPLACE AND JOHNSON COVES
International Passamaquoddy Engineering Board

PLATE 8


Continue to existing road at Lubec Narrows
CAMPOBELLO ISLAND
LUBEC CHANNEL LIGHT
Lubec Channel
RANGE MARK 45
MINK POINT
SERVICE ROAD
DUCK POINT
POND
Great Duck Pond
DAM
INDIAN POINT
NEW BRUNSWICK
MAINE
LOCK
EXCAVATED CHANNEL
BREAKWATER
C A N A D A
MIDDLE GROUND
LIBERTY POINT
RANGE MARK 48
RANGE MARK 47
SUGAR LOAF RK
ROUND ROCK
OCEAN
LIBERTY POINT LEDGE
LOWER POOL
CHARLOTTE CO
WASHINGTON CO
DAM
Quoddy Roads
107-D
U N I T E D S T A T E S
LARRABEE
RANGE MARK 41
SERVICE ROAD
RANGE MARK 42
M-2
RADIO TOWER
M-1
WEST QUODDY HEAD
LOOKOUT TOWER
LIGHTHOUSE (C)
QUODDY (C)
KEY MAP
AREA 6
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
GENERAL PLAN - AREA 6
QUODDY ROADS
International Passamaquoddy Engineering Board

railroad and highway over the headrace channel. A shallow dam about 2,400 feet long across the mouth of Carryingplace Cove from Mathews Island to Moose Island would separate the headrace from the lower pool. The tailrace would be about 2,700 feet long with the bottom varying from el. -70 to el. -47.

A dam across Quoddy Roads to separate the lower pool from the ocean would extend from Campobello Island in Canada to the United States mainland near West Quoddy Head. The location of the dam and a small boat lock are shown on plate 9.

The dam would be 6,900 feet long with the bottom at about el. -35 at the deepest point. The navigation lock, located on a reef off the south shore of Campobello Island, would provide clear dimensions of 95 feet by 25 feet with sills at el. -20.2, providing a 12-foot draft at mean low water.

Other Two-Pool Plans Considered

Cobscook Bay has much flatter shores in the tide range than Passamaquoddy Bay. For this reason, the area of the tidal pools would be larger if Cobscook Bay is used as the high pool and Passamaquoddy Bay is used as the low pool. Because the energy which a tidal power project can generate increases with the pool area, the possibility was studied of using Cobscook Bay as the upper pool. Two arrangements of this type are shown on plate 10.

The arrangement entitled "Cobscook Bay High" has dams in the same locations as in the selected plan, but with the pools reversed so that all of Passamaquoddy Bay is located in the low pool. This arrangement would produce about 11 percent more energy than the selected plan, partly because the two pools would have a greater combined area and would be more nearly equal in size at the reversed operating levels, and partly because more gates for filling and emptying the pools were included in this study. The cost of this plan would be 7 percent greater, but the comparative index would be about 4 percent less than that of the selected plan.

An important advantage of the selected plan over the "Cobscook Bay High" plan is that all of Passamaquoddy Bay and Western Passage would be in the upper pool where the water surface would vary between el. 3 and el. 12.2, instead of the present maximum variation between el. -13.4 and el. 13.9. This would improve navigation and harbor depths for ports in Canada and the United States. The controlling depth for navigation in St. Croix River to Calais, Maine, and St. Stephen, New Brunswick, would be 22 feet at mean low stage of the upper pool, instead of the existing 7 feet at mean low tide. At extreme low water the depth would be 19 feet instead of 2.5 feet. In the "Cobscook Bay High" arrangement, controlling navigation depths in the lower St. Croix River would be 9 feet at mean low stage and only 11 feet at average stage of the lower pool. For these reasons the "Cobscook Bay High" plan was not adopted.

The St. Andrews arrangement (plate 10) would divide Passamaquoddy Bay between the upper and lower pools with a dam extending from St. Andrews to Deer Island. The westerly part of Passamaquoddy Bay, including the St. Croix River tidewater area, would be located in the upper pool together with Cobscook Bay and Friar Roads. This arrangement would have about the same total pool area as the selected plan, but the two pools would be more nearly equal in area and thus would produce slightly more energy.

The St. Andrews arrangement was compared with a preliminary layout of the selected plan, which has the same total number of gates (180). It was found that the St. Andrews plan would produce 1.6 percent more energy, including an adjustment for hydraulic losses in emptying gate flow at low water stages through the somewhat restricted Letite Passage. The estimated construction cost of this arrangement is 0.7 percent greater than the selected plan, including an allowance for foundation settlement based on visual examination of drill cores then being taken on the alignment of the dam between St. Andrews and Deer Island. Subsequent drilling and correlated records of penetration of overburden by sonic soundings indicated that the cost of this dam would be substantially greater than the earlier estimate due to the depth and extent of soft clay in that area. Since at best, the St. Andrews arrangement would offer no significant economic advantage over the selected plan, further foundation exploration and design studies of this arrangement were not made.

The pool in Cobscook Bay could be closed by dams at Treat and Dudley Islands, as shown in the "Treat Island Plan" on plate 11. Compared with the selected plan, the dams at this location would require less fill, but the energy output of the project would also be reduced due to the smaller area of the lower pool. The dams would extend from Eastport to Lubec, Maine, along the alignment considered by both Dexter P. Cooper in his studies of two-pool projects, and by the U.S. Army Corps of Engineers in the 1935-37 study of a single-pool project in the United States.

In the Treat Island plan shown on plate 11, the area of the high pool would be the same as that of the selected plan, while the exclusion of Friar Roads would reduce the area of the low pool by 9.1 square miles (22 percent of the low pool). With the reduced area of the low pool, a power plant with 20 units would result in the lowest comparative index. The construction cost would be 30 percent less, and energy output would be 26 percent less than that of the selected plan. When operating costs were included, however, the estimated cost of energy from this plan would be about one-seventh of a mill less per kw.-hr. than from the selected plan. Because this difference is so small, and because the selected plan would develop the potential of the site more fully, the Treat Island plan was not considered further.

The energy output of a two-pool plan would be increased if the powerhouse discharge is excluded from the lower pool and diverted directly to the ocean during a part of each low tide. This is, in effect, a two-pool operation part of the time and a single-pool operation the remainder of the time, with a gain in energy output resulting from the increased storage space made available in the smaller pool. The gain is greater in arrangements in which the pools differ widely in size and in which many generating units are used. This plan would require an enclosed tailrace with two sets of gates which would be operated to direct the discharge alternately to the ocean or to the lower pool. Plate 11 shows such an arrangement and an enlarged diagram of the powerhouse area at Carryingplace Cove.

The possibility of using alternate discharge to the ocean was examined with other powerhouse locations, but none was as favorable as the plan described above. The plans with alternate discharge to the ocean were abandoned because of greater comparative indexes and higher operation and maintenance costs.

AUXILIARY POWER PROJECTS

For load carrying purposes power from the tidal project is limited to the capacity it can furnish under most adverse conditions. All output in excess of this capacity is not dependable for serving loads and would have value only as a non-firm energy. This excess generation is considerable and to make it dependable for serving loads, it must be firmed up by the use of an auxiliary source of power.

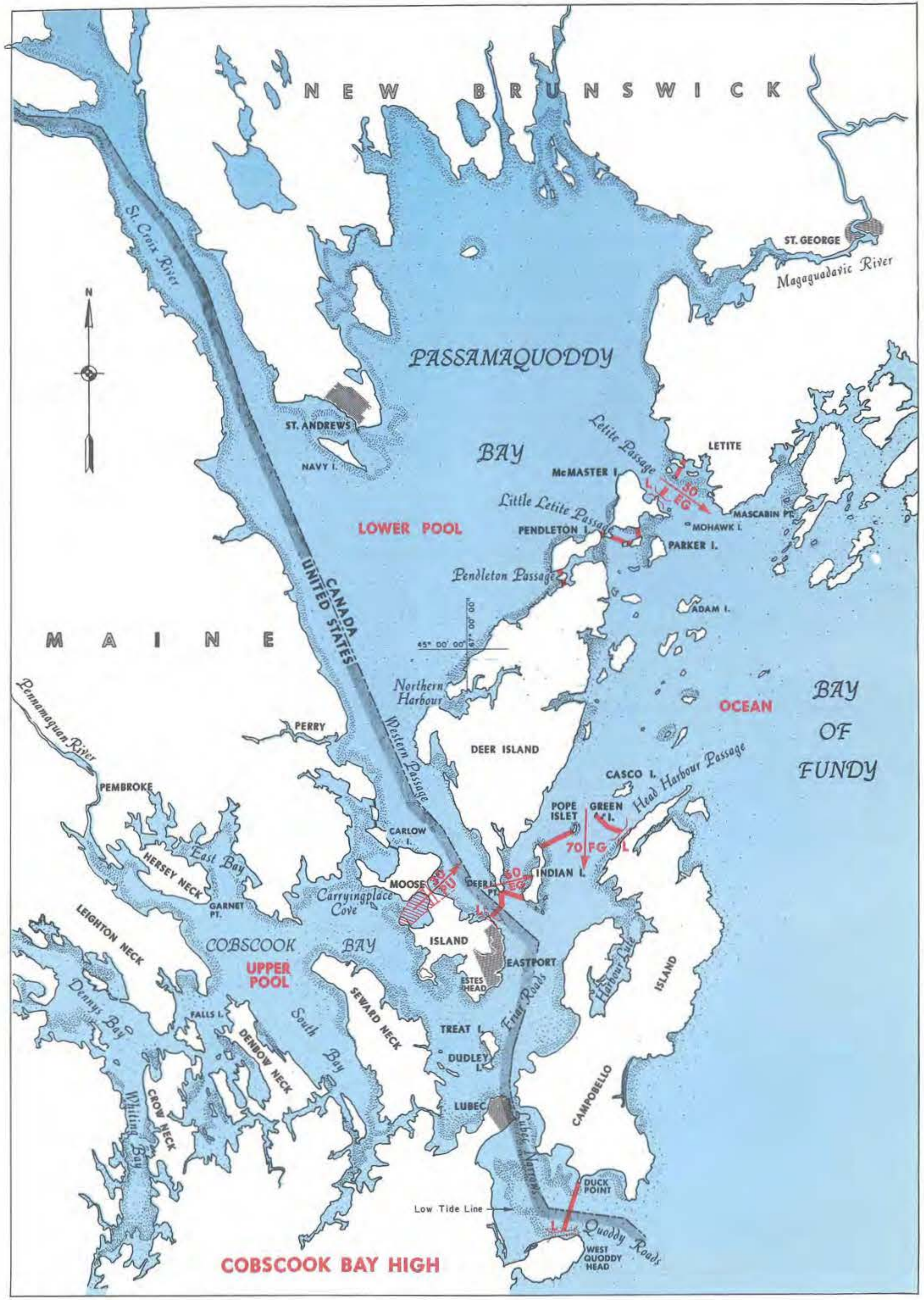
Comparison of Tidal Power Output with Normal Load Pattern

Each tide would fill the upper pool of the tidal project regardless of the amount of water used to generate energy in the previous cycle. Water left unused would be wasted. Somewhat similar in this respect to a "run-of-the-river" hydroelectric plant where no storage is available, energy generated by a two-pool tidal plant must take full advantage of the ebb and flood of the tides. Power must be generated from each tide before the next tide occurs or it is forever lost.

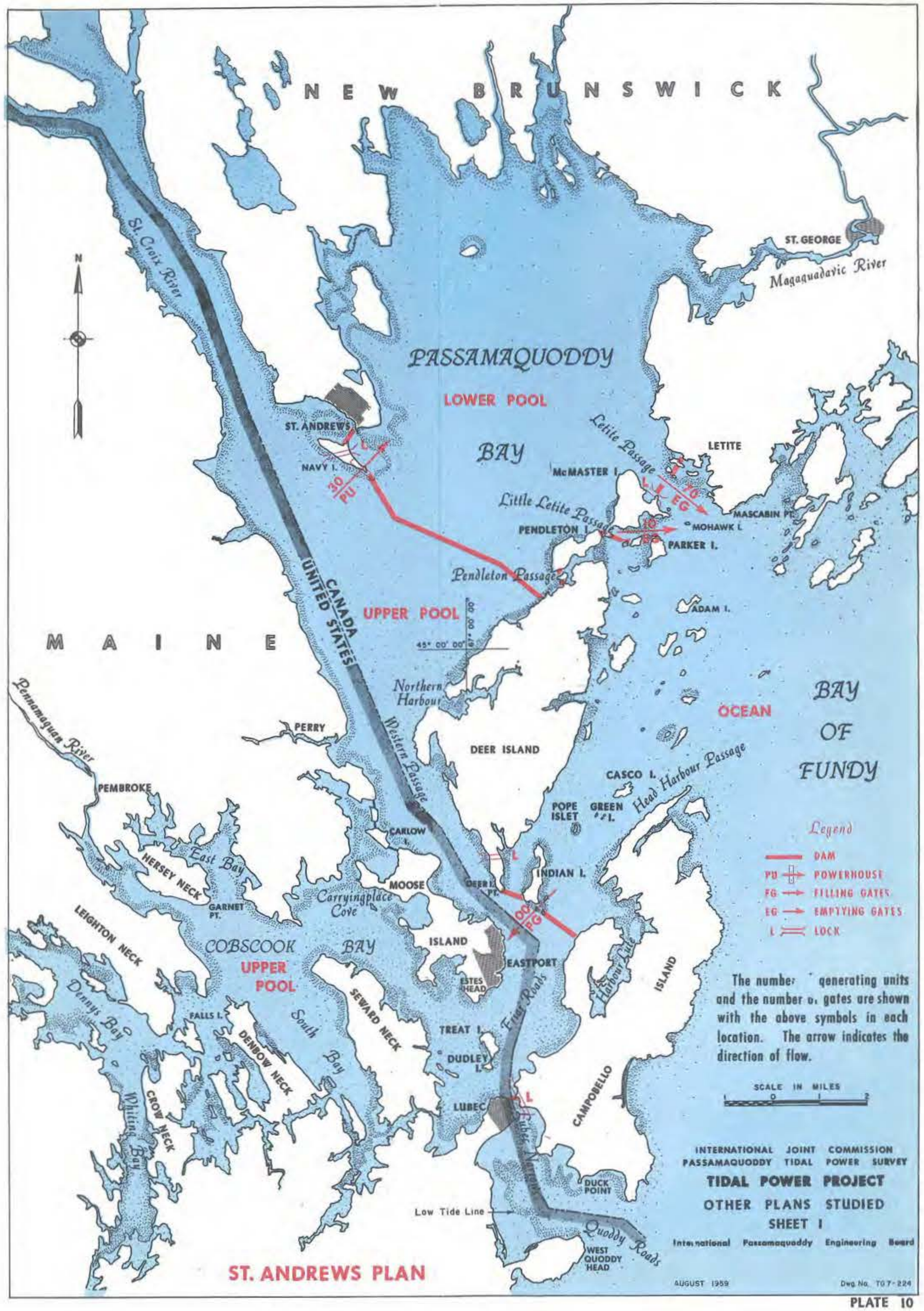
The tides follow closely the cycles of the moon as it circles the earth at varying distances. There are two high tides in a lunar day of 24 hours and 50 minutes. Therefore, high and low tides occur 50 minutes later each day. If a two-pool tidal plant is operated to extract as much energy as possible from the tides, maximum power production would occur shortly after low tide. Minimum power production would occur 2 to 3 hours before low tide.

Use of electricity follows the pattern of the 24-hour solar day. Maximum and minimum demands for energy occur at about the same time each day, minimum demand occurs on weekends and holidays, and the pattern of use during each week is approximately the same. Therefore, the maximum demand can occur at times of minimum tidal power production with the two continually shifting with respect to each other so that the minimum demand would also occur at times of maximum tidal generation.

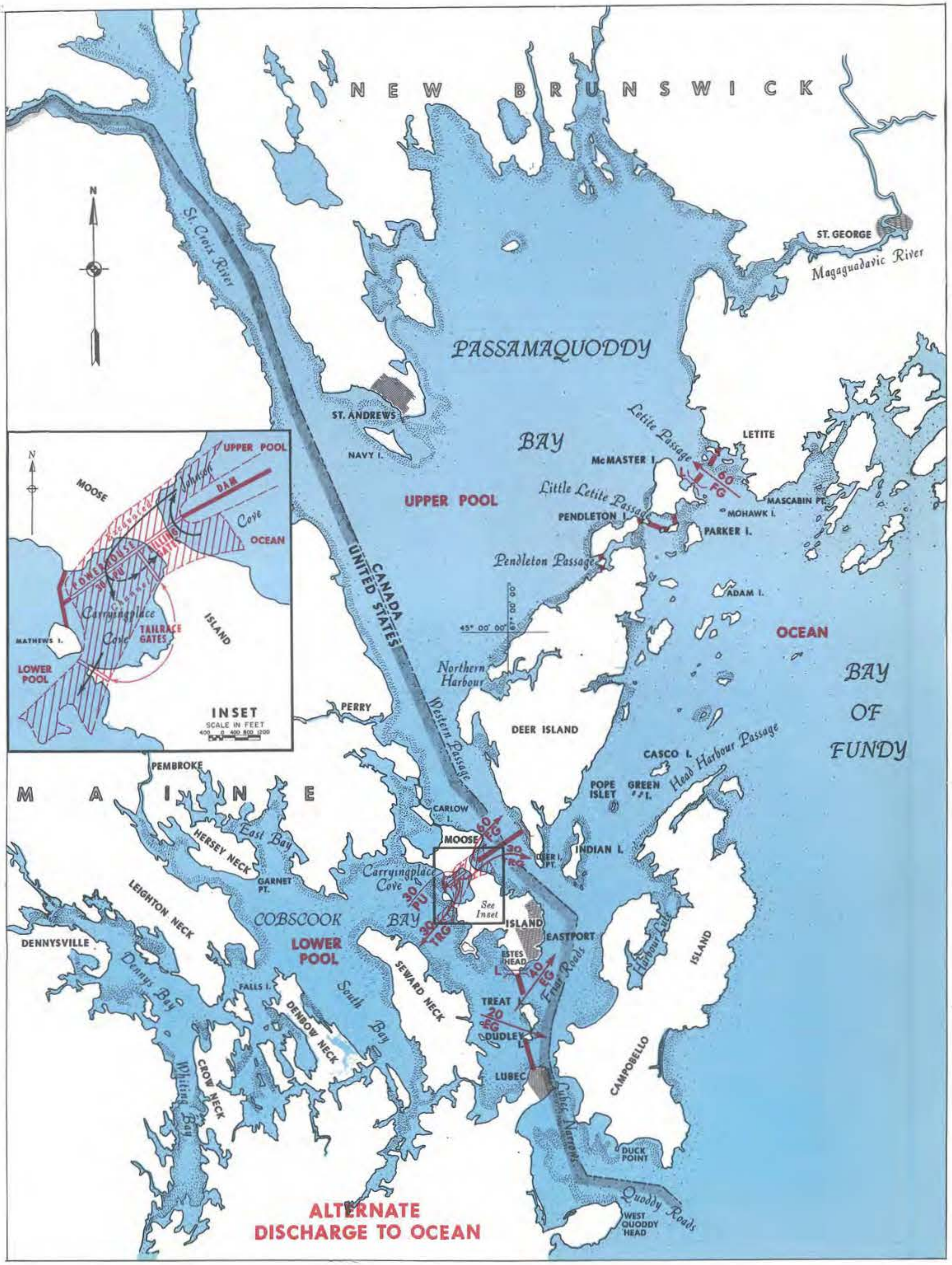
In addition to the day-to-day variation in the tides, they also vary through a 14.8-day cycle from spring tide (high ranges) to neap



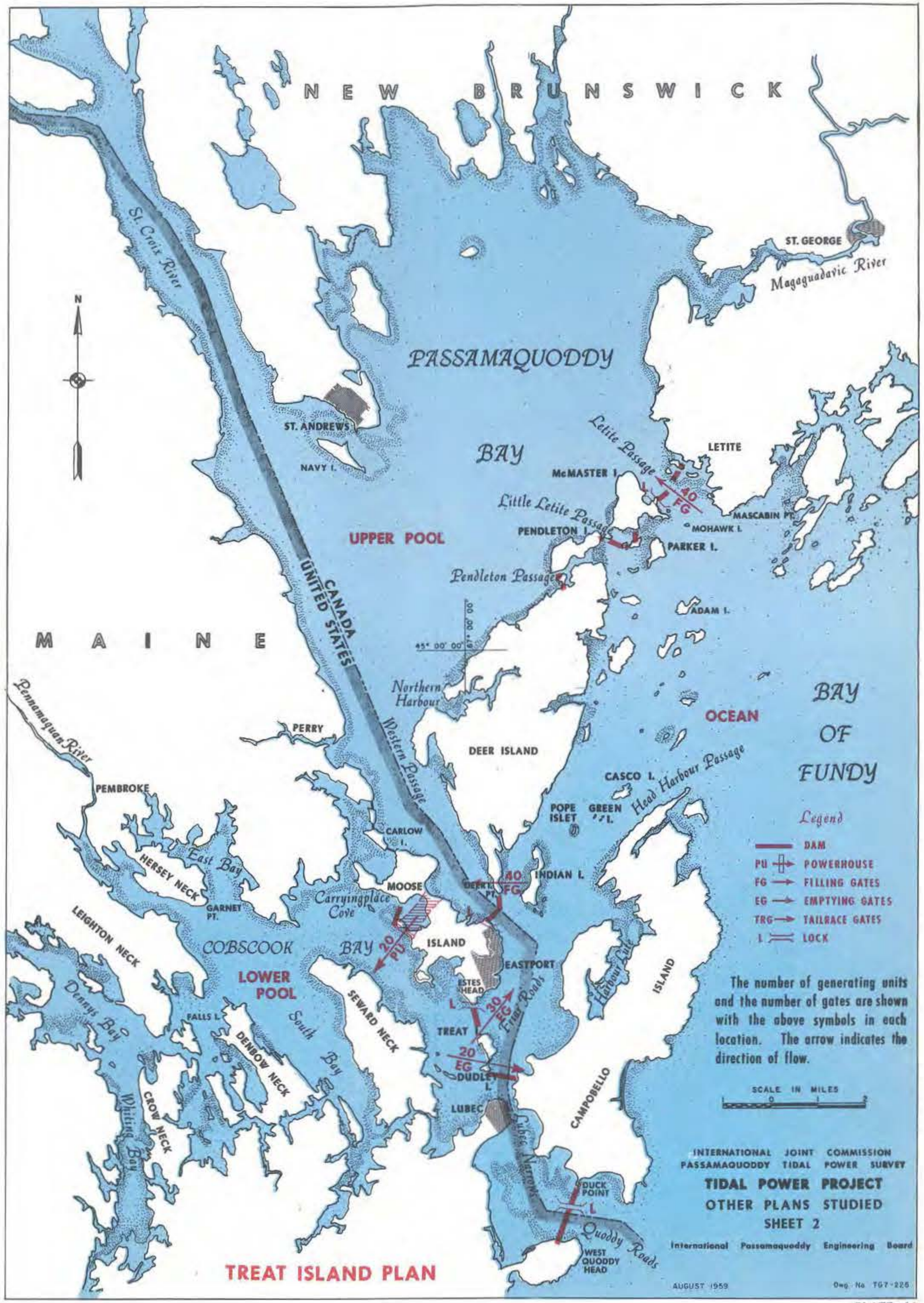
NEW BRUNSWICK
ST. GEORGE
Magaguadavic River
St. Croix River
PASSAMAQUODDY
BAY
ST. ANDREWS
NAVY I.
LETITE
Letite Passage
McMASTER I.
Little Letite Passage
PENDLETON I.
MOHAWK I.
MASCABIN PT.
PARKER I.
LOWER POOL
Pendleton Passage
ADAM I.
45° 00' 00"
67° 00' 00"
MAINE
CANADA
UNITED STATES
Northern Harbour
OCEAN
BAY OF FUNDY
Pennamaquan River
PERRY
Western Passage
DEER ISLAND
CASCO I.
Head Harbour Passage
POPE ISLET
GREEN I.
PEMBROKE
CARLOW I.
70 FG
L
INDIAN I.
MOOSE
DEER I. PT.
30 PU
60 EG
HERSEY NECK
East Bay
GARNET PT.
Carryingplace Cove
ISLAND
LEIGHTON NECK
COBSCOOK BAY
UPPER POOL
EASTPORT
ESTES HEAD
Harbour de Lute
ISLAND
SEWARD NECK
Friar Roads
Dennys Bay
FALLS I.
DENBOW NECK
South Bay
TREAT I.
DUDLEY I.
CAMPOBELLO
LUBEC
Whiting Bay
CROW NECK
Lubec Narrows
DUCK POINT
Low Tide Line
Quoddy Roads
WEST QUODDY HEAD
COBSCOOK BAY HIGH



NEW BRUNSWICK
ST. GEORGE
Magaguadavic River
St. Croix River
PASSAMAQUODDY
LOWER POOL
BAY
ST. ANDREWS
NAVY I.
30 PU
L
LETITE
Letite Passage
McMASTER I.
70 EG
Little Letite Passage
PENDLETON I.
MOHAWK I.
MASCABIN PT.
10 FG
PARKER I.
Pendleton Passage
UPPER POOL
ADAM I.
45° 00' 00"
MAINE
CANADA
UNITED STATES
Northern Harbour
OCEAN
BAY OF FUNDY
Pennamaquan River
PERRY
Western Passage
DEER ISLAND
CASCO I.
Head Harbour Passage
POPE ISLET
GREEN I.
PEMBROKE
CARLOW I.
INDIAN I.
MOOSE
DEER I. PT.
HERSEY NECK
East Bay
GARNET PT.
Carryingplace Cove
ISLAND
LEIGHTON NECK
COBSCOOK BAY
UPPER POOL
EASTPORT
ESTES HEAD
Harbour de Lute
ISLAND
SEWARD NECK
Friar Roads
Dennys Bay
FALLS I.
DENBOW NECK
South Bay
TREAT I.
DUDLEY I.
CAMPOBELLO
LUBEC
Whiting Bay
CROW NECK
DUCK POINT
Low Tide Line
Quoddy Roads
WEST QUODDY HEAD
Legend
DAM
PU POWERHOUSE
FG FILLING GATES
EG EMPTYING GATES
L LOCK
The number of generating units and the number of gates are shown with the above symbols in each location. The arrow indicates the direction of flow.
SCALE IN MILES
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
OTHER PLANS STUDIED
SHEET 1
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. T07-224
ST. ANDREWS PLAN



ALTERNATE DISCHARGE TO OCEAN



TREAT ISLAND PLAN

tides (low ranges) and back to spring tides. The spring tides occur whenever the sun, the moon, and the earth are in line, with the higher tides occurring at the time of the new moon when the sun and moon are on the same side of the earth. The maximum spring tides occur when the new moon is at perigee, the point in the moon's orbit closest to the earth.

Plate 12 shows the output of the tidal plant for three consecutive weeks compared with a typical load curve. The load curve shown has a total annual energy of 8,450 million kw.-hr. and a load factor of 60 percent. It is representative of the combined utility loads in Maine and New Brunswick expected in about 1975.

Tidal Power in a Large System

If the tidal power were a small portion of the total power required by the market, the fluctuations in output due to the varying tides would not be a serious problem. The other generating plants in the power system could adjust their output to supply the difference between the tidal plant output and the demand. The proposed tidal power project would, however, furnish a sizeable amount of power to the market of the region. Thus, the other plants in the system would be required to generate power at varying rates according to the difference between the tidal plant output and the demand. On a long term basis, and using the typical load illustrated on plate 12, the other plants would have to operate on a 49.8 percent load factor. The continually changing tidal output would cause the load on the remaining plants to change continually. The generating pattern would also change, and the pattern for any 2 consecutive days would not be the same. These variations would be greater than are normally experienced by a generating plant. Since these variations would be less acceptable than regulating for the load alone, the addition of an auxiliary source of power to the tidal plant would be essential.

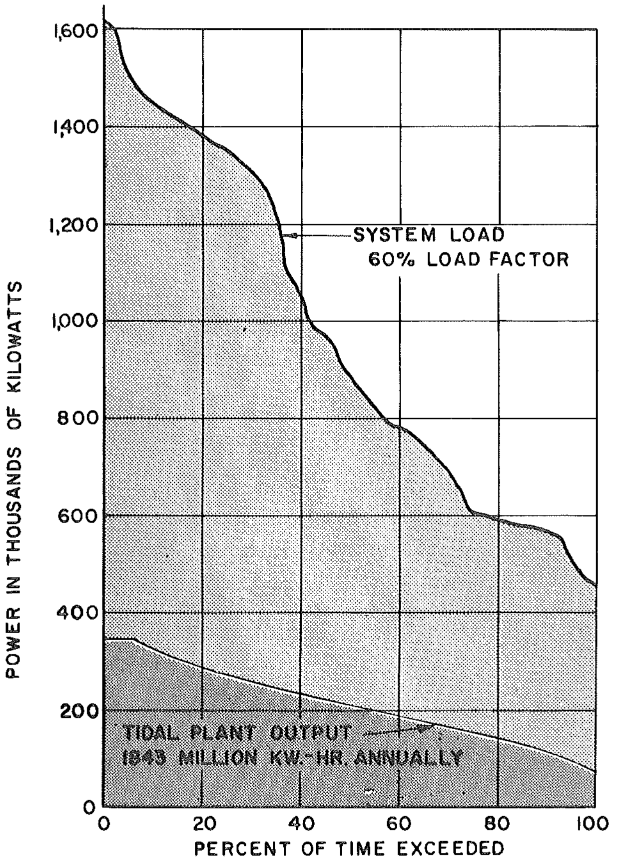
Tidal Power Supplemented by Auxiliary Power

The primary purpose of an auxiliary to the tidal plant is to supplement the tidal plant output during periods of low generation. The combined output would supply a portion of the system load so that the pattern of the remaining load would be acceptable to the other generating plants of the system.

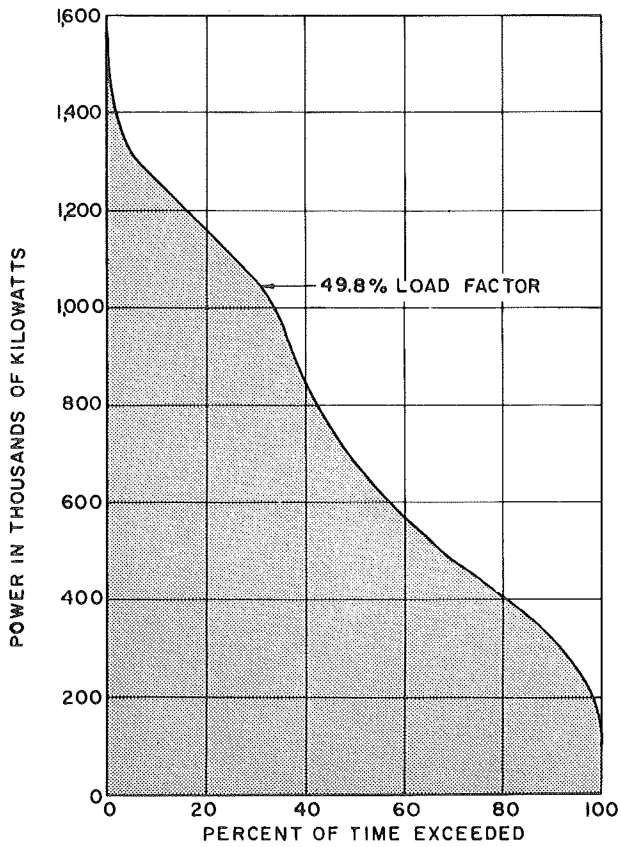
The difficulties of matching the tidal project output with the normal pattern of the load was recognized during the several previous investigations of potential tidal power projects in the Passamaquoddy-Cobscook Bay area. Dexter P. Cooper considered a pumped-storage plant at the Haycock Harbor site southwest of Lubec, Maine. The U.S. Army Corps of Engineers, in their 1935-37 studies, considered auxiliary pumped-storage projects at Haycock Harbor and at a site near Calais, Maine. The U.S. Corps of Engineers also considered a diesel-powered generating plant to firm the output of the one-pool project under construction at that time. The International Passamaquoddy Engineering Board report of March 1950 indicates that plans for auxiliary power projects should include consideration of pumped-storage plants and river hydroelectric plants in Maine and New Brunswick.

The design of an auxiliary power source must take into consideration both capacity and energy. The capacity problem can be solved simply by designing the auxiliary plant for a given dependable capacity; the combined dependable capacity is then the sum of the individual capacities. The energy poses a greater problem, since the auxiliary power generation requirements would be high during neap tides and considerably less during spring tides.

Solution of the auxiliary energy problem required a study of the differences between various assumed load curves and the tidal plant output. This was done by comparing a lunar month of tidal plant output with a weekly load curve, assuming that each hour of tidal plant output could occur during any hour of a representative load curve. The representative weekly load curve was adequate for this purpose since its shape and load factor could be modified and used repeatedly to approximate monthly or annual load curves.



DURATION CURVES OF SYSTEM LOAD AND TIDAL PLANT OUTPUT

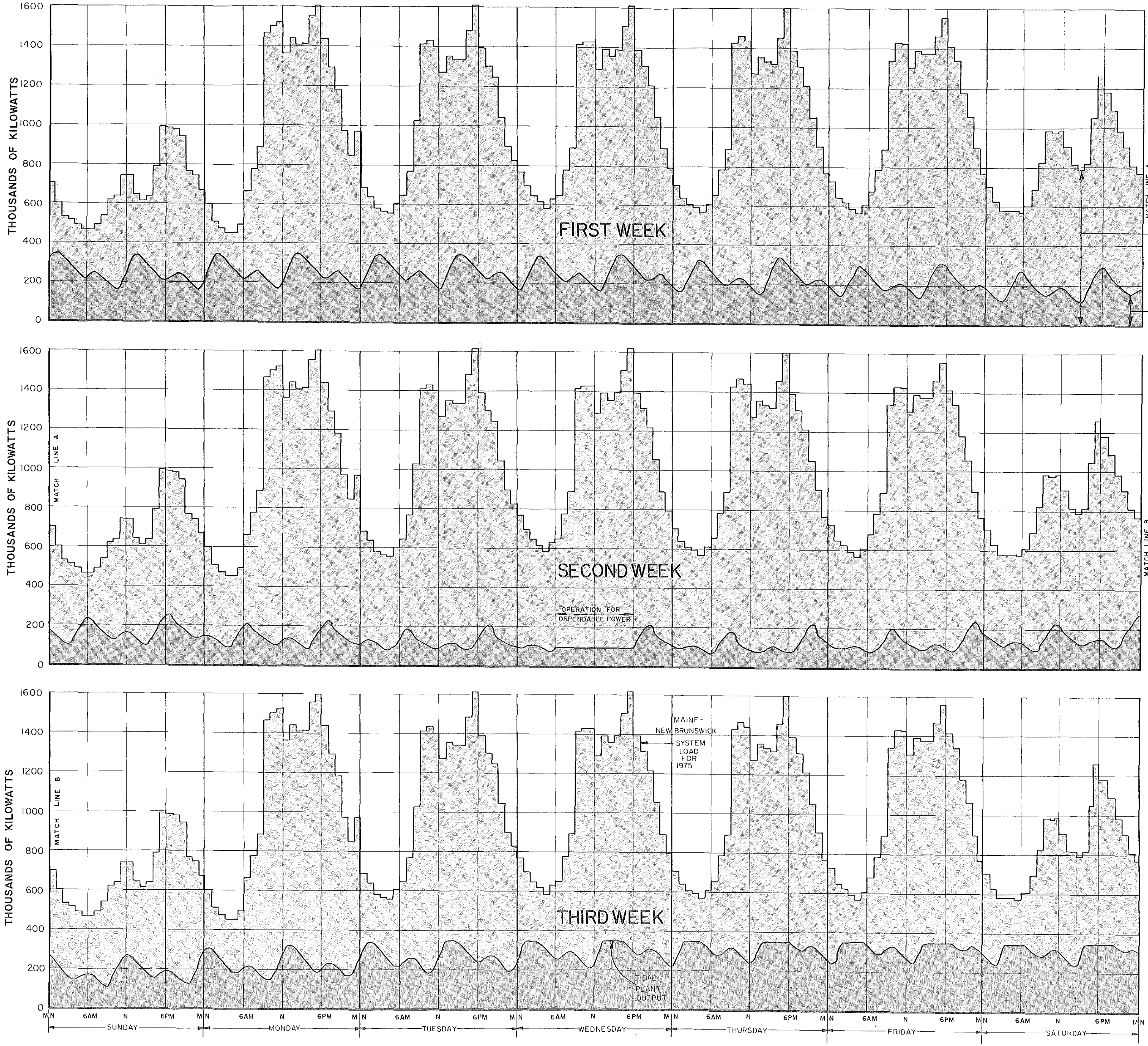


DURATION CURVE OF SYSTEM LOAD MINUS TIDAL PLANT OUTPUT

A study was made using the 706 hourly values of tidal plant output in one month and the 168 hourly values of a load curve for one week. The energy content of the load was varied by multiplying each value of the load curve by a coefficient. This did not change the load factor. The difference between each value of the load and energy value of the tidal plant output was obtained by an electronic computer requiring 118,608 separate subtractions. From these differences, counted according to magnitude by the computer, duration curves were plotted. Use of the electronic computer enabled rapid determination of the firming energy requirements from various auxiliary power sources. Duration curves of system load and tidal plant output are as illustrated. The duration curve of system load minus tidal plant output was derived from the results of the electronic computer studies.

One method of firming the tidal plant output would be to store a portion of the tidal plant energy by pumping water to a storage reservoir during times of high tidal plant output. The stored water would then be used to generate power when the tidal plant output is low. By alternately pumping and generating, the pumped-storage auxiliary would regulate the tidal plant output to meet the varying load demand. The pumped-storage operation would actually result in a decrease in total energy because of pumping and regeneration losses. This type of operation is illustrated on plate 13, which shows 3 typical weeks of tidal plant output modified by a pumped-storage plant to fit a normal load pattern.

Another method of firming the tidal plant output would be to add energy to the tidal plant output from an auxiliary power source



INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

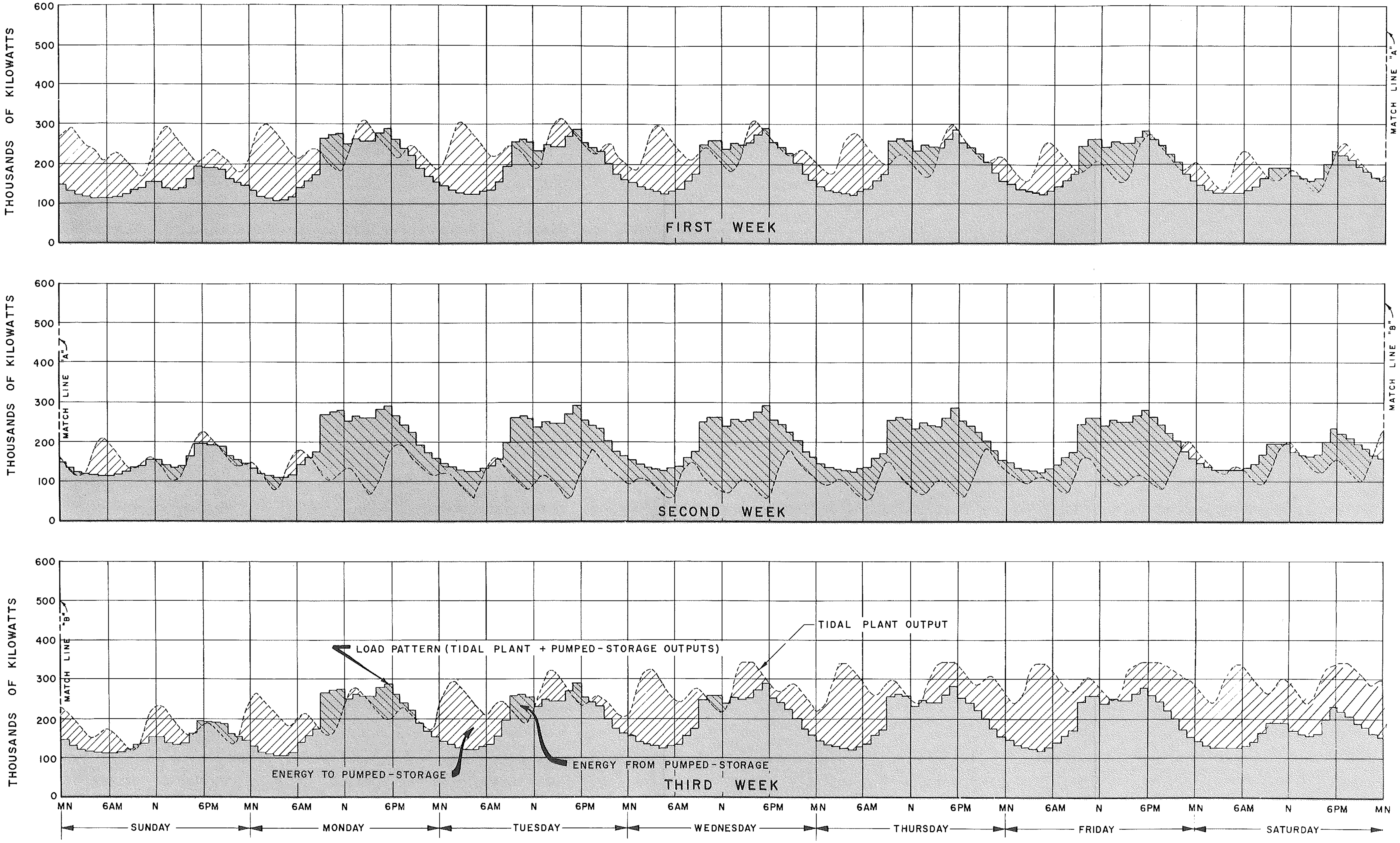
TIDAL POWER PROJECT

OUTPUT AND LOAD PATTERN
TIDAL PLANT ALONE

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7 - 226

PLATE 12



INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

OUTPUT AND LOAD PATTERN
TIDAL PLANT WITH PUMPED-STORAGE

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No TG7 - 228

PLATE 13

such as a hydroelectric or steam-electric plant. The auxiliary energy would be added so that the combined tidal plant and auxiliary energy would form a pattern similar to the system load. As the energy provided by the auxiliary is increased, the more closely could the combined tidal plant and auxiliary output form a constant proportion of the system load. This type of operation was assumed for analysis of auxiliary river hydro developments and is shown for 3 typical weeks of operation on plate 14. This plate is based on using the proposed Rankin Rapids development as the auxiliary. The tidal plant outputs are plotted on the bottom of the system load or are "base loaded." The crosshatched area above the base load represents the energy from the auxiliary. The difference between the system load and the tidal plant added to auxiliary outputs would constitute the load supplied by the remainder of the system. As shown in the illustration, the total energy output of the tidal plant and auxiliary would be included in the system load. Also, since the load factors of the system load and the difference (system load minus tidal plant plus auxiliary outputs) would be about 60 percent and 59 percent respectively, it is concluded that no unreasonable operating conditions would be imposed on the rest of the system.

River Hydro Auxiliary

A conventional hydroelectric project as an auxiliary to a Passamaquoddy tidal power project, not considered in previous examinations, was first studied in detail for this report. Three possible river hydro auxiliaries were considered after all available data on undeveloped hydroelectric power sites in the major river basins of Maine, and in the adjoining areas of New Hampshire and New Brunswick, had been examined to determine suitable sites for specific studies. The most up-to-date information on undeveloped waterpower in the area of the proposed tidal power project is contained in the report entitled "The Resources of the New England - New York Region," completed in March 1955 by the New England - New York Inter-Agency Committee, and also the the "Interim Report on the Water Resources of the Saint John River Basin," April 6, 1953, which was submitted to the International Joint Commission by the International Saint John River Engineering Board. Study of all available data led to the conclusion that the Rankin Rapids project on the upper Saint John River in Maine would provide the largest power and storage potential with the lowest at-site cost of any single project or combination of projects considered feasible for development. Study of other large potential sites on the Kennebec River and the Penobscot River revealed either excessive costs or that these sites were already in the planning stage of development by utility companies and probably would not be available for public development as part of the proposed international Passamaquoddy tidal power project.

The development of the Rankin Rapids site has received some opposition from people interested in preserving the fishing and white-water canoeing on the Allagash River, which would be flooded by the Rankin Rapids reservoir. Because of this opposition an alternate development was considered consisting of a high-head dam at Big Rapids, located on the Saint John River upstream from the mouth of the Allagash River, and a low-head project at the Lincoln School site located a short distance downstream from Rankin Rapids. The locations of these sites, all of which are in Maine, and their relation to the tidal project, are shown on plate 15. Three plans of development were selected for an initial study of the river hydro auxiliary to the proposed tidal power project. These were (a) Rankin Rapids, (b) Big Rapids, and (c) Big Rapids and Lincoln School.

The Lincoln School project would be a low-head development and would not develop a significant amount of storage for regulating river flows. Because of the low head and lack of storage, the Lincoln School site is not as desirable as either Rankin Rapids or Big Rapids sites. For this reason an auxiliary power project at the Lincoln School site alone was not considered.

Previous studies of the Rankin Rapids site had considered a development which would yield a regulated flow of 4,100 c.f.s. from a reservoir with a maximum elevation of 810 feet. This reservoir would furnish 1.46 million acre-feet of storage and allow a drawdown of 34 feet. It appeared that more storage, higher head, and greater drawdown would yield a more favorable project.

Studies were therefore made using 2.0 and 2.8 million acre-feet of useful storage with maximum pool levels at el. 810 and el. 860. These storage volumes would yield corresponding regulated flows of 5,150 and 5,950 c.f.s. Regulation to provide the average stream flow of 6,780 c.f.s. was not considered practicable. Preliminary estimates of costs and energy showed that the project with 2.8 million acre-feet of storage, with maximum pool level at el. 860, had the greatest excess of annual benefits over annual costs. Accordingly, this level of development was selected for further detailed study.

At the Big Rapids site, the maximum pool level was set at el. 910. A higher level would sharply increase the costs. With a drawdown of 35 feet, active storage would be 1.54 million acre-feet. This amount of storage would be sufficient to regulate the river flow to 3,540 c.f.s. To regulate to the average river flow of 4,214 c.f.s. at the site would require 3.64 million acre-feet of storage.

The upper limit of the development at the Lincoln School site is el. 630, the tailwater level of the Big Rapids development. No significant storage is available because of the small area of the pool at this elevation. With a 4-foot drawdown, 22,000 acre-feet of storage would be available to smooth out the Big Rapids discharge caused by the fluctuation in demand inherent in the operation of the tidal plant, and thus prevent waste of water at Lincoln School.

No structures specifically for regulating downstream discharges were planned for either the Rankin Rapids or Big Rapids - Lincoln School projects. However, minor regulation would be obtained incidentally from the latter project. If desirable, some regulation of releases from the auxiliary power plant at either of these two projects could be obtained through a load-sharing arrangement with downstream plants combined with the use of small amounts of reservoir storage at the downstream plants.

Pertinent data on the three sites developed during these studies are shown in the following table:

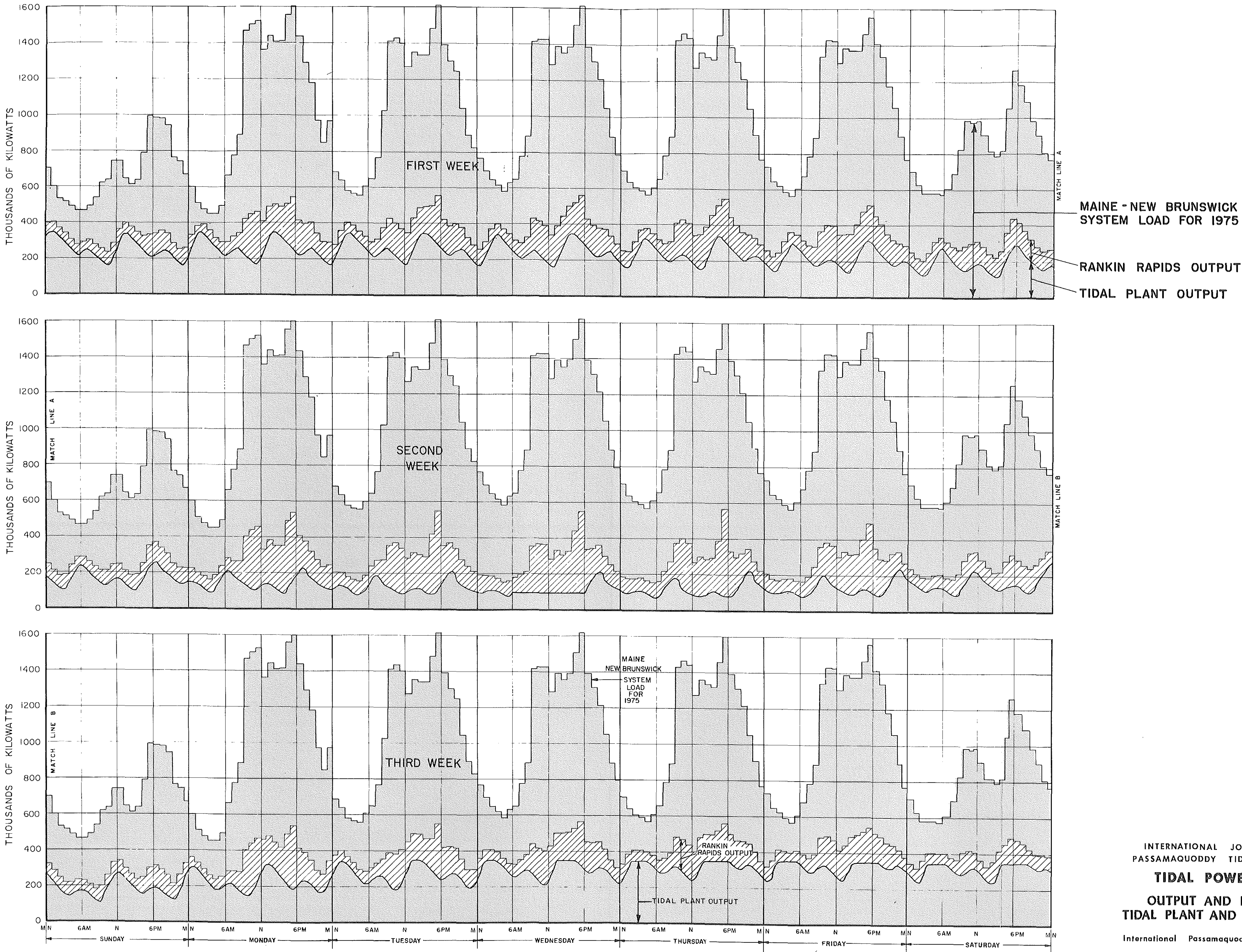
Project	Rankin Rapids	Big Rapids	Big Rapids plus Lincoln School
Drainage area, sq. mi.	4,060	2,419	4,066
Maximum normal operating pool, el. feet, m.s.l.	860	910	910 and 630
Active storage, million acre-feet	2.8	1.54	1.56
Average stream flow, c.f.s.	6,780	4,214	6,780
Regulated flow, c.f.s.	5,950	3,450	3,700 (1)
Dependable capacity, 1,000 kw.	460	338	392
Average annual energy million kw.-hr.	1,220	695	1,005
Relative cost	1.00	0.77	0.98
Relative annual energy	1.00	0.57	0.82
Relative cost per kw.-hr. of annual energy	1.00	1.35	1.20
Relative dependable capacity	1.00	0.73	0.85
Relative cost of dependable capacity	1.00	1.06	1.15

(1) Approximate

The Rankin Rapids auxiliary would produce 525 million kw.-hr. per year more than Big Rapids and 215 million kw.-hr. per year more than the combined Big Rapids and Lincoln School project. The increased capacities would be 122,000 kw. and 68,000 kw., respectively. In addition, the cost per unit of energy and of capacity would be less than at either Big Rapids or Big Rapids and Lincoln School. The Rankin Rapids project would have about $3 million more power benefits per year than the other combinations.

The Rankin Rapids project, because of its greater drainage area, larger storage, and increased regulated outflow, would improve conditions for further power development on the downstream Saint John River to a greater extent than would either of the other developments.

For the above reasons the Rankin Rapids project was selected as the river hydro auxiliary to the proposed international Passamaquoddy tidal power project.



INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

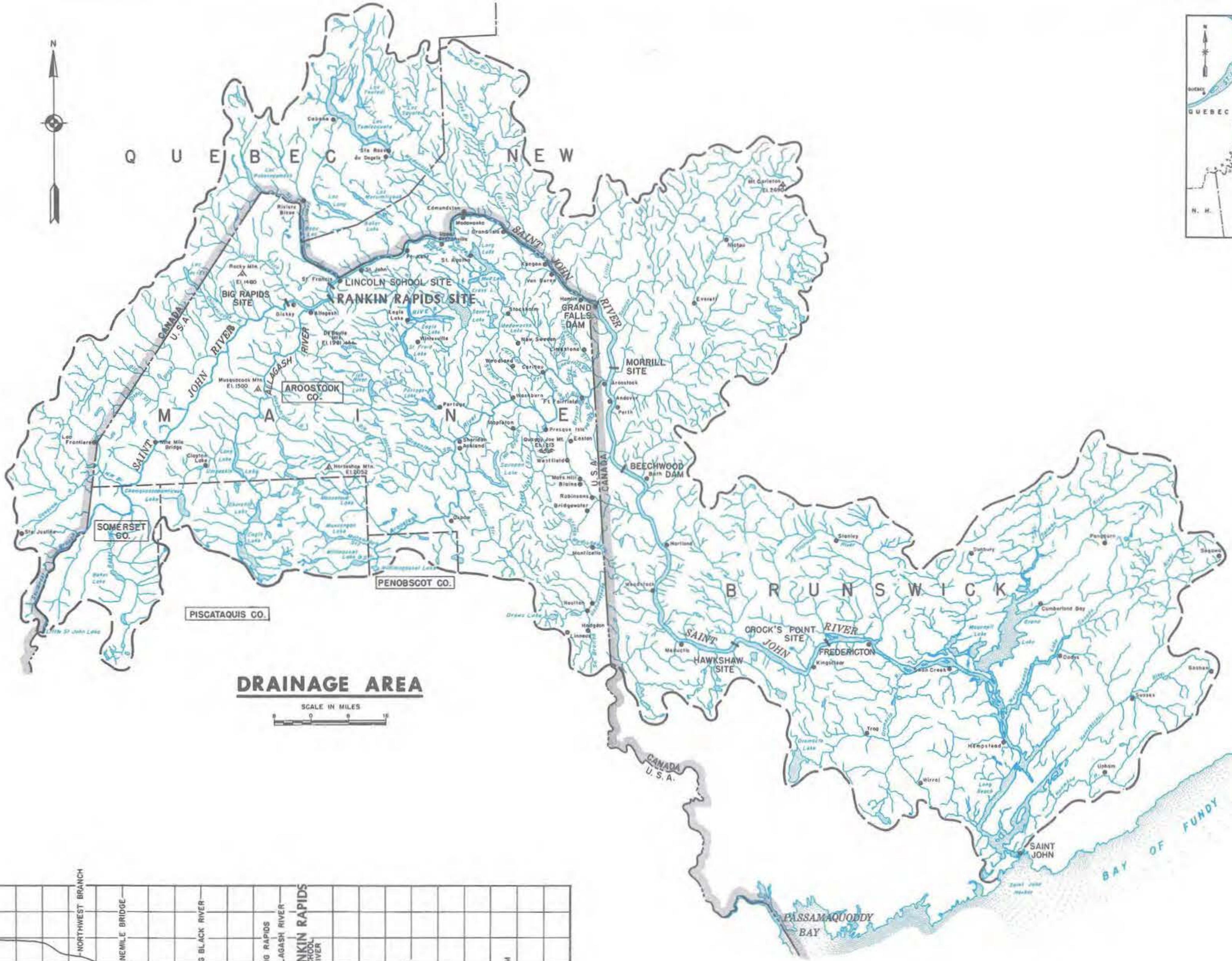
TIDAL POWER PROJECT

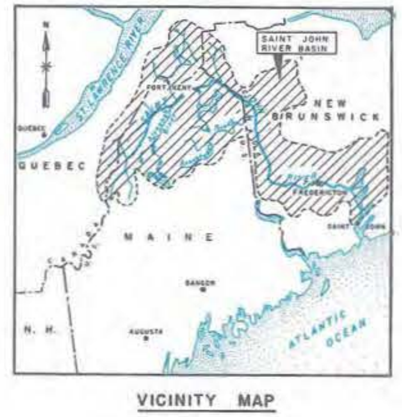
OUTPUT AND LOAD PATTERN
TIDAL PLANT AND AUXILIARY POWER

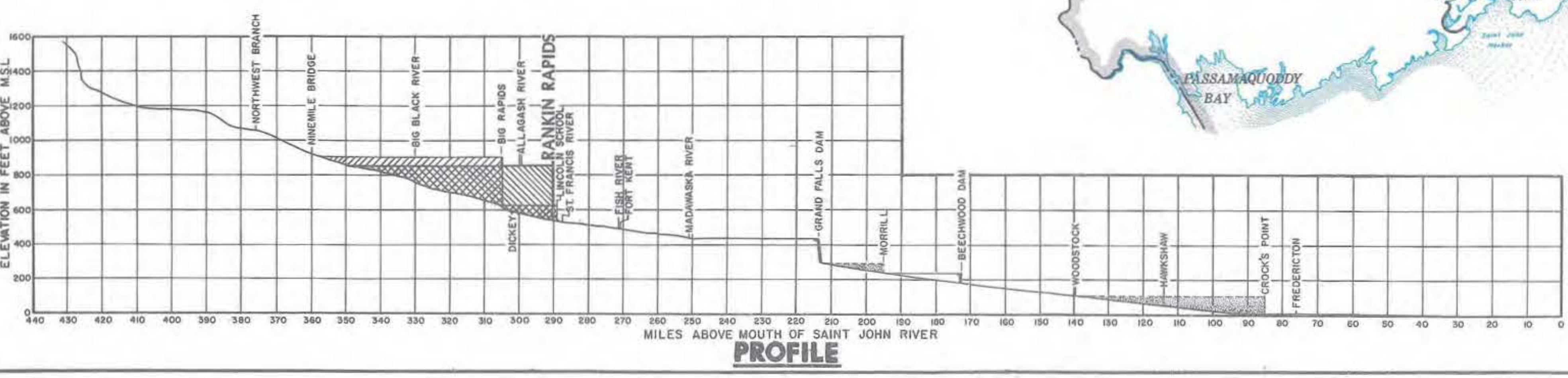
International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-229

PLATE 14







INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

SAINT JOHN RIVER

DRAINAGE AREA AND PROFILE

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. T67-230

The Rankin Rapids project could also be built primarily to carry a part of the load in Maine. If this were done, capacity could be added for firming the tidal project energy. The energy accompanying the firming capacity would be borrowed when the tidal plant output is insufficient to meet the load, and repaid when tidal energy exceeded the load.

Fish and Wildlife, River Hydro Auxiliary

Because of the opposition of certain groups in the United States to the development of the Rankin Rapids site, the Engineering Board undertook to secure the views of the Northeast Region, Bureau of Sport Fisheries and Wildlife, Fish and Wildlife Service of the United States Department of the Interior. The Bureau stated that the Rankin Rapids project would injure the fish and wildlife assets of the area more than the Big Rapids - Lincoln School combination. Regardless of the auxiliary project selected, certain measures would be required for lessening, or compensating for, the fish and wildlife losses. The measures recommended by the Bureau are as follows:

(1) Establishment of a framework for management of fish and wildlife resources.
(2) Provision of public access.
(3) Purchase of additional land for wildlife management purposes.
(4) Modification of land clearing plans.
(5) Construction of barrier dams.
(6) Provision for minimum flows as required to benefit downstream fisheries.
(7) Provision for a fish hatchery and rearing facilities.
(8) Management of tributary streams.
(9) Subimpoundments for waterfowl within reservoir maximum flow line.
(10) Control of reservoir pool elevations and provisions for spawning beds.
(11) Control of release temperatures.

Consideration should be given to all the measures listed above if construction of the Rankin Rapids auxiliary is undertaken.

Pumped-Storage Auxiliary

Of primary importance in selecting a site for a pumped-storage auxiliary is a reservoir large enough and high enough to store energy and develop capacity at a low cost. The minimum requirements are capacity to store water equivalent to 25.8 million kw.-hr. of energy output with a dependable generating capacity of 228,000 kw. Additional storage would be desirable if it could be obtained at a small increase in cost. Leakage from the reservoir must be small and, if salt water is used, this leakage cannot be allowed to damage adjacent properties.

Three sites in the vicinity of the tidal power project appeared to satisfy these requirements, the first two being those studied by the U.S. Army Corps of Engineers in 1935-37: the Haycock Harbor site, about 10 miles southwest from Eastport, Maine; the Calais site about 20 miles northwest from Eastport; and a new site on the Digdeguash River, New Brunswick, which flows into Passamaquoddy Bay from the north (plates 2 and 3).

Investigation of the Haycock Harbor site showed that development of a pumped-storage plant was possible but more costly than the Calais site. Also, the foundation conditions are poor and sources of embankment materials are limited. The cost of the pump-turbine equipment would be high because of the low head available at the site. For these reasons, Haycock Harbor as a site for a pumped-storage plant was not considered further.

In 1935, the Calais site was planned for storage of 16 million kw.-hr. This storage was comparable to the Haycock Harbor site and was adequate for firming the tidal power output from the one-pool scheme then being studied. Since the international two-pool tidal power project would require greater storage, further study of the site was undertaken. With a maximum pool at el. 201 and a drawdown of 34 feet, the required energy storage of 25.8 million kw.-hr. would be available. Numerous saddle dams would be required to form the reservoir, but no spillway would be required, and care of water during construction would not be a problem. At el. 201 the pool would cover about 6,400 acres, of which about 2,500 acres are now fresh water lakes. The remainder of the area is in forest and marsh and contains a few camps and unimproved roads.

The International Passamaquoddy Engineering Board, in its 1950 report, referred to the Digdeguash River in New Brunswick as a possible site for a pumped-storage project. A survey of the site showed that 28 million kw.-hr. of energy could be generated from the storage in a pool with maximum el. 180 and with a 40-foot drawdown. The drainage area and profile of the Digdeguash River are shown on plate 16.

Preliminary studies showed that of the three sites considered for the pumped-storage auxiliary, only the Haycock Harbor site was definitely unsuitable. No significant differences in advantages were revealed between the Digdeguash and Calais sites. Therefore, further studies of these two sites were made.

Pertinent data developed by these studies and used in the selection of the Digdeguash site as the pumped-storage auxiliary are shown in the table following. Earth dams would assure the least costly project at both sites. Development of the required dependable capacity of 228,000 kw. at the Digdeguash site would cost about $1.5 million more than at the Calais site, but would provide 2.4 million kw.-hr. more storage. In addition, the flow of the Digdeguash River would permit generation of 30 million kw.-hr. of energy per year. This added energy more than offsets the cost advantage of the Calais site. Therefore, the Digdeguash site was selected for specific study for the pumped-storage auxiliary to the tidal power project.

Pertinent Data for Selection of Pumped Storage Auxiliary

	Digdeguash	Calais
Drainage area, sq. mi.	176	19
Average annual runoff, 1,000 acre-feet	265	Negligible
Max. reservoir operating el., ft.	180	201
Min. reservoir operating el., ft.	140	167
Usable storage, 1,000 acre-feet	204	158
Energy produced at bus bar from storage and head, million kw.-hr.	28	25.8
Annual energy from fresh water inflow, million kw.-hr.	30	None
Mean pumping head, feet	161	183
Mean generating head, feet	153	177
Dependable capacity, 1,000 kw.	228	228
Embankments		
Total length, feet	5,500	23,800
Max. height, feet	190	100

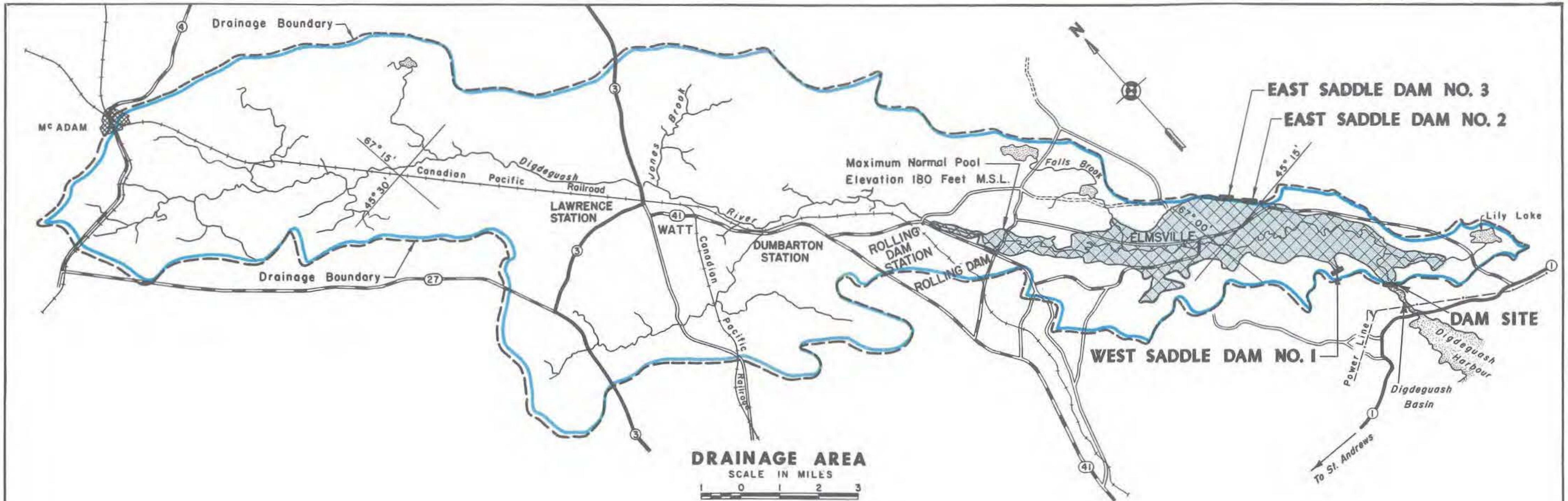
Steam-Electric Auxiliary

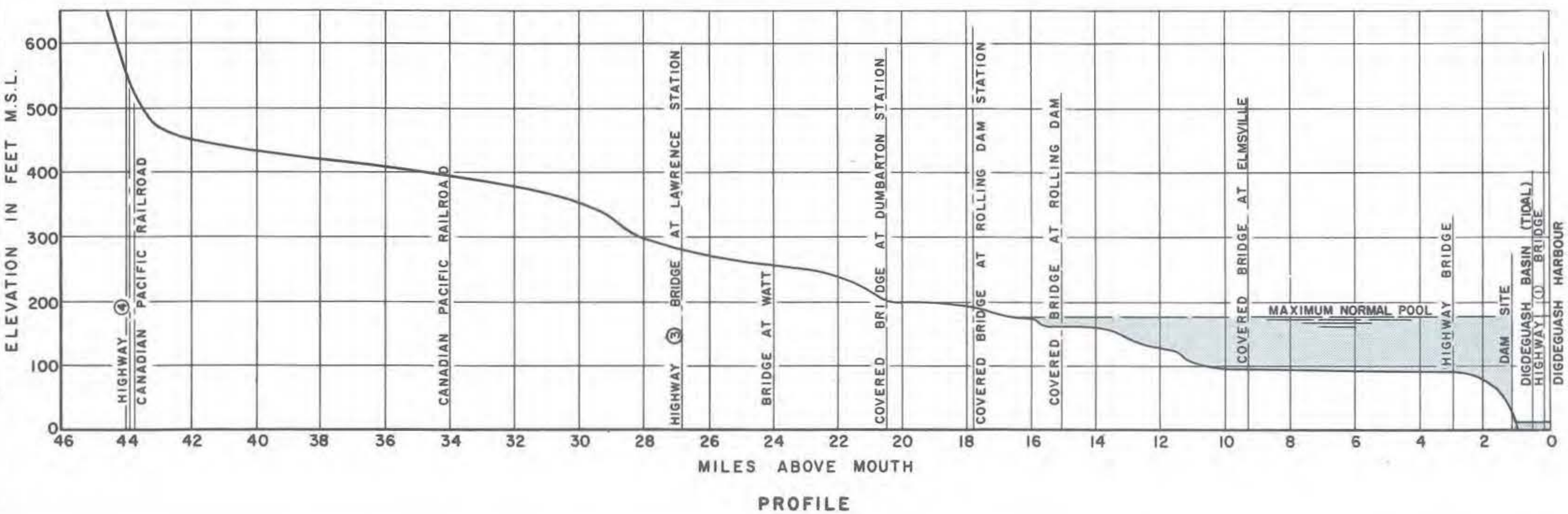
A steam-electric plant could be used as an auxiliary to the tidal project if operated in the same way as the river hydro auxiliary previously described. This alternative was examined in some detail.

The size of the steam auxiliary was assumed large enough to firm the output of the tidal plant up to its rated capacity of 300,000 kw. Since the tidal plant would have a dependable capacity of 95,000 kw., a steam-plant would need to supply a maximum of 205,000 kw. In studying the steam auxiliary, it was assumed that the 300,000 kw. load would have a load factor of 62 percent. This load would have an annual energy of 1,630 million kw.-hr.

A study of the relation between the relatively stable load pattern and the continually varying output of the tidal plant indicated that about 500 million of the 1,843 million kw.-hr. of annual tidal energy would not fit under the load curve. The steamplant would then be needed to fill a deficiency of nearly 300 million kw.-hr. between the assumed load and the tidal energy under the load curve. The plant load factor on this basis would be 17 percent.

While not common, there have been instances in recent years of steam-electric plants designed and built for low load factor operation. Construction for this specific purpose usually leads to economies in construction cost. This follows as a result of the less exacting operating requirements of such plants compared with modern base load stations. Considering the variation in required output of the auxiliary steamplant, a total installation of 220,000 kw. in five 44,000 kw. units is appropriate. By constructing all five units at once, and using a simple steam cycle and moderate temperature-pressure conditions, and holding duplication of auxiliary equipment to a minimum, it is estimated that the plant could be built for $175 per kw. at January 1958 price levels.





PROFILE

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

DIGDEGUASH RIVER
DRAINAGE AREA AND PROFILE

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-231

PLATE 16

The principal characteristics of the steam-electric auxiliary station are as follows:

Generating station

Total installed capacity, kw.	220,000
Maximum demand on plant, kw.	205,000
Average annual generation, million kw.-hr.	300
Units, number	5
Unit size, kw.	44,000
Unit cost, $ per kw.	175
Fuel, type	Oil
Heat rate, B.t.u. per kw.-hr.	12,200

Step-up substation

Total capacity, kv.-a.	240,000

Although the average annual load factor of the auxiliary steamplant would be relatively low, the plant's capacity would be connected to the load for substantial periods of time each year. This is estimated at upwards of 4,000 hours. The demands on the station would fluctuate through a wide range, because of the independently varying magnitudes of load and tidal power output. Individual units would be subject, therefore, to an unusual amount of loading and unloading. It was assumed, for this reason, that the fixed fuel requirements would be somewhat greater than normally encountered in conventionally operated steamplants.

In addition to supplementing the tidal power output, the auxiliary steam-electric plant would also provide required reserves. In terms of unit sizes, this means a 44,000 kw. machine would be available for this purpose. Operating with an overload of 15 percent, the remaining four units could deliver the 200,000 kw. that would occasionally be required when tidal power is at a minimum.

The estimated capital cost and the various components of annual cost of the steam-electric auxiliary, based on a 35-year amortization period, on Federal financing at 2 1/2 percent interest rate, and on 0.25 percent for insurance, are as follows:

Capital cost		
Generating station		$38,500,000
Step-up substation		3,013,000
Transmission lines		55,000
Total		41,568,000
Annual fixed costs		
Fixed charges		
Generating station	1,895,000	
Step-up substation and transmission lines	151,000	
Total		2,046,000
Operation and maintenance - administrative and general		
Generating station	725,000	
Step-up substation and transmission lines	97,000	
Total		822,000
Fixed Fuel		
Generating station		420,000
Total annual fixed costs		3,288,000
Annual variable costs		
Generating station		
Fuel	1,320,000	
Operation and maintenance	90,000	
		1,410,000
Total annual cost		$4,698,000

The estimated cost of the steamplant of $41,568,000 would be about the same as the cost of a pumped-storage plant. However, the annual cost would be considerably more, because of the need for buying fuel. In addition, it would be difficult to operate the steam auxiliary under such variable load conditions, and to dispose of the part of the tidal plant energy not under the load curve. For these reasons, no further consideration was given to a steam auxiliary.

COMBINATIONS FOR ECONOMIC ANALYSIS

On the basis of the foregoing, the following four plans of power development were selected for evaluation of economic justification:

(1) Tidal project alone.
(2) Tidal project and all of Rankin Rapids as the auxiliary power source.
(3) Tidal project and incremental capacity only at Rankin Rapids as the auxiliary.
(4) Tidal project and the Digdeguash pumped-storage project as the auxiliary.

It was assumed for this study that the United States and Canada would share equally both the costs and benefits of the four combinations.

CHAPTER III

SITE CONDITIONS

One of the first phases of the tidal power survey was the compilation and analysis of all available information pertinent to the project sites being considered. These data were used to select the project arrangements described in chapter II. As these project plans were developed, additional information was collected from the field for use in the specific design studies. All available data, together with the tidal project construction accomplished by the U.S. Army Corps of Engineers in 1935-37, and the field operations for obtaining new information are described in the following paragraphs. Also described are site conditions of the proposed tidal power project, and of the river hydroelectric and the pumped-storage auxiliaries considered in this survey.

PREVIOUS STUDIES, AND 1935-37 CONSTRUCTION IN UNITED STATES

Previous studies of the general region of the proposed tidal project and its auxiliary components, and of the specific sites considered for development, have produced a great amount of basic data. Topographic and hydrographic surveys, tidal and climatic observations, and geological reconnaissance were made by United States and Canadian agencies as part of the systematic coverage of the entire region. Similar and more detailed investigations specifically for a tidal power project were made by Dexter P. Cooper in 1926-28, and by the U.S. Army Corps of Engineers in 1935-37. In 1935-37 three small dams were built by the U.S. Army Corps of Engineers, two of which closed the tidal passages northwest of Eastport, Maine. Data obtained from these previous studies are described below.

Topographic Surveys

The United States Geological Survey and the Canadian Department of Mines and Technical Surveys made topographic surveys of the entire tidal project region. Results of these surveys are available in published quadrangle sheets with contour intervals of 20 feet on U.S.G.S. sheets and of 50 feet on Canadian sheets. During the 1920's Dexter P. Cooper made field surveys and prepared topographic maps of the general project area and of specific areas proposed for structures. In 1935-37, the U.S. Army Corps of Engineers made new surveys and maps of the project area and of structure sites proposed at that time for the all-United States tidal power project. Horizontal and vertical control surveys were of high order and bench marks and triangulation stations were carefully selected and clearly identified. The basic control of that period was fully adequate for extending the surveys into adjacent areas involved in the current survey.

Looking south from Canadian mainland showing Letite Passage, McMaster Island, Little Letite Passage and Deer Island.

Hydrographic Surveys

The entire area of the proposed tidal power project has been surveyed for navigation at various times since 1866 by the U.S. Coast and Geodetic Survey, the International Boundary Commission, the Canadian Hydrographic Service, and the British Admiralty. The results of these surveys, compiled as Hydrographic Chart 801 of the United States Coast and Geodetic Survey, were used for general studies. The survey manuscripts were used for additional details in some areas. Underwater mapping by Dexter P. Cooper during the 1926-28 period included reconnaissance of approach channel areas, fairly complete data on prospective structure sites, and a careful survey of the Cobscook Bay shore in the tide range.

During the 1935-37 investigations by the U.S. Army Corps of Engineers, new hydrographic surveys were made for the structures proposed at that time. In the summer of 1951, the Water Resources Division of the U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers, conducted fathometric surveys in several locations in the Passamaquoddy Bay area using both high- and low-frequency sonic sounding devices. In addition to water depths, the data obtained permitted some interpretation of the extent and thickness of the unconsolidated underwater sediments overlying bedrock.

Tide Observations

Various agencies have intermittently measured the tides in the Cobscook and Passamaquoddy Bays and adjacent areas over the past 100 years. The United States Coast and Geodetic Survey measured the tides for the longest continuous period, from 1929 through 1957, at their station in Eastport, Maine. The U.S. Army Corps of Engineers observed the tides at several locations in Cobscook Bay for periods of about 1 month each during the 1935-37 period. Dexter P. Cooper did similar work in the 1920's. The U.S. Coast and Geodetic Survey made short-term observations at various locations on a number of occasions dating back to 1841. These observations were made primarily for hydrographic surveys. The data from these early observations fulfilled the needs of the current survey, except that some additional measurements were needed for verification and refinement.

Information on tidal currents in the area was meager, the most complete record being measurements made in 1935-37 by the U.S. Army Corps of Engineers in the reach from Eastport to Lubec, Maine, where the main closure dam was planned at that time.

Climatic Conditions

The United States Weather Bureau has observed precipitation, temperature, wind, and other phenomena at a number of locations in the region of the tidal project. The weather station at Eastport, Maine, has been in service since 1885, and thus provides records that show reliably the average and extreme conditions of the area.

Stream Flow

Information on stream flow was useful for the design of the tidal power project and the pumped-storage auxiliary, but was essential for the design of the river hydro auxiliary. The U.S. Geological Survey publishes runoff records of 4 stations on the St. Croix River, and the Water Resources Branch of the Department of Northern Affairs and National Resources of Canada publishes records for the Magaguadavic River, both of which drain into Passamaquoddy Bay. Stream flow information from these two sources was adequate for estimating fresh water inflow to the tidal project. This information was also used to estimate fresh water inflow to the Digdeguash pumped-storage project.

The U.S. Geological Survey publishes runoff records for a number of stations in the upper Saint John River basin. These records provided an adequate basis for studies of the Rankin Rapids river hydro auxiliary and the alternate auxiliary plants considered in the area.

Geological Surveys

General geologic data were obtained from publications of the Geological Survey of the United States Department of Interior and the Canadian Department of Mines and Technical Surveys. Dexter P. Cooper apparently made no geological surveys during his studies. A comprehensive program of field investigations was started by the U.S. Army Corps of Engineers in 1935 under the guidance of a staff geologist. A consulting geologist was also retained. Detailed reconnaissance and summary reports were made on each site of a major tidal plant structure, and at Haycock Harbor and Calais, the two sites considered for auxiliary pumped-storage plants. The Haycock Harbor site is located about 10 miles southwest of Eastport, Maine, and the Calais site is about 20 miles northwest of Eastport. The geologists also searched the area for suitable construction materials. Much of the data obtained in 1935-37 was used in the current survey.

The interim report of April 6, 1953, to the International Joint Commission by the International Saint John River Engineering Board, entitled "Water Resoures of the Saint John River Basin," contains the results of geological investigations. The results of these investigations were sufficient for the current survey of the Rankin Rapids site.

Subsurface Explorations

The first subsurface explorations for the proposed Passamaquoddy tidal power project were made by Cooper in 1926-28. These explorations consisted of numerous wash borings and a few diamond drill holes taken at or near structure sites on land. The U.S. Army Corps of Engineers in the 1935-37 investigations started a major program of subsurface exploration both by contract and hired labor. About 2,300 explorations were made by various methods including core drilling, jet probing, earth auger borings, and test pits. Of particular significance to the present survey is the deep-water drilling performed in the channels between Eastport and Lubec, Maine, to obtain undisturbed samples of clay in areas of proposed foundations for tidal dams. In spite of all efforts, the samples suffered some disturbance, and information from the tests of the samples was not completely reliable. However, the records of the deep-water drilling performed in 1935 were helpful in planning similar work performed under more difficult conditions at greater depths during the current survey.

Explorations of the auxiliary pumped-storage sites made in 1935-37 at Haycock Harbor and at a site near Calais, Maine, were adequate for the current survey. Exploration of the Rankin Rapids site, the location of the proposed auxiliary river hydroelectric plant, was made during the investigation of the water resources of the Saint John River completed in 1953. These explorations provided sufficient data for the present survey.

Existing Construction

The U.S. Army Corps of Engineers built three rockfill dams in 1935-37 as part of the proposed Passamaquoddy tidal power project within the United States. One dam was constructed between Treat and Dudley Islands (plate 3), using materials excavated for the proposed gate structure on Treat Island. When project construction was stopped in 1937, no surface protection had been provided for the exposed dumped rock slope. Consequently, the waves have lowered the surface to approximately high tide level and flattened the slopes considerably.

Looking north from Lubec, Maine, with Dudley and Treat Islands in center, showing connecting dam built in 1935-37.

In addition to the Treat-Dudley Island dam, two small dams were built closing shallow channels between Moose and Carlow Islands and between Carlow Island and Pleasant Point, northwest of Eastport, Maine (plate 3). These embankments were 50 feet wide with top at el. 20. The rockfill section, built by dumping materials from a railroad trestle, was located on the Passamaquoddy Bay side of the embankment. The impervious zone consists of a blanket of random fill sloping toward the Cobscook Bay side of the dam.

Looking southeast toward Eastport, Maine, showing road on dams built in 1935-37.

Surface protection consists of derrick stone on the Passamaquoddy Bay side and dumped stone on the Cobscook Bay side. In 1955 these dams were widened on the Cobscook Bay side for construction of State Highway No. 190. The top width of the embankment was increased to nearly 100 feet and the top surface was raised from one to two feet. The existing dams and highway construction are in good condition, and these structures can be included, without modification, in the the plan of development of the proposed tidal power project.

FIELD OPERATIONS

In the fall of 1956, a field office was established in Eastport, Maine, for performing topographic and hydrographic surveys, observing tides and currents, making geological reconnaissance, conducting subsurface explorations, and gathering local data bearing on design and cost of the proposed international tidal power project.

In the spring of 1957, a soils laboratory was also established at the field office. This laboratory included a high-humidity sample storage room and was equipped to perform all usual identification and classification tests and to investigate the properties of undisturbed foundation clay samples. Greer Engineering Associates of Montclair, New Jersey, operated the laboratory under contract from April to October 1957. Thereafter, the field personnel operated the laboratory intermittently as needed until the equipment was removed in July 1958.

All major investigations were completed by October 1958 when the field staff was reduced to one engineer and one assistant for continued local coordination. This field office was closed in April 1959.

Topography of Tidal Project Area

The U.S.G.S. topographic maps with 20-foot contours, and the maps of the immediate project area with 10-foot contours prepared by the U.S. Army Corps of Engineers in 1935-37, were adequate for all general requirements within areas of the United States pertinent to this survey. More detail was needed, however, of the Canadian area of the proposed tidal project. This was furnished by Aero Service Corporation of Philadelphia, Pennsylvania, and their Canadian associate, Spartan Aerial Surveys, who produced maps at a scale of 1 inch equals 400 feet with a contour interval of 10 feet. Additional details at structure sites were obtained by the survey party of the Eastport field office.

Topography of Pumped-Storage Auxiliary Area

Topographic mapping for a pumped-storage auxiliary project was confined to the new site on the Digdeguash River in New Brunswick. Aero Service Corporation and Spartan Aerial Surveys conducted aerial surveys and produced maps at a scale of 1 inch equals 400 feet and a contour interval of 10 feet covering the basin of the Digdeguash River from Passamaquoddy Bay up to el. 200. Additional surveys by the Eastport field office staff provided more detail on the site selected for the structures, and also provided hydrographic data needed for investigating the channel capacity between the proposed auxiliary pumped-storage plant and Passamaquoddy Bay.

Underwater Mapping

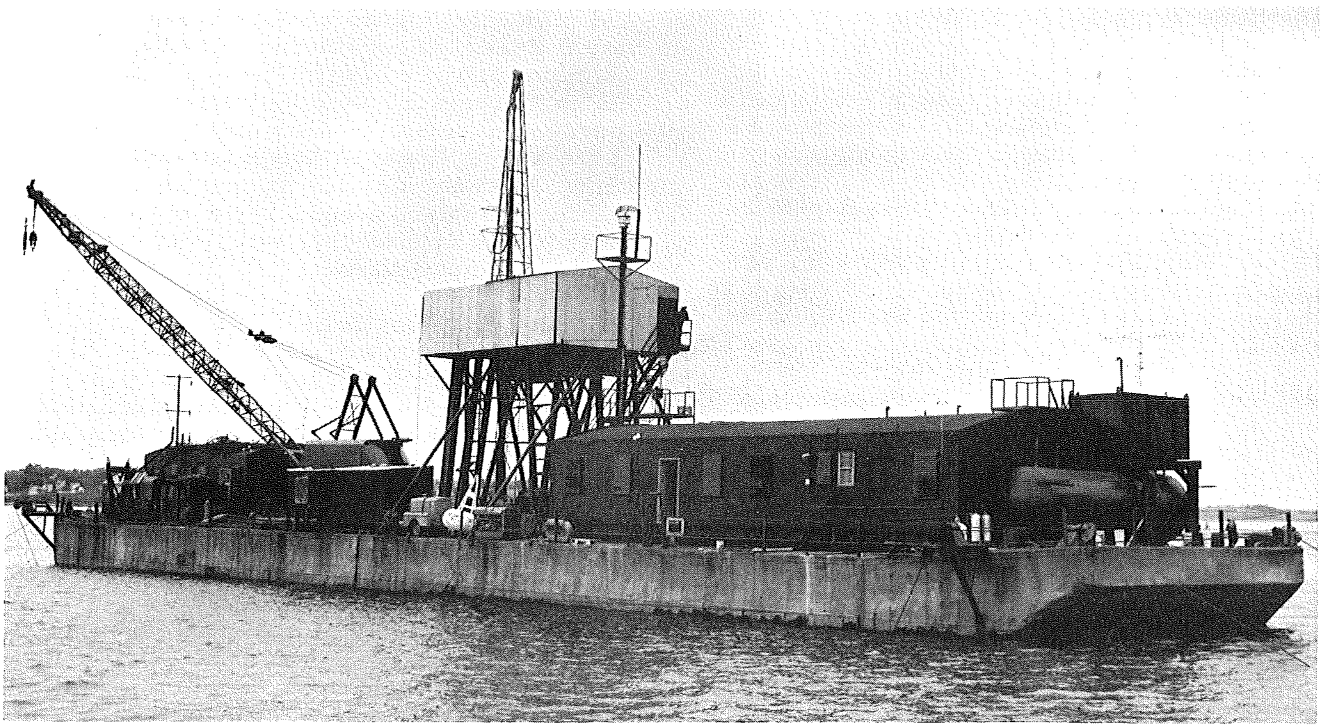
One of the most important and costly features of the international Passamaquoddy tidal power survey was the investigation of foundation conditions for the deep tidal dams. The high cost of conventional core borings in deep water and rapid currents led to the use of geophysical exploration. Sonic exploration was selected in view of the apparent success of preliminary sonic exploration performed in 1951, which provided a continuous bottom profile in areas investigated. This record furnished accurate water depths and some indication of occurrence and extent of materials overlying bedrock. Therefore, under a contract with the Fairchild Aerial Surveys Corporation of Los Angeles, California, underwater surveys were conducted in several areas, comprising approximately 100 miles of profile observation and record.

The results of the Fairchild sonic survey were added to base maps containing shore lines and land contours produced by Aero Service Corporation. The underwater contour interval was 10 feet. In areas where subaqueous overburden was indicated, additional contours were added to the maps to denote the top of bedrock. These maps were modifed later to incorporate data secured by the Eastport field office staff using a conventional recording survey fathometer, particularly in shallow water areas in the vicinity of proposed project structures.

Deep and Shallow Water Drilling

The largest and most important single phase of the field investigations was the exploration and sampling of foundations for the proposed deep tidal dams. Brown & Root Marine Operators, Inc., of Houston, Texas, did this work under a contract awarded in January 1957. The contract was for drilling and sampling in 15 deep water locations and in 6 shallow water locations where structures were planned. Approximately 980 linear feet of overburden were explored and sampled, and 420 linear feet of bedrock were drilled and rock cores obtained, at a total contract cost of about $550,000.

Deep-water drilling in 1957.



A special staff of unusually well-qualified technicians from the Waterways Experiment Station of the U.S. Army Corps of Engineers, Vicksburg, Mississippi, inspected all phases of the underwater drilling program. The program was a conspicuous success in spite of the difficult problems presented by the great water depths, the rapid change in depth due to the large tides, and the rapid currents. The undisturbed samples of clay from foundation areas investigated for tidal dams were obtained in excellent condition for laboratory tests and analyses.

Tidal Project Land Drilling

After reviewing all available geologic reports and data from prior explorations in the tidal power project area, a reconnaissance was made by staff geologists to correlate data from the several available sources, to inspect prospective sites, and to establish a land-drilling program for the current survey. A contract was awarded to Boyles Brothers, Ltd., of Moncton, New Brunswick, for drilling and sampling at 28 locations to investigate foundation conditions, and at 15 locations in 4 areas to investigate sources of rock for concrete aggregates and large stones for embankment slope protection. The Eastport field office staff made a number of additional auger borings and shallow test pits.

Auxiliary Project Land Drilling

Geocon, Ltd., of Montreal, Quebec, performed, under contract, subsurface explorations of foundation conditions at the pumped-storage auxiliary site on the Digdeguash River, New Brunswick, and at the alternate river hydro auxiliary sites at Big Rapids and Lincoln School on the Saint John River, Maine. Exploration and sampling were performed at seven locations for the Digdeguash project, at eight locations for the Big Rapids project, and at three locations for the Lincoln School project. In addition, the field office staff hand-augered several holes and dug a few test pits to explore the areas adjacent to the sites for construction materials.

Observations of Tides and Currents

Review and analysis of existing tidal data indicated the need for supplemental information, particularly about local variations in water surfaces in the tidal project area. Four automatic stage-recording instruments were installed and operated continuously to obtain a full year of record of stages at selected locations. A fifth instrument was used at five other locations to secure records at least 1 month long.

In February 1957, the field office staff measured the velocity of the tidal currents at eight locations in the vicinity of proposed tidal dams. During 1957, the Canadian Department of Fisheries made observations of current velocities at 16 locations in the project area.

TIDE PHENOMENA

Tides in the project area have a threefold bearing on the proposed tidal power project. First, the size of the tides influences the design of the project. Second, the tides influence the construction methods and thus affect cost. Third, the range of tides determines the amount of electricity the project can generate.

Astronomical Factors

The basic tide-producing force is the resultant of the gravitational effects of the sun and moon. At the time of new moon, when the moon is on the same side of the earth as the sun, the gravitational effects of the sun and moon combine to produce spring (maximum) tides. About two weeks later, when the moon has revolved to the opposite side of the earth from the sun, their gravitational forces also reinforce each other, and again cause spring tides, although not quite as high. At either quarter phase, when the sun and moon subtend a right angle at the earth, their forces oppose each other and cause neap (minimum) tides.

Since the moon is nearer to the earth than the sun, the moon influences the tides to a greater extent. The sun, because of its much greater distance from the earth, affects tides somewhat less than one-half as much as the moon, in spite of the sun's much greater mass.

The astronomical forces causing the tides vary continually, and consequently the tides also vary continually. The main factor is that the lunar day is 24 hours and 50 minutes long, compared to the solar day of 24 hours.

Thus high tides, since they follow the moon, are 50 minutes later each day. The earth, moon, and sun line up in that order once every 29.5 solar days. In this period the tide proceeds twice from spring to neap, and back to spring again.

Another important factor affecting the tides is the distance of the moon from the earth. Greatest spring tides occur when the moon is at perigee (nearest to the earth), and either new (earth, moon, and sun in line), or full (moon, earth, and sun in line). Neap tides at apogee (moon farthest from the earth) have the least range. The moon is at perigee every 27.5 days.

Other factors are also involved in the astronomical forces producing the tides, including among many the distance of the sun from the earth, the declination of both the moon and the sun, and other factors. The resultant effects of all tide-producing factors are completed in a cycle of about 18.6 years Thus, a 19-year record is generally considered to contain all variations of the tide cycle at any location.

Bay of Fundy Tides

As shown on plate 1 in the syllabus, the Gulf of Maine is a relatively shallow bowl on the continental shelf. The Gulf opens to the deep areas of the Atlantic ocean from about Cape Cod, Massachusetts, to Cape Sable on the southern tip of Nova Scotia, Canada. Even this opening is somewhat restricted by Georges and Browns Banks. The tides outside the Gulf are relatively small, averaging 3.1 feet at Cape Cod, and 4.4 feet at Halifax, Nova Scotia. The gulf is of such proportions, however, that small outside tides are amplified to 9.5 feet at Boston, Massachusetts, and 10.4 feet at Bar Harbor, Maine, both on the Gulf.

The Bay of Fundy opens on the Gulf of Maine and amplifies the tides a second time. At Eastport, near the mouth of Fundy, the average tide range is 18.1 feet. At Saint John, New Brunswick, farther up the bay, it is 20.6 feet. At the head of the Bay of Fundy the highest tides in the world occur. In the Minas basin the average tide range is 41.6 feet at Burntcoat Head, Nova Scotia.

Prediction of Tides

The fact that the tide-producing forces are astronomical makes it possible to predict tides with accuracy. The United States Coast and Geodetic Survey predicts the time and level of each high and low tide for a number of locations. The predictions for each calendar year are published in their "Tide Tables," and those for Eastport, Maine, are in the volume subtitled "East Coast, North and South America, including Greenland." The Canadian Hydrographic Service, Survey and Mapping Branch, Department of Mines and Technical Surveys also makes tide predictions and publishes them as "Tide Tables, Atlantic Coast of Canada."

Eastport Tides

Tides at Eastport, Maine, are characteristic of the tides in the general area and approximate a sine curve in shape. Two well defined high and low tides occur each lunar day. The two tides differ slightly. The tides follow the tide-producing forces previously described and vary continually as shown at the top of plate 17. Since the moon in its changing relationship with the sun and earth produces the most significant changes in the tides, this plate also shows the corresponding phases of the moon.

In computing power from the tides, the tidal range is most important. Tidal range is the difference in elevation between a low tide and the following high tide. At Eastport, the average tide range is 18.1 feet (observed), the maximum is 25.7 feet and the minimum is 11.3 feet (plate 17). As also shown on the plate (figure 3), the maximum high tide reached 13.9 feet above mean sea level, and the minimum high tide 4.5 feet. The minimum low tide reached 13.4 feet below mean sea level and the maximum low tide reached 4.4 feet below mean sea level (figure 4).

Observed mean monthly tide ranges show less variation than the individual ranges, the smallest being 17.10 feet and the largest 19.01 feet. Observed mean annual tides show even less variation, the smallest being 17.52 feet, and the largest 18.52 feet.

Individual tide ranges vary considerably from predicted values. In one year, 5 percent of the tide ranges exceeded predicted values by more than 0.88 foot, and 5 percent were less than predicted by more than 0.97 foot. These variations are mainly the result of wind and barometric pressure, which do not follow cycles as definite as other tide producing forces. For longer periods, the mean of the observed tide ranges agrees closely with the mean of the predicted ranges. However, the mean of 18.1 feet of the observed tide ranges is about 0.3 foot higher than the mean of the predicted tide ranges.

Both high and low tides in the Passamaquoddy Bay area are increased by high winds, but no systematic correlation with the winds at Eastport was observed. The most striking effect occurred on January 8, 1958, when a wind from the southeast averaging 30 miles an hour for 6 hours raised the low tide by 4 feet and the following high tide by 1 foot. At another time, however, the wind raised the high tide more than the low tide.

The tides at the filling and emptying gate sites are very nearly the same as at Eastport, Maine. In addition, the water levels in Passamaquoddy Bay and over most of Cobscook Bay are essentially the same during the tide cycles. These factors permit the use of the Eastport gage records for estimating tidal power. Exceptions are the Falls Island area and the Lubec Narrows area, where the water surface takes a considerable slope as the bays are filled and emptied by the tides. These areas were studied separately to determine effects on the power output of the tidal project.

The Eastport tide records indicated that the ocean level is rising relative to the land in the area. This phenomenon has also been observed along most of the east coast. It appears, however, that this rise is taking place at such a slow rate that no consideration need be given it in the design of the tidal power project.

Drs. Arthur T. Ippen and Donald R.F. Harleman of the Massachusetts Institute of Technology were engaged to determine whether construction of the tidal power project would influence the resonant system of tides in the Bay of Fundy. These studies showed that the Bay of Fundy system was only moderately resonant and that the tidal project would not change conditions measurably. These conclusions were verified by officials of the Canadian Hydrographic Service.

The Committee on Tidal Hydraulics of the U.S. Army Corps of Engineers was asked whether the tidal project would influence the tides at the filling and emptying gates, which change would influence the amount of tidal power generation. It was the Committee's opinion that no measurable effect would occur.

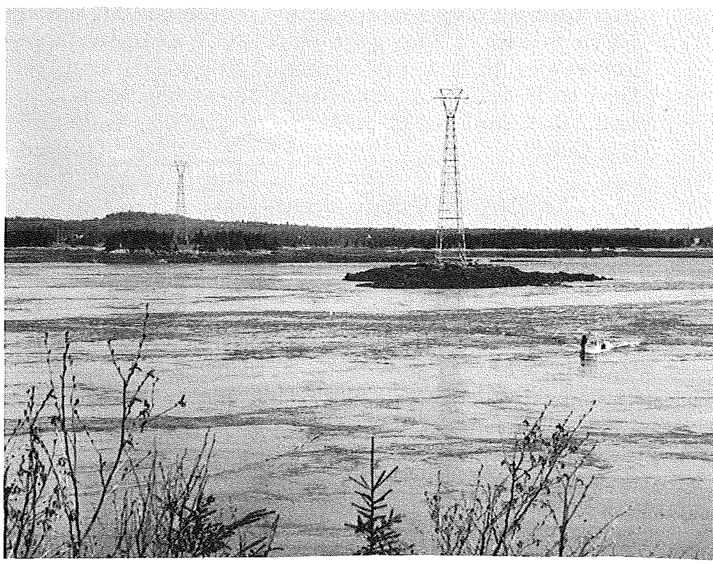
TIDAL PROJECT FOUNDATIONS AND MATERIALS

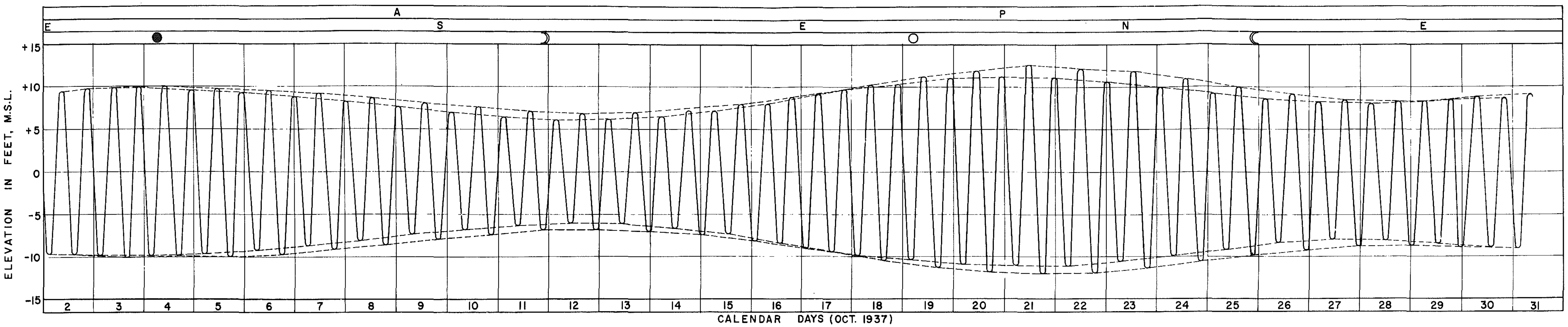
Information on site geology, foundation conditions, and construction materials obtained in previous studies were used as applicable in the current survey. Additional investigations were made to supplement and extend these data in specific areas. The site conditions described below are based on the composite results of all available data.

Site Foundations

The proposed international Passamaquoddy tidal power project would include about 20 dams and concrete structures, 2 large channel excavations, and several cofferdams, a few of which would be larger than some of the permanent dams. Bedrock is exposed or occurs at shallow depths at locations selected for all concrete structures and in some of the tidal dam locations. All structures, except the dams, would be founded directly on bedrock that has been found adequate for the proposed construction.

Electric power line towers on Dry Ledge and McMaster Island in Letite Passage.

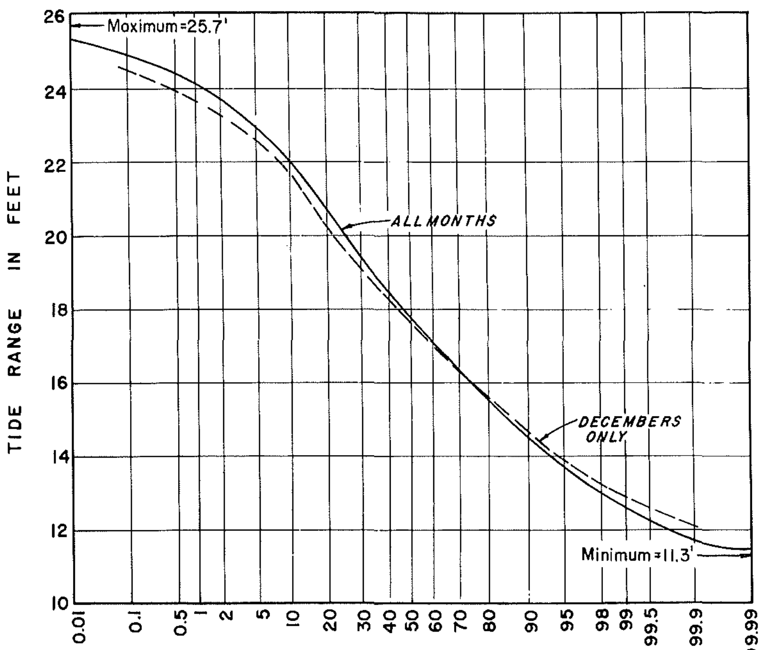




NOTE:
THIS CURVE IS BASED ON PREDICTED TIDES.

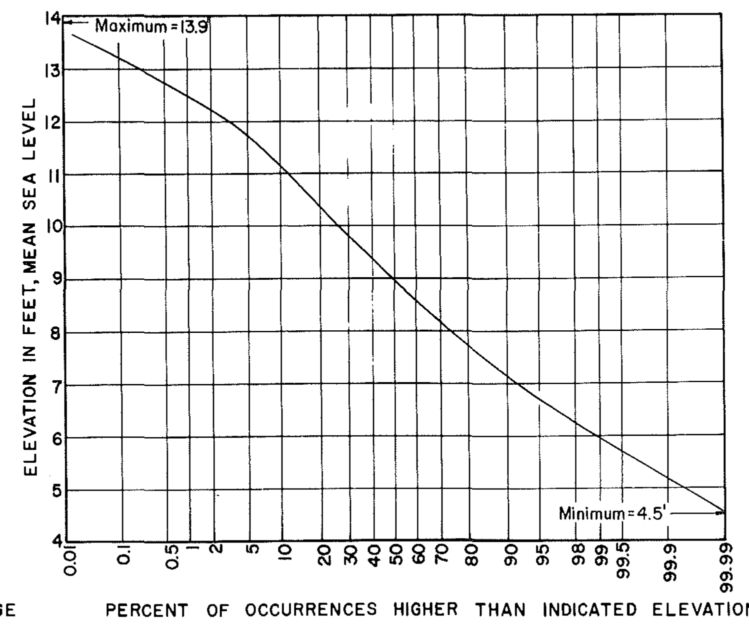
FIGURE 1 — TYPICAL MONTH OF TIDES

SYMBOL EXPLANATION		
● NEW MOON	E	MOON ON THE EQUATOR
☽ FIRST QUARTER	N	MOON FARTHEST NORTH OF EQUATOR
○ FULL MOON	S	MOON FARTHEST SOUTH OF EQUATOR
☾ LAST QUARTER	A	APOGEE - MOON FARTHEST FROM THE EARTH.
	P	PERIGEE - MOON NEAREST TO THE EARTH.



PERCENT OF OCCURRENCES LARGER THAN INDICATED TIDE RANGE

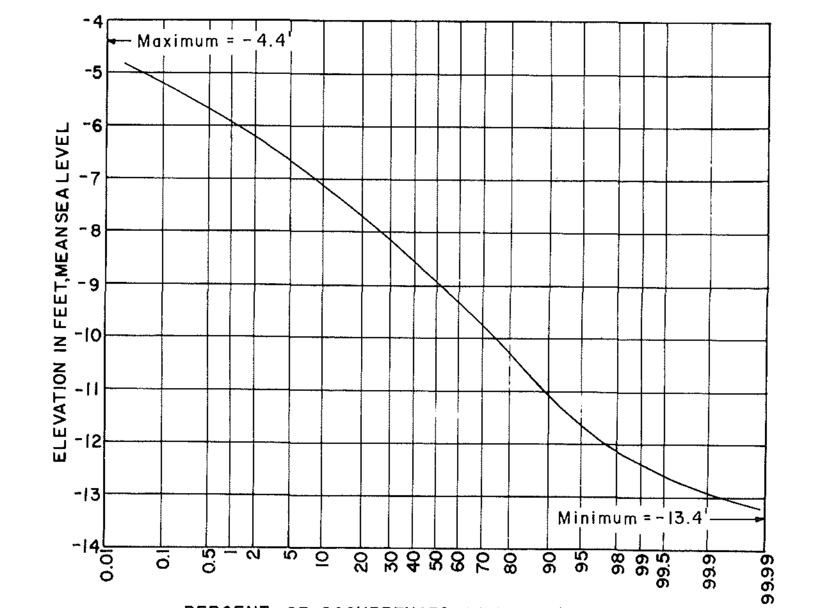
FIGURE 2 — TIDE RANGE OCCURRENCE CURVE



PERCENT OF OCCURRENCES HIGHER THAN INDICATED ELEVATION

FIGURE 3 — HIGH TIDE ELEVATION OCCURRENCE CURVE

NOTE:
OCCURRENCE CURVES ARE BASED ON 19 YEARS OF OBSERVED TIDES AT EASTPORT, MAINE.



PERCENT OF OCCURRENCES HIGHER THAN INDICATED ELEVATION

FIGURE 4 - LOW TIDE ELEVATION OCCURRENCE CURVE

INTERNATIONAL JOINT COMMISSION

PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

TIDE RANGE AND HEIGHT
EASTPORT, MAINE

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-232

PLATE 17

Overburden apparently covers most of the ocean floor in the project area. The thickness and physical properties of this overburden depend on several factors, including the amount and type of sediment deposited during glaciation, irregularities of the bedrock surface, the velocity of tidal currents, and the amount and type of material weathered and eroded from the existing land masses. Conditions in each of the six project structure areas are described below.

As shown on plate 4, in Letite Passage (area 1) two tidal dams would be separated by a set of filling gates. Bedrock composed of rhyolite, basalt, and diabase is exposed both above and below sea level or is covered by shallow deposits of till or granular overburden. The maximum depth of the principal passage varies from 150 to 190 feet, and underwater slopes are relatively flat, except in the deepest part of the channel where slopes of approximately 1 on 3 occur. Gate structures would be founded on bedrock and tidal dams would be founded on either bedrock or on shallow layers of compact overburden so that no significant foundation settlement would occur.

Area 2 includes Little Letite and Pendleton Passages located between McMaster and Deer Islands (plate 5). In this area bedrock is generally exposed and overburden is limited to shallow beach deposits which extend out into the depressions in the highly irregular rock surface. Excellent foundation conditions exist for the five shallow dams and the small navigation lock proposed in this area, as well as for the prospective future large lock in the vicinity of Jameson Island.

The proposed structures in area 3, Head Harbour Passage, include two large dams separated by the emptying gates, and a navigation lock adjacent to the shore of Campobello Island (plate 6). Geological evidence indicates that the preglacial bedrock channel in Head Harbour Passage, located between Green Islet and Campobello Island, is about 400 feet below sea level. This depth was indicated by the 1951 sonic survey, but the Fairchild survey in 1957 failed to penetrate the granular material in this passage. A geologic fault zone trending northeastward is known to exist but is now inactive.

The deepest dam in Head Harbour Passage would be constructed across a bedrock valley which appears to extend down to approximately el. -400. The valley is filled to about el. -334 with clay of glacial origin which is overlain to el. -280 by granular deposits. These granular deposits are derived apparently from postglacial erosion of the present land mass. Consequently, the tidal dam at this location must be designed for the relatively low strength of the deep clay in the foundation and the consolidation of this clay as the dam is built on it. Elsewhere the bedrock is partially covered by shallow deposits of granular overburden that offer no problems as a foundation for the dams.

Two dams, the remainder of the filling gates, and a ship lock would be located in area 4, in Western Passage and Indian River (plate 7). Bedrock in area 4 is composed of a heterogeneous mixture of rock types which have been altered by metamorphism and intruded by volcanic flows. Overburden consists largely of granular materials occurring as glacial outwash deposits and of more recent accumulations derived from erosion of the present land mass. Geologic evidence indicates that bedrock occurs at about el. -385 near the proposed location of the tidal dam in the Western Passage. The deepwater drill hole encountered granular overburden at el. -230 and penetrated it to el. -280 without change. It was concluded that all material above bedrock in this location is granular.

In Indian River, the axis of the dam between Deer and Indian Islands was located on a rock ridge partly overlain by shallow granular materials. A layer of soft clay was encountered immediately to the north. This layer of soft clay extends partly under the proposed dam, which is designed for this relatively weak foundation material. All other permanent structures in area 4 would be founded on bedrock.

The powerhouse, its headrace and tailrace, the switchyard, and a small dam would be constructed in area 5, comprising Carryingplace and Johnson Coves (plate 8). The powerhouse foundation would extend deep into bedrock. The foundation for the switchyard would be partly rock or the till forming Mathews Island. The remainder of the switchyard foundation would be a granular fill. The low dam between Mathews and Moose

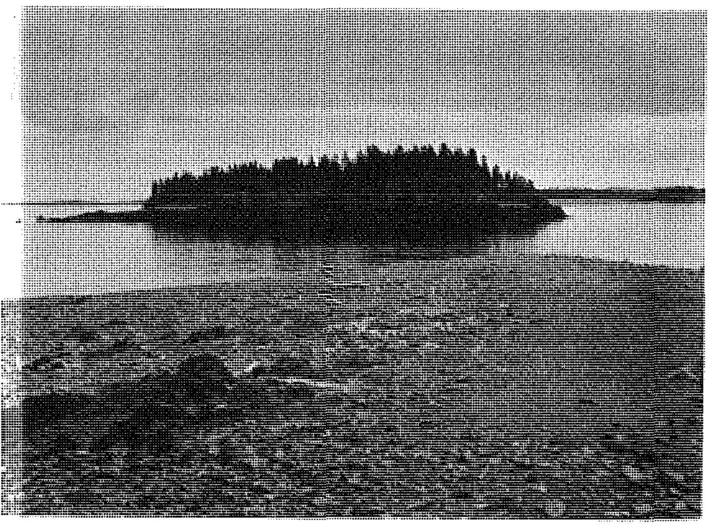
Islands would have a shallow clay foundation over bedrock. One of the principal site conditions of concern in area 5 is the 17 million cu. yds. of clay which must be excavated from the powerhouse headrace and tailrace areas. The use of this material is discussed later in connection with the design of tidal dams.

Area 6 includes the tidal dam and small boat lock at Quoddy Roads (plate 9). Bedrock composed of black metamorphosed Quoddy shale occurs at the Campobello Island abutment area and extends down into the channel area. Basalt and diabase occur in the area of the south abutment at Quoddy Head. In the channel area, firm clay fills the bedrock valley to about el. -35 in the vicinity of the proposed tidal dam.

Materials for Dams

To construct the most economical project, as much of the required excavation as possible should be used in construction of the tidal dams. All borrow needed for these dams should be taken from the most economical sources. Use of structure excavation and selection of borrow sources for construction of tidal dams and cofferdams depends largely on the suitability of the excavated materials for placement under water in rapid tidal currents. Materials available from structure excavations and prospective borrow sources are discussed below.

Pope Islet as seen from Sandy Ledge (near Green Islet) at low tide.



Materials available from proposed excavation for project structures and channels would include about 20 million cu. yds. of overburden. This includes excavation of about 17 million cu. yds. of silty clay to form the intake channel and tailrace at Carryingplace Cove. Overlying the clay in the isthmus between Johnson and Carryingplace Coves is about 1.5 million cu. yds. of granular material which would also be excavated for the intake channel. Excavation for the filling and emptying gates and the approaches to these gates and for navigation locks would also provide considerable amounts of granular material. The thickness of this material varies greatly because it fills in depressions and covers the rough topography of the bedrock surface.

In the Letite Passage area, about 400,000 cu. yds. of granular material may be developed in excavation of the approach areas and for the gate structures. In the Head Harbour Passage area some granular material appears on Sandy Ledge in the form of small beaches around portions of the three islands and in the several small channels. An average of 3 feet of this material in the approach and structure areas would result in about 300,000 cu. yds. of overburden excavation.

Excavation for the filling gates on the lower end of Deer Island would also encounter small quantities of granular material on the island. Beach deposits occur principally along the southern tip of the island and along the east side of the island in Indian River. Granular material 10 feet thick was encountered in Indian River, indicating the extent of overburden that must be excavated for the approach channel to the gates. A minimum of approximately 300,000 cu. yds. of this material would be excavated in the channels and from the gates on both sides of the island. Approximately 200,000 cu. yds. of silty sand and some gravel would be excavated at the proposed navigation lock in Western Passage.

Rock excavation at the proposed powerhouse, gate, and lock locations would produce material that could be used in the dams. Much of this rock is fine-grained, dense and brittle, and would tend to break into stone of small size. Some of the metamorphosed sediments would break into tabular pieces with one dimension two to three times greater than the shortest. Random fractures and occasional shear planes would cause some of the rock to break into large stone. Excavations for the gates and approach areas in the Letite Area would be in more massive rock formations and could produce much of the riprap and derrick stone necessary for the dams in that area. If the excavations fail to produce sufficient rock of large size needed in this area, additional diabase-type rock can be quarried locally.

Overburden materials which can be borrowed for construction of dams include relatively thin and discontinuous deposits of till, glacial outwash deposits of gravel and sand in various degrees of separation of size fractions, beach deposits of sand, and clay occurring generally below sea level.

After preliminary reconnaissance had indicated the general types and occurrence of available materials, a more specific search was made to determine the best sources of material for the tidal project. The three determining factors on which selection was made are (1) the suitability of the materials for specific function in the dams, (2) the accessibility and sufficient quantity for economical development, and (3) the distance from the source and the methods needed to transport the materials to the site and place them on the dam.

Because the channel excavation in Carryingplace Cove would furnish more clay than can be used, the borrow investigations were directed to locating suitable sources of granular materials. Since all the granular materials of the region came from the same geological source, the factors enumerated above led to the choice of two major sources. One borrow source, estimated to contain more than 5 million cu. yds. of gravel and sand, is located on Campobello Island in a zone extending across the narrow portion of the island near Friar Bay. The second source is a large glacial terrace estimated to include more than 16 million cu. yds. of sand and gravel. This source is located at Bethel, New Brunswick, about two miles east of the Digdeguash River, lying between the Canadian Highway No. 1 and the north shore of Passamaquoddy Bay. Several smaller sources of similar materials occur throughout the project vicinity. Although these minor sources were not explored in detail during the current survey, they should be considered further if the tidal project is authorized for construction.

Bedrock outcrops are conspicuous throughout the tidal project area. Extrusive volcanic rocks are most common, and the more massive intrusive formations outcrop in several locations. Large exposures of granite occur along both sides of the St. Croix River, a few miles upstream from St. Andrews, New Brunswick, and granites exist generally about 10 to 20 miles north of Passamaquoddy Bay. All of the rock types in these locations are sufficiently durable for rockfill embankment construction and most are suitable for slope protection against wave action.

The principal limitation of the basaltic (extrusive) rock is that it cooled fast on deposition and developed many cracks. For this reason, it breaks into relatively small pieces when excavated. The largest stones obtainable by normal quarry operation would be about 1 cu. yd. in size. Where larger stones are required, they would be obtained by selective quarrying in the more massive diabase (intrusive) formations. The two prospective quarry sites in diabase rocks most feasible for development are located at Man of War Head on Campobello Island and near Northwest Harbour on Deer Island (plate 2). Other sources exist in the vicinity and could be explored for more detailed design studies.

Concrete Aggregates

The search for concrete aggregates was made concurrently with the geological reconnaissance of the area and the search for materials for the tidal dams. Natural sand and gravel deposits and the potential quarry sites were both considered as possible sources. Samples were obtained from the best of these sources. They were tested for suitability as concrete aggregates at the materials laboratory of the Engineer Division, South Atlantic, in Marietta, Georgia, with the assistance of the Ohio River Division Laboratories, Mariemont, Ohio, and the Waterways Experiment Station, Vicksburg, Mississippi, all agencies of the U.S. Army Corps of Engineers.

The tests included routine identification and classification, petrographic analyses, and determination of thermal expansion and durability in concrete mixtures as indicated by many cycles of alternate freezing and thawing of test beams. In view of the intensive studies by the U.S. Army Corps of

Engineers in 1935-37, the current work was limited to reviewing existing data and extending the studies to cover the new sources considered.

The concrete aggregate studies led to the following conclusions:

(1) Natural sands in the project vicinity are generally suitable for use as fine aggregate, although some processing would be required to obtain proper gradation.

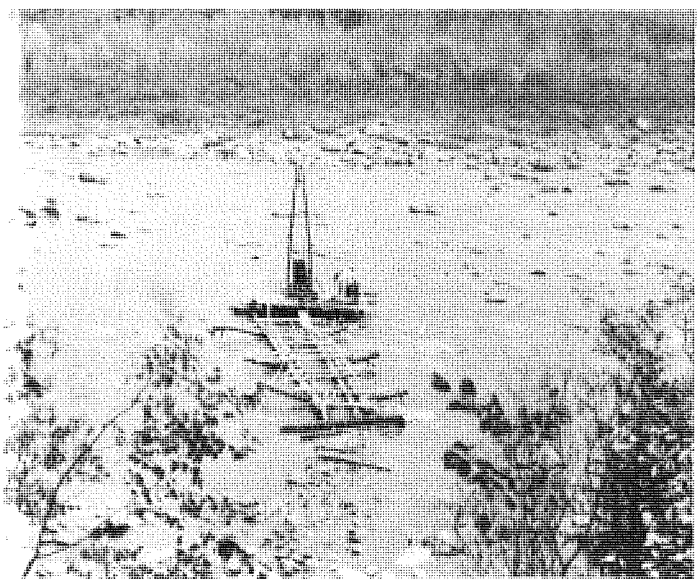
(2) Natural gravels in the project vicinity are not suitable as coarse aggregate because many rock types are included that have a wide range of thermal expansion coefficients.

(3) The diabase is suitable for both coarse and fine aggregates.

(4) Granite from the area was not tested specifically but, on the basis of past general experience, it is suitable for both coarse and fine aggregates.

The diabase formation at Man of War Head on Campobello Island was selected as the best source of concrete aggregates for the tidal project. A conveniently located quarry at this location could produce the large stones for the tidal dams, and the smaller material could be processed into the required aggregate. Using one quarry as a source for two materials would reduce costs.

Foundation exploration in the Upper Saint John River.



A quarry in the basalt outcrop at Shackford Head on Moose Island would provide a source of concrete aggregates for the powerhouse without involving water transportation.

Concrete Design

Preliminary concrete mix designs established the quantities of materials required and provided a basis for estimating the cost of concrete construction. The proportions of cement, water, fine aggregate, and appropriate combinations of coarse aggregates were computed for several mixtures using both natural and processed aggregates. The mixtures were designed in accordance with conventional requirements to provide maximum salt water durability in a climate with frequent freezing and thawing.

All concrete for the powerhouse, gate structures and locks would use Portland cement conforming to U.S. Federal Specification SS-C-192, Type II (moderate heat of hydration) with no admixture except an air entrainment agent. Adequate quantities of good quality fresh water could be obtained in the vicinity of each major tidal project structure for the manufacture and curing of concrete.

RANKIN RAPIDS FOUNDATIONS AND MATERIALS

Information on foundation conditions and construction materials for the Rankin Rapids project were obtained from previous studies with minor additional investigation during the current survey.

Site Foundations

The Rankin Rapids site, located approximately 3 1/2 miles upstream from St. Francis, Maine, was investigated in 1951-52, when nine test borings were made. Exploration data were reported previously in an interim report to the International Joint Commission by the International Saint John River Engineering Board, dated 6 April 1953, entitled "Water Resources of the Saint John River Basin." During the current survey, field work was limited to detailed site reconnaissance and extension of investigation of prospective sources of construction materials.

At the Rankin Rapids dam site, the Saint John River flows in a northerly direction over a shallow gravel and boulder bed about 550 feet wide. The preglacial bedrock valley extends under the left bank of the stream and is about 80 feet below present stream level. In this preglacial valley there is a deep deposit of compact glacial silt. The bedrock valley walls rise steeply and are covered generally by a dense glacial till with a terrace deposit of stratified sand and gravel just above stream level on the left bank.

Bedrock consists of indurated shale striking N. 45° E. with nearly vertical dip, and occurs in both valley walls with an outcrop on the right bank near present stream level. This bedrock would provide entirely adequate foundations for all major concrete structures, and it is also suitable for tunnel construction.

In view of the deep overburden in the valley bottom, the site is not favorable for construction of a concrete dam. The dense glacial till is adequate to support an embankment of the height considered for development, using nominal slopes. Over the center valley section, where the glacial silt occurs in the foundation, some flattening of side slopes would be required to insure stability. Underseepage would not be a problem in the glacial till, although cutoff treatment would be necessary in the sand and gravel terrace deposit on the left bank.

The west abutment of the dam was explored by a single boring which penetrated 5 feet of compact glacial till over bedrock composed of diabase with numerous shale inclusions. This boring and geological reconnaissance of the immediate vicinity showed that the bedrock would be structurally adequate as a foundation for the concrete structures of the project.

In 1951, subsurface explorations were made at lower elevations than presently proposed for development of this site. However, based on results of these borings and a geological investigation of the right valley wall, it was concluded that bedrock would be encountered at shallow depth below ground surface and that this bedrock would be the same type of indurated shale found generally throughout the project vicinity. Consequently, adequate foundation for all concrete structures appears assured.

Diversion tunnels for the project would be located in the right abutment. Shale at this location is hard and dense with little alteration showing along cleavage planes and joints. Since the joints in these shales are relatively tight, very little grouting would be necessary. The tunnels would be excavated in a direction nearly normal to the strike of steeply inclined beds which would tend to minimize overbreak.

Materials for Dams

Materials at or near the dam site occur in sufficient quantities for construction of an earth dam. The glacial till is an excellent material for the impervious portion of the dam, having high shear strength and low permeability. The terrace deposits of sand and gravel are well suited for the pervious sections of the dam. Rock for slope protection can be developed from boulders in and along the stream channel, from required structure excavations, and from nearby bedrock exposures.

Concrete Aggregates

The predominant native rock in the vicinity of the proposed project is shale, and the overburden largely derived from it contains numerous platy fragments. Preliminary reconnaissance indicated that these shale rocks, together with sands and gravels with substantial amounts of platy fragments, would not be suitable for durable concrete aggregates. The nearest known sources of commercially available aggregates are the limestone quarries in the vicinity of Presque Isle, Maine. Transportation of these aggregates would require a rail haul of more than 80 miles, including about 3 1/2 miles of new trackage from St. Francis, Maine, to the project site. This new trackage would be required for transportation of materials and equipment if the auxiliary project is built.

Outcrops of granite at Deboulie Mountain, about 16 road miles south of Rankin Rapids, were found during a field reconnaissance for a nearer source. Visual inspection indicates that this rock is suitable for production of good quality concrete. Preliminary cost analysis indicates that this source is economically feasible for development of aggregates for the proposed project, although the quarry site is now accessible only over logging roads.

Concrete Mixtures

Concrete for proposed project structures would be composed of coarse and fine aggregate produced by quarrying the granite at Deboulie Mountain. Portland cement conforming to U.S. Federal Specification SS-C-192, Type II (moderate heat of hydration) would be used with no admixture except an air entrainment agent. Fresh water for mixing and curing concrete could be obtained from the Saint John River.

DIGDEGUASH FOUNDATIONS AND MATERIALS

Field investigations for a prospective pumped-storage project on the Digdeguash River were made during the current survey. Information on foundation conditions and construction materials are presented in the following paragraphs.

Site Foundations

The Digdeguash dam site was investigated in 1957 when Geocon, Limited, of Montreal, Quebec, drilled five test borings. Two drainage area saddles were investigated for saddle dams by one test boring in each. Reconnaissance was made at the same time to determine the bedrock conditions in the reservoir, to locate embankment and aggregate materials, and to investigate possible intrusion of salt water through the reservoir rim into adjacent drainage areas.

The dam site is located about 1/4 mile above the Digdeguash Falls where the river empties into Passamaquoddy Bay. Bedrock at the dam site is dense, fine-grained basalt which is massive and shows only minor weathering. Some minor grouting would be required to seal off the relatively tight fractures and joints in the rock. The dam site is forested and a thin deposit of glacial till also partly covers the bedrock. This material must be removed before placing embankment material and, where weathering occurs in the upper part of bedrock, a shallow cutoff trench would be necessary. The rock of Digdeguash Falls is mainly a hard siliceous rhyolite which is difficult to drill. Bedrock is entirely adequate as a foundation for all project structures.

Salt water would not leak from the reservoir to contaminate adjacent areas, because bedrock is tight and because saddles in the bedrock in the rim of the drainage area are filled with relatively impervious glacial till.

Materials for Dams

The glacial till near the site would provide a suitable material in sufficient quantity for the impervious core of the main dam and for the saddle dams along the sides of the reservoir. The till forms a relatively thin mantle on the valley bottom and on the sides of the valley walls within the reservoir basin. The structure and channel excavation in areas of the dam site and the saddle dams would supply a mixture of till and rock suitable for the random fill. Pervious material could be obtained from the extensive gravel and sand terrace located along Highway No. 1, about 2 miles east of the Digdeguash River, the Bethel terrace previously described. Rock for the shell of dams and for riprap could be obtained from rock excavation at the dam site and from sources close to the saddle dams.

Concrete Aggregates

Basalt and rhyolite rocks from excavations for structures and channels at the damsite are of suitable quality for processing into concrete aggregate. Unlimited quantity of sound rock occurs in the project vicinity which could be quarried if required. Ample quantities of sand suitable for concrete fine aggregate occur in the Bethel glacial outwash terrace. Gravel from this source is not suitable for coarse aggregate.

Concrete Mixtures

All concrete for principal structures would be made with durable local aggregates, using Portland cement conforming to U.S. Federal Specification SS-C-192, Type II (moderate heat of hydration) with an air entrainment agent as the only admixture. Adequate fresh water of suitable quality for production and curing concrete is available from the Digdeguash River.

CHAPTER IV

TIDAL PROJECT DESIGN

Specific designs of the selected tidal project arrangement, shown on plate 2 in the syllabus and in greater detail on plates 4 through 9, were made to provide a basis for a firm estimate of the cost of the project. The designs and studies of the project components including dams, construction cofferdams, powerhouse, filling and emptying gates, navigation locks, and other features are described in the following paragraphs. Methods of preventing corrosion of metal parts in sea water, the studies made to determine the staff needed to operate and maintain the project, and the detailed studies to determine the power which the project would generate are also described.

DAMS AND COFFERDAMS

The 35,700 linear feet of tidal dams that would form the upper and lower pools of the tidal power project and the cofferdams required for construction are major items in the cost of the project. The dams would be constructed of dumped rock and earthfill. Approximately 2,900 linear feet of these dams (about 8 percent of the total length) must be built in water depths ranging from 125 to 300 feet and subject to rapid tidal currents.

The primary requirements of the tidal dams are that they must be constructed from materials available in the area and must remain stable and sufficiently watertight under heads up to 23 feet. Some precedent for methods of construction and cost of dams of this type are found in the construction of the causeway across the Strait of Canso between Cape Breton Island and the mainland of Nova Scotia, and the railroad fill across Great Salt Lake, Utah, built for the Southern Pacific Company. However, in view of the special problems encountered in the construction and closure of deep tidal dams for the tidal power project, several prominent hydraulic and soils engineers were consulted. Extensive model tests were also conducted to determine the best design and methods of construction and closure of deep tidal dams.

The design of dams and cofferdams made in previous investigations of tidal power projects in the Passamaquoddy area and the designs selected for cost estimates in the present study are discussed in the following paragraphs.

Previous Studies

The tidal power project studies and basic data compiled by Dexter P. Cooper were reviewed thoroughly and used where applicable in the current survey. The typical cross section of the tidal dams designed by Cooper is composed largely of rockfill and clay sections to make use of materials excavated for structures and channels. According to this design, rockfill would be placed first to close off tidal flow. To prevent seepage, a clay blanket would then be placed over the rockfill on the high-water side of the dam. However, it was found after further study of Cooper's design that the 1 on 4 slope of the clay surface of the underwater embankment would be unstable if used for construction of deep tidal dams. No record was found of construction cofferdam designs that may have been developed by Cooper.

The U.S. Army Corps of Engineers designed dams for the one-pool project entirely in the United States on which construction was started in 1935. The work of the Corps of Engineers included hydraulic model tests of closure methods and investigation of the deep clay foundation at the dam sites between Eastport and Lubec, Maine. The cross section adopted in 1936 consisted essentially of a rockfill embankment with a blanket of gravel, sand, and clay on the pool side of the dam. Analyses made in 1936 indicated that the foundations would be displaced under the weight of the rockfill, and that the embankment would subside substantially. Thereafter, the rockfill would be raised to full height and the blanket materials added for seepage control. Cofferdam designs had not been developed when all project construction ended in 1937.

Foundations and Materials

The subsurface exploration program in 1957-58 indicated that foundation conditions vary considerably over the project area. The foundation conditions influenced both the selection of tidal dam locations and the cross section of dam designed for each area. Bedrock in the foundation area for tidal dams consists largely of basalt, with some diabase and minor amounts of indurated shale. All of these rocks are entirely adequate for structural foundations for the dams. Overburden consists of sand, gravel, and boulders with deposits of silty clay in some locations. Clay in the foundation was found to require a dam of special design. Where no clay was encountered in subsurface explorations, the foundation, consisting of bedrock or granular overburden, would permit construction of embankments with exterior slopes as steep as placement in tidal currents would allow for the type of materials used. Where clay does occur in foundation areas the extent, thickness, and physical characteristics have a definite effect on the design of the embankment and on the method or sequence of construction.

The project has been arranged, as far as practicable, to locate tidal dams on foundations of bedrock or on granular overburden. However, the selected arrangement does involve clay in foundation areas under the deep valley portion of the Head Harbour Passage dam east of the emptying gates, the northerly slope of the Indian River dam, and the central portions of Carryingplace Cove and Quoddy Roads dams.

It was evident at the beginning of the current survey that construction of the dams for the proposed project would require large quantities of materials, and that large quantities of earth and rock would be excavated for the channels and foundations of the powerhouse, gate structures, and navigation locks. Therefore, to attain minimum project cost, the dams were designed for efficient use of materials excavated for channels and structures. Construction was planned and scheduled so that materials from required excavation and from borrow could be transported and placed by the cheapest methods and without stockpiling. All rock from required excavations could be used effectively in the dams. Similarly, the relatively small amount of granular overburden could be incorporated in the embankments.

The efficient use, or disposal, of approximately 17 million cu. yd. of clay excavated for the structures and channels in and adjacent to Carryingplace Cove posed a major problem. This problem is discussed later in connection with the type of material used for seepage control.

Abundant rock outcrops from which supplementary rockfill and riprap may be quarried occur generally throughout the project area. Gravel and sand occur less abundantly in the project vicinity but in sufficient quantities to satisfy borrow requirements.

Design of tidal dams is also influenced by tidal hydraulic conditions that would be encountered during construction. The tidal dams must be designed so that practical methods of construction can be used for transportation, placement, and retention of materials of sufficiently fine gradation to control seepage through the dams. The existing tides range from 11.3 to 25.7 feet, averaging 18.1 feet, and tidal current velocities range up to about 10 feet per second in the natural channels. Current velocities over the unfinished dams would increase as the construction of dams reduces the channel openings and as the several natural channels are successively closed.

The head differential across the dam openings and the resulting velocities during the construction period would be held to a minimum if the total differential is divided or cascaded between two or more locations. Divisions of this head differential can be accomplished by simultaneous construction of the dams in Western Passage and Head Harbour Passage, after construction of the other dams is complete. In order to make the pool levels follow the rise and fall of the ocean tides as closely as possible and thereby create a minimum head differential, construction would be scheduled to make final closure of the dams after the filling and emptying gates are completed. The gate structures would then be used to pass tidal flows and thus reduce the head on the dams. Closure from the ocean could be made for each pool separately, or for the combined pools by cascading. Cascading was selected as the more favorable method. Subsequently, the dam in Western Passage, separating the two pools, could be closed in still water.

Wave heights used in the design of dams were computed using a wind velocity of 60 miles an hour, of unlimited duration, blowing over a fetch that would produce maximum wave action on the face of the dams. The maximum wind velocity of 60 miles an hour is based on records of the United States Weather Bureau station at Eastport, Maine, from 1885 to 1953. Fetches were adjusted to account for reduction in wave height due to shoaling and refraction around islands.

Construction Sequence and Methods

The sequence of project construction has an effect on tidal dam design for two principal reasons. The first reason is that excavations for the powerhouse, filling and emptying gates, and navigation locks would produce a large proportion of the materials used for tidal dam construction. Economy of construction procedure requires that excavated materials be scheduled for immediate use without stockpiling and rehandling. Thus, the construction schedule must take into account the interrelation between excavation for the channels and structures of the powerhouse, gates and locks, and the concurrent fill in tidal dams and cofferdams. The second reason is that successive closures of the dams and completion of gates to reduce flows through closure sections must be scheduled so that final closure can be made under the least difficult conditions.

Other scheduling problems, of less importance to design of dams, are preserving existing natural navigation channels until the locks are ready for use, starting powerhouse construction early to effect timely project completion, and holding to a minimum the use of locks for movement of construction materials. Therefore, a preliminary construction schedule, incorporating the above considerations, and consistent with economical use of excavated materials, was assumed for hydraulic analysis. According to this schedule, the lower part of the dams would be built by scow-dumping. A fairly uniform crest height would be maintained along the entire length of the dam to an elevation of about el. -25. Above this level closure would be made by dumping material outward from the shore. During this latter stage of construction, tidal velocities would increase in severity, requiring progressively larger stones, until the closure of the dam is completed.

The influence of construction methods on design of tidal dams is mainly that of costs and control of seepage. The large quantities of excavated materials which must be transported and placed require methods that would employ the largest and most efficient equipment operated as continuously as possible. However, the materials must also be placed in the dams in such a way that the dams will be stable and sufficiently watertight. Tidal currents have little effect on methods of placement of large rocks, but finer materials would drift farther during placement in deep water and some of the finest materials may be washed away before they are covered. Three methods of placement of materials are considered best for various site conditions. These include use of bottom-dump scows, use of end-dumping trucks working out from shore, and use of special bottom-dump buckets which would be lowered through water by crane to discharge within a few feet of the selected locations.

The first two methods would be used where method of placement is not critical for such materials as rock, lumps of clay, and even gravel when the loss of fines is of no consequence. Standard marine construction equipment would be used. Bottom-dump buckets would be used only where it is necessary to retain the finer portions of granular materials for proper transition between different types of materials and for control of seepage through the dams. Special equipment with a very large bucket would be necessary for the controlled underwater placement of granular material.

Flow Conditions During Construction

Direct observations of flow and hydraulic analyses indicated that tidal currents up to 10 feet per second occur in the existing natural channels across which the tidal dams would be constructed. Simple volumetric routings of tidal inflow, outflow, and change in storage were performed to determine the head on the dam openings during various phases of the construction schedule. Due to constriction, local currents over the partially completed dams would be somewhat faster than the averages computed from the head difference on the dam.

Hydraulic computations for all construction phases were made for mean tide conditions for comparable analysis of various design concepts. Conditions at spring and neap tides were computed for several phases in order to investigate the range of conditions. The variations in tidal range throughout the year indicate that certain periods would be most favorable for construction of those project features most critical from the standpoint of tidal heights or rapid currents. The results of the analyses are summarized on plate 18.

Hydraulic Model Tests

While foundation explorations, tidal observations, and project arrangement studies were in progress, the necessity for investigating the hydraulic aspects of deep tidal dam construction became evident. In view of the unprecedented nature of the problems, it was concluded that the investigation could best be conducted by an expert with extensive hydraulic laboratory facilities close at hand. Dr. Lorenz G. Straub, an internationally recognized consulting hydraulic engineer with particular experience in the field of sedimentation and closures at dams, was especially qualified to conduct this phase of the investigations. He is also the director of the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota. Accordingly, contracts were awarded to Dr. Straub and to the University of Minnesota to investigate the hydraulic aspects of design of the tidal dams and to determine feasible cross sections and methods of embankment construction and closure.

As a basis for the hydraulic laboratory model tests and analyses, Dr. Straub was furnished all available pertinent information. Physical data included maps and charts showing land topography, shore configuration, and soundings in water areas; data on tides and currents in the project area; information on materials that can be used in the dams; and samples of selected materials, including clay from Carryingplace Cove. Design data included plans showing the arrangement of the project; drawings of the several dam designs considered at the time; estimates of the maximum heights of waves at each dam site, and their periods; construction schedules; and results of routing tide flows through the several passages under various degrees of completion of the dams, assuming use of gates to pass the flow during closure.

Hydraulic model tests for the dams and closures were conducted at a scale of 1 to 100 in three flumes, 40 to 50 feet long, with separate water sources and movable weirs at each end. Motorized devices operated the weirs continuously so that water surfaces could be controlled to represent the prototype conditions at the dams and to simulate the ebb and flow of the tide across the partly built dams. The small flume, 6 inches wide with water depth of 1 foot, was used for pilot studies. An intermediate flume, 30 inches wide with a water depth of 2.75 feet, was used to test the dumping of materials from scows to build the dams; and the largest flume, 7 feet wide with water depth of 2 feet, was used to test the end-dumping of material by trucks. A total of 110 separate tests were made in the flumes primarily to determine the feasibility of placing available construction materials by methods adapted to large-scale, low-cost construction operations and to investigate the stability and permeability of the sections composed of the various materials. Observations were also made of deposition patterns, side slopes, scour, and retention of materials under varying flow conditions.

Dr. Straub's studies were started on the basis that the problem consisted of (1) constructing a rockfill to close off most of the flow and (2) adding a second stage to provide seepage control. It was quickly determined that the rockfills could be built, including closure of the crest, by truck-dumping from the shore into the channel area. Furthermore, this could be done with the rock produced in the structure excavations, which would normally have a maximum size of about 1 cubic yard. This is a substantial reduction from the maximum stone size planned for the 1936 design and is due largely to the benefit of using gates to pass flows during closure of the dams.

Further study and experimentation indicated that control of seepage was a considerably more difficult problem than first estimated. Small-scale model tests are not suitable for investigation of underwater embankment construction with cohesive materials. For this reason, the investigations by Dr. Straub did not involve use of clay for control of seepage in the embankment, but were limited to granular materials. It was found necessary to use materials of such small size that 10 percent would be finer than 1 millimeter (prototype scale) in order to avoid seepage quantities that would significantly affect power generation. On this basis, a uniformly graded fine sand, or a well graded sandy gravel containing fine sand, is needed

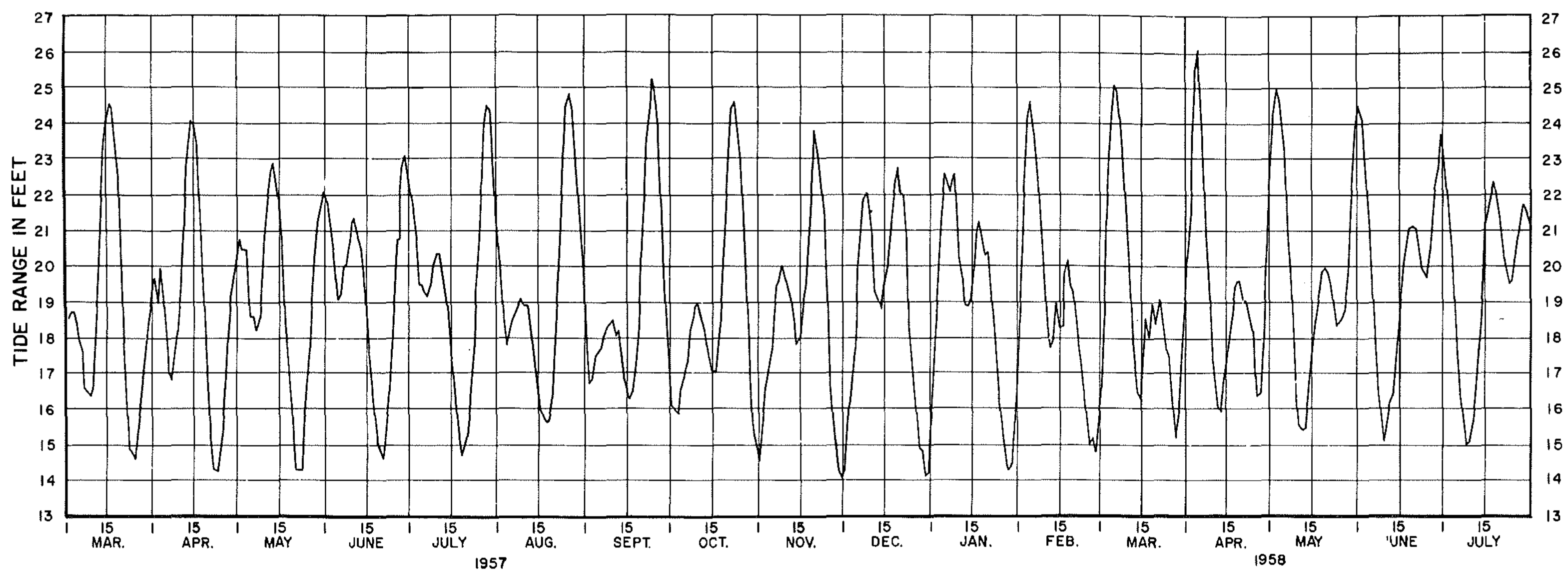


FIG. 1. MAXIMUM DAILY TIDE RANGE (OBSERVED) AT EASTPORT (1957-58)

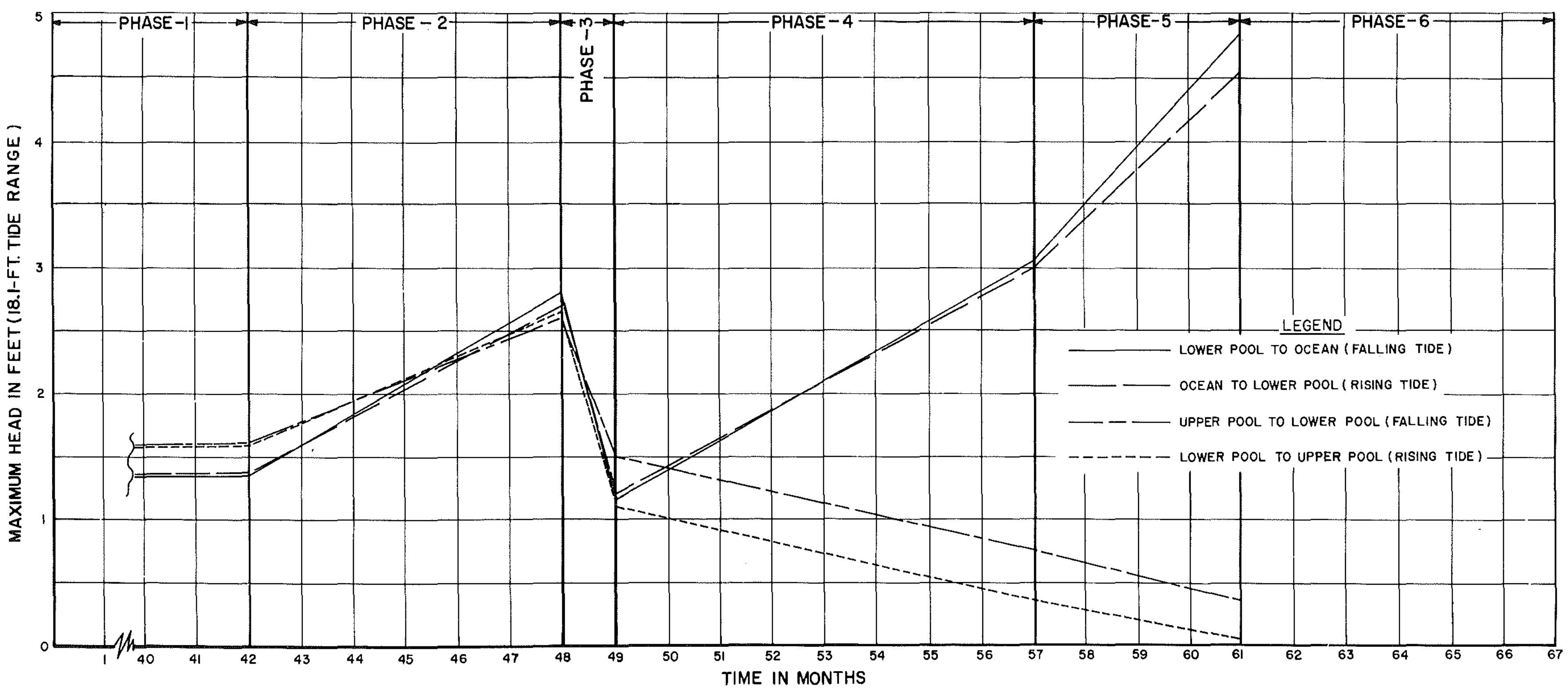


FIG. 2. MAXIMUM HEAD IN FEET ON THE DAMS IN WESTERN PASSAGE AND HEAD HARBOUR PASSAGE WEST DURING CONSTRUCTION (FOR 18.1-FT. TIDE RANGE)

NOTE:

The construction phases and times have been approximated for the purpose of hydraulic analysis.

Dam profiles are shown on plates 20, 21, and 22.

Phase-1: Construction of all dams completed except Head Harbour Passage West, Western Passage above El.-110 ft., and Head Harbour Passage East above El.-90 ft. (no discharge through gates).

Phase-2: Construction of dam in Head Harbour Passage East completed and dam in Western Passage raised to El.-63 ft.

Phase-3: Gate cofferdam materials removed and gates opened.

Phase-4: Dam in Head Harbour Passage West raised to El.-25 ft.

Phase-5: Construction of dam in Head Harbour Passage West completed.

Phase-6: All gates closed and construction of dam in Western Passage completed.

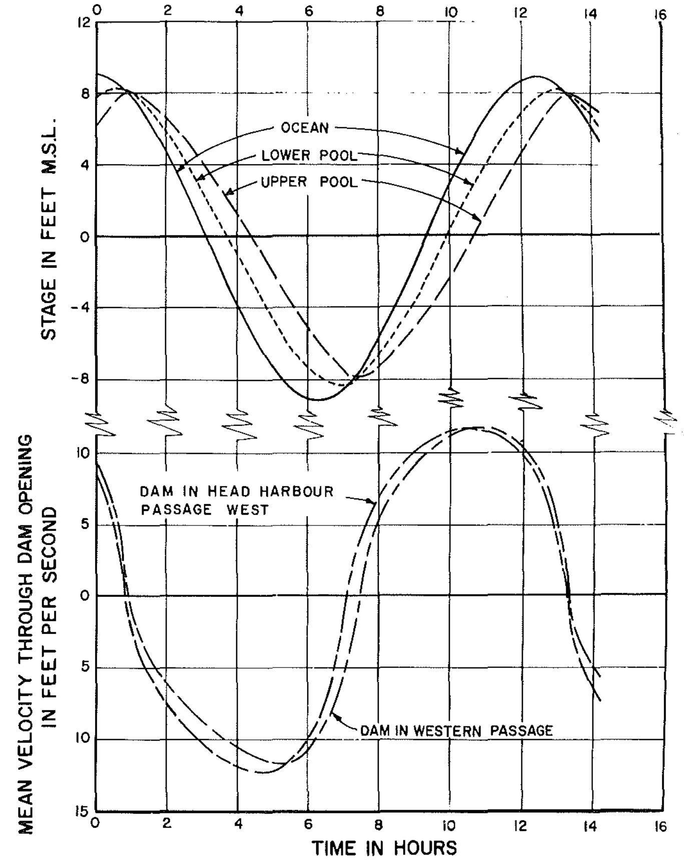


FIG. 3. STAGES AND VELOCITIES (END OF PHASE - 2)

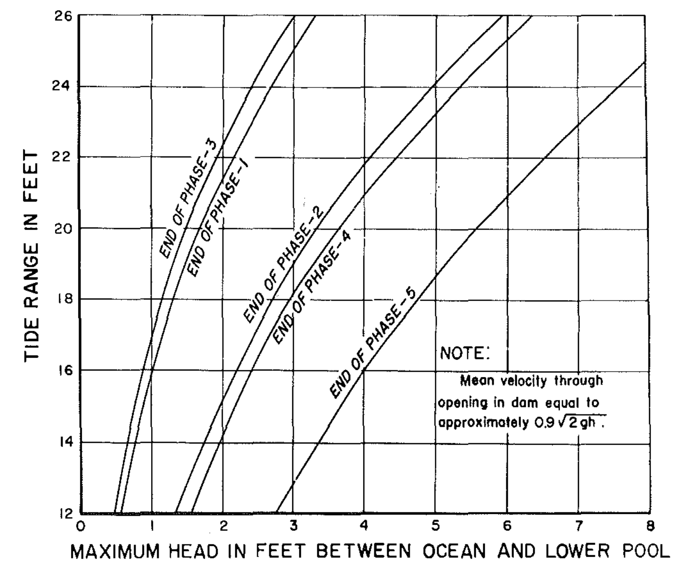


FIG. 4. TIDE RANGE VS. MAXIMUM HEAD ON THE DAM OPENING IN HEAD HARBOUR PASSAGE WEST

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

HYDRAULIC CONDITIONS DURING CONSTRUCTION

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-233

in the portion of the dam that controls seepage. If bottom-dump scows are used, only uniformly sized material would be adaptable to this method. The only available granular material meeting this requirement is a fine sand of which a large portion would be lost if dumped in swift currents of considerable depth. It was found that this loss could be held to a minimum by using a large bottom-dump bucket lowered to the approximate point of deposition before discharging.

Embankment Design Studies

The designs of the tidal dams are based on four general criteria: function, compliance with established design methods, feasibility of construction, and cost. The first criterion requires the erection and maintenance of dams high enough to prevent overflow and sufficiently resistant to percolation of water through the dams to prevent significant power losses. In the design studies it was assumed that gross leakage of less than 3,000 c.f.s. would be acceptable. Although this amount of seepage is relatively high, it is only about 1 percent of the discharge through the powerhouse. The second criterion includes application of the usual engineering design standards for development of a structurally adequate embankment, taking into account foundation settlement and consolidation within the embankment. The third criterion, construction procedure, contains the greatest element of uncertainty. The principal construction problem is that of determining an economical and feasible method of placing granular materials in flowing water without excessive loss of fines. Each of the several designs considered was studied to determine its construction feasibility. The fourth criterion, that of cost, is largely governed by the construction procedures necessary to build dams that meet the design requirements.

The fundamental type of structure selected for the tidal dams is a rockfill embankment. This selection is based upon the availability of rock and its suitability for underwater placement. A large proportion of the rock required could be obtained from excavation from foundations for the proposed powerhouse, filling and emptying gates, and navigation locks.

After adopting a rockfill type of embankment, another basic problem was selection of the type of material for the impervious zone. This problem became a matter of choosing either a silty clay or a sandy gravel. The advantages of using clay are that (1) it provides the greatest resistance to seepage of any of the locally available materials, and that (2) a supply of clay sufficient to construct the impervious zones of the dams would be excavated for the powerhouse approach channel. Therefore, if not used in the dams, this clay would be wasted.

Due to several unknown factors, it was concluded that clay should not be considered at great depths at this time. These factors are that definite knowledge based on experience is not available on how clay would react if dumped in deep tidal currents, on how an underwater fill consisting of lumps of clay would behave in rapid currents, or on how far the tidal currents would carry clay into the rockfill portions of the dams.

Use of sand and gravel for the impervious zone is also possible. ("Impervious" here means only that the material is relatively tight when compared with the adjacent dumped rockfills.) Use of sand and gravel for the impervious portion of the tidal dams is possible only because head differentials are low and because leakage of several thousand cubic feet per second is very small in comparison with the total flow through the powerhouse. Hydraulic analysis of placing materials in flowing water indicated that discharging from bottom-dump scows should be limited to shallow depths and to placement of uniformly sized material if a relatively impervious zone is to be achieved. Even with these limitations, the materials would tend to spread widely and an appreciable loss of the finer sizes would occur.

The most appropriate location for the impervious zone of the tidal dams was also studied. There are two basic designs. The first design includes a central core composed of the least pervious material in the embankment and supported by massive outer fills of coarser materials to provide structural stability. The second design is the blanket type in which a relatively thin layer of impervious material is placed over a more pervious embankment on the side of the dams where high water generally prevails. Sufficient cover to prevent surface erosion is then added.

The location of the impervious zone largely dictates the order of construction and also the construction method. Use of a blanket type of impervious zone would permit construction of the rockfill first, after which the impervious blanket would be added. The rockfill embankment could be constructed by scow-dumping, truck end-dumping, or by a combination of these methods. A central core type of constructionhas the advantage of providing greater protection against erosion of the impervious materials. However, the core and outer rockfill materials must be placed at the same time. Either basic method, properly used, would produce an adequate structure.

The base of the tidal dams includes that portion of the structure below el. -25 in which materials would be placed from scows. The dimensions of the base in the deeper passages was determined from the results of the hydraulic model studies which indicated that a width of approximately 400 feet at el. -25 was necessary for construction of stable rockfills with sufficient room for crest construction of appropriate design. Exterior slopes of 1 on 1.75 were found stable for the deep-water portions of the cross section where good foundation conditions prevailed. However, where clay was encountered in the embankment foundations, it was necessary to increase the width of the base by adding berms and flattening slopes to obtain adequate foundation stability.

The dam crest is that portion of the structure above el. -25 where construction by large bottom-dump scows is not feasible because of rapid currents or lack of depth for floating plant. Closure against transverse currents would be encountered in all crest construction. The earlier closures would have smaller current velocities. The first step in the crest construction would be to build an end-dump rockfill of sufficient size to remain stable in the transverse current. This fill would be dumped on one shoulder of the previously constructed base, with side slopes as steep as practicable and with a top width of about 40 feet at a level slightly above high tide. The resulting fill would form a working platform for subsequent operations. Either a blanket or core type of impervious zone could be constructed after the rock closure is completed.

The general cross sections first considered were studied for construction feasibility and economy of material in order to determine which particular combination of design features provided the greatest advantage. Design analyses were made to investigate the stability, amount of settlement, and quantity of seepage for those design cross sections considered most applicable to the project.

Selected Designs of Tidal Dams

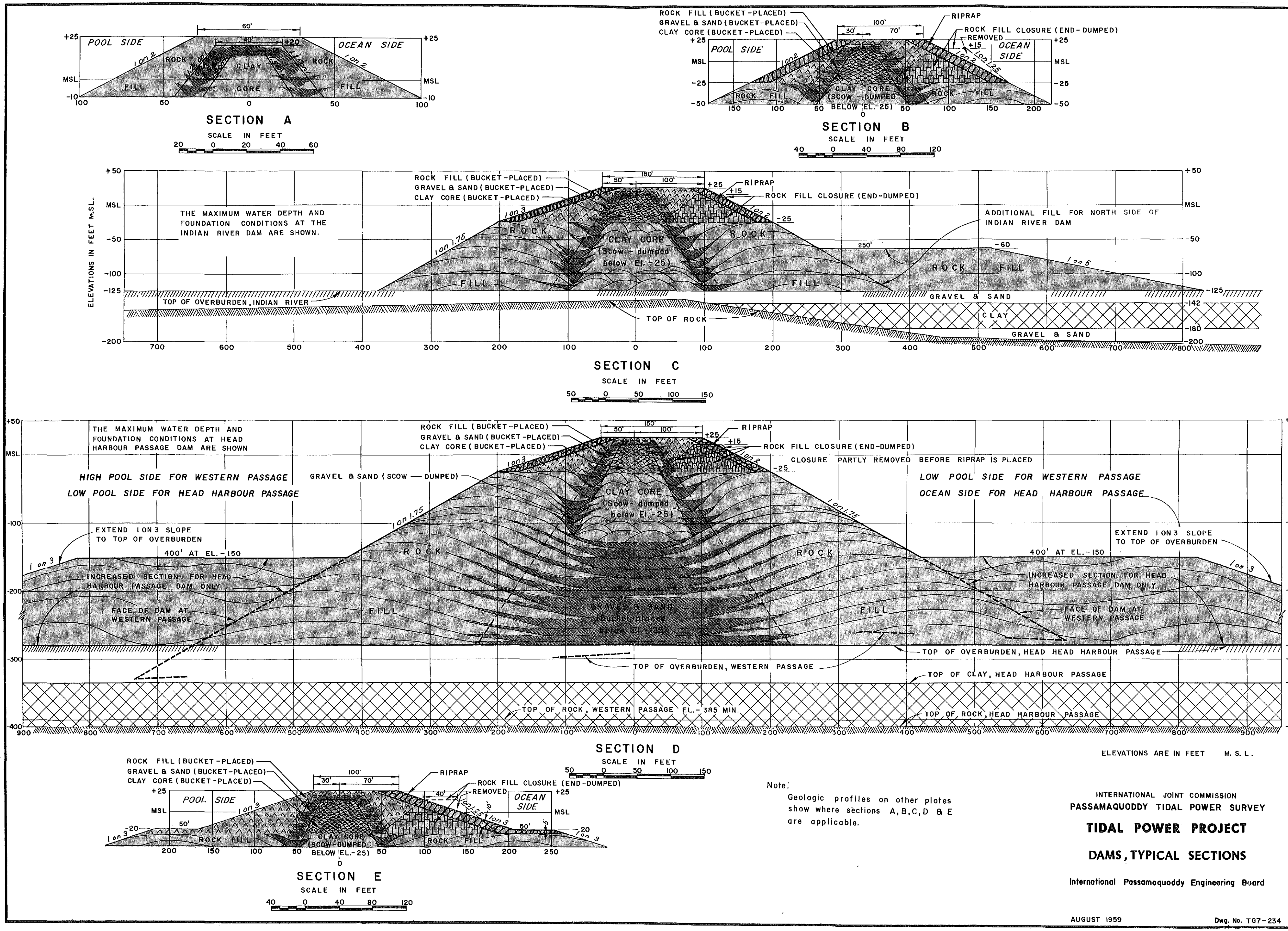
A tidal dam design using a partial clay core was selected for this project. Several proposed cross sections are shown on plate 19, and the locations of these sections are indicated on the profiles shown on plates 20, 21, and 22. This design was selected because of its technical adequacy, feasibility of construction, and because it has the lowest practicable cost of the several designs studied.

The selected design includes a clay core for all dams except where bottom depths are below el. -125. At these greater depths a granular core of sand and gravel is planned. This sand and gravel zone extends up on both sides of the clay core as a transition between the core and the dumped-rock outer fills. These rockfills provide the structural stability of the dam. Riprap would be placed on the exterior surfaces in the zone of wave action.

Embankments that do not extend below low tide level would be constructed by end-dumping, as indicated in section A on plate 19. Elsewhere, the base of the dam would be constructed from scows and the crest portion would be built in two stages by land-based operations. The first stage would include a dumped-rock closure and the second stage would include the construction of the impervious zone, transition, and rock exterior portions.

Conditions investigated included stability of the embankment, stability of the embankment and foundation as an integral unit, and preservation of exterior surfaces against erosion and wave action.

Settlement of the proposed tidal dams involves two distinct design problems. The first problem concerns foundation settlement where clay occurs. Conventional analyses, based on data from limited laboratory consolidation tests of undisturbed samples indicate that maximum foundation settlement would be about 1 foot for the small dam at Carryingplace Cove, 3 feet for the Quoddy



Note: Geologic profiles on other plates show where sections A, B, C, D & E are applicable.

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

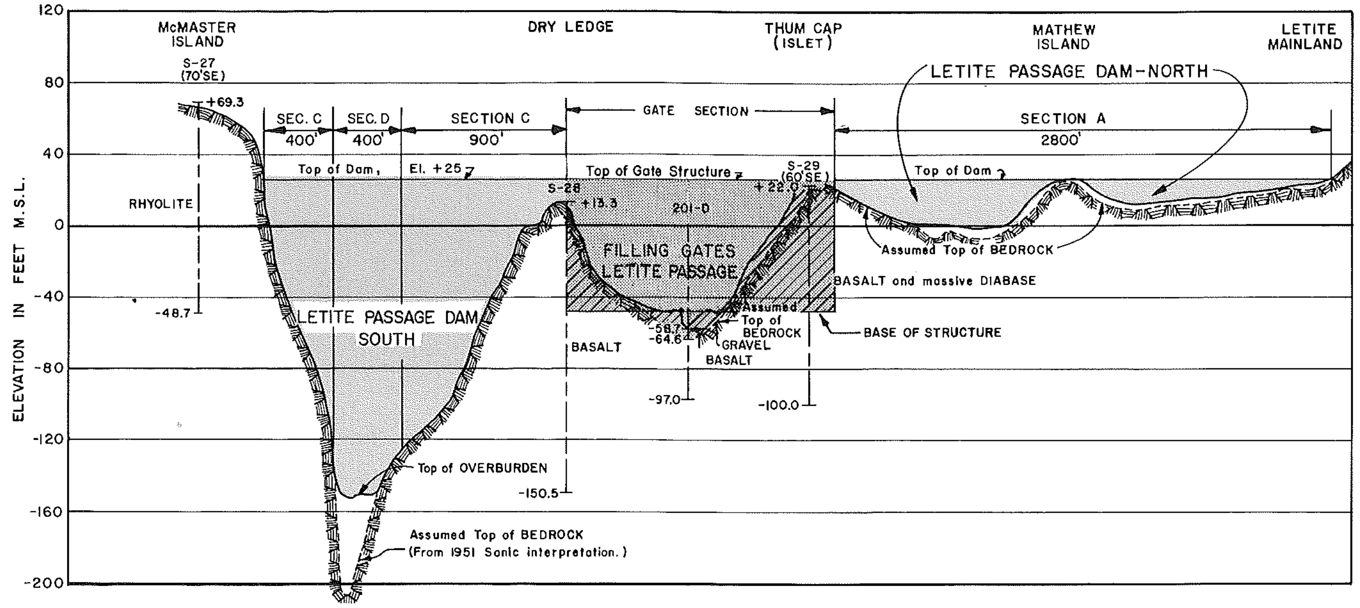
DAMS, TYPICAL SECTIONS

International Passamaquoddy Engineering Board

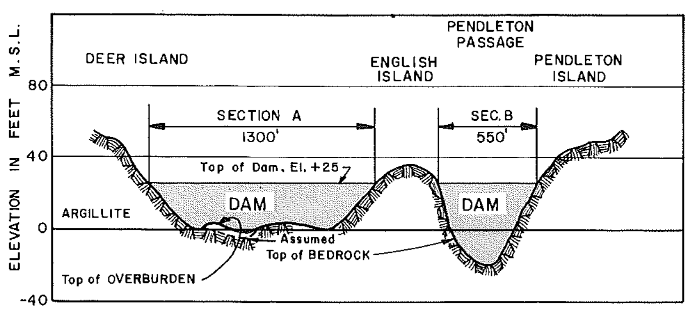
AUGUST 1959

Dwg. No. TG7-234

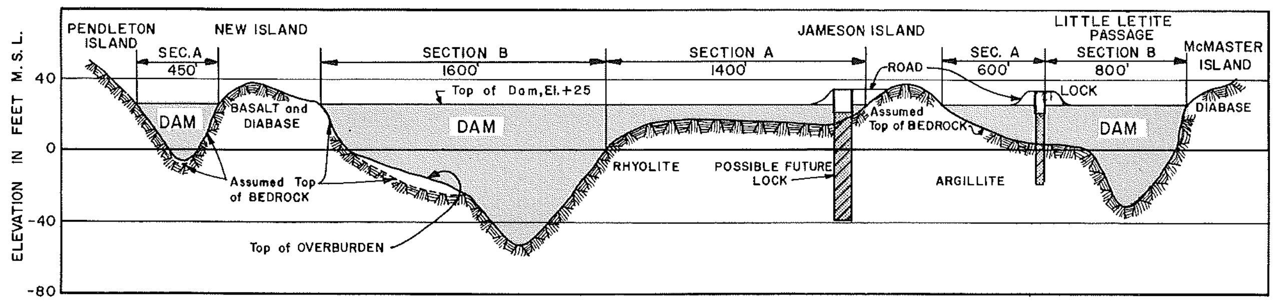
PLATE 19



AREA I - LETITE PASSAGE - PROFILE ALONG ℄ GATES and DAMS



AREA 2-PENDLETON PASSAGE-PROFILE ALONG ℄ DAMS



AREA 2-LITTLE LETITE PASSAGE-PROFILE ALONG ℄ DAMS

DRILL HOLE LEGEND

S-27 — Drill hole number
(70'-SE) — Offset from ℄
+69.3 — Top Elevation.
RHYOLITE — Material Encountered
-48.7 — Bottom Elevation.

Notes:
All elevations are referred to mean sea level.
Sections A, B, C, and D refer to cross sections shown on plate 19.

HORIZONTAL SCALE IN FEET
400 0 400 800 1200

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

GEOLOGIC PROFILES
AREAS 1 AND 2

International Passamaquoddy Engineering Board

AUGUST 1959

Dwg. No. TG 7-235

PLATE 20

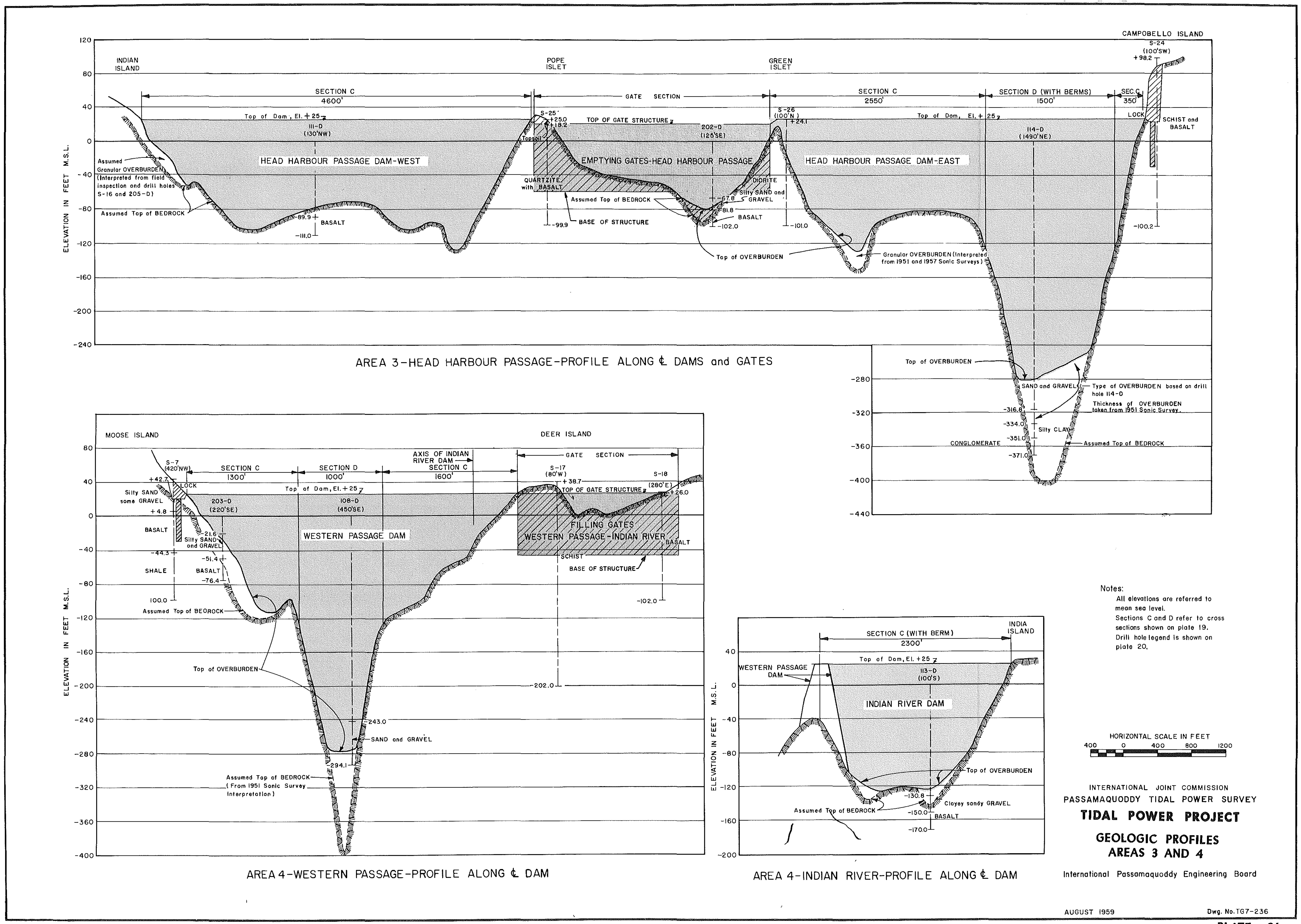
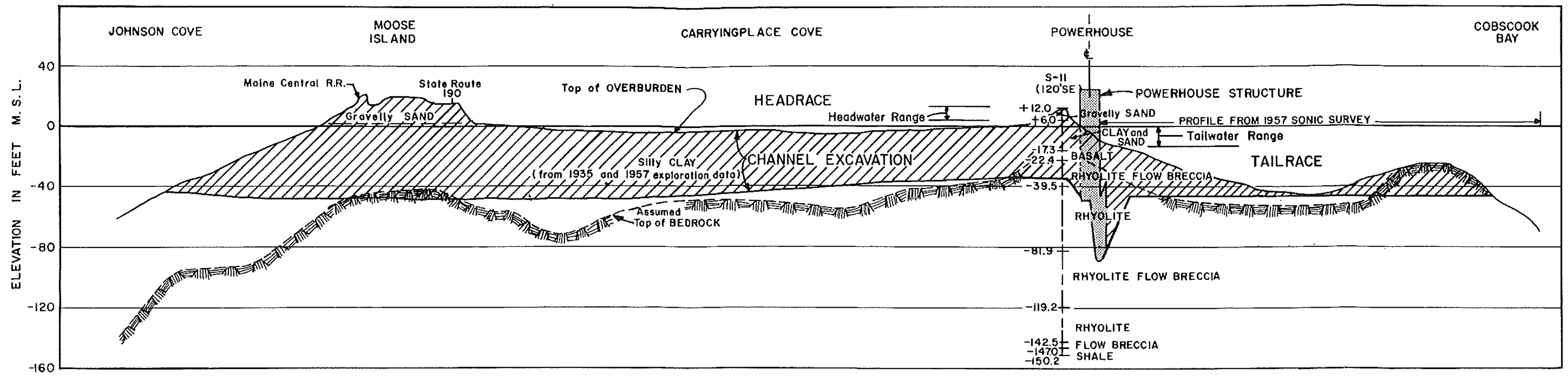
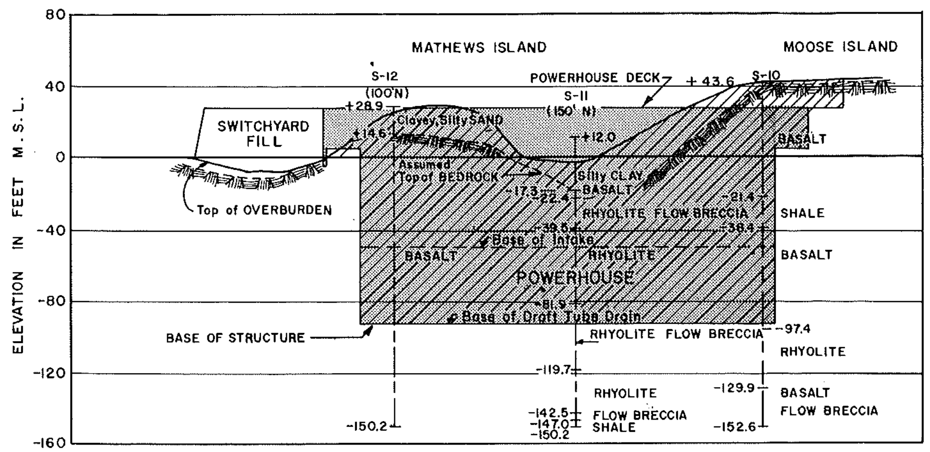

AREA 3-HEAD HARBOUR PASSAGE-PROFILE ALONG ℄ DAMS and GATES
INDIAN ISLAND
POPE ISLET
GREEN ISLET
CAMPOBELLO ISLAND
SECTION C 4600'
GATE SECTION
SECTION C 2550'
SECTION D (WITH BERMS) 1500'
SEC.C 350'
Top of Dam, El. + 25
TOP OF GATE STRUCTURE
HEAD HARBOUR PASSAGE DAM-WEST
EMPTYING GATES-HEAD HARBOUR PASSAGE
HEAD HARBOUR PASSAGE DAM-EAST
Assumed Granular OVERBURDEN (Interpreted from field inspection and drill holes S-16 and 205-D)
Assumed Top of BEDROCK
BASALT
QUARTZITE with BASALT
DIORITE
Silty SAND and GRAVEL
BASE OF STRUCTURE
Top of OVERBURDEN
Granular OVERBURDEN (Interpreted from 1951 and 1957 Sonic Surveys)
SCHIST and BASALT
LOCK
SAND and GRAVEL
Silty CLAY
CONGLOMERATE
Type of OVERBURDEN based on drill hole 114-D
Thickness of OVERBURDEN taken from 1951 Sonic Survey.
ELEVATION IN FEET M.S.L.
AREA 4-WESTERN PASSAGE-PROFILE ALONG ℄ DAM
MOOSE ISLAND
DEER ISLAND
SECTION C 1300'
SECTION D 1000'
AXIS OF INDIAN RIVER DAM
SECTION C 1600'
WESTERN PASSAGE DAM
FILLING GATES WESTERN PASSAGE-INDIAN RIVER
Silty SAND some GRAVEL
SHALE
SCHIST
AREA 4-INDIAN RIVER-PROFILE ALONG ℄ DAM
INDIA ISLAND
SECTION C (WITH BERM) 2300'
INDIAN RIVER DAM
Clayey sandy GRAVEL
Notes:
All elevations are referred to mean sea level.
Sections C and D refer to cross sections shown on plate 19.
Drill hole legend is shown on plate 20.
HORIZONTAL SCALE IN FEET
400 0 400 800 1200
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
GEOLOGIC PROFILES
AREAS 3 AND 4
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-236

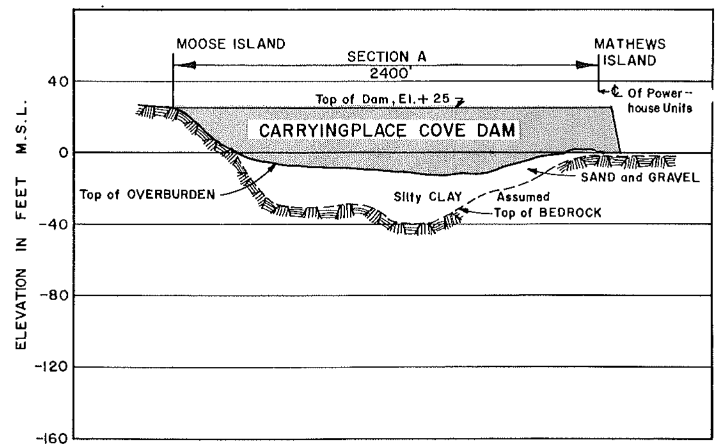
PLATE 21



AREA 5 - JOHNSON COVE TO CARRYINGPLACE COVE - PROFILE ALONG ℄ HEADRACE AND TAILRACE

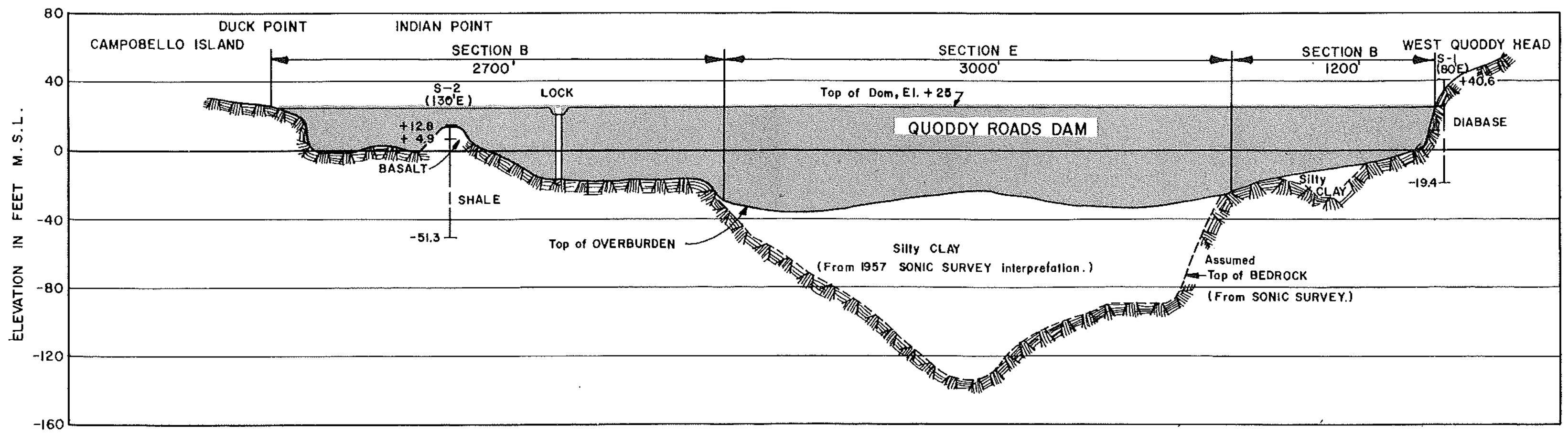


AREA 5 - CARRYINGPLACE COVE - PROFILE ALONG ℄ POWERHOUSE



AREA 5 - CARRYINGPLACE COVE - PROFILE ALONG ℄ DAM

Notes:
All elevations are referred to mean sea level.
Sections A, B, and E refer to cross sections shown on plate 19.
Drill hole legend is shown on plate 20.



AREA 6 - QUODDY ROADS - PROFILE ALONG ℄ DAM

HORIZONTAL SCALE IN FEET
400 0 400 800 1200

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

GEOLOGIC PROFILES
AREAS 5 AND 6

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-237

PLATE 22

Roads dam, and 7 feet for the Head Harbour Passage dam. It is estimated that 50 percent of the settlement of the dams in Head Harbour Passage and Quoddy Roads would occur within 5 to 10 years after construction, with ultimate settlement at a progressively slower rate for more than 50 years. The small dam on a shallow clay layer in Carryingplace Cove would settle in a much shorter time.

The second problem is that of settlement within the dams due to consolidation of the clay core. At this stage of the investigation, the consolidation characteristics of the clay core are a matter of speculation, depending on the method of construction and how successfully the construction can be controlled. Refinement of the settlement computation is not within the scope of the present survey, since the only requirement is that a reasonable allowance be made to balance the shrinkage. For the purpose of this survey, it is considered sufficient to provide for a top elevation of 25 feet above mean sea level at time of completion of construction.

Seepage through and under the dams was estimated, using flow nets for generalized flow areas. Estimated total seepage is 500 c.f.s. for the selected designs. This range of seepage is so small in comparison with the powerhouse flow that the effect of seepage losses on power production would be negligible.

Consultants

In addition to the highly specialized hydraulic engineering studies by Dr. Straub, expert advice on design of the tidal dams was obtained from consultation with Dr. Arthur Casagrande, Professor of Soil Mechanics and Foundation Engineering, Harvard University, and Mr. G. E. Bertram, Chief, Soils Branch, Engineering Division for Civil Works, Office, Chief of Engineers, U.S. Army.

Other Designs Considered

In an attempt to gain further advantages from the basic concept of the partial clay core design, two modifications of the partial clay core were considered. The first and most conspicuous change was the extension of the clay core to the full depth of dams in the deep passages. The second change is a narrowing of the rock outer fill by steepening the upper external slope from 1 on 3 to 1 on 2. The principal advantages of this design would be the better use of required structure excavation and a corresponding decrease in embankment borrow requirements. However, the problems of construction procedure to obtain satisfactory placement and retention of clay confined within the design zone, particularly below el. -125, are such that full-scale field tests of placement procedures would be necessary before this design could be adopted.

In view of the unsolved problems of underwater placement of clay, a tidal dam composed entirely of granular materials was also considered. Seepage losses for this design would be in the range of 7,000 c.f.s. This design was not adopted because the cost analysis, including power losses due to seepage, indicated that the granular design was less favorable than the adopted partial-clay-core design.

Cofferdam Design

Several cofferdams would be required to unwater foundation areas prior to construction of the powerhouse, filling and emptying gates, and navigation locks. Foundation conditions for most of the proposed cofferdams consist of bedrock with shallow granular overburden. However, clay occurs in the cofferdam foundations of the powerhouse and channels in the vicinity of Carryingplace Cove.

The permanent tidal project structures were located on predominant underwater ridges. Thus, the cofferdam foundations are generally located in water deeper than the excavation required for permanent structure foundations. Cofferdam alignments necessarily extend across local depressions in the bay bottom, the deepest being about el. -120 in Head Harbour Passage. Hydraulic conditions include tides with variations up to 26 feet and surface waves of up to 10 feet. Existing tidal currents up to 10 feet per second prevail locally. The water surface on the outside of the cofferdams would be at ocean level, while the water surface inside the cofferdams would be about el. -50 at the filling gates and powerhouse tailrace and el. -65 at the emptying gates. Thus, the head conditions on the cofferdams would be much more severe than those on the permanent tidal dams.

The cofferdams were designed as stable structures durable enough to last from 1 to 3 years in the severe exposure conditions of the project site. The total cost of building a cofferdam, keeping it pumped out, and then removing it was held to a minimum. In some locations it was found cheaper to use the expensive method of underwater excavation rather than to move the cofferdam into deeper water and to excavate the material in the dry.

Cofferdams required in locations where water depths extend below el. -60 would be embankments composed of a clay core with rock outer fill. The design of major embankment cofferdams would be similar to that proposed for the tidal dams, including crest construction. Benefits of this design include efficient use of excavated materials and the opportunity for full-scale testing of embankment construction for the permanent dams. Structural stability of the cofferdams was analyzed by the same method used for tidal dams. Settlement would not be a serious problem because continuing maintenance would keep the cofferdam crests at a sufficient height. Seepage through the clay core would be negligible, and underseepage would require only nominal pumping. Minor embankments would be used as applicable in shallow water.

In view of the large volume of materials required for the cofferdams, the economy of using steel sheet pile cofferdams was considered. The supporting berms of these cofferdams would require substantially less material than that required for embankment cofferdams. Analyses showed that the cellular cofferdam of conventional design, using a standard commercially available piling without supporting berms, would be appropriate for locations where firm foundation exists at depths no greater than about 45 feet below sea level. The unsupported height would be limited by allowable interlock stresses. Where firm bottom exists between about el. -45 and -60, a cloverleaf type of sheet pile design was used.

A log crib cofferdam with timber sheathing is less costly than either embankment or steel sheet-piling cofferdams in locations where the bottom is above el. -20, and where the natural downward slope of the foundation is fairly steep in a direction normal to the axis of the cofferdam. The particular advantage of the crib cofferdam lies in the narrow width of structure for the height required. A wider structure must extend into deeper water or require underwater excavation after removal of the cofferdam.

POWERHOUSE

Design of the powerhouse selected for the tidal project has much more precedent than that of the dams. The Vargön power plant, for example, built in 1930-32 in Sweden, uses Kaplan turbines 315 inches in diameter in an outdoor powerhouse. The average head is about 13 feet. The turbines rotate at 46.9 r.p.m. and are direct-connected to generators rated 12,000 kv.-a. This is similar to the selected design of the tidal powerhouse which operates at an average head of 11 feet and uses 320-inch turbines at 40 r.p.m. connected to 10,000 kw. generators. On the other hand, considerable progress has been made in France in developing a turbine-generator unit of unconventional design specifically for the Rance tidal power project. Both types were considered in the design studies described below. The preliminary design of the powerhouse was made by the Stone and Webster Engineering Corporation of Boston, Massachusetts.

Previous Studies

Drawings and computations made during the 1919-35 work of Dexter P. Cooper, Inc., show that the powerhouse considered at that time was based on fixed-blade propeller turbines with a throat diameter of 320 inches, a speed of 40 r.p.m., directly connected to the generators. Some of the turbines apparently were without wicket gates. The generators were rated at 16,667 kv.-a., apparently to absorb the full output of the turbines without wickets at a maximum head of 25 feet. The units were set 64 feet apart. Twenty units were proposed for the initial installation, and 44 for ultimate installation in an outdoor powerhouse.

In 1935-37, the U.S. Army Corps of Engineers planned a powerhouse based on 320-inch, fixed-blade, propeller turbines. Each turbine, however, would have had conventional wicket gates. On the basis of model studies performed by United States manufacturers, unit spacing was 80 feet. The generators were rated at 12,222 kv.-a. each, and the five initial units would have been housed in a conventional indoor powerhouse.

Results of the hydraulic model studies made during the 1935-37 period were used during the current survey to establish the dimensions of the powerhouse water passages.

Location

The proposed tidal powerhouse would be located between Moose and Mathews Islands, Maine, as shown on plate 8. The approach channel would extend from Johnson Cove on the east side of Moose Island, across the narrow neck of the island and across Carryingplace Cove on the west side of Moose Island. Carryingplace Cove would be closed off from Cobscook Bay by a low dam from Moose to Mathews Islands. The tail-race channel would extend into Cobscook Bay to the southwest of the powerhouse. The powerhouse would be founded entirely on rock that is adequate for this purpose.

Turbines and Governors

The present turbine studies began with a review of the findings of the 1935 studies, and discussion of the problem with turbine manufacturers. It appeared from these sources that a unit with a 320-inch throat diameter would still be the largest practicable size. A speed of 40 r.p.m. (the same as used in both previous studies) was selected as a compromise between better turbine efficiency at a lower speed, and lower generator cost at a higher speed. The specific speed of the 40 r.p.m. unit for the expected output would also be as high as for any unit in current use in the United States. At a higher speed, a greater number of smaller units would be required, which would increase the size and cost of the powerhouse.

Six Canadian and United States manufacturers were asked to furnish performance curves for 320-inch, 40 r.p.m. turbines of both Kaplan and fixed-blade propeller types. Information was requested for their standard turbine setting and for a 65-foot gross water passage width if significantly different. Design data, dimensions, weights, and preliminary prices were obtained.

Analysis of the data showed that there would be no significant difference in cost of tidal energy between fixed-blade or Kaplan turbines, since the increased energy of the Kaplan unit would be offset by its greater cost. Therefore, a fixed-blade turbine was selected because of the lower maintenance cost of the simpler mechanism. Governor-controlled wicket gates would be used at each turbine to control speed, to avoid the need for emergency head gates at each of the 30 turbines, and to avoid high generator ratings. A composite layout of the water passages required for the turbine was then prepared as a first step toward design of the powerhouse structure. The gross width of the water passages is 65 feet.

The manufacturer of the bulb-type units designed for use in the Rance project also furnished costs and operating characteristics for this type of turbine. Layouts and estimates of a powerhouse using the bulb-type units showed that the powerhouse structure would cost about $300,000 less per unit than with conventional units. This saving, however, was more than offset by the $900,000 greater cost of the turbine-generator set, including import duties and transportation from France. Although the turbines were found equal to the best Kaplan turbine studied, measured in energy generated during an average year, the bulb-type units have several disadvantages: (1) their use would increase the cost of tidal power, (2) their rotative inertia is less than a conventional unit, (3) the design is relatively untried, and (4) little is known about the maintenance they would need. Therefore, no further consideration was given to this type of equipment for the purposes of the present survey.

Generators

The generators planned for the tidal project, which are rated at 10,000 kw., were found to provide the least costly tidal power. The generators could be operated continuously at 15 percent overload (11,500 kw.) at an elevated, but permissible, temperature. Generation would be at 13.8 kv.

The generators would be designed for operation at 40 r.p.m., with a maximum runaway speed of 100 r.p.m. The machines would be enclosed in steel air housings of the outdoor type, and equipped with air-to-water coolers, carbon dioxide fire protection, air brakes, and exciter. The turbine-generator unit would have sufficient combined inherent rotative inertia (WR^2) to provide adequate stability for the system under estimated critical conditions.

Powerhouse Arrangement

The powerhouse would be the outdoor type, with 30 main unit bays, each 78 feet wide, and two erection and service bays, 60 feet wide, at each end. Total length of the powerhouse would be 2,580 feet. Plate 23 shows a plan of the powerhouse. Only one generator bay is shown since the remaining 29 would be the same. Four 90,000 kv.-a. transformers would be mounted on the top deck, and two 220-ton and two 30-ton traveling gantry cranes would service generating units and gates.

The powerhouse arrangement was based on the 65-foot-wide water passage developed from manufacturers' proposals. Intake sections and draft tubes would have three passages 17 feet 4 inches wide, with two interior and two end piers, each 6 feet 6 inches wide, making a total bay width of 78 feet. The size of water passages was also important in establishing main floor levels of the powerhouse. Allowing for a 5-foot concrete slab over the highest point of the entrance scroll (el. 7), the lowest floor level of the powerhouse would be at el. 12. Allowing 12 feet for headroom and 3 feet for a roof slab established the next deck at el. 27. This deck was made the roof deck, since it would be well above maximum tide level of el. 13.9. The enclosed area at el. 12 would be adequate to house and support all powerhouse auxiliary electrical and mechanical equipment.

The generators would be set at el. 27, projecting above the roof deck, enclosed in weathertight, steel air housings with removable tops. Plate 24 shows a cross section through a generator bay. The main transformers would be located on the intake side of the deck at el. 27, with the power and control cable and electrical equipment galleries located directly beneath at el. 12. The corresponding gallery space on the downstream side of the main units would be used for mechanical equipment and piping.

Office buildings, each 120 feet long by 43 feet wide, would be constructed at each end of the powerhouse for project administrative staff. The buildings would be located on the low-pool side of the structure, beside the erection bays. The building at the northwest end would be one story high, and the building at the southeast end would be two stories high. Plate 25, an architect's drawing of the powerhouse, shows the latter building. An access road and a rail spur would connect to the southeast end of the powerhouse. The southeast office building, being most accessible, would include visitors' facilities on the lower story. The room would contain large viewing windows overlooking the powerhouse and pools.

The outdoor powerhouse was selected after a comparison showed that the cost would be several million dollars less than the cost of a conventional indoor powerhouse and about a million dollars less than the semioutdoor type. An outdoor powerhouse, however, requires protection of the units when disassembled for service. In the selected design shown on plates 23, 24, and 25, this protection is provided by large rolling doors on the powerhouse cranes which can entirely enclose the area below.

Headrace and Tailrace

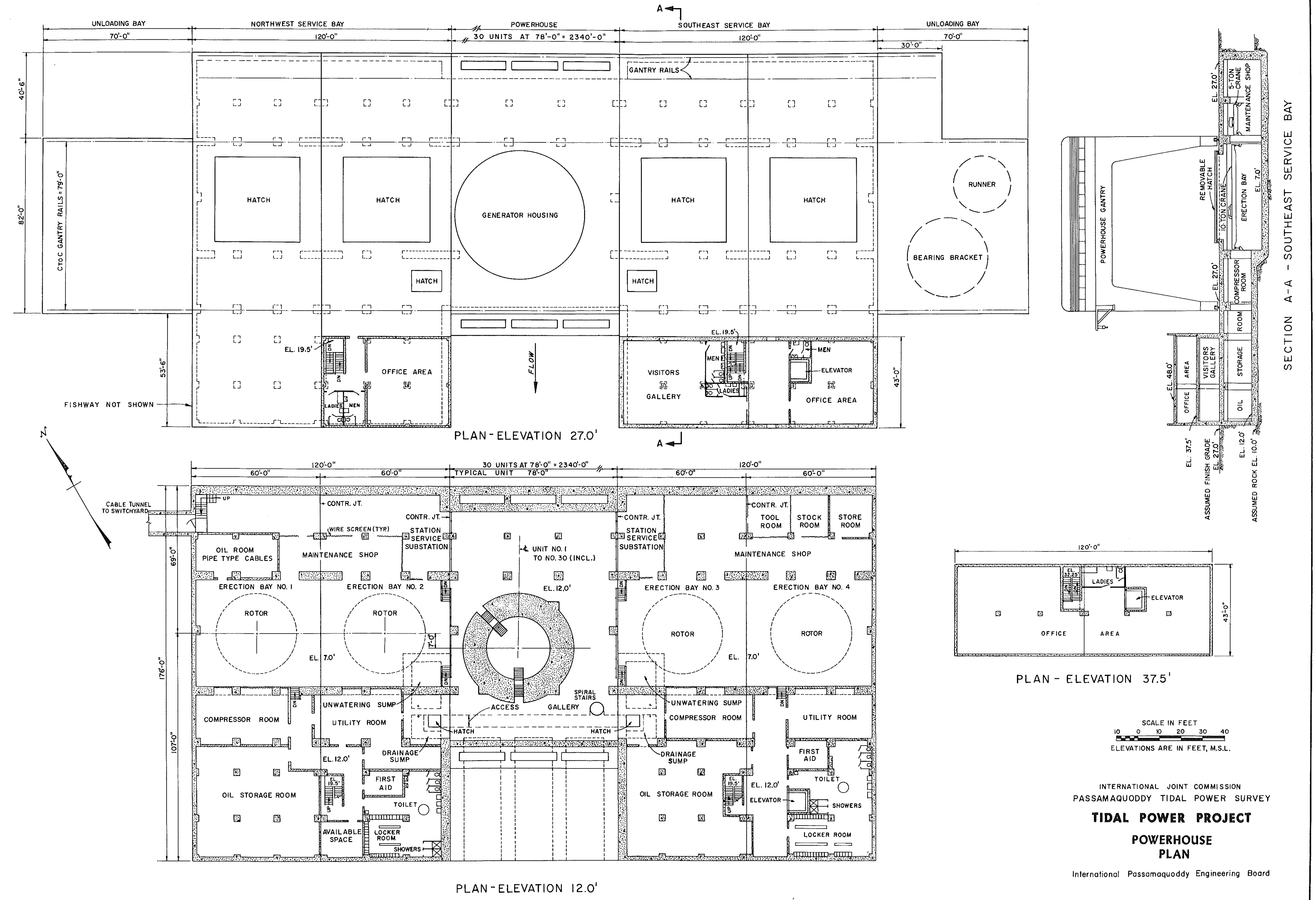
The powerhouse headrace and tailrace channels were designed for economy by balancing the gain in tidal energy against the increased cost of excavating a larger channel. These studies led to the headrace and tailrace arrangement shown in plan on plate 8. Average velocity in the headrace and tailrace would be about 2.8 f.p.s.

The powerhouse headrace would be about 6,300 feet long and would connect the powerhouse to the high pool at Western Passage. Bottom width would vary from 2,340 feet near the powerhouse, at el. -33, to about 1,700 feet at Moose Island, at el. -50. A bridge would be constructed across the headrace at Moose Island for access between Eastport and the mainland.

The tailrace, about 2,700 feet long, would connect the powerhouse to the low pool. It would have a uniform bottom width of 2,340 feet and would be excavated to a bottom of el. -47 to el. -70.

Gates

Three full sets of intake gates would be provided for the 30 units. This number would be sufficient to unwater 2 units simultaneously while leaving a reserve set for emergencies. Each set would consist of one wheeled and two slide gates. The gates, constructed in two sections, would be 40 feet high by 17 feet 4 inches wide, and would operate in slots on



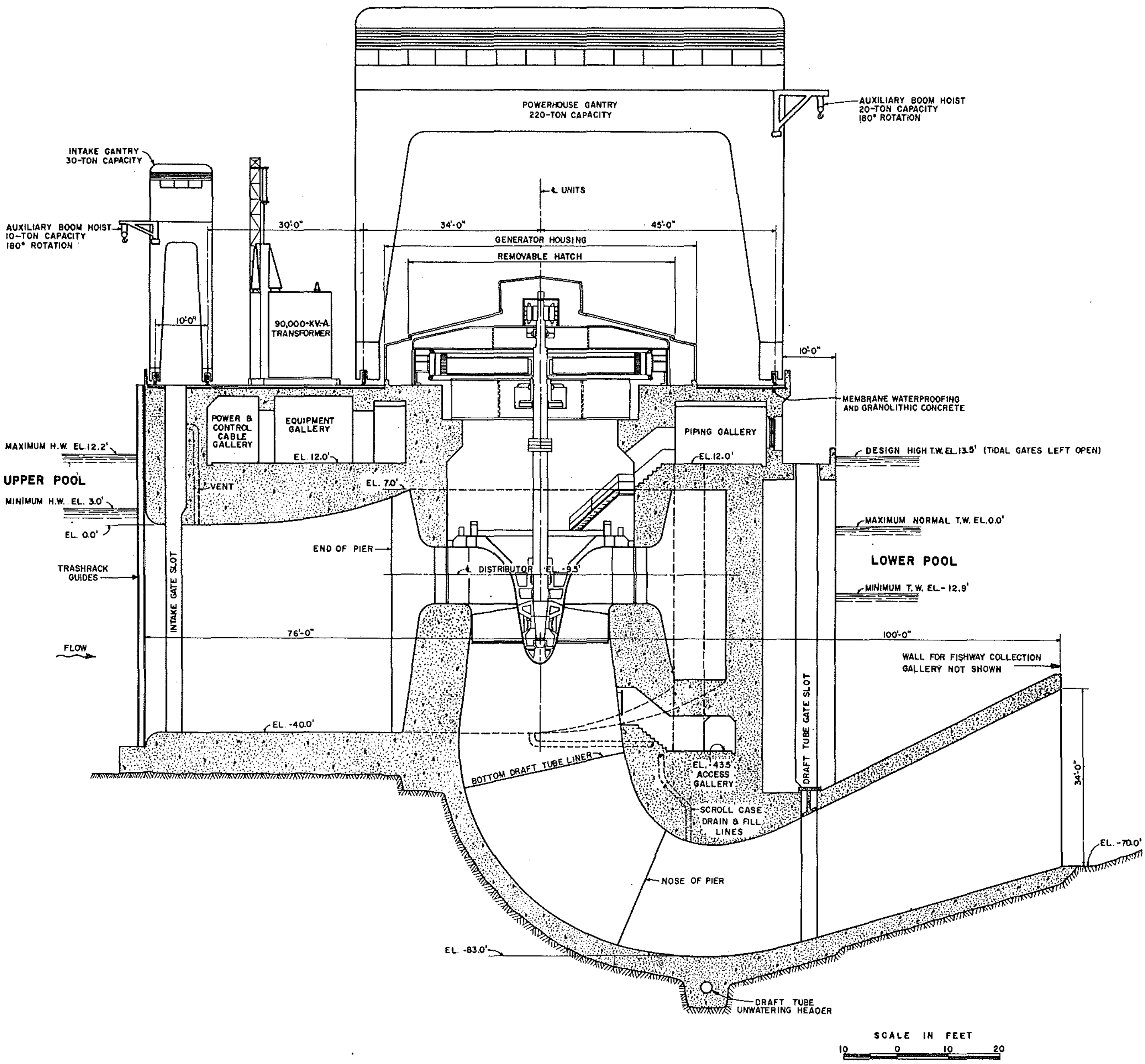
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

POWERHOUSE PLAN

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-238



ELEVATIONS ARE IN FEET, M.S.L.

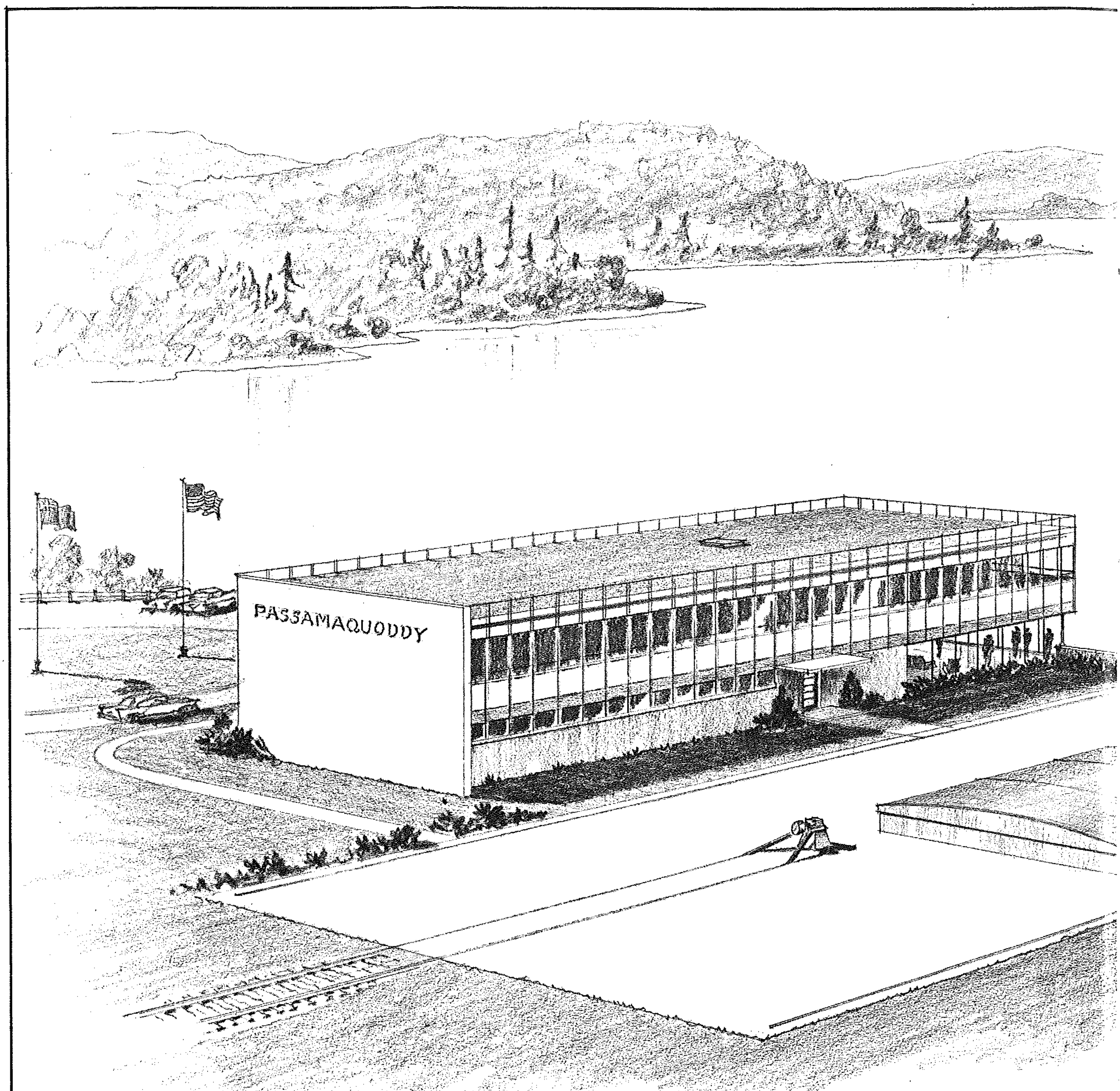
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

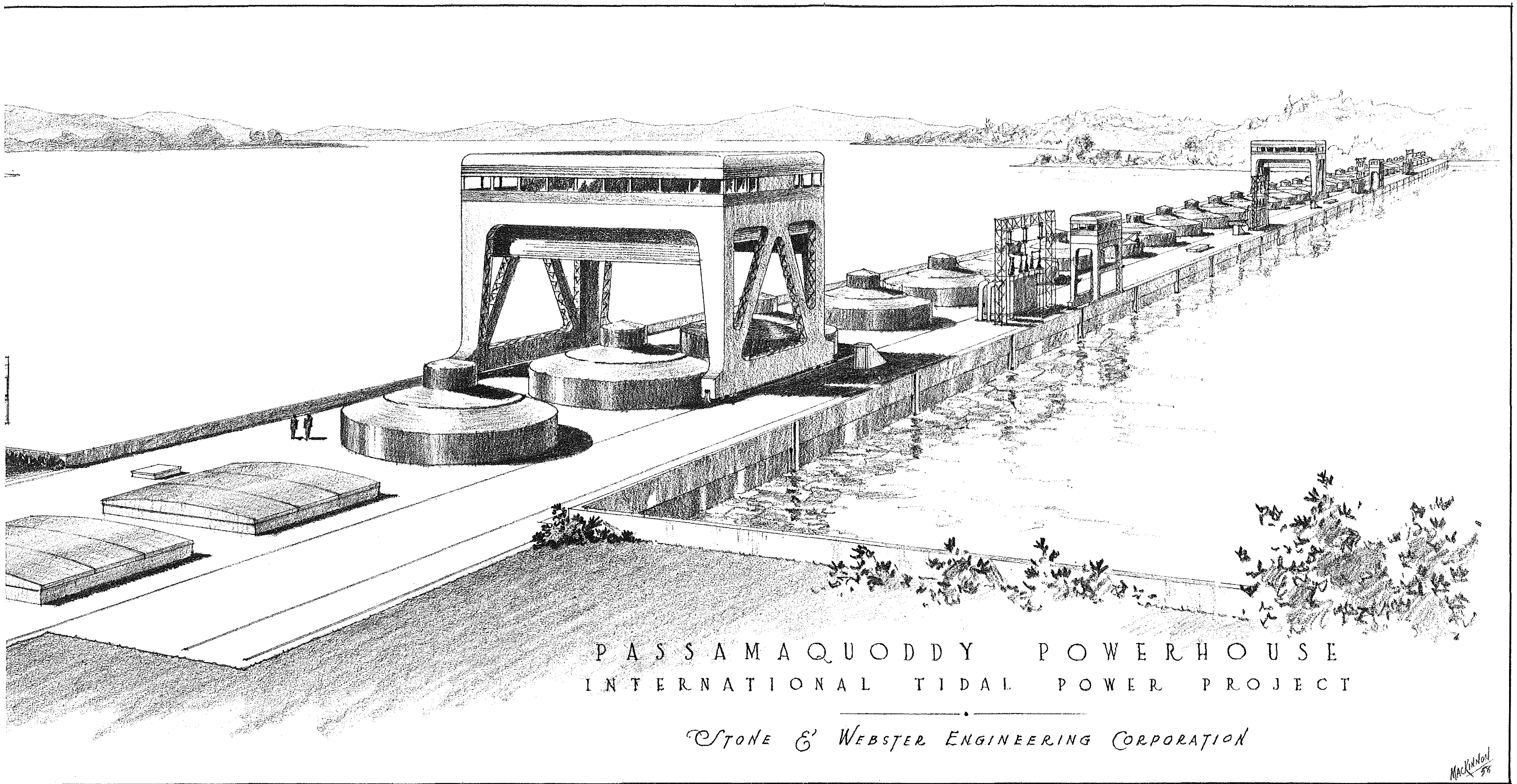
TIDAL POWER PROJECT

POWERHOUSE
TYPICAL SECTION

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-239


PASSAMAQUODDY


PASSAMAQUODDY POWERHOUSE
INTERNATIONAL TIDAL POWER PROJECT
STONE & WEBSTER ENGINEERING CORPORATION
MACKINNON 58

the upstream side of the powerhouse. The gates would be placed by the intake gantry crane. When not in use, gates would be stored in gate slots and supported by latches. The gates would be designed for emergency closure under full flow conditions with wide open turbine wickets. Under these circumstances, the slide gates would be placed in the outer water passages and then the wheeled gate would be placed in the middle passage. Under these conditions, the gates would close under their own weight.

Similarly, three full sets of draft tube gates, also constructed in two sections, would be provided, each 25 feet high by 17 feet 4 inches wide. Because these gates would always be placed under a balanced head, all would be slide gates. Gate slots would be provided on the downstream face of the powerhouse. The gates would be handled by a 20-ton auxiliary jib hoist on the downstream side of each powerhouse gantry crane. The gates, supported by latches, would be stored in gate slots.

Trashracks and Stoplogs

Trashracks for the powerhouse would be set in structural steel guides attached to the upstream pier noses of the intake. Three racks, each 15 feet high by 22 feet wide, would be provided for each water passage, or nine sections for one generating unit. Three spare sections would also be provided, making a total of 273 trashrack sections. The rack sections would be handled by a 10-ton auxiliary jib hoist on the upstream face of the intake gantry crane. Equipped with a bucket, this auxiliary hoist would also serve to remove trash.

Special stoplogs would operate in the trashrack slots to permit maintenance of the intake gate slots. Only sufficient stoplogs to close off one unit intake would be provided since this type of maintenance would be undertaken infrequently.

Cranes

Two 220-ton double-trolley gantry cranes, with spans of 79 feet, would operate along the full length of the powerhouse and erection bays. The principal function of the cranes would be to handle the generators and turbines during erection and subsequent maintenance. The cranes would also be used to untank transformers, to unload railroad cars, and to perform general construction work. Each crane would have two trolleys, each equipped with one 110-ton main hook and one 25-ton auxiliary hook. For major lifts, such as a generator rotor or turbine runner, the two trolleys of a crane would be linked with a lifting beam for concerted action. The largest single load on the crane would be a turbine runner, estimated to weigh 410,000 pounds.

Each crane would have large rolling doors to permit complete enclosure of the area under the crane to service the generating units during bad weather. A 200-kw. diesel generator set would be installed in each crane for hoisting and propulsion power in order to eliminate a costly collector system and to avoid the problem of protecting this system against severe marine exposure.

In addition to the 25-ton auxiliary hooks, each crane would be equipped with a 20-ton jib crane on a downstream corner of the crane housing. This jib would rotate 180°, and would handle the draft tube gates. The jib hoist drive would be located in the gantry crane housing for weather protection.

Two 30-ton fixed-hoist gantry cranes would handle the intake gates. The cranes would have a span of 10 feet and would operate the full length of the powerhouse and erection bays. The single main hook would handle the intake gates, and a 10-ton auxiliary jib crane would be pivoted on an upstream leg for handling stoplogs and trashracks. The maximum crane load would occur when raising, or "cracking" an upper gate section to rewater a scroll case after maintenance. Total load is estimated at 30,000 pounds of gate weight plus 25,000 pounds of frictional load.

The decision to provide two cranes of each type was based upon the size of the plant and the maintenance schedule. Although no precedent for such a tidal plant exists, it appeared that one main crane would be used almost continuously for scheduled maintenance work. The second unit was therefore included for emergency repairs and also to permit doubling up of maintenance in good weather in order to avoid outages during the winter when electrical load would be greatest and weather worst. Similarly, the two intake gantry cranes would permit rapid closure during an emergency. Two cranes working together would reduce closure time to less than half the time required by a single crane.

Main Transformers

The generators would be grouped 8-7-7-8, with a 3-phase step-up transformer for each group. The first two transformers would have high voltages of 230 kv. for the United States distribution system, and the remaining two transformers would have high voltages of 138 kv. for the Canadian distribution system. The transformers would all be 3-phase, forced oil-air type, delta-wye, rated at 90,000 kv.-a.

The transformers would be mounted on the upper deck (el. 27) between the intake and the powerhouse gantry crane rails at nearly equal intervals along the length of the powerhouse. Since the transformers would be located between the cranes, they would be designed for minimum width.

Locating the transformers directly above the power and control cable galleries simplifies the low voltage connection between switchgear and transformer. The high-voltage circuits between the transformers and the switchyard at the northwest end of the powerhouse, would consist of high-pressure, oil-filled, pipe-type cable run in the power and control cable gallery.

Plate 26 is the main one-line diagram of the powerhouse and the switchyard.

Switchyard

The switchyard would be the rigid aluminum bus type with steel H-frame dead-end structures. The selected main-and-transfer bus layout would consist of a 230-kv. section and a 138-kv. section, each with two outgoing lines. The two sections would be interconnected through a 90,000 kv.-a. autotransformer as shown on plate 26. Motor-operated disconnects would be provided for emergency or maintenance use of each transformer bus and spare breaker. Pneumatically-operated oil circuit breakers would have a rating of 1,200-kv.-a., 3-cycle operating speed, and 5 million kv.-a. interrupting capacity. Disconnect switches would be 1,200-amperes, nonload break, and suitably interlocked. Manual grounding switches, potential devices, and carrier coupling devices would be provided on all lines. Lightning arrestors would be used to protect the pipe-type cables and autotransformer. All normal switching would be controlled from the central supervisory board in the powerhouse.

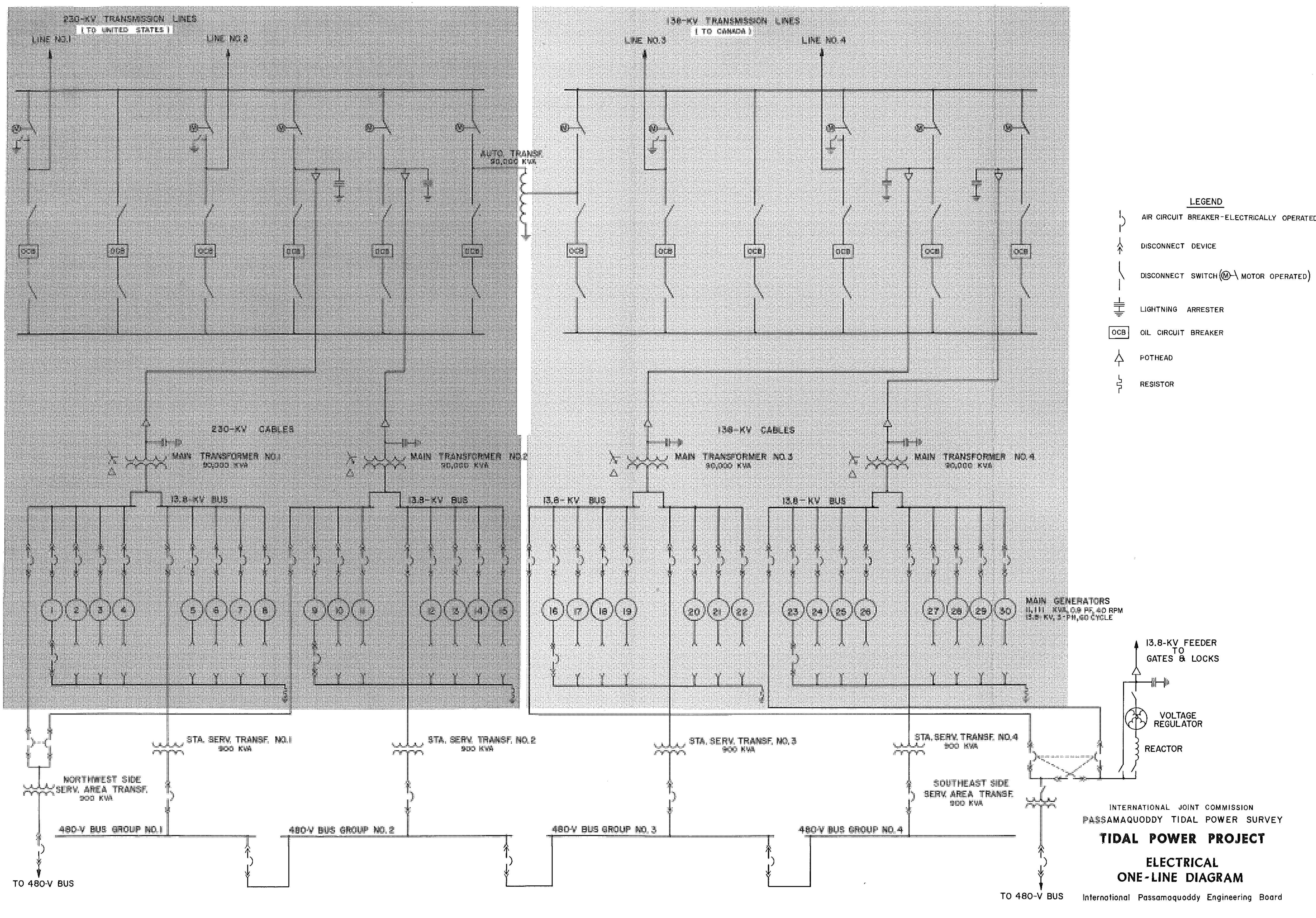
Corrosion Prevention

Prevention of corrosion of metals exposed to sea water is a considerable problem in any marine installation. Corrosion would be particularly serious in a tidal power plant because the turbines, for example, would be immersed in sea water at all times. Corrosion can be controlled to some extent by using metals with a high degree of natural resistance, by using protective coatings, or by using cathodic protection currents to counterbalance the corrosion reaction. The most economical method is usually a combination of all three.

Corrosion is basically an electrochemical process. Every metal has a different degree of resistance to corrosion, which can be measured. It is possible, therefore, to arrange all metals in order according to their relative resistances, and from this list select metals and combinations of metals which will corrode the least. Because it is generally found that the more resistant metals are much more expensive than carbon steel, it is not feasible to depend upon the high natural resistance alone. Protective coatings, such as paints, plastics, and even metals, do not afford complete and continuous protection, but must be renewed at intervals. Cathodic protection, either the impressed voltage or sacrificial anode type, can protect many of the less resistant metals, but not under all conditions. In addition, this type of system must be maintained continually to be fully effective.

The most suitable corrosion resistant metal, according to most of the experts consulted, is an 18 percent nickel, 8 percent chromium, and 3 percent molybdenum stainless steel called AISI Type 316. This metal is costly, however, and thus cannot be used every place corrosion resistance is needed. The powerhouse design is based on using AISI type 316 steel for important elements that cannot be protected cathodically or by coatings and on using the less expensive methods elsewhere. The treatment at the powerhouse would be as follows:

(1) Turbine blades, hub, discharge ring, speed ring wearing surfaces adjacent to wickets, wicket top and bottom plates, and the topmost 4 feet of the draft tube liner would be AISI Type 316 steel.



INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

ELECTRICAL
ONE-LINE DIAGRAM

International Passamaquoddy Engineering Board

AUGUST 1959

Dwg. No. TG7-241

(2) Turbine runner cone, head covers, speed ring, draft tube liner, wickets, and stay vanes would be structural grade carbon steel, protectively painted with a standard four-coat vinyl system, and further protected with an impressed voltage cathodic protection system.

(3) Trashracks and trashrack guides would be fabricated from structural grade carbon steel and protectively coated with a coal-tar, enamel primer coat and an impressed voltage cathodic protection system. The anodes would be located to protect the adjacent bulkhead and stoplog slots as well.

(4) Stoplogs and bulkhead gates would be fabricated from structural grade carbon steel, with a four-coat vinyl paint system for protection. Guides would be of rolled or cast carbon steel painted with a standard four-coat vinyl system covered by a two-coat antifouling vinyl system. Certain embedded portions not easily accessible for painting and subject to abrasive action would be fabricated of corrosion resistant alloy iron. Slot metals would be further protected by impressed voltage cathodic protection.

Powerhouse Control and Operation

The power plant, under fully automatic control, would normally be operated to generate the maximum amount of energy from the tides. The wicket setting of each turbine would be maintained automatically at a pre-established opening determined by the gross head on the plant. Water-level sensing elements would provide information for this phase of the automatic operation. The sequence of stopping and starting units would be preprogrammed by electronic computer from tide cycle predictions and recorded on punched cards or tapes. These cards or tapes would then control the actual stopping and starting of the units automatically. Synchronizing and loading would also be automatic. The main supervisory control board would be equipped with a 30-unit status board permitting the withholding of selected units from the automatic control if required.

Special operation for increased capacity can also be programmed for automatic control. This type of operation would be used principally during the lowest neap tides.

A central supervisory board would be located at the center of the plant and would provide equipment for automatic or manual control of all 30 plant units. Controls would also permit remote manual operation of switchyard breakers and disconnects. Provision is made for automatic synchronizing in the switchyard as well as continuous telemetering of all four outgoing lines. The supervisory center would also automatically control the auxiliary power plant by carrier telemetering.

A unit group control center would be located adjacent to each of the four groups of seven or eight generators. From this center, an operator could control all operations for starting, loading, and stopping the generators in his group. Group control centers, however, would normally be reserved for emergency control of a unit within the group.

FILLING AND EMPTYING GATES

The filling and emptying gates of a tidal power project must meet operating requirements not usually demanded of conventional gates. Designed for the highest possible hydraulic efficiency, tidal project gates must be capable of passing, with minimum loss, an unusually large volume of water at low head. The 90 filling gates of the proposed two-pool project, for example, operating only 22 percent of the time, must handle an average flow of 270,000 c.f.s. which continuously discharges through the turbines. In addition, the gates must be rugged, reliable, easily repaired, and capable of operating with a minimum amount of power. Each of the gates of the selected project must be operated twice during each tidal cycle, or 1,412 operations in one year, amounting to a total of 225,920 separate operations of the 160 gates of the selected project. How these special conditions are met in the design of the gates is described in the following paragraphs.

Design studies established the sites best suited for the gates, their optimum number, and the type best suited for the tidal power project. A wheeled vertical-lift gate, 30 feet square, in a submerged "venturi" setting was selected.

Previous Studies

In Dexter P. Cooper's studies of a tidal power project, gate structures for filling the upper pool and emptying the lower pool were designed with submerged water passages.

Vertical-lift gates, 30 feet by 30 feet in size were planned with the sill of the filling gates at el. -38.5 and the emptying gates at el. -53. The gates would have been submerged when closed except for exposure of the upper few feet of the filling gate for short periods during lower than average tides. When open, each gate would have been enclosed in a well above the water passage beneath the deck of the structure. To attain increased hydraulic efficiency, the water passage was planned with a bellmouth entrance and a flaring exit tube. Owing to the general shape of the tubular water passage and the resulting recovery of velocity head in the flaring tube, this type of structure is called a "venturi" setting. The gate would have moved on wheels and would have been suspended at the center by a chain passing over a sheave to a counterweight. The counterweight would have hung in a well in which the water level would have been raised to immerse and lighten the counterweight, or lowered to increase the weight. Raising and lowering the water level in the well would have lowered and raised the gate.

Corps of Engineers' studies of a single-pool tidal project in 1935-37 included hydraulic model tests of water passages of the venturi type designed by Cooper. Tests were made of variations in the shape of the entrance roof; in the shape, length, and elevation of the exit roof; in the length of the piers; in the effect of covering the gate slots in the roof; in the bottom elevations of approach and discharge channels; and variations in the elevations of the water surface. The model was also tested with the roof of the water passage removed.

Since the model tests indicated a substantially greater discharge with the roof removed from the gate passage, it was decided that gate structures with unroofed sluices would provide discharge capacity at equal or lower cost than the venturi tubes. Filling gate structures of the open (unroofed) type were, therefore, designed for the single-pool project in 1936.

After a study of several types of gates including miter, sector, taintor, and roller gates, the vertical-lift type with two leaves was selected in 1936. The gates would have been 60 feet wide and 38.5 feet high with the sill at el. -25. Since the piers would have been 16 feet thick, they would have been about 170 feet long for hydraulic efficiency. The gates would have moved on fixed rollers and would have been raised and lowered by fixed hoists and electric motors using a wire rope suspension connected to counterweights. Steel towers above the deck of the structure would have supported the upper sheaves.

Heaters were found necessary to prevent icing in the gate slots. An air bubbler system was also considered to prevent freezing of the seal between the upper and lower gate leaves.

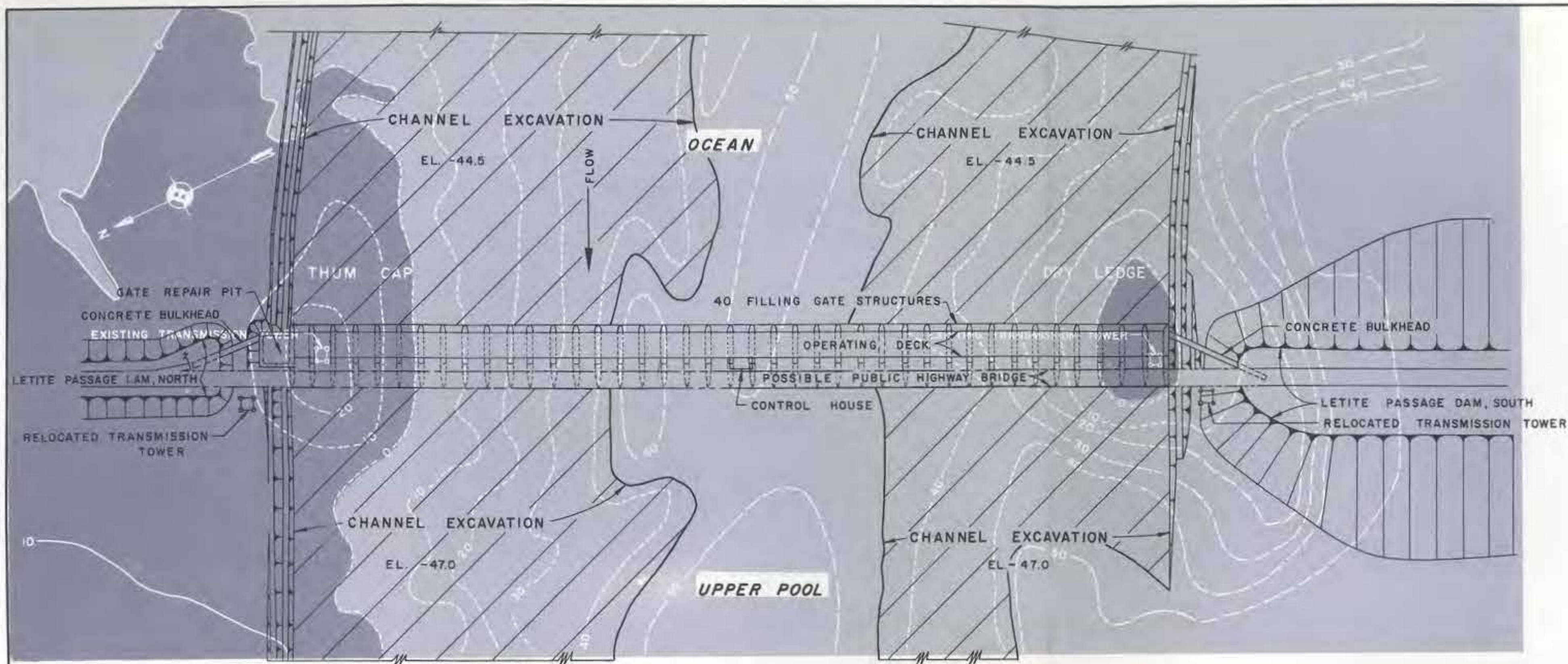
Gate Sites

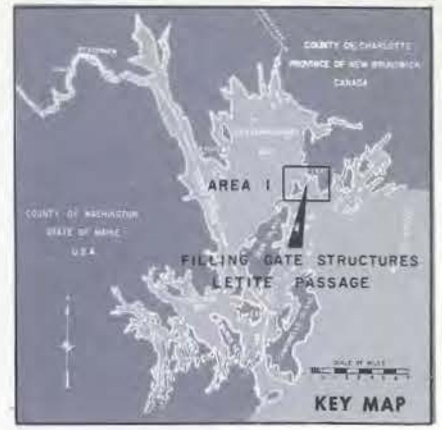
The locations of the gates were determined as a part of the studies which established the general arrangement of the tidal project. Filling gates could be located at several places in the Letite Passage area. The site shown on plate 4 was selected as the most favorable, because the adjacent dams would be shorter and require less fill, the foundation would not be too deep, and Dry Ledge and Thum Cap Islets would provide abutments between the gate structure and the adjacent dams. Little Letite Passage was not used because it could handle only about 10 percent of the required filling gate capacity, and because a few gates at separate locations would be costly to operate and maintain. It was found most economical to locate some of the filling gates in Letite Passage and the remainder on Deer Island Point where they would discharge to Western Passage. Dividing the flow to the upper pool in this way would minimize both construction cost and hydraulic losses at the filling gates and in the channels.

The emptying gates in Head Harbour Passage were found more economical at the selected site between Pope and Green Islets than at a site on Indian Island. Lubec Narrows has too little discharge capacity to justify installation of supplementary gates at Quoddy Roads. Plates 27, 28, and 29 show general plans of the gate structures at each site.

Number of Gates

In the later stages of the studies of the project arrangement, the number of filling and emptying gates were varied to determine the effect on cost and energy output. The optimum number of gates (the number giving lowest cost of energy) was found to be 40 filling gates at Letite Passage, 50 filling gates at Western Passage - Indian River,





PLAN

SCALE IN FEET
100 0 100 200

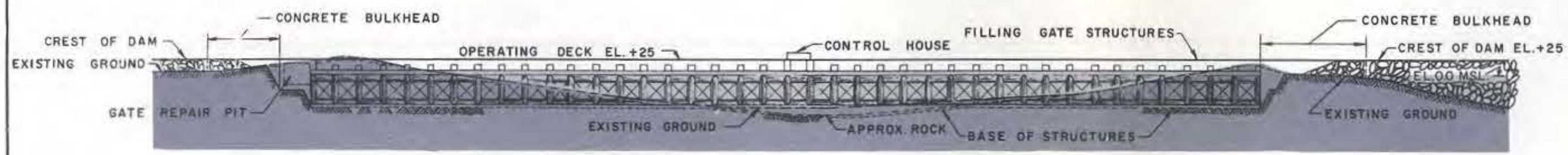
CONTOUR INTERVAL 10 FEET

LEGEND

LAND, EXISTING

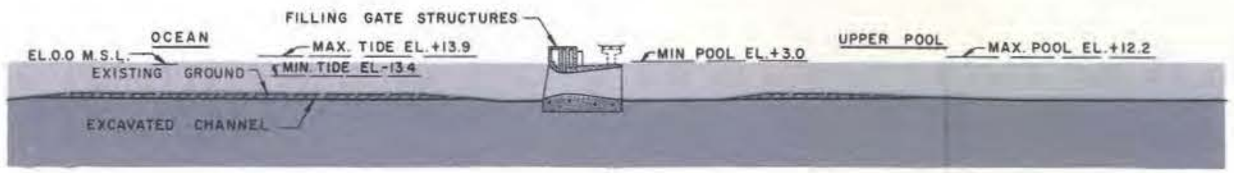
WATER, EXISTING

EXCAVATED AREA



ELEVATION

SCALE IN FEET
100 0 100 200



CHANNEL PROFILE

SCALE IN FEET
100 0 100 200

ELEVATIONS ARE IN FEET M.S.L.

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

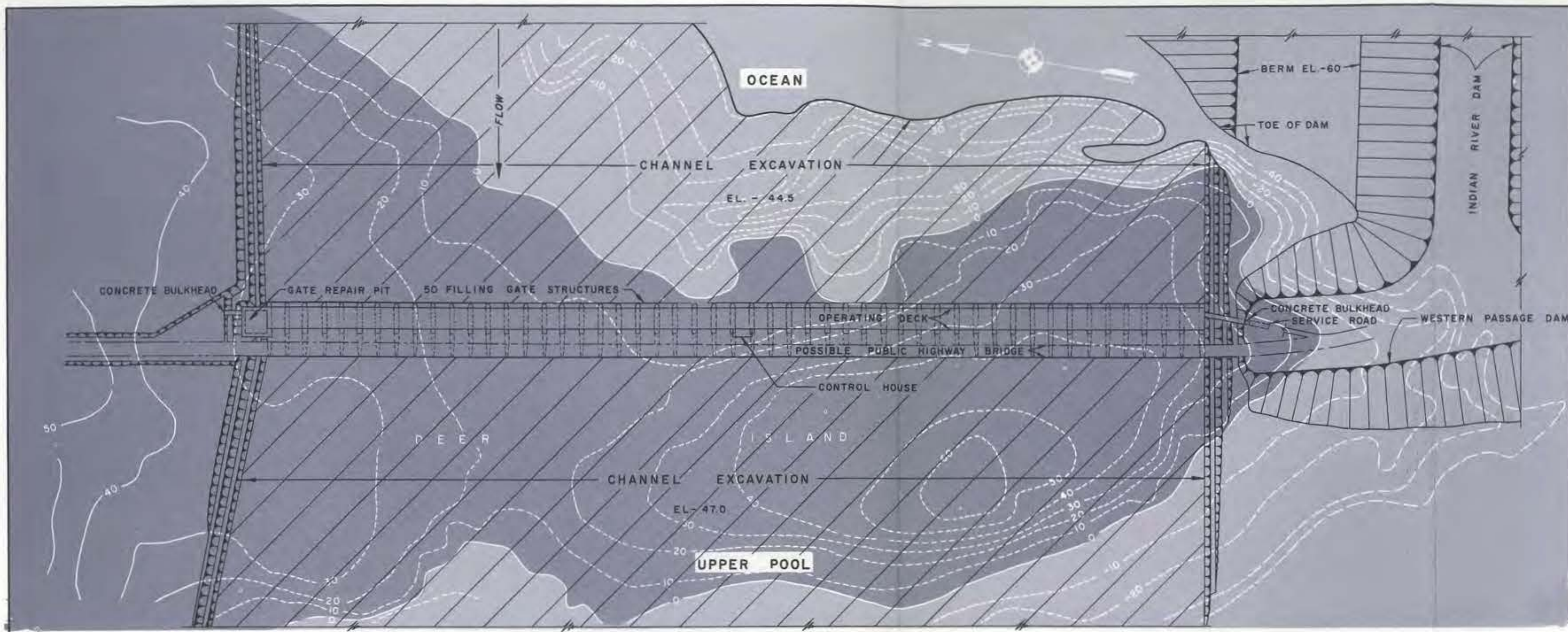
TIDAL POWER PROJECT

FILLING GATES
LETITE PASSAGE

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-242

PLATE 27



LEGEND

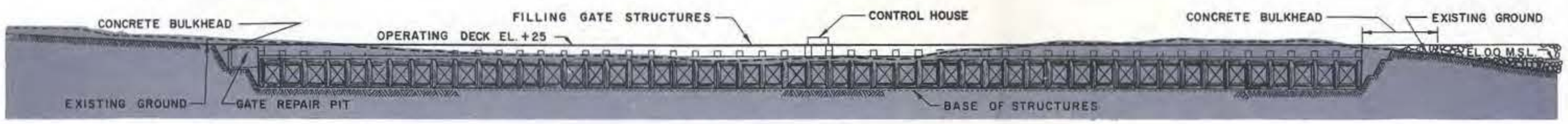
LAND, EXISTING

WATER, EXISTING

EXCAVATED AREA

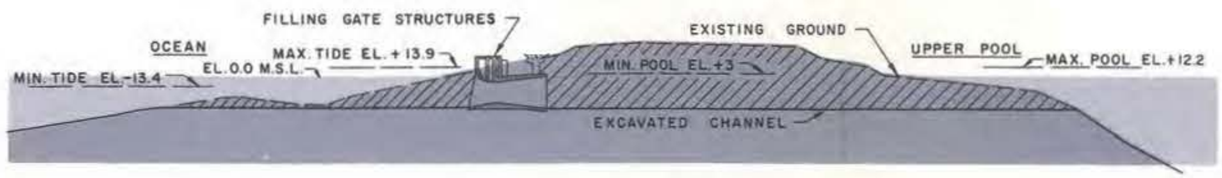
PLAN

SCALE IN FEET
100 0 100 200



ELEVATION

SCALE IN FEET
100 0 100 200



CHANNEL PROFILE

SCALE IN FEET
100 0 100 200

ELEVATIONS ARE IN FEET M.S.L.

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

FILLING GATES
WESTERN PASSAGE - INDIAN RIVER

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-243

PLATE 28

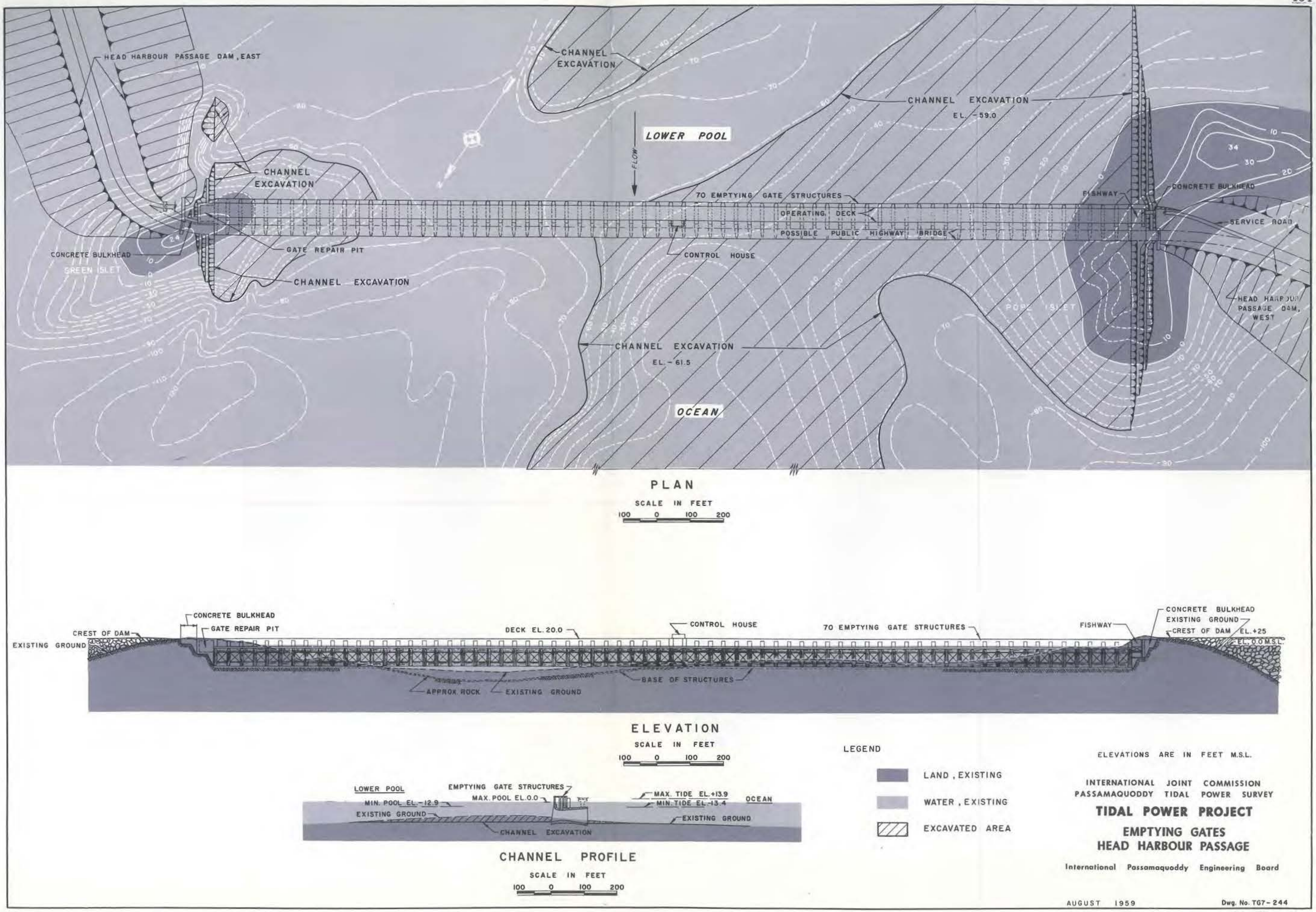

HEAD HARBOUR PASSAGE DAM, EAST
CHANNEL EXCAVATION
LOWER POOL
FLOW
CHANNEL EXCAVATION
EL. -59.0
CHANNEL EXCAVATION
70 EMPTYING GATE STRUCTURES
OPERATING DECK
POSSIBLE PUBLIC HIGHWAY BRIDGE
FISHWAY
CONCRETE BULKHEAD
SERVICE ROAD
CONCRETE BULKHEAD
GREEN ISLET
GATE REPAIR PIT
CONTROL HOUSE
CHANNEL EXCAVATION
POOL ISLET
HEAD HARBOUR PASSAGE DAM, WEST
CHANNEL EXCAVATION
EL. -61.5
OCEAN
PLAN
SCALE IN FEET
100 0 100 200
CONCRETE BULKHEAD
GATE REPAIR PIT
CREST OF DAM
EXISTING GROUND
DECK EL. 20.0
CONTROL HOUSE
70 EMPTYING GATE STRUCTURES
FISHWAY
CONCRETE BULKHEAD
EXISTING GROUND
CREST OF DAM
EL. +25
EL. 0.0 M.S.L.
BASE OF STRUCTURES
APPROX ROCK
EXISTING GROUND
ELEVATION
SCALE IN FEET
100 0 100 200
LOWER POOL
EMPTYING GATE STRUCTURES
MAX. POOL EL. 0.0
MIN. POOL EL. -12.9
EXISTING GROUND
MAX. TIDE EL. +13.9
MIN. TIDE EL. -13.4
OCEAN
EXISTING GROUND
CHANNEL EXCAVATION
CHANNEL PROFILE
SCALE IN FEET
100 0 100 200
LEGEND
LAND, EXISTING
WATER, EXISTING
EXCAVATED AREA
ELEVATIONS ARE IN FEET M.S.L.
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
EMPTYING GATES
HEAD HARBOUR PASSAGE
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-244

PLATE 29

and 70 emptying gates between Pope and Green Islets. Discharge capacity at each site would be 415,800 c.f.s., 553,000 c.f.s., and 837,500 c.f.s. respectively, at a 1-foot head. Discharge capacity of the gate structures is based on model tests of the water passages made during the Corps of Engineers' studies in 1935-37 and on computed losses in the natural and excavated channels.

Operating Requirements

The filling gates would remain open while the tide is higher than the upper pool and would be closed while the tide is lower than the pool. The gates would be opened and closed when the ocean and pool levels are nearly equal. Emptying gates would be operated in the same way except that they would remain open while the tide is lower than the low pool and closed while the tide is higher.

Should a gate fail to operate on time, the powerhouse output in that tide cycle would be reduced. If one gate remained open throughout a tide cycle, the output for that cycle would be reduced by about 2 percent by a filling gate or 3 percent by an emptying gate. Failure to open a gate would have much less effect, unless a considerable number of gates failed during the same tide cycle. A closed gate would cause a loss of about 0.15 percent in that cycle. Reliability of gate operation is essential to maintaining the dependable capacity of the project which would vary, if a gate were inoperable, in about the same proportion as the energy output in a critical tide cycle.

Since a large number of gates must be opened and closed within a short time, it is also important to minimize the power required to operate each gate.

The gate structures would perform an important function during construction of the project. It is planned that they be completed and opened to pass the ebb and flow of the tides as the tidal dams are closed, making the closure of the dams much easier.

Physical Conditions

The effect of ice must also be considered in operation of the tidal project. Surface ice in the gate channels is not expected to be troublesome because of the substantial channel depth and because the rapid currents in these channels would mix cold surface water with the deeper warmer water. Greater icing could result from wind-driven spray freezing on exposed structures, equipment, and machinery which could be immobilized by ice. Gate slots, hoists, cables, and sheaves, if exposed, would be subject to ice accumulations. Therefore, the design of the gates and structures includes protection against the effects of icing.

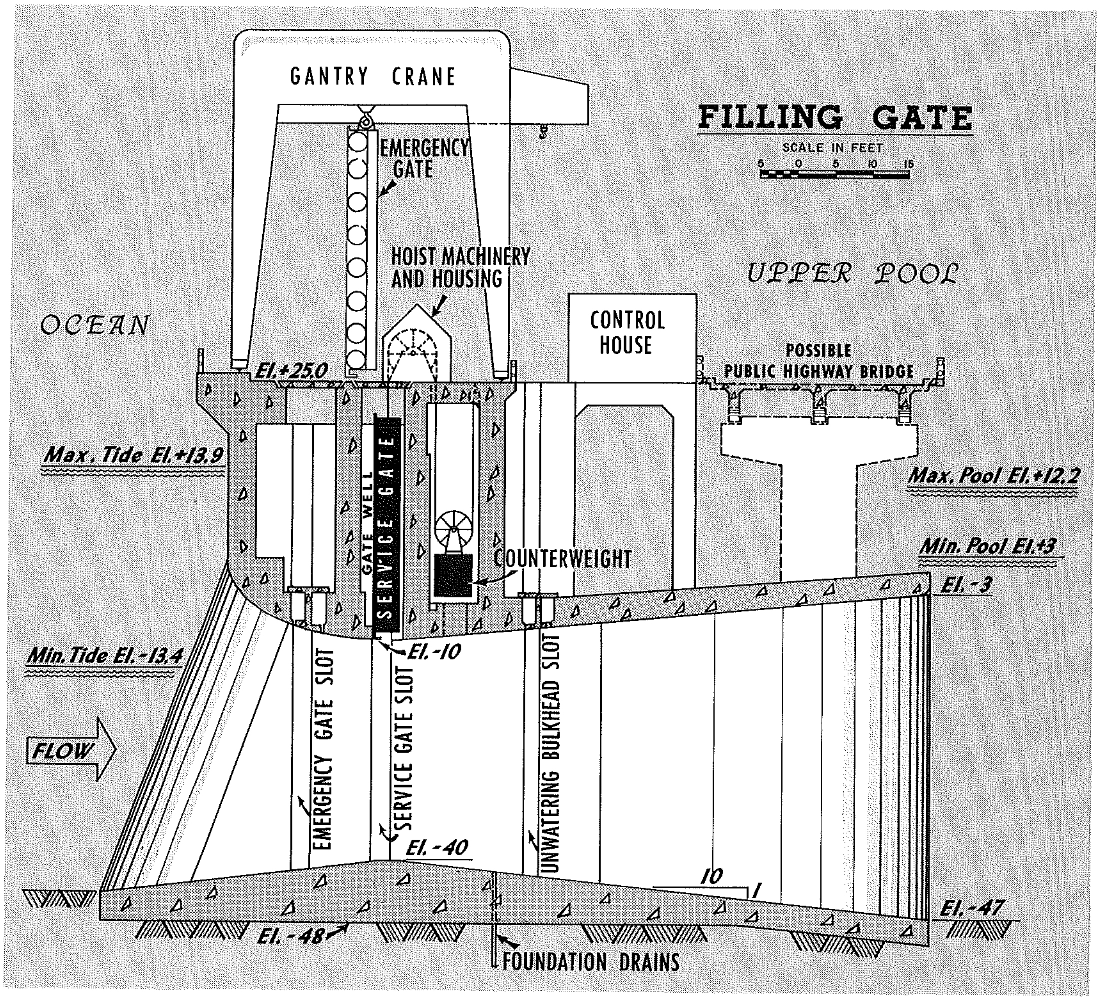
The maximum wave heights at each structure (based on a wind of 60 miles per hour and unlimited duration) would be 10 feet at the filling gates in Letite Passage, 3 feet at the Western Passage - Indian River filling gates, and 5 feet at the emptying gates. The maximum static head on the gates and gate structures in normal operation would be about 23 feet opposite to the direction of flow. Slightly greater head could result from reduced operation of the powerhouse. The head in the direction of flow normally would not exceed 3.3 feet, although the gates and structures are designed for greater heads. The maximum static heads, in the direction of flow, would follow the failure of all of the gates for either the high or low pool to open during a spring tide cycle. The emptying gates were designed for a head of 15 feet and the filling gates for a head of 11 feet under these conditions. It was assumed that in an emergency, or by accident, a gate may be opened, closed, or in motion at any time.

Selected Type of Gate and Water Passage

Vertical-lift gates in submerged tubes of venturi shape were selected for specific designs and cost estimates. Extensive studies of all types showed that gates of this type would be most economical and would provide reliable operation and ready means for inspecting, maintaining, and replacing the gates. The filling gates would be 30 feet square with the sills at el. -40. Emptying gates of the same size would be set 13 feet lower, but otherwise would be similar to the filling gates since the advantages of the submerged vertical-lift gates are even greater with a lower sill.

Gate Bay Arrangement - Filling Gates

Each of the water passages in the filling gate structures would be a tube of venturi shape with the exit submerged by the upper pool at all times. The entrance would be



submerged by the tide most of the time, including the normal periods of gate operation and discharge. The tube would be 30 feet square at the throat and flare to a width of 36 1/2 feet and a height of 44 feet at the exit. The vertical-lift service gate would operate in slots at the throat of the tube. The single-leaf wheeled gate would be raised and lowered in an enclosed well above the water passage. Each gate would be counterweighted and operated by an individual hoist powered by a 1 1/2 hp. electric gearmotor. Slots would be provided for a crane-operated emergency gate similar to the service gate but slightly higher.

The service gate and counterweight would be enclosed beneath the deck of the structure, with the hoist machinery in a metal housing above the deck. Hatch covers over the gate wells would permit removal of the gates. Removal of the service gate would also require removal of the hoist assembly. A service gate removed for maintenance or repair would be carried to the gate repair pit at one end of the gate structure and replaced by a spare service gate.

Stoplog bulkheads would be provided to unwater the service-gate well and that part of the venturi tube which includes the service-gate slots. Stoplogs would be placed in the emergency-gate slots and in a third set of slots on the opposite side of the service-gate slot.

A control house at each gate site would be located over the exit tube of a gate bay near the center of the gate structure. A lane for service vehicles would be located over the emergency-gate wells, and a public highway bridge could be built on piers over the discharge end of the venturi tubes.

Gate Bay Arrangement - Emptying Gates

The arrangement of the emptying-gate bays would be similar to that of the filling gates, except that the venturi tubes would be 13 feet lower. However, the deck of the structure would be 5 feet lower, at el. 20.

Design Criteria

The gate structures and gates were designed for the water levels, heads, and maximum wave heights at the project. The structures were also designed to withstand earthquake forces with an acceleration of 0.1 gravity and wind loads up to 30 pounds per square foot. Foundation uplift and unwatered buoyancy were included in the design. Significant loading from sheet ice would not occur.

The gate wheels and tracks are designed for impact from surges in the venturi tube caused by surface waves outside the structure when the head is nearly balanced. Since the gates would be operated under these conditions, heavy gate tracks would be provided for the full operating height on both sides of the slot. This makes the wheels and tracks adequate for delayed operation under maximum head, and adequate for conditions which may result when a gate is inoperable in a partially open position. The venturi tubes are designed for all flow or pressure conditions that may occur when a gate remains open with flow in either direction.

Operating Facilities

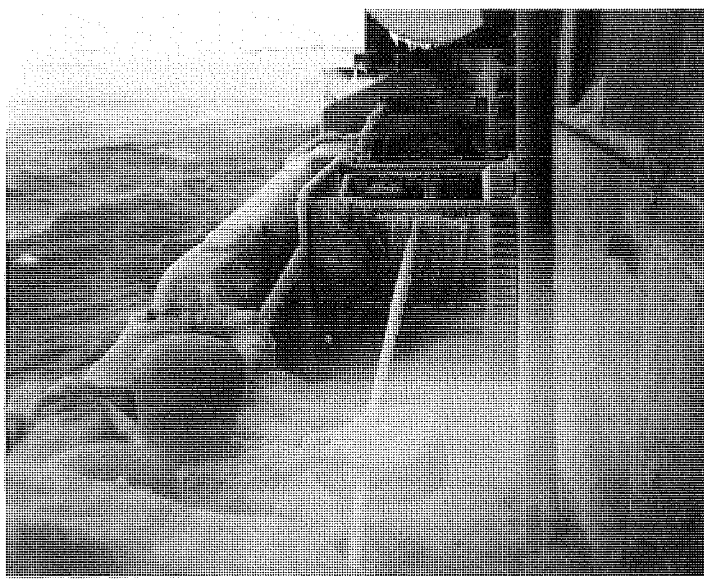
Operating facilities at each gate site would include individual gate hoists, a gantry crane, a spare service gate, an emergency gate, stoplogs for two unwatering bulkheads, standby diesel-electric power, a gate repair pit, and a central control building.

An operator would be available at each gate site at all times. Operation of the gates would be automatically controlled by a differential float device sensitive to the difference in elevation between the pool and the ocean. The gates would be started in sequence in a 1-minute period to limit the power demand and would open or close in about 5 minutes. Alternate manual controls for the system would be provided in the control house. Each gate could be operated individually at the gate hoist, although not from the control house.

Protection Against Ice Conditions

The use of vertical-lift gates in a submerged water passage would protect the gates from icing. The gates would be submerged when in the closed position, except for the upper few feet of the filling gates and the corresponding length of slot which would be exposed during short periods of lower than average tides. The gates would be submerged for at least 3 hours prior to opening so that ice, which may form during the exposure period, would melt. With this exception, the equipment would be fully enclosed, including the gate slots, the hoisting machinery and wire rope, the counterweight, and the raised gate. Heating equipment would be provided in the gate hoist housing, the repair pit, and the control house. The enclosed gate wells would be heated by the changing water in the well. If required, heated air could be circulated through the gate wells from the repair pit. Portable steam generators also would be available for deicing hatch covers and other equipment.

Ice formation on steamship EUREKA in Friar Roads



Corrosion Control and Selection of Metals

Cathodic protection anodes installed on both faces of the service gate would inhibit salt water corrosion of the gates and of the metal in the emergency-gate slot and in the unwatering bulkhead slot. The service gates would be fabricated of structural-grade carbon steel and coated with a coal-tar enamel primer. The gate tracks in the service-gate slot, and in the emergency-gate slot, would be of stainless steel, AISI Type 316, and bolted to structural grade carbon steel bed plates. The bed plates, which would also provide a surface for the gate seals, would be protected by a six-coat antifouling vinyl paint system.

The metals in the service-gate slot would be made accessible for maintenance by unwatering the gate bay between stoplog bulkheads. The other slots could be unwatered individually by small semicircular caissons.

Channels

The loss in energy output due to hydraulic losses in the natural passages and excavated channels was calculated. The computations showed that the excavated channels, as designed, were about as large as economically justified.

Flow in Letite Passage would be restricted appreciably from Mascabin Point to Letite Rock, a distance of about 2 miles. However, most of the head loss would occur in the gate passages and in that part of the channel enlarged by excavation.

Flow to the Indian River - Western Passage filling gates would pass between Deer Island on one side and Indian Island and Head Harbour Passage dam on the other. A marked restriction would occur in the channel at the north end of Indian Island, but the principal head loss would be caused by the gate passages and the excavated channel through Deer Island Point.

At the emptying gates, flow would approach the gates from Head Harbour Passage, which is nearly 300 feet deep. The channel would be excavated mainly in two areas on the east side of Pope Islet and at Sandy Ledge. Beyond these areas, and at both sides of Sandy Ledge, the flow would be about 100 feet deep.

Other Gates Considered

The studies leading to the selection of the vertical-lift gate in a submerged venturi setting covered the whole range of gate types, including vertical-lift, wicket, miter, flap, taintor, drum, and roller gates. Both timber and steel construction were considered. The settings included submerged venturi tubes like the selected type, a short tube with a higher roof, and settings without a roof as in the 1936 design.

Arrangements with drum and roller gates were found comparatively expensive. Gate leaves hinged at one side as miter gates and single-leaf flap gates are not suitable for opening or closing in flowing water or under wave conditions. They would also be damaged by static head if they were to seat against ice or debris.

Taintor gates or wicket gates could not be maintained or replaced as readily as vertical-lift gates which, even in a submerged setting, could be removed from their slots and replaced by a spare gate without unwatering the structure.

Wicket gates could be removed more readily for maintenance and replacement than taintor gates, but could not be inspected in place to the extent possible with vertical-lift gates. Because wooden wicket gates would be low in cost and suitable for project conditions, this type was included in detailed comparative studies.

The wicket gate would be similar to a butterfly valve, but with straight sides. The wicket gate could be set either in a submerged or an open setting, although the open setting would be more difficult to protect against icing. This type of gate could be removed for maintenance and replacement, but it could not be inspected in place to the extent possible with the vertical-lift gate. A wood leaf was found practicable for a wicket gate, making the arrangement low in cost. Like the butterfly valve, the leaf would remain in the flow when the gate is fully open. The relatively thick wood leaf, however, would restrict flow to such an extent that the advantage of low first cost would be completely offset.

Sliding gates of the vertical-lift type were considered because the gates would normally operate under nearly balanced heads. Sliding gates were not selected, however, because they would require greater power in normal operation, and if unbalanced heads occurred due to delayed operation or waves, sliding gates would require still more power. Sliding friction might prevent lowering by their own weight if closing were delayed until the unbalanced head becomes substantial.

Wheeled gates of the vertical-lift type, designed for the project studies, would be capable of opening or closing under any head at the project. The wheels and the track would be adequate to withstand the impact of wave pressure during operation under nearly balanced static heads.

Vertical-lift gates would require little power for operation, if made of steel and provided with a counterweight. Although vertical-lift gates of timber would cost less than steel, they would require more power in operation because the counterweight would be greatly unbalanced by varying submergence of the gate.

Vertical-lift gates were examined in both the open or unroofed setting, in a submerged venturi tube, and in a short tube with a higher roof. It was found that the unroofed setting would discharge more water than the selected submerged venturi setting, but that this advantage would be offset by increased costs of the open setting, including the cost of enclosures for the gates and the cost of heating to prevent icing on the closed gates and in the gate slots. The short tube with a higher roof would also require additional structure to enclose the gate when open. Although this type costs about the same as the venturi setting, it was not selected because it reduced the output of the tidal project.

Costs of cofferdams and channel excavation for the gates would be a significant part of the total project cost. This suggests that units of the gate structure could be constructed in a dry dock or basin, floated to the site and sunk into position. Therefore, a structure with an unroofed water passage and a sill at el. -25 was studied for this purpose. Sites where such gates could be constructed with a reasonable amount of underwater excavation or a minimum amount of foundation fill are limited. There are, however, possible locations of the tidal dams that would provide sufficient length to place all the filling and emptying gates on the crest of the dams. This would lead to considerable savings in the tidal dams as well as in excavation and cofferdams, but is dependent upon the design and economical construction of gate bay units. These units must withstand settlement without structural damage and without excessive cost to maintain the closures between units. Completely satisfactory solutions for the problems were not developed and consequently this design was not used.

NAVIGATION LOCKS

Previous Studies

Dexter P. Cooper's plan for an international two-pool project included navigation locks for access to Passamaquoddy and Cobscook Bays. At the dam in Western Passage a lock 666 feet by 80 feet with a 24.7-foot depth at mean low water was planned for the Deer Island side of the passage. At the Treat Island dam, which would have enclosed Cobscook Bay, a lock 202 feet by 45 feet with a 16.3-foot depth was planned for a site at the south shore of Dudley Island. A future lock about 110 feet long was indicated in Letite Passage for alternate access to Passamaquoddy Bay. The lengths given were measured from pintle to pintle of the proposed miter gates. The lock chamber would have been filled and emptied through culvert systems in the lock walls.

The U.S. Army Corps of Engineers, in their study of a single-pool project for Cobscook Bay, planned a lock on the north end of Treat Island with clear length of 360 feet, a 56-foot width and a sill 16.3 feet below mean low water.

Because tides would reverse the head on the gates, miter gates would be forced open. Double-opposed miter gates and sector gates were studied as a means of overcoming this difficulty. Sector gates were selected for economy and for advantages resulting from capability of operation under head.

Filling the lock with flow between the sector gate leaves was tested in the 1935-37 period in a hydraulic model. The model indicated a maximum hawser pull of 10 tons with a filling time of 11.5 minutes. When dentated baffles were mounted on the gate leaves, the maximum hawser pull was reduced to 4 tons with a filling time of 7 minutes. Tests of culvert systems with a filling time of 6.4 minutes indicated maximum hawser pulls of 5.8 to 11.6 tons, depending upon the type of culvert valves and rate of operation. Since design studies indicated that baffles on the sector gates would unbalance the load on the gate hinges and possibly cause vibration, it was planned to use sector gates without baffles and to limit the hawser pull by adjusting the lock filling time.

Current Navigation Traffic

Records of marine traffic in the area of Passamaquoddy and Cobscook Bays were furnished by the U.S. Army Engineer Division, New England; the Harbours and Rivers Engineering Branch, Department of Public Works of Canada; and by the Department of Transport of Canada. Residents of the project area also furnished information. Since the number of large vessels is small, traffic studies were made primarily to determine the maximum dimensions of vessels serving the area.

The largest vessels using Cobscook Bay in 1954-58 were three oil tankers that regularly serve tank farms at Garnet Point (plate 2). The largest of these is 300 feet by 43.2 feet with a draft of 16 feet. The average monthly shipment of petroleum products was 18,000 barrels in 1957-58. These vessels normally use Head Harbour Passage, but may pass through Quoddy Roads at times. Other traffic through Quoddy Roads consists of fishing vessels, the largest being 84 feet by 19 feet with a draft of 10 feet. A channel of 12-foot depth in Lubec Narrows was authorized by the United States in 1879 and 1894 and completed in 1905.

The largest composite dimensions of vessels recorded in Passamaquoddy Bay in 1954 were 329 feet by 50 feet with a 19-foot draft. Fifteen different vessels longer than 200 feet were reported to have called at St. Stephen, Calais, or St. Andrews during 1954 Such vessels normally use Western Passage to enter or leave Passamaquoddy Bay. The traffic through Letite Passage consists mainly of smaller fishing vessels with dimensions not usually exceeding 62.5 feet by 16 feet and 7.7-foot draft, although some larger vessels occasionally use this route.

Possible Future Traffic

Predicting the cargo, volume, and size of vessels of future ship traffic in the project area depends upon several uncertain factors, including the possible effect of the tidal power project. There is no definite indication that the project would result in an increase in the size of vessels entering the pools. The world trend toward large vessels, however, indicates that the vessels using the area would also increase moderately in size. The Department of Transport of Canada indicated that planning should provide for a lock at Passamaquoddy 859 feet long, pintle to pintle, 80 feet wide and 30 feet deep. Locks of these dimensions would be similar to those of the St. Lawrence Seaway and would have a clear length of 800 feet in the chamber. The lock at Canso Causeway connecting Cape Breton Island with the mainland of Nova Scotia is also of this size.

Lock Locations and Sizes

Navigation access to the pools adequate for current traffic, with a moderate increase in vessel size, would be maintained during and after construction of the project. In the initial construction of the project, locks in Head Harbour Passage (plate 6) and in Western Passage (plate 7) would have clear dimensions of 415 feet by 60 feet with a 21-foot depth at mean low water. Locks in Little Letite Passage (plate 5) and in Quoddy Roads (plate 9) would be 95 feet by 25 feet with a depth of 12 feet.

A possible future lock of large size could be constructed in Little Letite Passage (plate 5) if justified by the need for larger vessels entering Passamaquoddy Bay. The cost of providing for possible future traffic by constructing larger locks in Head Harbour Passage and Western Passage as part of the initial project was compared with the cost of a possible future lock in Little Letite Passage (assuming clear dimensions of 800 feet by 80 feet with a 30-foot depth). The plan containing the possible future lock would have a smaller the possible future lock would have a similar project cost but would defer nearly one-half the lock cost. The costs of the 415-foot locks in the initial construction, which would be adequate for current traffic, with a moderate increase in vessel size, are included in the tidal power project costs.

Water Levels and Currents

Water levels in the upper and lower pools would vary less than the present tides, while tide levels outside the pools would remain unchanged. Although the peak rates of inflow to the upper pool and outflow from the lower pool would not be reduced greatly, the periods of flow would be reduced to about 3 hours in each tide cycle.

Filling gate flows would prevail about 22 percent of the time and would produce strongest currents in Letite Passage and in Indian River between Deer Island and Indian Island. Currents caused by filling gate flows would not appreciably affect the approaches to any of the proposed locks, except the upper pool approach to the Western Passage lock. This lock would be located at the south end of the Western Passage dam opposite the filling gates on Deer Island Point (plate 7). It is expected that the filling-gate flows would produce intermittently an eddy moving counterclockwise along the shore of Moose Island and along the face of Western Passage dam. The eddy current at the northwest approach of the lock was estimated to be less than 1 knot in a northeasterly direction.

In Letite Passage, when the filling gates are open, a considerable current would run toward the gates, starting at a line from Mascabin Point to Parker Island (plate 4). Vessels travelling to or from the small lock in Little Letite Passage at this time would cross a maximum current of 3 1/2 knots in the vicinity of Mohawk Island about 1 mile from the lock. These vessels would pass to the north of Parker Island. Vessels bound for the possible future large lock in Little Letite Passage would use a channel excavated through the south end of Parker Island, and these vessels would enter only the fringe of the area intermittently affected by the filling gate current. This would occur at a distance of 3,400 feet or more from the end of the lock approach wall. The locations of the locks and channels in Little Letite Passage are shown on plate 5.

In Head Harbour Passage, flow toward the emptying gates, which would be open about 24 percent of the time, would induce currents in the lower pool approach to the lock (plate 6). The main current, at some distance from the lock, would be less than 3 knots. If an eddy forms at the dam, it would move clockwise with a velocity of less then 1 knot in the immediate approach to the lock.

The flow to the powerhouse would produce currents of small velocity in Western Passage that would affect slightly the upper pool approach to the Western Passage lock.

Lubec Narrows would be dredged to a width of 520 feet at el. -30 to increase the project power output. After project completion, currents in Lubec Narrows would be less than under existing conditions. Approaches to the lock in Quoddy Roads would not be subject to appreciable currents.

Lock Approaches

Vessels could approach any of the locks at a slight angle to the approach wall without making a close turn. The course between Head Harbour Passage lock and Western Passage lock would require a turn of about 90 degrees with a radius of 1 1/2 miles, which is approximately the same as now required in the existing passages. Except at the Quoddy Roads lock, the approaches would be sheltered, because the length of fetch for waves from the direction of the beam or quarter would not be more than 2 miles. A breakwater would be built on the south side of the excavated approach channel at the seaward approach to the Quoddy Roads lock, where the southeast fetch from Grand Manan Island would be about 7 miles. In Head Harbour Passage and Western Passage, waves approaching the lock entrances would have narrow fetches of several miles; in the immediate approaches to the locks, however, these waves would be attenuated by the shoreline.

General Description of Locks

Each lock would be located on shore, or on a reef where bedrock is at an elevation high enough for structural foundations. Locating the locks on land has several advantages:

(1) Decreased height and length of cofferdams provide savings in construction and pumping.

(2) Bedrock foundations are at a suitable elevation for the full length of the structures. By locating the lock on a promontory, approaches favorable to navigation are provided without requiring the ends of the structures to be in deep water.

(3) Because the lock wall would be separated from the dam by existing bedrock,

it can be designed for the less severe loading of free-draining rock backfill, instead of earthfill in the dam with its high saturation line.

General plans of the locks in Head Harbour Passage and Western Passage are shown on plate 30.

Gates would be the double-leaf sector type, selected primarily because sector gates can operate under reversing head conditions. The sector gates would be used for filling and emptying the locks, except for the short by-pass culverts used for the initial stage of the filling cycle when the head exceeds 12 feet. Clearances for sector gates are sufficiently large so that icing would not be troublesome A portable steam generator and lance would be provided at each lock for emergencies.

The walls of the lock chamber would be reinforced concrete of semigravity design with rock backfill. This type was estimated to cost 20 percent less than gravity concrete walls without reinforcing steel. In those parts of the lock walls where the elevation of bedrock is above the top of the wall, a concrete facing anchored to the rock would cost 40 percent less than the semigravity wall. However, this type was not used in the lock designs because grout encasement adequate to protect the anchors against corrosion by sea water was considered uncertain.

Culverts would not be required in the lock walls except for short by-passes around the upper gate. The top of the chamber walls would be at el. 20. The bedrock floor of the lock would require concrete paving only in the vicinity of the gate sills.

An approach wall would be provided at each end of all the locks for snubbing vessels or mooring small vessels before entering the chamber. These walls would have a clear length about equal to that of the longest vessel using the lock. If additional moorings are required by future traffic, they would be constructed of piling driven into overburden or drilled into bedrock. Both approach walls would be located on the landward side of the lock passage and their faces would be straight extensions of the chamber walls.

Locating the approach walls on the landward side would provide more favorable navigation courses for vessels and would make it feasible to locate the walls on land or in shallow water. The side of the approach channel opposite the approach wall would be flared in excavation. Since no wall would be constructed on that side, the excavated face would be located to allow for some scaling of the slope without causing interference with navigation.

At the upper pool approach to the Western Passage lock, a jetty or rockfill would be provided opposite the approach wall to protect the approach channel from the eddy current caused by opening the filling gates on Deer Island Point. The top of the approach walls would be at el. 20 except for the approach walls at el. 7 in the low pool.

Stoplogs at each lock would permit unwatering of the lock chamber and the gate bay areas. A dam would not be required for emergency closure in any of the locks because the sector-type gates would permit closing either the upper or lower gates under head. Guard fenders would not be required for the sector gates because one set of gates would be available to close the pool in case of damage to the other set.

Armor for the surface and corners of the lock walls would not be provided because experience has shown that armor is unnecessary where traffic does not exceed a few million tons per year.

Check posts would be provided on the top of the wall for the full length of the approach walls and both chamber walls. Floating moorings would not be included because of the expense of maintaining them in salt water. Large vessels capable of putting personnel ashore on the lock wall could use the check posts on the top. Smaller vessels could use recessed mooring hooks provided in the face of the wall at 5-foot vertical intervals throughout the length of the walls.

A bridge across each lock would be required for a service road to connect all parts of the tidal power project. Bridges of the single-leaf bascule type would be constructed at elevations high enough to permit small vessels to pass without opening the bridge and also to permit workmen on the lock wall to pass freely underneath.

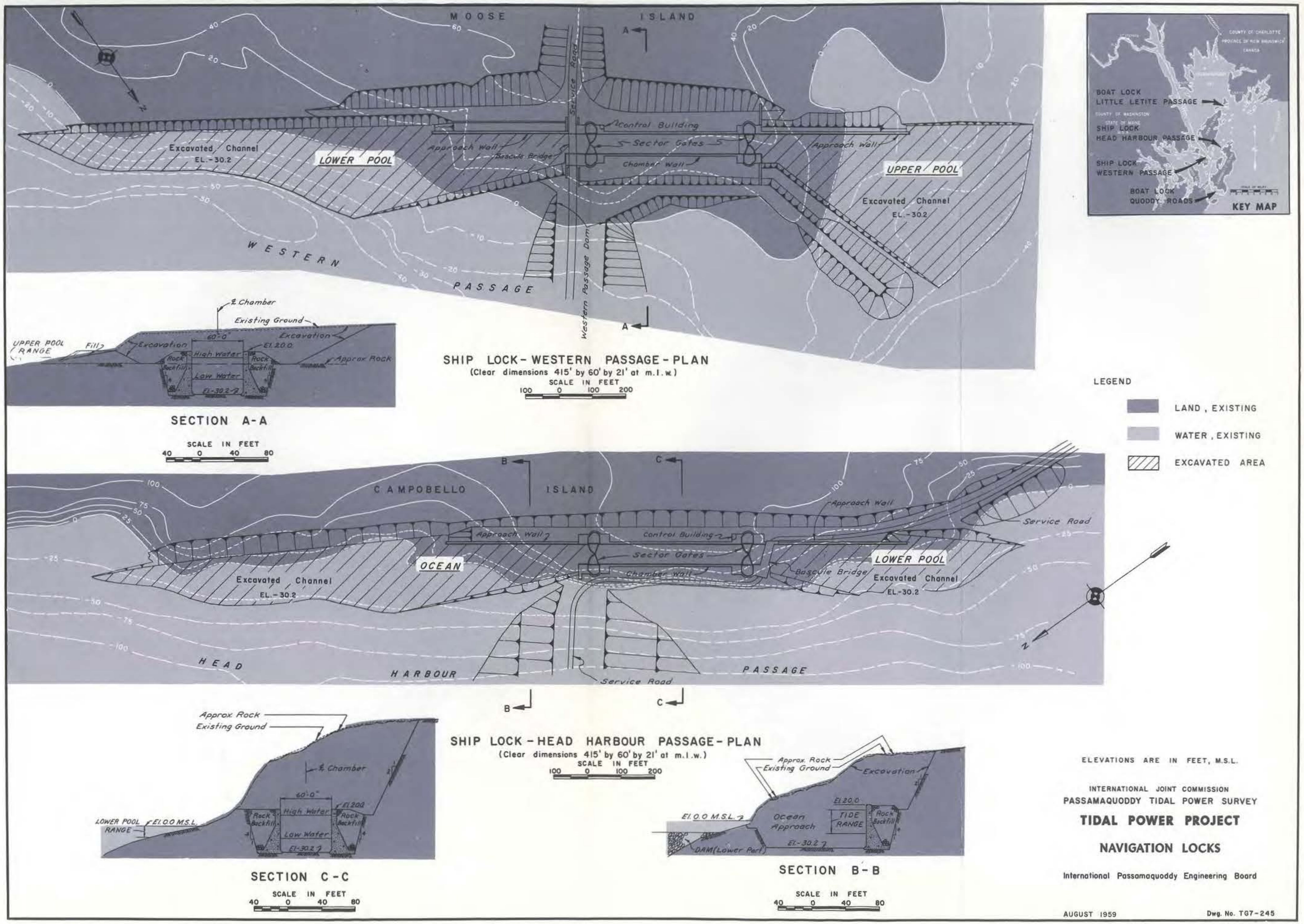

MOOSE ISLAND
WESTERN PASSAGE
Excavated Channel EL. -30.2
LOWER POOL
UPPER POOL
Control Building
Approach Wall
Sector Gates
Bascule Bridge
Chamber Wall
Service Road
Western Passage Dam
SHIP LOCK - WESTERN PASSAGE - PLAN
(Clear dimensions 415' by 60' by 21' at m.l.w.)
SCALE IN FEET
SECTION A-A
UPPER POOL RANGE
Fill
Excavation
Existing Ground
℄ Chamber
High Water
Low Water
Rock Backfill
Approx. Rock
El. 20.0
El. -30.2
KEY MAP
BOAT LOCK LITTLE LETITE PASSAGE
SHIP LOCK HEAD HARBOUR PASSAGE
SHIP LOCK WESTERN PASSAGE
BOAT LOCK QUODDY ROADS
LEGEND
LAND, EXISTING
WATER, EXISTING
EXCAVATED AREA
CAMPOBELLO ISLAND
HEAD HARBOUR PASSAGE
OCEAN
LOWER POOL
Excavated Channel EL. -30.2
SHIP LOCK - HEAD HARBOUR PASSAGE - PLAN
(Clear dimensions 415' by 60' by 21' at m.l.w.)
SECTION C-C
LOWER POOL RANGE
El. 0.0 M.S.L.
SECTION B-B
Ocean Approach
TIDE RANGE
DAM (Lower Part)
ELEVATIONS ARE IN FEET, M.S.L.
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
NAVIGATION LOCKS
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-245

PLATE 30

A single control building at each lock would be located at the gate near the bascule bridge. An operation control booth would be provided near the other gate.

Design Criteria

Conventional engineering criteria were followed in the structural, electrical, and mechanical designs for the locks.

Corrosion Control

Impressed-voltage cathodic protection would control salt-water corrosion of the sector gates and the bypass filling gates. Cathodic protection inhibits corrosion by reversing the naturally occuring electro-chemical forces. An impressed voltage system uses an outside anode and a source of low voltage direct current to achieve this effect. All exposed metal above mean sea level would be painted with a standard vinyl system. Below mean sea level, all metal would receive one coat of coal-tar enamel primer, which has proved satisfactory at the Panama Canal lock gates, together with properly controlled cathodic protection.

Ship Lock In Head Harbour Passage

The Head Harbour Passage lock on the northwest shore of Campobello Island about 3/4 of a mile north of Wilsons Beach (plate 6) would permit passage between the ocean and the lower pool during and after construction of the dam in Head Harbour Passage. The lock would be 415 feet by 60 feet with a 21-foot depth at mean low water. The location at a slight bulge in the shore line would permit nearly straight approaches to the lock. The shore is a fairly regular rock bluff with a steep and wooded hillside above. The structures would be located entirely on land with the centerline of the lock about 100 feet from the water. The lock could be built in an excavation in bedrock without a cofferdam. Cofferdams would be required, however, for excavation of an approach channel at each end.

Ship Lock In Western Passage

The Western Passage lock would be located on the northeast shore of Moose Island near Dog Island (plate 7), near the developed area of Eastport. This lock would permit passage of vessels between the lower pool and the upper pool. It would be 415 feet by 60 feet with a 21-foot depth at mean low water. Large vessels travelling between the ocean and the upper pool would use this lock and the Head Harbour Passage lock in turn. The alignment of the lock on one side of a promontory would permit straight approach courses of adequate length. The shore of Moose Island at the lock site is a sandy bluff overlying bedrock that outcrops at the waterline. The structures would be located behind the bluff in a moderately sloping meadow with an average elevation of 45 feet. The total area for the structures is above high tide, except for 250 feet of the upper approach wall which would be constructed on a reef of bedrock exposed at low tide. Most of the structures could be built without cofferdamming, but separate cofferdams would be needed for excavation of an approach channel at each end.

Boat Lock In Little Letite Passage

The boat lock at Little Letite Passage would be located on the north promontory of Jameson Island (plate 5). This lock would be 95 feet by 25 feet with a depth of 12 feet at mean low water. Large vessels would use the locks in Head Harbour Passage and Western Passage. The lock centerline and the excavated approaches would run approximately east and west with approach walls on the south side.

Boat Lock In Quoddy Roads

The boat lock in Quoddy Roads would be located in the northern part of the dam on a reef lying below low tide off Campobello Island near Duck Point and Indian Point (plate 9). This lock would provide passage between the ocean and the lower pool and would be 95 feet by 25 feet with a depth of 12 feet. Large vessels would use the Head Harbour Passage lock. The structures would be founded on a bedrock reef projecting underwater from Duck Point. The lock centerline and the excavated channel would run approximately east and west with approach walls on the north side.

Possible Future Ship Lock In Little Letite Passage

A cost estimate was made of a possible future ship lock constructed between the upper pool and the ocean with clear dimensions 800 feet by 80 feet with a 30-foot depth at mean low water. The lock would be located on Jameson Island with the ocean approach excavated through the narrow southern part of Parker Island (plate 5). The upper pool approach would extend through Little Letite Passage between McMaster Island on the north and Pendleton and New Islands on the south. The centerline of the lock would run north of northwest. Approaches would be straight, except for a slight deflection to clear Adam Island more than 1 1/2 miles southeast of the lock. The excavated approach channel at the southeast end of the lock would be 3,400 feet long from the end of the approach wall to deep water.

FISHWAYS

The International Passamaquoddy Fisheries Board requested that fishways be provided in the tidal project for the passage of anadromous fish. In accordance with this request, two fishways were included in the project plan, one at the emptying gates and the other at the powerhouse. These fishways are shown on plate 31.

SERVICE FACILITIES

Maintenance shops, warehouses, access roads, floating equipment, motor vehicles, and other service facilities would be needed for the operation and maintenance of the tidal power project after construction. The cost of these facilities, described below, was estimated and included in the estimate of project first cost.

Shops, Warehouses, and Utilities

A sufficient number of maintenance shops and associated warehouses would be provided to carry out an intensive program of preventive and periodic maintenance. The shops would be equipped to repair those damages most likely to occur frequently. Heavy maintenance would be done under contract with commercial firms. A central maintenance shop in the powerhouse would serve as maintenance headquarters for the gates, dams, and locks of the tidal project. The location of this shop was based upon predominance of work in the powerhouse area, and the availability of crane and hoist facilities. Separate repair facilities for motor vehicles would be housed in the storage garage nearby. Powerhouse galleries and service bays would serve for storage of spare parts and materials, with some additional space for inflammable materials outside the powerhouse.

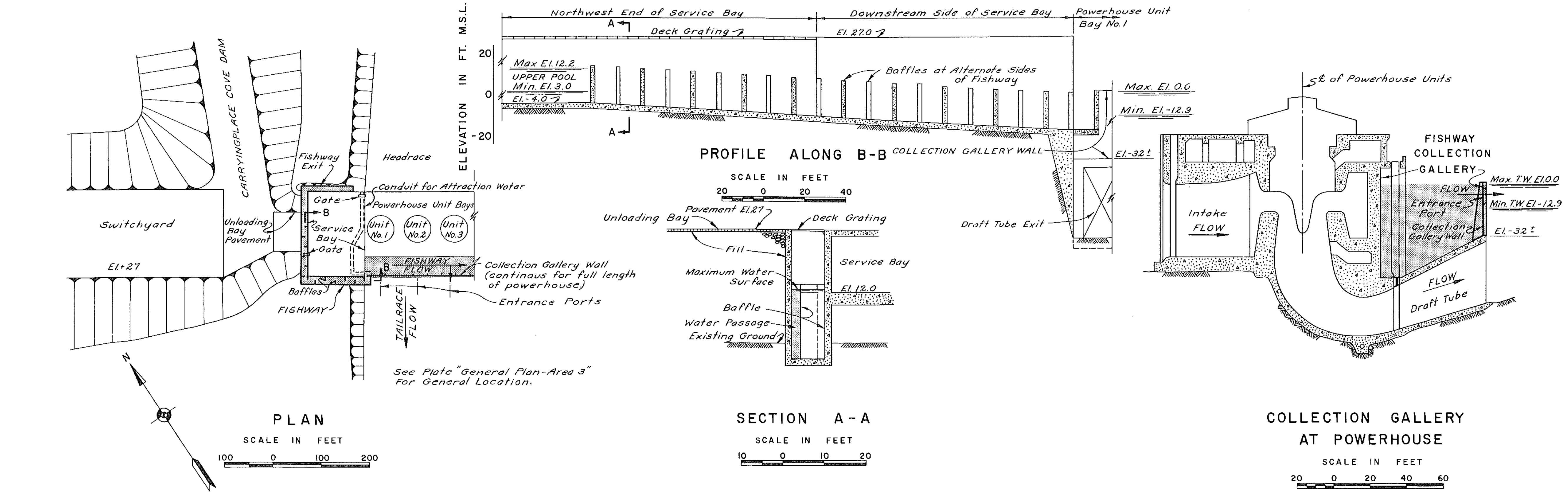
Water, electric light and power, heat, and sewage treatment and disposal would be provided at the powerhouse, gates, locks, shops, and housing areas.

Land Plant

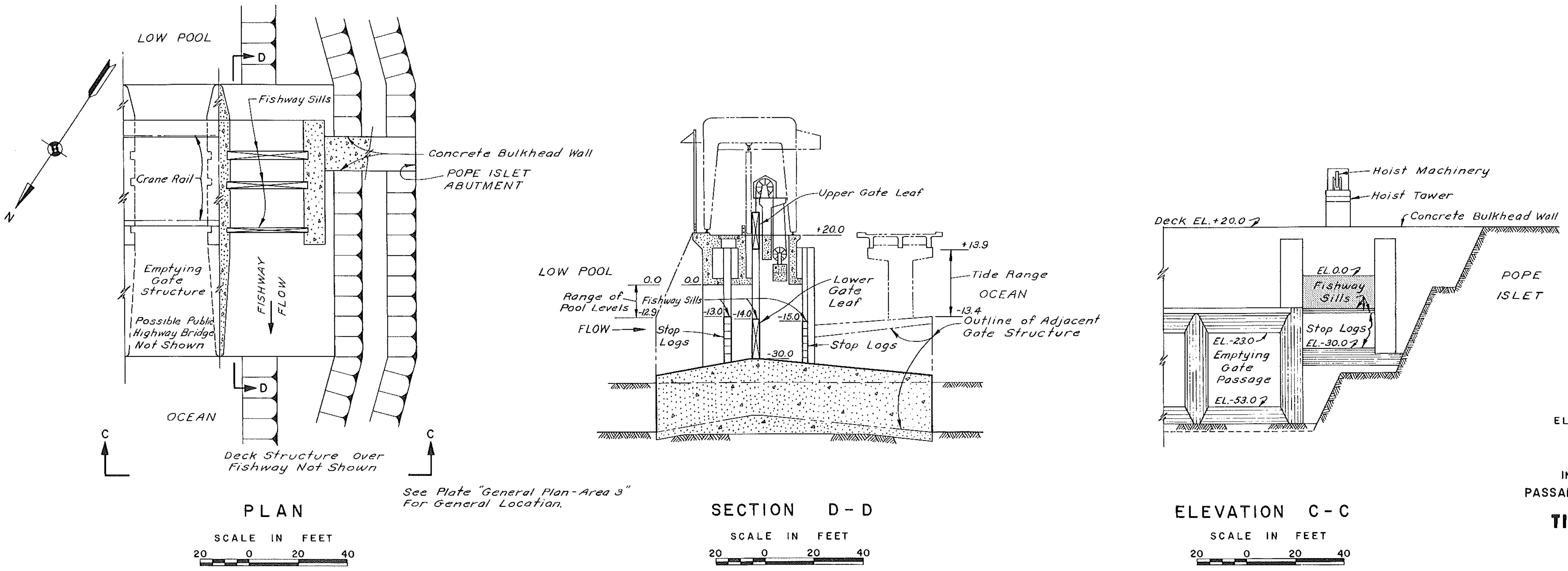
Land plant, consisting of standard passenger vehicles and light and heavy trucks, would be located at the tidal powerhouse. Most of the vehicles would be 1/2-ton pickup trucks for transporting personnel, tools, and supplies. A few passenger sedans would be provided for use by the executive and administrative staff. Standard type trucks for heavy hauling and maintenance would be equipped with a removable snowplow for winter clearing of service and access roads. Special equipment used infrequently, such as motor cranes, low-bed trucks, mobile sandblasters and similar equipment, would be located only at the tidal project, and made available to the auxiliary power plant as required.

Floating Plant

The floating plant, consisting of workboats, scows, and launches, would be provided for maintenance of the tidal project. A single, 100-ton, floating derrick lighter would be used mainly for maintenance and repair of the sector gates of the navigation locks. At the other parts of the tidal project the need for a floating derrick would be infrequent, but could be provided by mounting a motor crane on the deck of a work scow. Only floating plant less than 65 feet long would be self-propelled to avoid hiring licensed marine personnel for the infrequent operation of the larger units. A tow boat would be rented to move the derrick lighter during lock overhaul periods. The maintenance, repair, and layup of floating plant, other than normal servicing, would be performed by local commercial establishments under contract.



FISHWAY AT POWERHOUSE



FISHWAY AT EMPTYING GATES

ELEVATIONS ARE IN FEET, M.S.L.

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

FISHWAYS

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-246

Employee Housing

On-site project housing would be built for operation and maintenance superintendents, powerhouse shift supervisors, and maintenance foremen who would be on 24-hour call for emergencies, and who would be the first called in case of trouble. It is anticipated that the local communities would be able to provide housing for all other project personnel after departure of the construction personnel. Project housing would be in duplex units, with a garage and adequate land. Streets, sidewalks, and all utilities would be provided.

Access

Access to and around the tidal project would be provided by access and service roads and a railway spur. These facilities would be used during construction of the tidal project and after its completion. Access roads would be constructed to connect each part of the tidal project to the nearest public highway. Service roads would be constructed across all dams, gate structures, and navigation locks to provide, with the access and public highways, a complete highway loop around the tidal power pools. A railroad spur would be constructed to the tidal powerhouse.

RELOCATIONS

Relocation, or modification, of all existing public and private facilities that would interfere with the construction and operation of the proposed project were included in the estimated total cost of the project.

Criteria

The procedure followed in the preparation of the estimate of work for this survey is that highways, roads, railroads, pipelines, communication and powerlines, utilities and cemeteries that interfere with the maintenance or operation of the proposed project will be relocated as necessary to provide the same service as before the project was constructed, without loss to the owner. These facilities are divided into those that will no longer be required after the project has been built and consequently will have no further use since they terminate within the project area and those that have a continuing utility.

In the first case, adjustments are made to account for the remaining life of the utility, removal costs, and salvage value. The residual net cost becomes a project cost. The second category are those facilities which run through the project area and provide service to an area beyond. This type of facility would require a relocation outside the project area or a major adjustment to allow continued service without interference with the project operation. It is the usual custom to reach an agreement with the owner as to the extent of relocation necessary to carry on the service required after the project is built. The agreement would provide that the owner construct the new line or readjust the existing line, and remove the existing facility, the net cost of which becomes a project cost.

In relocating cemeteries the usual practice is to obtain an agreement with the cemetery association and the next of kin of the interred and then proceed with the actual disinterrment, purchase of a new cemetery site and reinterrment of the deceased in the new cemetery. This procedure is a rather long and costly one, but is a necessary procedure and commonly ends in the exercise of an eminent domain procedure.

No payments are made for the roads or bridges which would be abandoned because of the project. The cost of necessary new roads and bridges to replace existing ones are included in the project cost.

Relocations in United States

In the tidal project area in the United States, the isthmus on Moose Island between Carryingplace Cove and Johnson Cove would be entirely removed for the approach channel to the powerhouse. The isthmus carries a number of utilities connecting with Eastport, Maine, which would have to be relocated. These are listed as follows:

a. Maine State Highway 190.
b. A single-track branch of the Maine Central Railroad to Eastport.
c. An 8-inch waterline to the City of Eastport, Maine, connecting with Boyden Lake, 15 miles to the northwest.
d. Two power circuits of the Bangor Hydro-Electric Company.
e. One cable and 22 wires of the New England Telephone and Telegraph Company.
f. Western Union communication lines.

Each of these facilities would be relocated on a new bridge, 2,340 feet long, built across the approach channel at the location shown on plate 8. The bridge would have 15 steel deck-girder spans. The piers would be streamlined to reduce head losses. Design loadings are Cooper's E-65 for the railroad and American Association of State Highway Officials standard H-20 for the highway. The bridge was located to provide the easiest grades and straightest alignment for the relocated railroad.

The only cemetery in the United States requiring relocation is on Mathews Island and contains 6 graves.

Several navigation aids, including the lighthouse on Dog Island immediately east of Moose Island, and a few international markers, would require relocation if the project is constructed. The aids will also need adjustment during construction. A lump sum allowance was made in the estimate of these items.

The U.S. Coast Guard operates a lifeboat station on Quoddy Head which would be located in the low pool of the tidal project. Preventing access to the ocean would make this station ineffective, and the lock at the opposite end of Quoddy Roads dam is too far away to permit rapid access to open water. The First Coast Guard District advised that it would cost $475,000 to relocate the station. This sum would provide a new boathouse, launchway, barracks, equipment building, lookout tower, and associated utilities similar to those at the existing station. Since the boathouse and launchway appear to be the only facilities needing relocation, construction of an entirely new station would involve a betterment. Furthermore, it appears that the station may be relocated whether the tidal project is built or not. The division of cost between factors of betterment, changing service requirements, and relocation because of the proposed tidal project can be better determined when construction is authorized. For purposes of the present survey, $200,000 was included in the project cost estimate for this item.

The existing airport southeast of the powerhouse site would not be affected adversely by the construction.

Relocations in Canada

In the Canadian area of the tidal project, The New Brunswick Electric Power Commission operates a submarine power cable running from Deer Point on Deer Island to Indian Island to Campobello Island. In order to continue this service, that portion of the cable with an approach on Deer Island must be moved in a northeasterly direction to a new location out of the project area before construction of the dam. A longer submarine cable crossing and a change in the line on Indian Island would be required. The Commission also operates an overhead power transmission line running from the mainland of New Brunswick across Letite Passage to Deer Island. Two of the towers in the Letite Passage area would require relocation for tidal project construction.

One cemetery containing 35 graves at Cummings Cove on Deer Island would be relocated.

LANDS AND DAMAGES

Although most of the project would be constructed in tidal water, some lands would be required. Land would be needed for dam and gate structure abutments, for the powerhouse and locks, borrow areas, contractors' work areas, and for storage areas. When in operation, the tidal project would change the regimen of the tides in the high and low pools and, by so doing, could damage structures now located on the waterfront. The costs of lands and damages were included in the estimate of tidal project first cost.

Since the project cost estimates include only the at-site developments, no lands or rights-of-way for power transmission lines are included, except for the lines needed to serve the various project components.

Lands Required in the United States

The area of land required for each element of the tidal project was outlined, including an allowance for working space and contractor's plant. Areas needed for borrow pits, landing areas on the shores, access highways, and project powerlines were also outlined. The total needs in the United States include 365 acres, varying from cut-over brush to land which may be used for commercial warehouses. About 279 acres of tidal flats adjoining the 365 acres would be acquired with the shoreline. Improvements in these areas include one sardine cannery, one warehouse, seven houses, six cottages, six barns and outbuildings, and one pier. These lands would be acquired in fee simple. In addition, 1.8 miles of right-of-way, 100 feet wide, would be required for access roads, haul roads, and railroad relocation. Plates 32 and 33 show where real estate rights would be required.

All areas required for the project were inspected to determine the cost of the rights required. The estimates are based on the fair market value of the lands and improvements, with an allowance for severance where it would occur. The value of standing timber is included in the value of the land. Fair market value was estimated from records of sales of comparable properties and information from experienced realtors and local officials. An allowance was made for resettlement damage in accordance with United States Public Law 534, Section 401b.

Lands Required in Canada

The lands needed in Canada for the tidal project were determined in the same way as those in United States. The total land requirements amount to 1,540 acres of land with 240 acres of adjoining mud flats. Eleven houses and 3 cabins would be acquired. Right-of-way would amount to 2.4 miles for access roads and 4.6 miles for project powerlines. The lands for project construction would be taken in fee simple, and the road and powerline right-of-way would be acquired by easement. Plates 32 and 33 show where real estate rights would be required.

In Canada, government takings are usually by expropriation. Appraisers visited the area and estimated the cost of acquiring the land by this method using recent takings of similar lands actually acquired. Forceful taking is estimated to make real estate costs 10 percent greater, and is considered in taking of inhabited areas.

Waterfront Damages

The project would cause a permanent change in the tide regimen in both the high and low pools. In the high pool, the average change in pool level would be about 4 feet, instead of the present average tide range of 18.1 feet, and the average level would be about el. 6.3, instead of the present mid-tide el. 0. Extreme high tide would be el. 12.2 instead of the present tide el. 13.9. Extreme low tide would be about el. 3 instead of the present el. -13.4.

In the low pool, the average change in pool level during emptying would be about 7 feet and the average level at about el. -5.0. Extreme high tide would be el. 0 instead of the present 13.9. Extreme low tide would be el. -12.9 instead of the present el. -13.4. In addition, the upper pool would rise about as fast as it does now, but it would recede much more slowly. The time between high tides would remain unchanged. In the low pool, the tide would recede about as fast as it does now, but it would rise more slowly.

The shore installations in both the upper and lower pools were surveyed to determine the damages resulting from these changes in tidal levels. In the low-pool area, many of the older docks and piers were built for use only during high tide, and consequently these facilities could not be used if the tidal project were built. However, lengthening the piers would overcome most of this difficulty. The cost of this work was estimated and taken into account as a part of the cost of the tidal power project. It was found that a cannery, for example, could not continue operations because of changed conditions if the tidal project were built. Where this occurs the damages were included in the project cost as direct damages. The damages were estimated on the basis that the facility would be relocated to a place where it could continue operating in the same way it operates now.

Damages to privately owned waterfront facilities in the low-pool area in Canada were estimated by Canadian representatives. The Canadian Government generally builds a good pier which extends to deep water at all tides at each shore town. These piers are of either pile or crib construction and generally use treated timber to prevent rapid decay and to repel the attack of marine borers. Canadian authorities assign no value to damages to Government piers in the low pool.

In the high pool on the United States side, no recognizable damages would occur. On the Canadian side, however, two large lobster holding pounds might be damaged by the tidal power project. Both pounds are located in North Harbour, on Deer Island, New Brunswick. The lobster pounds must be drained and cleaned periodically. Since this may be impossible if Passamaquoddy Bay becomes the high pool of the tidal power project, these pounds would be relocated if necessary. The estimated cost of these relocations is included in the first cost of the tidal project.

Weirs

The shores of both the high and the low pools contain numerous fixed weirs for catching sardine herrings. In Canada, the weir owners obtain a license from the Department of Fisheries on a yearly basis to construct and maintain weirs in specific locations. If this license is not renewed by the Department of Fisheries, the weir owner has no recourse if Government-authorized action destroys or reduces the effectiveness of his weir.

In the United States, licenses to construct and operate weirs are granted locally with the approval of the State of Maine and with further approval by the Chief of Engineers, U.S. Army, in the form of a revocable license to maintain the weir in navigable waters in a specific location. While these licenses are considered to run without date of termination, they may be terminated should it become in the interests of the Government to do so. Many weirs are built without the formality of licenses and therefore the owners do not enjoy even a temporary right to occupy the weir site. Consequently, weir owners do not enjoy a compensable interest should the weirs be destroyed or their use reduced by public action. No more than six existing weirs would be affected directly by the construction of the tidal project. The value of a weir in good condition is about $5,500, and its life is a matter of a few years if not repaired each season.

Changed Water Conditions

The tidal project would reduce the flow into and out of the 142 square miles of pool area to about 15 percent of the present flow. This reduced flow would cause a change in the quality of the water, in addition to changing the water levels. The decreased flow of ocean water would reduce the dilution of both fresh water and pollution entering the tidal pools. Since all fresh water would run through the lower pool, the greatest reduction of salinity would take place in Cobscook Bay. The pollution, according to U.S. officials, is so small in the bays that reducing dilution would cause no appreciable change in the existing conditions.

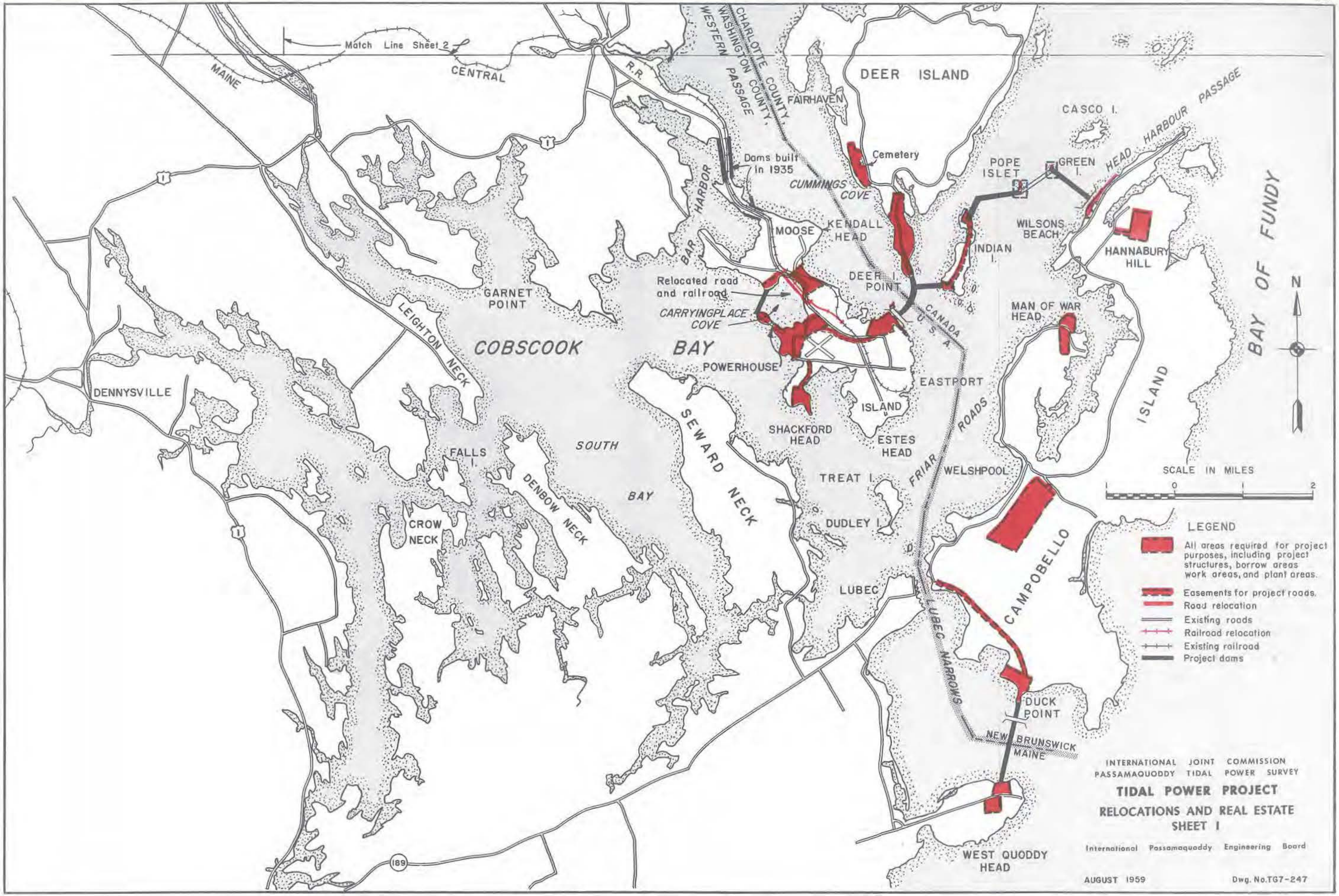
The decreased flow in the pool areas would result in a decreased vertical mixing of the waters, producing a greater stratification of waters in the bays. The lighter fresh water would tend to stay on top and areas with surface salinities of 20 parts per thousand would be increased. The normal salinity is about 30 parts per thousand. In Cobscook Bay, a thin layer probably less than a yard thick would form above Leighton Neck, which would be brackish with salinities less than 20 parts per thousand.

Decreased mixing would also increase the range of surface temperatures. The summer maximum would be raised by 15° to about 68° Fahrenheit and winter minimums would be lowered 2° to 3° to about 30° Fahrenheit. The combination of the lowered surface salinity and lower winter temperature would increase icing in the bays. Bottom salinity probably would not change.

Changes in water quality may have both damaging and beneficial effects in the tidal pools. However, no significant effects to which definite money values can be assigned were identified. For this reason, no allowence is made in the estimate of project first cost for this factor.

Marine Borers

Oceanographers and biologists state that marine borers may possibly become more active in the bay areas after construction of the tidal project. However, the numerous factors involved make prediction difficult. Borers are more active in warmer water, but less active in brackish water. The net result in the tidal pools appears to be conditions more favorable to the borers. However, increased activity does not always accompany more favorable conditions. At the present time, borers are active in parts of Cobscook Bay, making it necessary to replace wooden piling about every 7 years. Since there is only a possibility that marine borers may become active, no allowance was made in the project first cost for the possible damages.


Match Line Sheet 2
MAINE
CENTRAL
R.R.
CHARLOTTE COUNTY
WASHINGTON COUNTY
WESTERN PASSAGE
DEER ISLAND
FAIRHAVEN
CASCO I.
HEAD HARBOUR PASSAGE
Cemetery
Dams built in 1935
CUMMINGS COVE
POPE ISLET
GREEN I.
WILSONS BEACH
BAR HARBOR
MOOSE
KENDALL HEAD
INDIAN I.
HANNABURY HILL
BAY OF FUNDY
Relocated road and railroad
CARRYINGPLACE COVE
DEER I. POINT
GARNET POINT
LEIGHTON NECK
COBSCOOK BAY
CANADA
U.S.A.
MAN OF WAR HEAD
N
POWERHOUSE
EASTPORT
ISLAND
DENNYSVILLE
SOUTH BAY
SEWARD NECK
SHACKFORD HEAD
ESTES HEAD
FRIAR ROADS
FALLS I.
DENBOW NECK
TREAT I.
WELSHPOOL
SCALE IN MILES
1 0 1 2
DUDLEY I.
CROW NECK
CAMPOBELLO
LEGEND
All areas required for project purposes, including project structures, borrow areas work areas, and plant areas.
Easements for project roads.
Road relocation
Existing roads
Railroad relocation
Existing railroad
Project dams
LUBEC
LUBEC NARROWS
DUCK POINT
NEW BRUNSWICK
MAINE
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
RELOCATIONS AND REAL ESTATE
SHEET I
International Passamaquoddy Engineering Board
WEST QUODDY HEAD
189
AUGUST 1959
Dwg. No.TG7-247

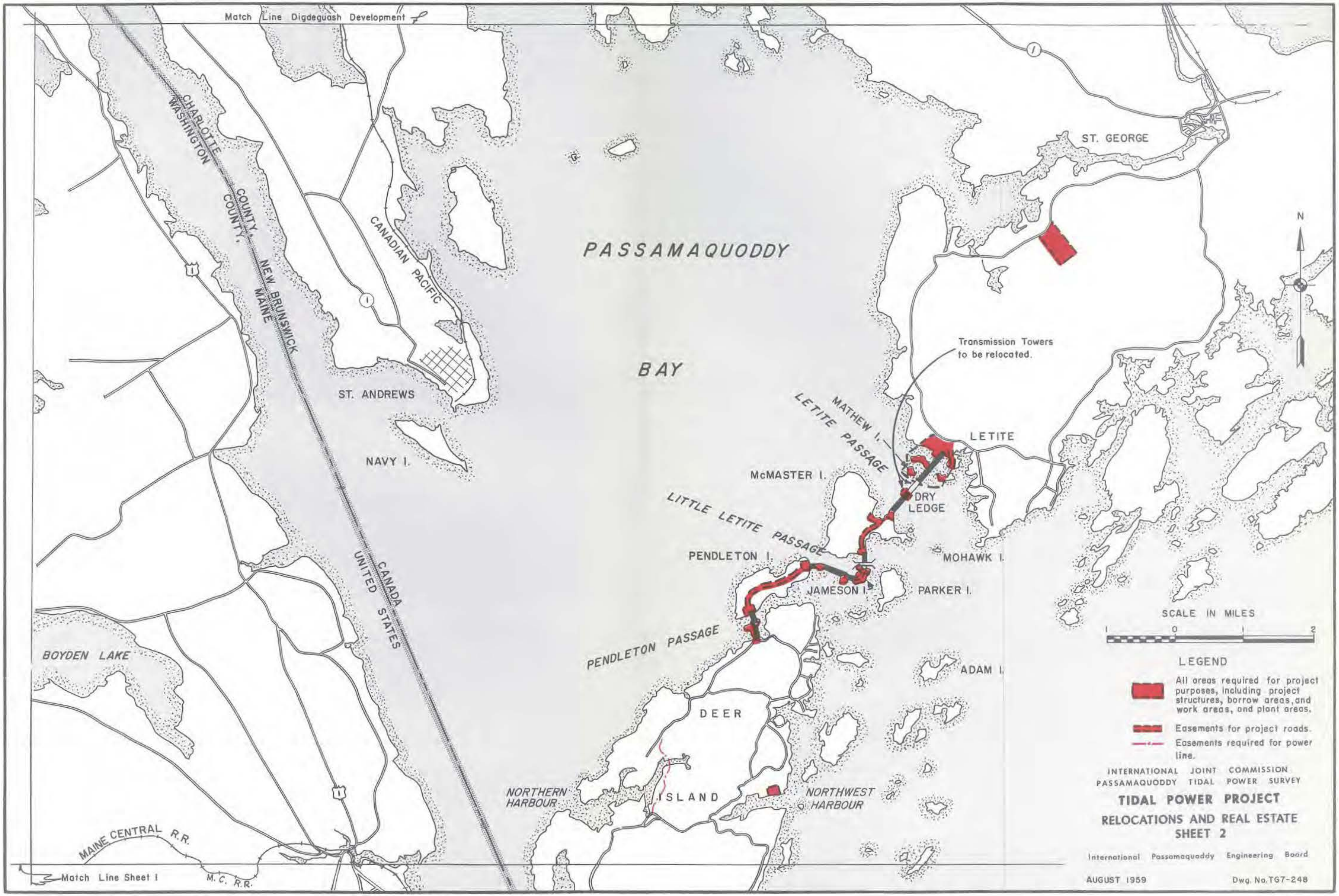

Match Line Digdeguash Development
PASSAMAQUODDY
BAY
CHARLOTTE COUNTY, NEW BRUNSWICK
WASHINGTON COUNTY, MAINE
CANADA
UNITED STATES
CANADIAN PACIFIC
ST. ANDREWS
NAVY I.
ST. GEORGE
Transmission Towers to be relocated.
MATHEW I.
LETITE PASSAGE
LETITE
McMASTER I.
DRY LEDGE
LITTLE LETITE PASSAGE
PENDLETON I.
MOHAWK I.
JAMESON I.
PARKER I.
PENDLETON PASSAGE
ADAM I.
BOYDEN LAKE
DEER
ISLAND
NORTHERN HARBOUR
NORTHWEST HARBOUR
MAINE CENTRAL R.R.
Match Line Sheet I
M.C. R.R.
SCALE IN MILES
1 0 1 2
LEGEND
All areas required for project purposes, including project structures, borrow areas, and work areas, and plant areas.
Easements for project roads.
Easements required for power line.
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
RELOCATIONS AND REAL ESTATE
SHEET 2
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-248

PLATE 33

CONSTRUCTION SCHEDULE

The construction schedule, as shown on plate 34, is based on a 6-year program found best suited for the tidal power project. The initial investment, project first cost and interest during construction, would be greater if a 5- or an 8-year schedule were used. About 2 years are needed before the major work shown on the schedule can be started to allow for design, purchase of major equipment, and award of initial contracts for construction.

Construction of the tidal power project within the 6-year program would require working throughout the entire year, even though dense fogs and storms, at times, would hinder water transportation, and extremely cold weather would delay placing of concrete. Therefore, unit prices and the 6-year construction schedule include allowances for delays due to bad weather.

The project can be separated easily into contracts of reasonable size and duration to assure competition during bidding and to avoid the danger of large price level changes during a long contract period. However, because rock, sand, gravel, and clay from required structure excavations would be used to build the dams and cofferdams, all excavation must be carefully coordinated with the fill operations.

Following about 4 months for mobilization of equipment, many of the structures could be started at the same time in the spring of the first year. Because steel cell and crib cofferdams are planned for most of the structures, starting construction of one cofferdam ordinarily would not depend on the progress of excavation in another area. An exception to this is the cofferdam for the Head Harbour Passage gate structure, where material for the embankment portion of the cofferdam would come from excavation for other structures. The largest excavation that can be made with a minor cofferdam is at the Western Passage gates, because the area for the structure is largely on land. The schedule allows time for construction of a wharf and a special conveyor for loading scows for transporting the excavated material to cofferdams and dams.

The powerhouse would take the longest time to construct. In order to make an early start the material for building the cofferdams would be borrowed. Excavation would proceed from the southeast end of the site toward the northwest end. In about 6 months, excavation for the first unit would be completed, and placing of concrete started for the substructure. In another 6 months, installation of the equipment would be started for the first unit. The progress on each succeeding unit would follow at intervals of 6 weeks, which is the time allowed for installing the main generating equipment, all of which would then be completed in 42 months.

The construction schedule of the three gate structures is based on working on all three sites at the same time. Excavation at each site would be completed early at one end of the structure to allow concrete work to start on one unit. Work on the adjacent unit would follow a similar schedule but would begin about 1 week later. When about one-third of the total concrete is placed, installation of the equipment would start in the first completed structure. Because the Head Harbour Passage site contains the largest number of gates, these emptying gates would be finished last. As the construction at each site is completed, the cofferdam surrounding the site would be removed, and the gates would be opened after all excavation is completed.

Construction of the locks would be completed before closing the dams so that navigation could be continued without interruption.

By the middle of the fourth year, all major dams would be completed except the Western Passage dam, which would be getting underway; Head Harbour Passage dam, east, would be constructed to el. -85; and Head Harbour Passage dam, west, would not yet be started. Head Harbour Passage dam, east, would be completed at the end of the fifth year. The final closure of the combined pools would be made by the Head Harbour Passage dam, west, which would be started in the fifth year and completed by about the middle of the sixth year.

The Western Passage dam between the upper and lower pools would be completed during the sixth year in quiet water after all the other dams, except Carryingplace Cove dam, have been completed and the gates closed. The small dam at Carryingplace Cove would not be built until all the clay has been removed by a floating dredge from the headrace between the bridge and the power plant.

OPERATING STAFF

The cost of operating and maintaining a powerhouse is an important part of the cost of the power generated. For a new plant of conventional design, this cost can be estimated easily from experience at similar existing plants. No previous experience exists for operation of tidal power plants. Conventional hydroelectric plants are a partial guide, but they do not have the added problems arising at tidal projects from salt water. A detailed analysis indicated that a staff of 154 would be needed to maintain and operate the tidal power project.

Executive Staff

The administration of the international Passamaquoddy tidal power project has not been established. It was assumed only for the purpose of estimating costs that a single international agency would maintain and operate the tidal project and its auxiliary. The executive staff would be headed by two power commissioners, one from each country. The commissioners would be supported by seven other administrators, making a total executive staff of nine.

Project Engineer

A project engineer would be responsible for the physical functioning and care of the tidal project and the auxiliary power plant. He would be supported by an assistant and a technical section of four employees. Reporting to him would be the group at the auxiliary power plant and the tidal plant operation, maintenance, and service sections.

Operation Section

A staff would be provided sufficient for 7-day, 24-hour operation of the tidal power plant, the filling and emptying gates, and the navigation locks. The powerhouse would be equipped with a central supervisory control room from which all operations of the power plant would be controlled by two senior operators. Additional subordinate operators would each oversee a group of seven or eight main generating units. These roving operators would perform switching functions as directed from the control room, but they would also be alert for indications of impending equipment trouble. These operators would also operate the group control rooms should control be shifted from the central supervisory control room.

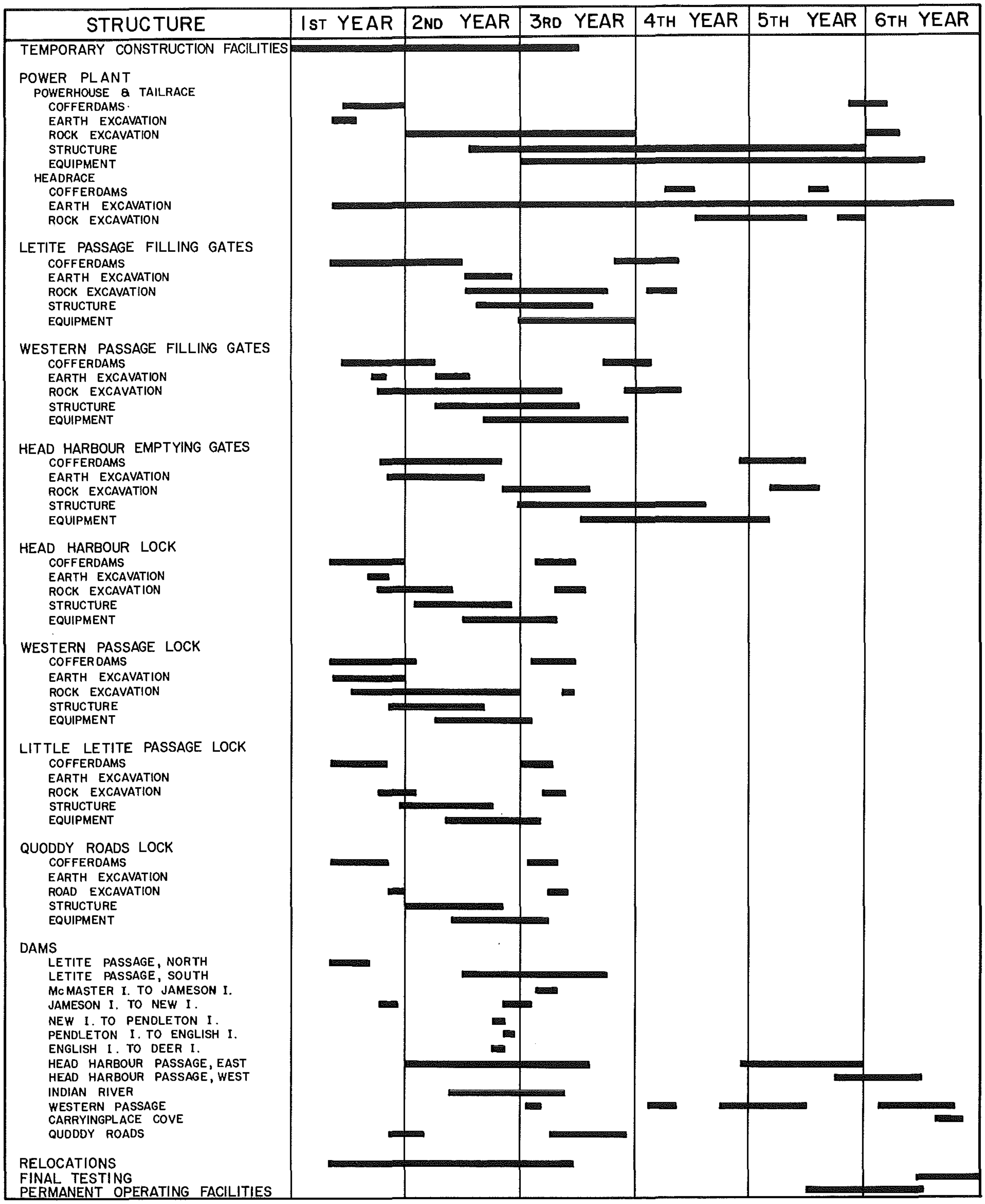
A two-man crew would be assigned on each shift to each navigation lock, except the one at Quoddy Roads. These operators would be assigned normally to a station at the navigation lock to operate the lock gates, filling valves, and bascule bridges, but a short time before scheduled operation of the adjacent tide gates they would shift station to the gate control house. One operator would oversee the automatic operation of the tide gates from the control house status board. The second operator would be on hand to start local operation of a gate, or group of gates, in the event of a control malfunction. This plan would require interruption of lock traffic during the period of gate operation. The use of a single crew for this dual function is warranted by the low volume of marine traffic, the short but critical operating time of the tide gates, and the high cost of full-time staffing of these components.

At the Quoddy Roads lock, the small size of the lock and lack of an adjacent gate structure combine to permit reducing the number of operators to one each shift. In order to permit effective operation of the locks with such small crews, regulations for lock users would require using vessels to provide all line-handling personnel, both aboard ship and on the lock wall, as necessary for safe lockage.

Maintenance Section

Maintenance personnel would be provided for a single 5-day, 40-hour week shift, but provision would be made for a portion of the crews to remain on 24-hour call for emergencies. Maintenance forces would be divided into mechanical, electrical, and general. The maintenance crews would be further subdivided by assignment to either the power house, the gates and locks, or to other features. However, to keep personnel requirements low, only craftsmen required much of the time would be assigned to a specific crew. Craftsmen required only occasionally would be drawn from the powerhouse maintenance crew which would function as a central reserve. From this central group, certain personnel would be assigned to the gate and lock maintenance crews, or to the auxiliary, as required to assist in scheduled or emergency maintenance.

CONSTRUCTION SCHEDULE



INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

CONSTRUCTION SCHEDULE

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-249

PLATE 34

Service Section

Warehousing, supply, inventory, and timekeeping functions would be handled for the entire project by a seven-man service section located at the tidal power plant.

It is expected that local fire companies could be retained under contract to provide the necessary fire protection for the project. At the tidal plant, because of its critical nature, a firefighting-guard would be on duty each shift. This man would patrol the project in a small radio-equipped truck or station wagon with first-aid and fire-extinguishing equipment. He would function as a watchman to sound the alarm in case of trouble, and he would also take preliminary fire-fighting measures. No provision was made for security of the national military type.

POWER FROM THE TIDAL PROJECT

The amount of electricity that the tidal project could generate was analyzed, taking into account many factors not specifically evaluated in the power studies for conventional hydroelectric projects. Special studies included turbine efficiency and its variation with head, change in generator efficiency with output, and surface slopes in the pools. This close analysis was necessary because the influence of each of the factors on total power generation was unknown and had to be determined before a firm evaluation of the power benefits of the project could be made.

Power Computations

Because the ebb and flood of the tides cause the head on the turbines to change rapidly, tidal plant output must be computed for short intervals to be reasonably accurate. The net head on the turbines would vary with an average tide from about 5.5 feet to 16.5 feet in 12.4 hours. In addition, in each lunar month, or 29 1/2 solar days, the tide would change twice from spring to neap and back to spring again. These conditions make computation of tidal power an exceedingly time-consuming process if done by conventional manual methods. For this reason, and because the problem was highly repetitive, the computation was programmed for a high-speed electronic digital computer.

The program for the computer was made flexible, so that pool areas, filling and emptying characteristics, turbine and generator efficiencies, and turbine discharge could be changed easily. Sixty-five computer runs were made, each for a lunar month. The weight of sea water was taken as 64.0 pounds per cubic foot. The results of the computations proved to be a powerful tool in selecting the type of turbine, including the blade setting for the selected fixed-blade propellor type, the rating of the generator, and the type and number of filling and emptying gates. By using varying pool areas, the computer furnished information that was invaluable in selecting the best tidal project arrangement. After the details of the turbines, generators, gates, channels, and pool areas were established, tidal power was computed for a period of 1 year. The indicated energy was 1,898 million kw.-hr. a year. This value was adjusted for factors not programmed into the computer, which are discussed below.

Slopes in the Pools

The tidal project would have a high-pool area of 101 square miles at its average level (about el. 6.3), while the low pool would have an area of 41 square miles at its average level (about el. -5.0). It was assumed in the computations by electronic computer that the water surface in these pools was level. A detailed study showed this to be essentially true for the upper pool, but that two restricted channels in the lower pool would reduce the energy generated. One of the restrictions is located at Falls Island in Cobscook Bay and the other at Lubec Narrows.

The Falls Island restriction was estimated to cause an energy loss of 25 million kw.-hr. a year. However, further study showed that the energy to be gained by improving the channel was not worth the cost. At Lubec Narrows, it was found that the energy to be gained by dredging the channel to a 520-foot width at el. -30 was worth the cost by a substantial margin. The cost of dredging this channel, therefore, is included in the estimate of project first cost. Possible construction of an international bridge from Lubec to Campobello Island was also taken into account. The net energy loss due to the improved channel and the new bridge would amount to 7 million kw.-hr. a year.

Leakage

The effect on power generation of leakage through the dams was first considered to determine how tight the dams must be and to determine what type of material would obtain the minimum acceptable tightness. The problem was reduced in importance when the partial clay core design of the tidal dams was selected. The leakage for this design is about 20 c.f.s., from the high pool to the ocean, 300 c.f.s., from the high pool to low pool, and 200 c.f.s., from the ocean to low pool. This combined leakage would result in a loss of 2 million kw.-hr. a year, or only about 0.1 percent of the total annual energy of the project.

Fresh Water Inflow

Fresh water inflow to the high pool, estimated at an average of 4,200 c.f.s., would be beneficial because it raises the high-pool level and increases turbine head. Fresh water inflow to the low pool, estimated at an average of 600 c.f.s., would raise low-pool levels and decrease turbine head. The net effect would be an increase of average annual energy by about 4 million kw.-hr.

Fishways

Operation of the fishways at the emptying gates and the powerhouse would also affect power output. The emptying gate fishway would tend to increase project energy, but the amount would be negligible. The powerhouse fishway would release water at the rate of 1,000 c.f.s. during about 8 months of the year. This flow would reduce the head on the power plant and reduce annual energy by 2 million kw.-hr.

Project Use

About 15 million kw.-hr. a year of tidal energy would be used for project purposes such as lighting, operating the filling and emptying gates, navigation locks, and other uses.

Scheduled Outages

It is estimated that each turbine would be out of service for preventive maintenance for a period of 2 weeks each year. Turbines would be serviced in pairs. By scheduling these preventive maintenance periods at times of neap tides, and by operating the remaining power units at increased gate openings, estimated energy losses from this cause could be limited to 8 million kw.-hr. annually.

Tidal plant energy would not be affected by preventive maintenance of the filling and emptying gates. It is planned to keep the gate structures operative during preventive maintenance periods by use of spare gate leaves.

Annual Tidal Plant Energy

The annual energy of the tidal power project alone is summarized below:

	Annual energy million kw.-hr.
Average year energy (from computer studies)	1,898
Corrections	
Low pool slopes	-32
Leakage	- 2
Fresh water inflow	+ 4
Fishways	- 2
Project use	-15
Scheduled outages	- 8
Net average annual energy	1,843

Tidal Project Dependable Capacity

The installed nameplate capacity at the tidal power plant would be 300,000 kw. The generators could be operated continuously at 15 percent overload at an increased but acceptable temperature. On this basis the plant could generate 345,000 kw. However, this high level of generation can be reached only during high tides, and then only during part of the tide cycle, unlike a conventional thermal power plant which can generate its rated capacity or more at any time. The dependable capacity of the tidal plant, therefore, is considerably less than the nameplate rating.

A steamplant can be assumed dependable 98 percent of the time. On a similar basis, a tide range (high tide level minus low tide level) was determined which was exceeded by 98 percent of the tide ranges. This amounted to a 13.2-foot range. The continuous power which the tidal power plant could generate through this tide range was then computed as a reasonable estimate of dependable capacity. This was 95,000 kw.

The operation for this capacity is diagrammed on plate 35. Operated at a load factor of 60 percent in the pattern of normal use, the project could supply a peak load of 107,000 kw. of dependable capacity. If the project were operated for maximum energy, the minimum momentary output would be 65,000 kw.

Variation of Tidal Power

The output of the tidal power project, without an auxiliary, would vary from hour to hour and day to day because of the continually varying tide ranges, as shown on plate 35. The average of the tide ranges approaches the mean tide range as the length of the period is increased. In the same way the variation in tidal power is narrower the longer the period analyzed. This is demonstrated in the following table:

	Energy in million kw.-hr.		
	Minimum	Mean	Maximum
Day	2.3	5.0	7.6
Week	20.5	35.2	49.7
Month	131	154	170
Year	1,738	1,843	1,923

Reliability of Tidal Plant Power

In the sense that the tides have not varied widely from their normal ranges of neaps and springs, the tidal plant output would be more reliable than a conventional hydroelectric development that may be subjected to prolonged periods of drought. Equipment failure and variation of the actual tide from the predicted tide would be the only elements, other than human failure, that would cause the output to vary.

Unscheduled shutdowns due to failure of equipment would not be excessive because standard type structures and equipment were used in the design. The problem of salt water corrosion was taken into account by the choice of materials and protective coatings. Allowance was also made for more frequent scheduled maintenance than is usual for a fresh water plant. The number of filling and emptying gates and turbines is large enough so that a failure of any one unit would not cause a large reduction in tidal plant output. One filling gate stuck in the open or closed position would reduce average power output by about 3 percent and 1 percent, respectively. One inoperative generating unit would reduce output by about 1.4 percent. Each of the three gate sites would be provided with a spare gate leaf, an emergency gate leaf, and stoplogs. Flow through an inoperative open gate could be stopped within one tide cycle and the gate could be repaired or the spare gate installed so that the energy loss would be negligible. Similarly, the spare gate could be substituted for an inoperative gate in the closed position and could be in operation within a short time.

The powerhouse would be equipped with gates which could be installed to prevent loss of water through a turbine with defective wicket gates. Since all 30 turbines would not operate during neap tides, spare turbines would be available part of the time. The energy and capacity loss due to an unscheduled shutdown of a turbine would thus be small.

Since the power output varies closely with the tide range, the accuracy with which the tides can be predicted is a direct measure of the predictability of power output. Continuous record of tide predictions and tide observations since 1930 for Eastport, Maine, are available. From these records, the differences in power and energy generation that would have occurred because the tides varied from predictions, were computed. The maximums are tabulated below:

	Max. ave. power difference in kw.		Max. ave. energy difference in millions of kw.-hr.	
Period	Greater than predicted	Less than predicted	Greater than predicted	Less than predicted
One tide cycle	24,600	34,800	0.31	0.43
Month	18,000	8,200	13.00	5.90
Year	17,200	3,500	151.00	30.60

During the period of record the average observed tide range was greater than the predicted tide by 0.32 feet, which is equivalent to 58.2 million kw.-hr. per year.

The predicted tide ranges used in the above analysis are taken from the tide tables published by the United States Coast and Geodetic Survey primarily for use by navigators. Closer predictions could undoubtedly be made. Power and energy predictions would thus be more accurate than is indicated by the past record.

FURTHER STUDIES REQUIRED PRIOR TO CONSTRUCTION

The studies conducted for this report were directed toward determining the cost of tidal power and did not include detailed investigations associated with the preparation of construction drawings and specifications. Final design investigations would require general and detailed hydraulic model studies, including a comprehensive tidal project model; extensive subsurface explorations, including additional deep-water drilling; reconsideration of the bulb-type turbine-generator sets and alternate discharge to the ocean; and detailed studies of many unprecedented problems of design, construction, and operation of a tidal power project.

In addition to the extensive but normal final design studies, as indicated above, some further special studies appear warranted in view of the substantial effect they could have on the cost of power. These studies are described below.

Dams

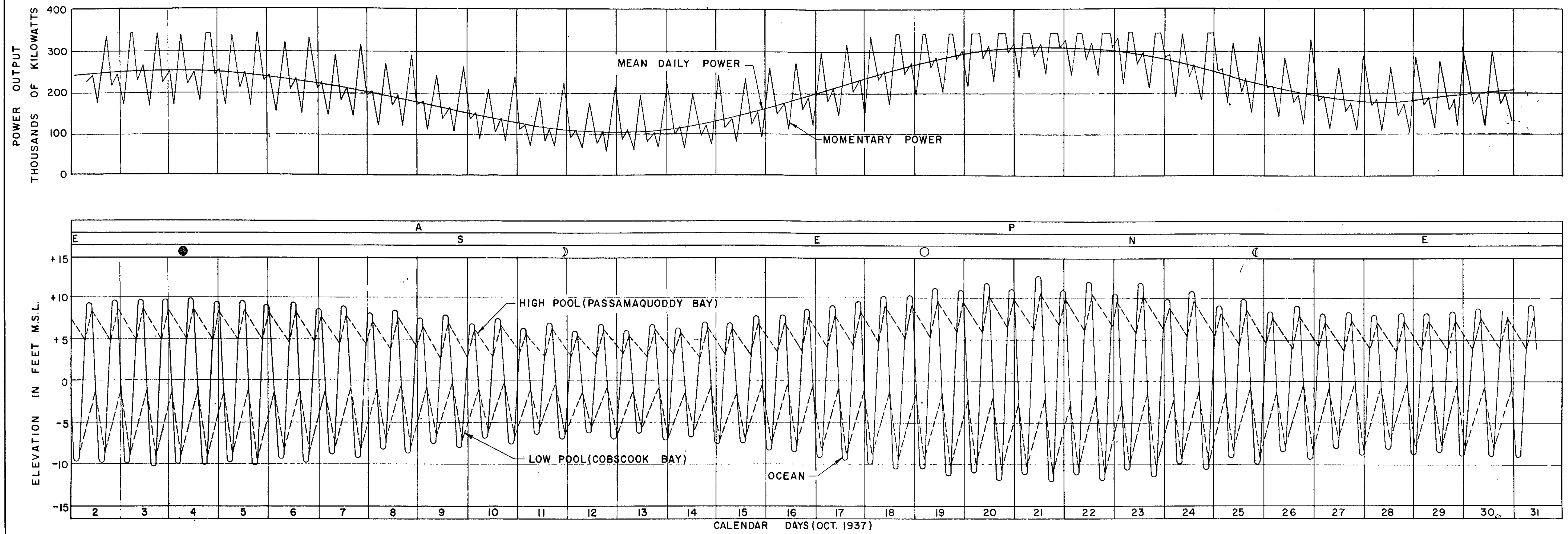
The criteria used for the design of tidal dams are construction feasibility, and the lowest practicable project cost. Further study to reduce the cost without sacrificing construction feasibility appears warranted. Cost reductions may be made by decreasing the gross volume of embankments, by changing the type or distribution of materials within the cross section, by changing the method or sequence of construction, or by a combination of these possibilities.

One specific proposal to reduce costs would be further consideration of the full clay-core design previously described in this report. Substantial economy would be gained if the clay core could be constructed to the full depth of the deeper passages. In view of the unprecedented nature of the design and attendant construction procedures, full-scale field tests of placing clay would be necessary before such a design could be accepted without reservation.

Gates

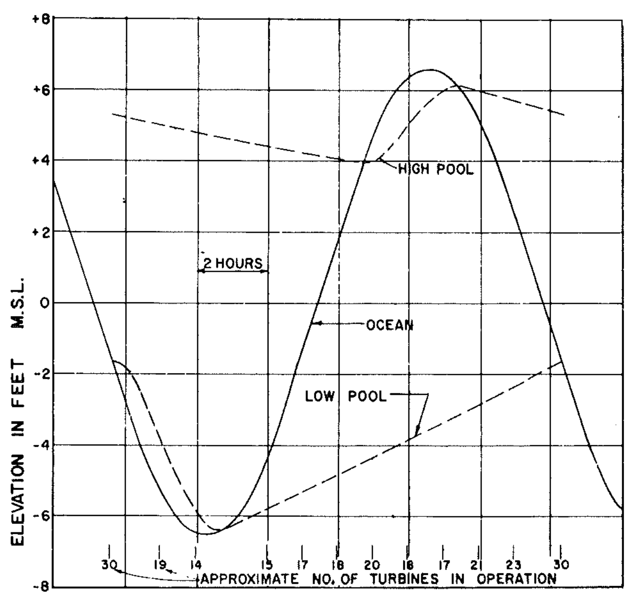
One of the larger costs of the tidal project are the cofferdams required for the gates. If gates could be designed to float in and to sink on underwater fill for the dams, much of the cofferdam expense could be reduced. This possibility was considered during the studies of the gates, but no satisfactory solution was found for the many unprecedented design problems encountered. The possibility should be considered further during design of the project since it could have a substantial effect on the cost of tidal power.

One large item of cost for vertical-lift gates was the heavy corrosion resistant tracks required on both sides of the slots for the service and emergency gate. Further studies to determine how these expensive tracks might be eliminated are warranted.

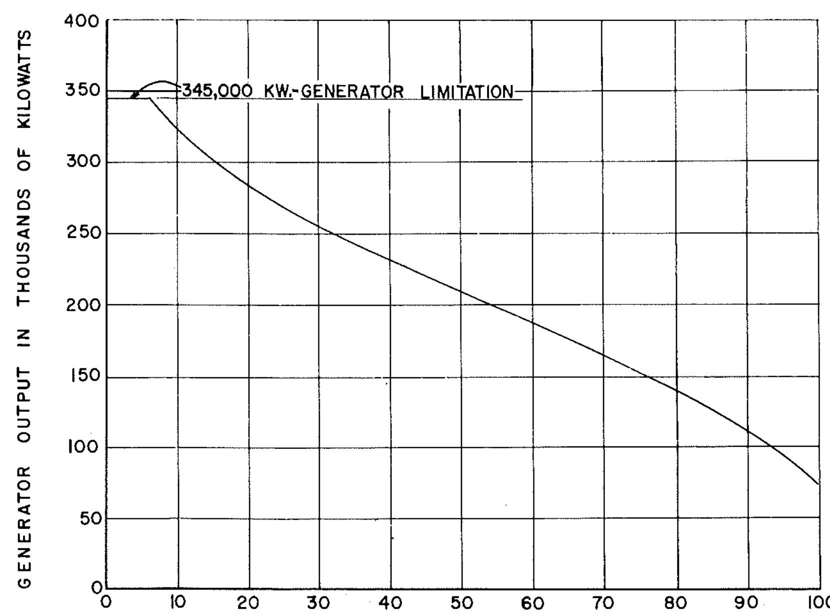


TYPICAL MONTH — TIDAL PLANT OPERATION

SYMBOL	EXPLANATION
● NEW MOON	E MOON ON THE EQUATOR
☽ FIRST QUARTER	N MOON FARTHEST NORTH OF EQUATOR
○ FULL MOON	S MOON FARTHEST SOUTH OF EQUATOR
☾ LAST QUARTER	A MOON IN APOGEE
	P MOON IN PERIGEE



OPERATION FOR CONSTANT POWER
OF 95,000 KILOWATTS
13.2-FOOT TIDE RANGE



TIDAL PLANT POWER DURATION CURVE

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TIDAL POWER PROJECT

TIDAL POWER VARIATION

International Passamaquoddy Engineering Board

AUGUST 1959

Dwg. No. TG7-251

PLATE 35

CHAPTER V

AUXILIARY POWER PROJECT DESIGNS

In order to make cost estimates of the auxiliary power plants comparable in accuracy to the cost estimate made of the tidal power project, specific designs were also made of the Rankin Rapids hydro and the Digdeguash pumped-storage auxiliaries.

RANKIN RAPIDS HYDRO AUXILIARY

The Rankin Rapids site is located on the Saint John River about 3 1/2 miles upstream from St. Francis, Maine, and about 175 miles northwest of the tidal power project (plate 1). The Rankin Rapids site was considered for development and included in the report entitled "The Resources of the New England-New York Region," completed by the New England-New York Inter-Agency Committee in March 1955, and in the interim report on "Water Resources of the Saint John River Basin," submitted to the International Joint Commission on April 6, 1953. The level of development and project layout, however, were changed in the course of the current study.

Site Development

An earth embankment would be the least expensive dam that could be built from materials available at the Rankin Rapids site. A concrete dam was found to be more expensive, because bedrock occurs 80 feet below the streambed, and the nearest source of suitable concrete aggregate is located in an undeveloped area 16 road miles to the south. The dam would be designed with a maximum operating pool level at el. 860. The project layout is shown on plates 36 and 37.

The Saint John River would be diverted through two 24-foot tunnels in the right abutment prior to the placement of the earth embankment across the river. The tunnels would be converted to low-level outlets by installing valves when they are no longer needed for diverting stream flow.

The powerhouse would be constructed in a deep excavation in the rock of the right abutment. This arrangement reduces costs by shortening the penstocks and providing material excavated from the tailrace for use in the dam. The penstocks would be constructed of steel and exposed on the slope downstream from the right abutment of the dam. Exposed penstocks are less costly than tunnels for carrying the water from the reservoir to the powerhouse.

A chute spillway would be located in the left abutment. It would consist of a concrete crest structure with gates, a concrete-lined chute leading down the slope of the abutment, and a stilling basin near the river.

Access to the project would be gained over Main State Highway 161, and by a rail spur planned for construction as a part of the river hydro auxiliary from the present railhead at St. Francis, Maine.

Energy

The reservoir, with 2.8 million acre-feet of active storage, could store excess flows during wet years for use during dry years. With a maximum operating pool at el. 860, the energy would be 1,070 million kw.-hr. in a minimum year, 1,220 million kw.-hr. in an average year, and 1,430 million kw.-hr. in a maximum year.

Capacity

The dependable capacity of the Rankin Rapids hydro auxiliary was selected so that the ratio of average power to dependable capacity of the tidal plant-Rankin Rapids combination would be about 60 percent. This factor is approximately equal to the load factor (ratio of average load to peak load) expected in the 1975-80 period for the combined market areas of Maine and New Brunswick. Therefore, a total dependable capacity of 555,000 kw. was selected for the combination. Using the 95,000 kw. as the dependable capacity for the tidal project (chapter IV), the dependable capacity of Rankin Rapids would therefore be 460,000 kw. The ratio of average power to dependable capacity becomes 57.7 percent for a minimum year, 63.0 percent for an average year, and 68.8 percent for a maximum year.

Incremental Capacity only at Rankin Rapids as Auxiliary

The concept of using capacity only at Rankin Rapids as an auxiliary to the tidal project assumes that the Rankin Rapids site would be developed first to serve the utility market of Maine, and that the total 1,220 million kw.-hr. of energy from the project would be used by that market. An additional 260,000 kw. of dependable capacity would be installed specifically for firming the tidal project energy. When the tidal plant output drops below the load, the deficiency would be borrowed from the basic Rankin Rapids project and repaid when tidal energy exceeds load. In this way, both Rankin Rapids and the tidal project could provide energy to the load in a similar pattern.

Occasionally, excess tidal energy would be greater than the load on Rankin Rapids, leaving a surplus of tidal energy after all that is needed is used by the basic Rankin Rapids project. This surplus energy is estimated at about 100 million kw.-hr. a year.

The average annual energy of this combination would be the same as that of the tidal project alone: 1,738 million kw.-hr. for the minimum year, 1,843 million kw.-hr. for the mean year, and 1,923 million kw.-hr. for the maximum year. The dependable capacity of this combination would be 355,000 kw. The ratio of average power to dependable capacity of the tidal plant, with 260,000 kw. of firming capacity at Rankin Rapids, would be 55.8 percent during a minimum year, 59.4 percent during an average year, and 61.9 percent during a maximum year.

Embankment

The cross section proposed for the dam (plate 37) takes into account the economical use of structure excavation and adjacent borrow materials of glacial till, silty sands, and gravels. A deep deposit of compact silt underlies the river and the left abutment, requiring flattened slopes in the lower zone of the central portion of the dam. Transition between zones of different materials, details of surface protection, and control of seepage would follow conventional practice.

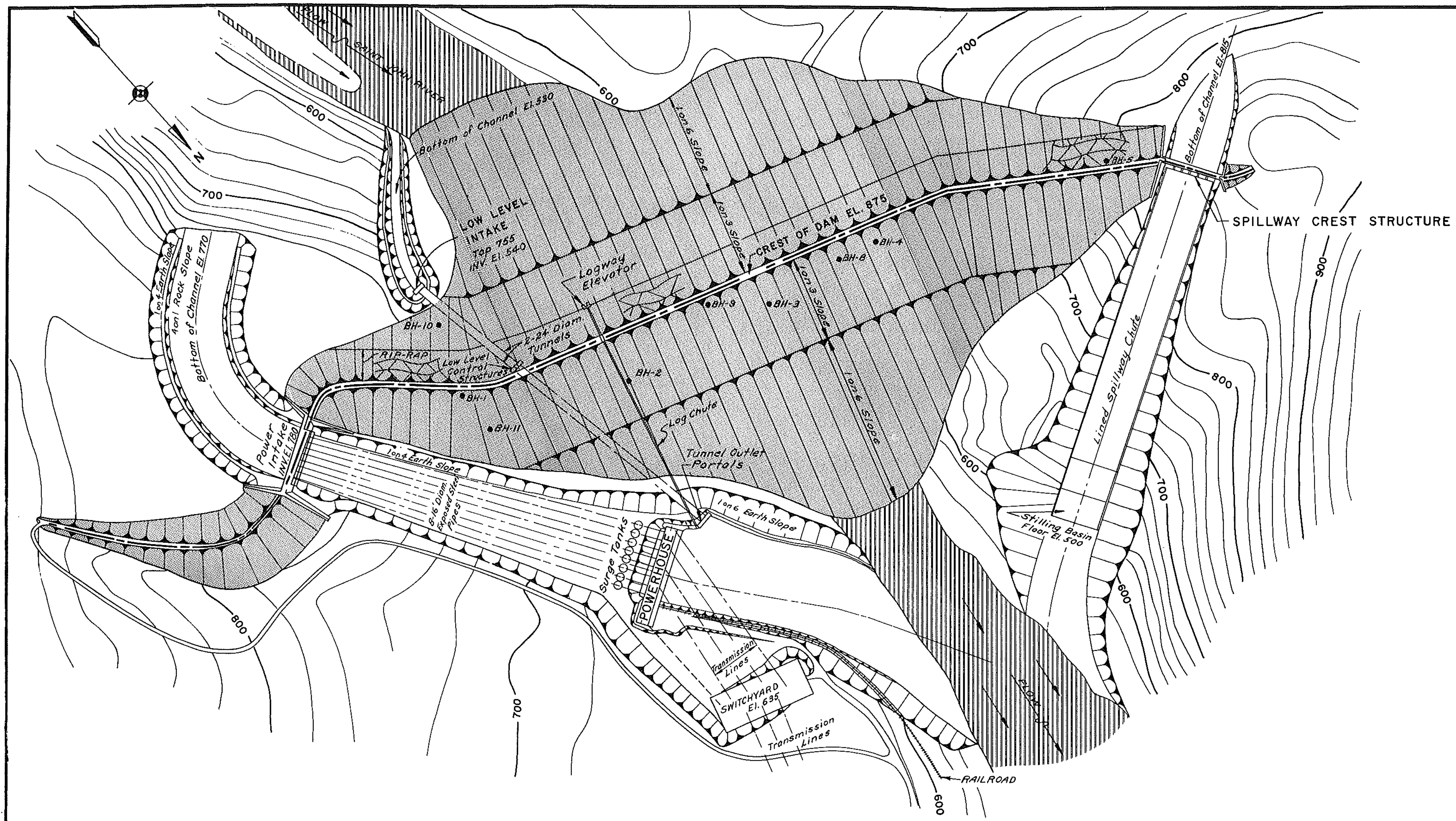
Riprap on the upstream face of the embankment is planned from el. 813 (10 feet below limit of drawdown) to the crest of the dam at el. 875. This layer of rock, selected for size and durability, would be 5 feet thick and would rest on a gravel filter. The remaining upstream and downstream surfaces of the dam would be faced with a varying depth of random rockfill. A small saddle dam on Falls Brook would be similar in design to the main embankment.

Care of Water During Construction

The two river diversion tunnels, 24 feet in diameter and lined with concrete, would be constructed in bedrock under the right abutment of the dam. The tunnels are designed for use during the critical period of the second year of embankment construction when the flow of the spring freshet must be passed without overtopping the dam. While being used for river diversion, the tunnels would not be equipped with gates or valves. A concrete intake structure would provide facilities for stoplogs.

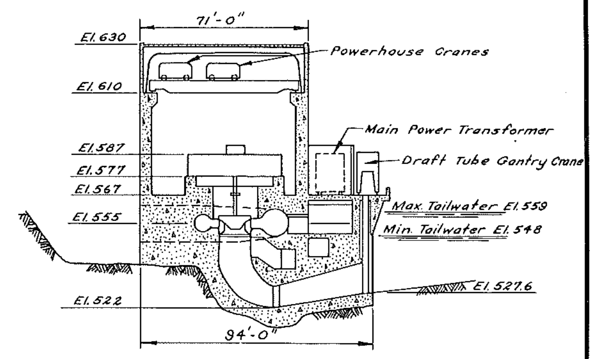
Low Level Conduits

The two diversion tunnels would be converted one at a time for use as low-level reservoir outlets after they have been used to divert the stream. As low-level reservoir outlets, they would maintain minimum downstream discharge and permit emergency reservoir drawdown. Two 90-inch-diameter, fixed-cone dispersion valves would be installed in each tunnel because (1) discharge requirements would be substantially less than for diversion, (2) the head would be considerably higher, and (3) control of flow is necessary. Cone valves were selected to assure reasonable freedom from cavitation, and because these valves can be installed with only minor modifications of the tunnels. An emergency vertical-lift gate, 6 feet by 10 feet in size, would be provided upstream of each valve. Valves, gates, and operating equipment would be housed in a pair of concrete lined shafts (plate 37).



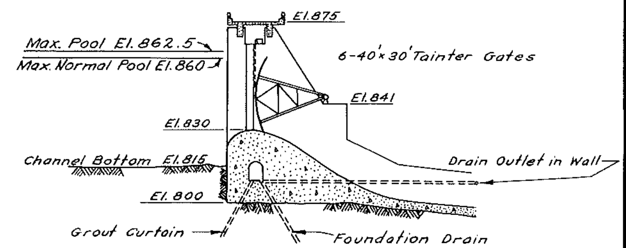
GENERAL PLAN

SCALE IN FEET
200 0 200 400 600 800 1000



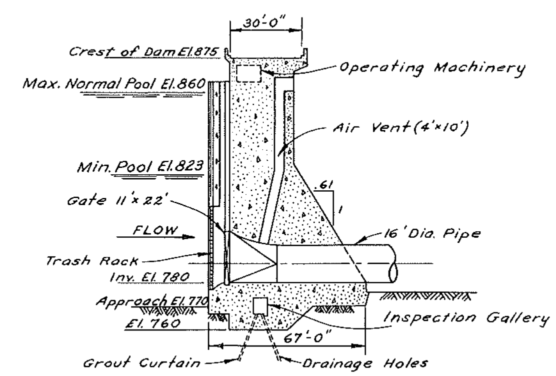
POWERHOUSE SECTION

SCALE IN FEET
20 0 20 40 60 80 100



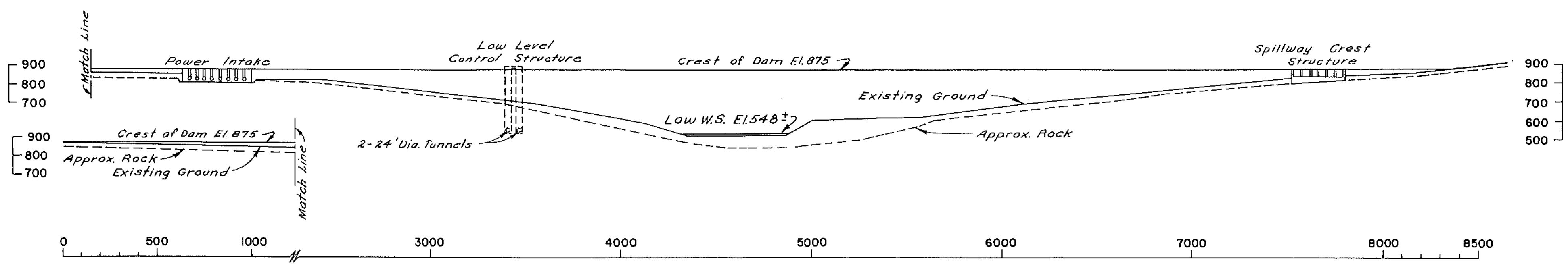
SPILLWAY CREST STRUCTURE

SCALE IN FEET
20 0 20 40 60 80 100



SECTION THRU POWER INTAKE

SCALE IN FEET
20 0 20 40 60 80 100



PROFILE OF DAM

SCALE IN FEET
200 0 200 400 600 800 1000

ELEVATIONS IN FEET M. S. L.

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

RANKIN RAPIDS DEVELOPMENT

PLAN, PROFILES, AND SECTIONS

SHEET I

International Passamaquoddy Engineering Board

AUGUST 1959

Dwg. No. TG7-252

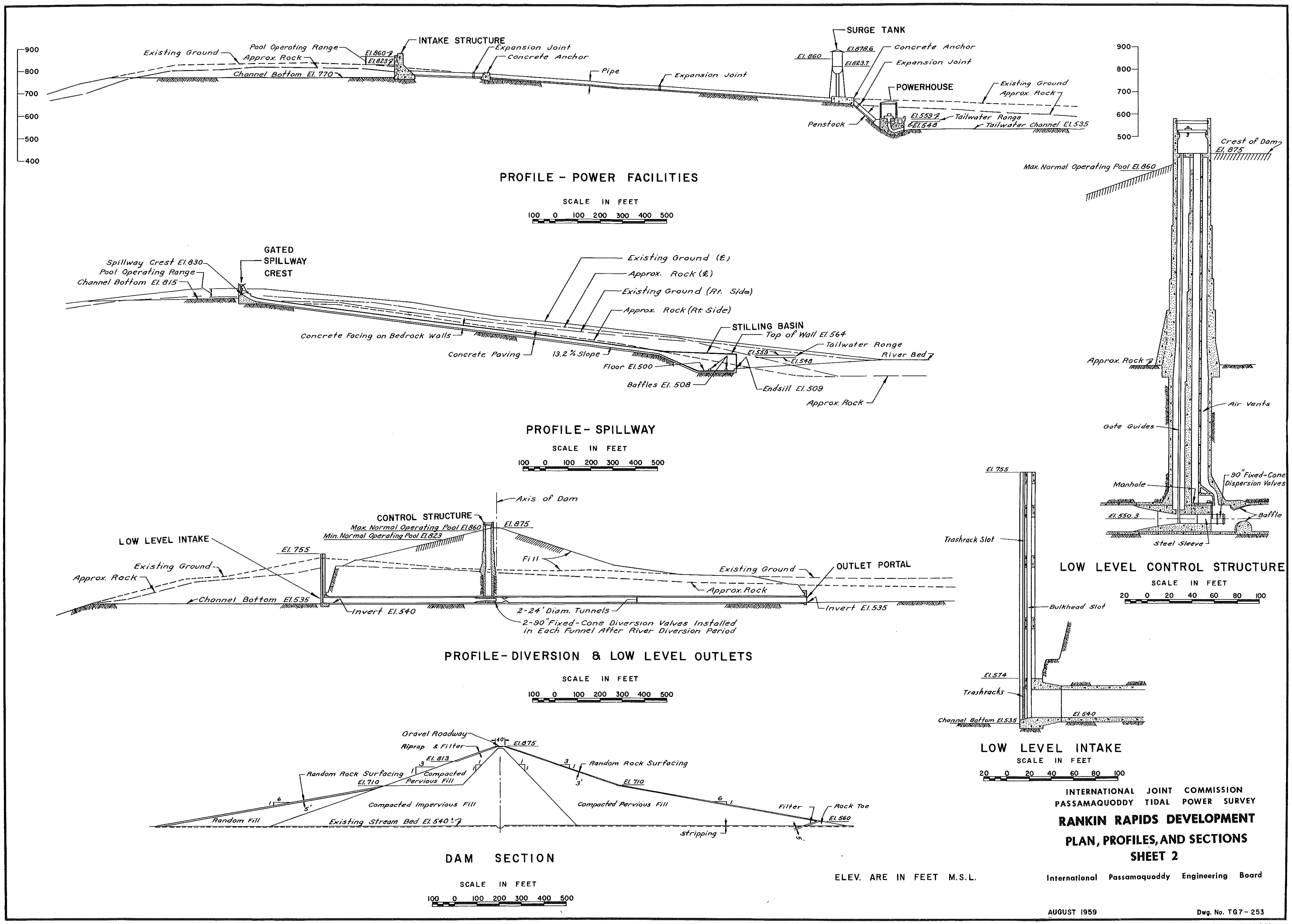

INTAKE STRUCTURE
Existing Ground
Pool Operating Range
Approx. Rock
Channel Bottom El. 770
El. 860
El. 823
Expansion Joint
Concrete Anchor
Pipe
Expansion Joint
SURGE TANK
El. 878.6
El. 823.7
Concrete Anchor
Expansion Joint
POWERHOUSE
Penstock
El. 553
El. 548
Tailwater Range
Tailwater Channel El. 535
Existing Ground
Approx. Rock
PROFILE - POWER FACILITIES
SCALE IN FEET
100 0 100 200 300 400 500
GATED SPILLWAY CREST
Spillway Crest El. 830
Pool Operating Range
Channel Bottom El. 815
Existing Ground (℄)
Approx. Rock (℄)
Existing Ground (Rt. Side)
Approx. Rock (Rt. Side)
STILLING BASIN
Top of Wall El. 564
Tailwater Range
River Bed
El. 559
El. 548
Concrete Facing on Bedrock Walls
Concrete Paving
13.2 % Slope
Floor El. 500
Baffles El. 508
Endsill El. 509
Approx. Rock
PROFILE - SPILLWAY
SCALE IN FEET
100 0 100 200 300 400 500
Axis of Dam
CONTROL STRUCTURE
Max. Normal Operating Pool El. 860
Min. Normal Operating Pool El. 823
El. 875
LOW LEVEL INTAKE
El. 755
Fill
Existing Ground
Approx. Rock
Existing Ground
Approx. Rock
OUTLET PORTAL
Channel Bottom El. 535
Invert El. 540
2-24' Diam. Tunnels
2-90" Fixed-Cone Diversion Valves Installed in Each Funnel After River Diversion Period
Invert El. 535
PROFILE - DIVERSION & LOW LEVEL OUTLETS
SCALE IN FEET
100 0 100 200 300 400 500
Gravel Roadway
Riprap & Filter
40
El. 875
El. 813
Random Rock Surfacing
El. 710
Compacted Pervious Fill
Random Rock Surfacing
El. 710
Compacted Impervious Fill
Compacted Pervious Fill
Random Fill
Existing Stream Bed El. 540±
Filter
Rock Toe
El. 560
Stripping
DAM SECTION
SCALE IN FEET
100 0 100 200 300 400 500
Crest of Dam El. 875
Max. Normal Operating Pool El. 860
Approx. Rock
Air Vents
Gate Guides
Manhole
90" Fixed-Cone Dispersion Valves
Baffle
El. 550.3
Steel Sleeve
LOW LEVEL CONTROL STRUCTURE
SCALE IN FEET
20 0 20 40 60 80 100
El. 755
Trashrack Slot
Bulkhead Slot
El. 574
Trashracks
El. 540
Channel Bottom El. 535
LOW LEVEL INTAKE
SCALE IN FEET
20 0 20 40 60 80 100
ELEV. ARE IN FEET M.S.L.
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
RANKIN RAPIDS DEVELOPMENT
PLAN, PROFILES, AND SECTIONS
SHEET 2
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-253

PLATE 37

Spillway

A chute spillway with a gated concrete crest would pass through the left abutment of the dam (plate 36). Owing to the alignment of the spillway in the hillside adjacent to the dam embankment, a concrete-lined chute and stilling basin would be required.

The crest structure would be a concrete ogee weir equipped with six taintor gates, 40 feet by 30 feet in size. The spillway, designed for a maximum possible flood, would be capable of passing a flow of 167,000 c.f.s. with a maximum surcharge of 2.5 feet above the maximum operating pool at el. 860.

The chute downstream from the spillway crest would be 280 feet wide with a slope of 13.2 percent. The concrete pavement would be 3 feet thick. Sidewalls would be 20 feet high to provide about a 10-foot freeboard. The chute would be 2,000 feet long and terminate in a conventional, concrete-lined stilling basin. The spillway discharge would return to the river by a 700-foot long connecting channel excavated for a short distance in rock.

Power Intakes

The most economical arrangement of penstocks and intake structure was achieved by placing the intake as high as practicable, considering the limit of reservoir drawdowr at el. 823. Invert of the 16-foot penstocks was set at el. 780, which would provide at least 27 feet of submergence for the top of the 16-foot penstocks. An excavated channel from the reservoir to the intake structure would have a bottom at el. 770.

The intake would be a concrete gravity structure placed in line with the embankment centerline, with a top elevation level with the dam crest. Each intake would have a single water passage and would occupy one concrete monolith. The water passage would be provided with an 18- by 35-foot trashrack and an 11- by 22-foot emergency vertical-lift headgate. The gates would be remotely controlled from the powerhouse. Stoplogs, placed in the trashrack slots, would be used when inspection or repair of the gate slots is necessary.

Pipelines, Surge Tanks, and Penstocks

The pipelines from the power intake to the surge tanks, and the penstocks from the surge tanks to the powerhouse, would be constructed of welded steel. All pipelines and penstocks would be 16 feet in diameter, which would produce a maximum velocity of 15 f.p.s. Skinplate thickness would be designed for maximum pressures accompanying emergency interruption of full turbine load with maximum pool head.

The pipelines and penstocks would not be covered by backfill, and no special protection would be needed to prevent the exposed pipelines from freezing. During extended periods of low load in cold weather, when some units are out of service, the penstocks would be drained to prevent icing.

Each pipeline would be equipped with a differential surge tank of steel. The surge tanks would be located 2,100 feet downstream from the power intakes and 200 feet upstream from the powerhouse. The surge tanks would be 53 feet in diameter with bottom of the tank at el. 797 and the top at el. 879. Each tank would be supported by a structural steel tower and connected to the penstock by a riser 16 feet in diameter.

Main Generating Units

The powerhouse would have a dependable capacity of 460,000 kw. at a minimum net head of 269 feet at full turbine gate opening. Eight main generating units were selected for minimum project cost and for maximum efficiency under the varying loads the auxiliary would carry. The turbines would operate normally near the gate opening for best efficiency, which would be close to the rated capacity of the generator. The turbine speed would be 163.6 r.p.m.

The generators would be of the umbrella type, rated at 50,000 kw. nominal capacity to correspond with the turbine output at best gate and rated net head (284 feet). The generators would have "Class B" insulation and be capable of continuous operation at 115 percent of nominal rating at an increased but acceptable temperature rise.

Powerhouse Structure

The powerhouse, constructed of concrete, would be located on the hillside about 1,000 feet from the toe of the dam on the right bank of the river. The powerhouse would be 584 feet long, with eight main-unit bays, a service bay, and a control bay. The main operating floor, erection area, tailrace deck, control room, office, and access to the powerhouse would be on a common level at el. 567. The main generating units and the erection area would be housed by a common superstructure and served by two 120-ton bridge cranes.

Highway and rail access would be made at the east end of the powerhouse. The rail spur would continue into the erection area at el. 567.

Transformers and Switchyard

Four 120,000 kv.-a., 3-phase transformers would be located on the deck of the powerhouse over the draft tube. The transformers would be connected to the switchyard by 230-kv. aerial lines. The switchyard, located about 700 feet from the powerhouse on the right bank of the tailrace (plate 36), would handle four incoming lines from the powerhouse and three outgoing lines.

Lands and Damages

The site of the Rankin Rapids dam and reservoir is located in Aroostook County, Maine (plate 38). The damsite is in the western part of St. Francis Plantation, about 3.5 miles upstream from St. Francis. The reservoir would extend from the dam about 49 miles up the main stem of the Saint John River, 54 miles up the Allagash River, 19 miles up the Big Black River, and 17 miles up the Little Black River. The total combined length of the reservoir along its four main arms is about 140 miles.

Land required for the project includes 98,725 acres for the reservoir, 775 acres for the dam and its appurtenances, and 20 acres for a separate borrow area, a total of approximately 99,500 acres. The reservoir area follows the contour at el. 865, 5 feet above the maximum normal operating pool level (el. 860) for flood surcharge and backwater slope. The downstream portion of the reservoir area is served by Main State Highway 161. An all-weather road follows the south bank of the Saint John River from St. Francis past the damsite to Dickey, Maine, a distance of about 15 miles. A bridge crosses the river at Dickey and an unsurfaced road extends up the Saint John River to Big Rapids. There are small permanent settlements, including schools and churches, along the roads. Many farms in the vicinity have been abandoned and are reverting to woodland. The total population of the reservoir area is approximately 880.

The area above the reservoir is wild, hilly land at an average elevation of 1,000 feet above mean sea level. The forests of the area were first cut for white pine, then for spruce, fir, and cedar. The cutting nearly ceased in 1922 and resumed again in 1946. Nearly every year since 1946, spruce and fir have been cut for pulp in Allagash Plantation and adjacent areas. Cutting of pulp and timber is the main economic activity of the area. There appears no likelihood that the economic pattern of the area or the use of the land will change in the future. In addition to the forest activities, there is some recreational activity in the wild land areas, including hunting, fishing, camping, hiking, and whitewater canoeing on the Allagash River.

Most of the land required for the project is in large tracts of timber held mainly for pulpwood cutting. Small ownerships, classified as rural-residential, are located along the valley in the lower part of the reservoir area. A total of 282 taxpayers own property in the reservoir area, 52 in St. Francis Plantation, 179 in Allagash Plantation, and the remaining 51 in unorganized townships. All houses in Allagash Plantation would be taken. The only utilities in the area, other than Maine State Highway 161, are the lines along the highway of the Maine Public Service Company, the Fort Kent Telephone Company, and an extensive single-wire telephone line of the Maine Forest Service.

An appraisal of the land required for the project was made under contract by an appraiser familiar with the locality. The land was classified according to its highest and best use, and appraised on the basis of fair market value as of January 1958. An allowance was made for both the value of the wood growth on the land and for severance.

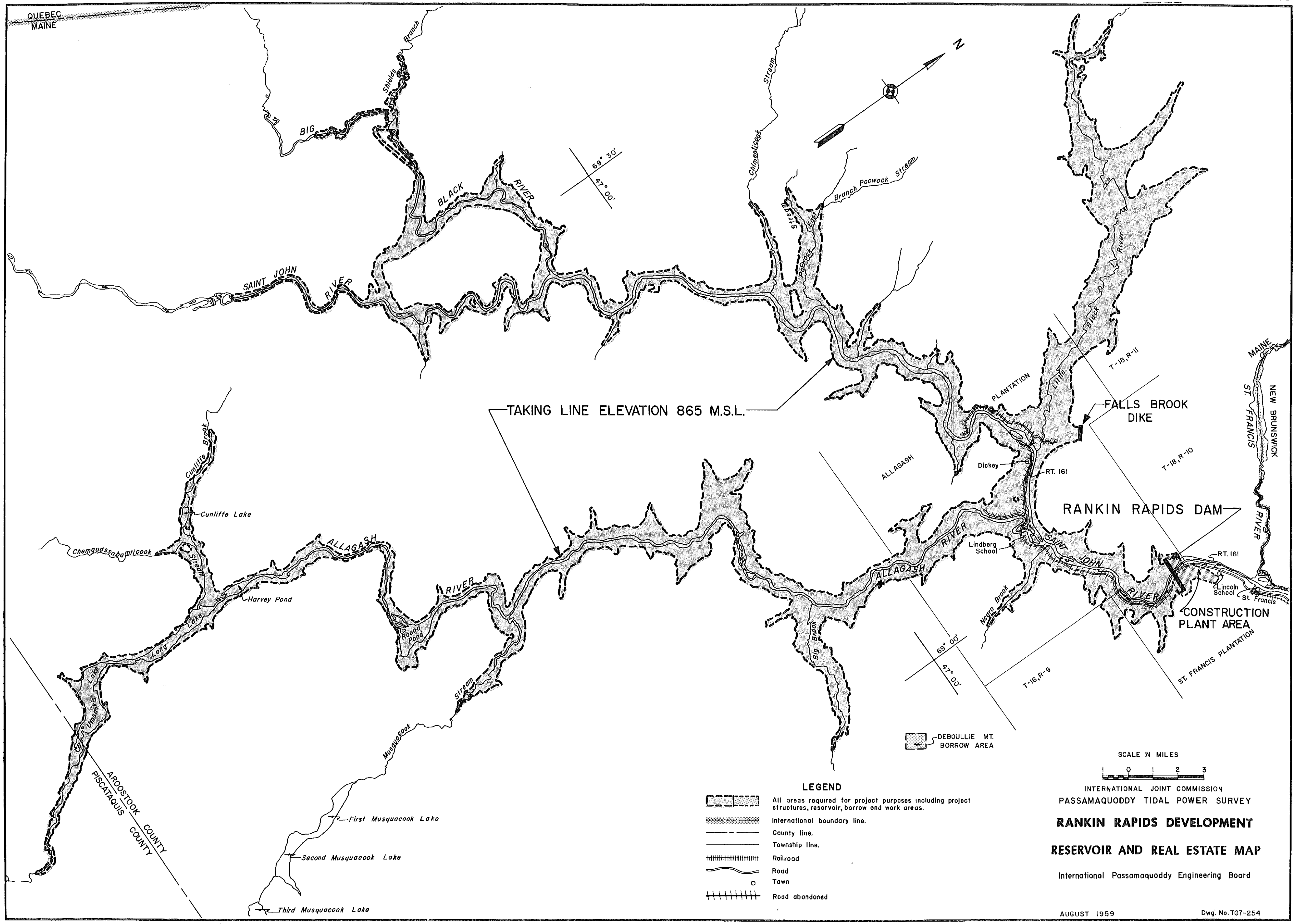

QUEBEC
MAINE
BIG
Shields Branch
BLACK
RIVER
SAINT JOHN
RIVER
Chimenticook Stream
Pocwock Stream
East Branch Pocwock Stream
Little Black River
TAKING LINE ELEVATION 865 M.S.L.
PLANTATION
ALLAGASH
FALLS BROOK DIKE
T-18, R-11
T-18, R-10
Dickey
RT. 161
RANKIN RAPIDS DAM
Cunliffe Brook
Cunliffe Lake
Chemquassabamticook Stream
Harvey Pond
Long Lake
Umsaskis Lake
ALLAGASH RIVER
Round Pond
Musquacook Stream
Big Brook
Lindberg School
Negro Brook
SAINT JOHN RIVER
Lincoln School
St. Francis
CONSTRUCTION PLANT AREA
ST. FRANCIS PLANTATION
T-16, R-9
MAINE
NEW BRUNSWICK
ST. FRANCIS RIVER
69° 30'
47° 00'
69° 00'
47° 00'
N
AROOSTOOK COUNTY
PISCATAQUIS COUNTY
First Musquacook Lake
Second Musquacook Lake
Third Musquacook Lake
DEBOULLIE MT. BORROW AREA
LEGEND
All areas required for project purposes including project structures, reservoir, borrow and work areas.
International boundary line.
County line.
Township line.
Railroad
Road
Town
Road abandoned
SCALE IN MILES
1 0 1 2 3
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
RANKIN RAPIDS DEVELOPMENT
RESERVOIR AND REAL ESTATE MAP
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-254

PLATE 38

Severance would result from the flooding of private woods roads by the reservoir, and the allowance was the estimated cost of other access. Improvements on the land were estimated separately.

An allowance of $10,000 was made for purchase of water rights for presently-breeched dams, one on the Saint John River and the other on the Allagash River. International water rights on the Saint John River arise from the treaty of August 9, 1842, between the United States and Britain (the Webster-Ashburton treaty), which provides for common use of the waters of the Saint John River to promote commerce and transportation for the benefit of the United States and Canada. The only use made of the river in the sense of the treaty is the floating of logs and pulpwood to downstream locations. The design of the dam provides for a log chute to maintain this traffic. Anadromous fish do not pass the damsite since they are blocked downstream at natural obstacles.

Resettlement costs were estimated in accordance with United States Public Law 534, Section 401 (b), and subsequent supplemental regulations. The direct cost of resettlement was estimated from experience with similar types of improvements. The allowances range from $200 for small camps to $2,000 for schools.

There are no mining operations and no known values of minerals in the project area.

Relocations

Construction of the Rankin Rapids auxiliary river hydro project would require relocation of the following:

Power pole line, Maine Public Service Company	10 miles
Telephone pole line, Fort Kent Telephone Company	10 miles
Single wire telephone line, Maine Forest Service	117 miles
Three cemeteries	250 graves

The estimated costs of pole line reclocations are the depreciated values of the lines and the cost of removal, less the salvage value of materials. The Maine Forest Service telephone line would require a substitute facility.

Maine State Highway 161, extending about 12 miles into the reservoir area, would not be relocated because the farms and dwellings served by it would be acquired for the reservoir and no areas beyond the reservoir are served by public highways. The many private woods roads in the area are maintained only when needed by the forest land owners. The value of these roads is reflected in the allowance for severance under lands and damages. After construction of the project, general access to the areas adjacent to the reservoir would be facilitated by water transportation on the reservoir. Therefore, no allowance was made for relocation of highways.

Service Facilities

The Rankin Rapids site is located 175 air miles from the tidal power project. For this reason the project would be essentially independent for all operating services and most maintenance work. The project would be provided with maintenance shops, vehicle servicing shops, warehousing, housing for key employees, land vehicles and equipment, and marine plant.

Reservoir Filling

Dead storage at the Rankin Rapids auxiliary hydro project would be 5.43 million acre-feet, or a little more than the average annual flow of 4.95 million acre-feet at the site. What portion of the flow at the site can be retained for filling the reservoir depends both on the permissible minimum flow immediately downstream from the dam, and on the water needed to operate downstream power plants. Permissible minimum flow was assumed to be 500 c.f.s. and the water needed at the Beechwood plant in New Brunswick was estimated at 9,700 c.f.s. Since much of the flow at Beechwood comes from tributary areas below Rankin Rapids, only sufficient water to maintain at least 9,700 c.f.s. at Beechwood would be released at Rankin Rapids. Given these conditions, about 4.14 million acre-feet could be stored at Rankin Rapids during an average year. About 1 million acre-feet of this storage would be filled during the June-February period and the remainder during the March-May spring freshet. This 4.14 million acre-feet of storage would raise the reservoir to about el. 800, submerging the power intakes and permitting generation of power.

Construction Schedule

The Rankin Rapids river hydro auxiliary could produce power from its first two generators about 3 1/2 years after construction is started, and all eight units could be on the line 1 year later. Construction of the project should be started at the same time as the tidal power project, so that the new capacity would be available for transmission into Maine and New Brunswick at a rate approximately equal to the rate of load growth. In this way, the first two Rankin Rapids units would be on the line 2 1/2 years before tidal power, and all eight units 1 1/2 years before tidal power is on the line.

As shown on plate 39, work would begin with excavation and construction of the diversion tunnels and earth embankment on the abutments. The tunnels would be completed early in the second year. After the spring freshet of the second year, the river would be diverted through the tunnels and the embankment started in the river channel. This embankment must be raised high enough (el. 710) during the second year so that the spring freshet of the third year will not overtop it. After the freshet of the third year, control valves would be installed in the tunnels and reservoir filling started. Other work would proceed at the same time. The spillway would be completed in the third year. The first two units of the powerhouse would be on the line about 1 year after filling is started. The reservoir would contain enough water for power production, if the river flow is average or more. The remaining six power units would be completed in the middle of the fifth year.

Operation and Maintenance

In staff organization, the Rankin Rapids auxiliary, with 39 employees, would be subordinate to the tidal power project. The project engineer would report directly to the project engineer at the tidal power project. The Rankin Rapids project engineer, aided by an assistant project engineer, would be in direct charge of all operation and maintenance. An administrative assistant and a general clerk would be charged with timekeeping, inventory, and records. Of the 15 plant operators, at least 3 would be on duty at all times. The senior operator would supervise the other two from the control room. Two assistants would work on the generator floor where they would check operation of the equipment. They would periodically visit and check the intakes, low-level conduits, spillway, and switchyard, and also perform the switching as ordered by the senior operator.

A high degree of automatic control and centralized operation would make it possible to function with only three operators on each shift. Because Rankin Rapids would be operated as the auxiliary to the tidal project, switching would be more frequent than usual. Automatic switching, therefore, besides reducing the number of personnel, would prevent errors in operation.

A 20-man force would maintain the project. This crew would handle all preventive maintenance. Additional men would be sent from the tidal plant when special skills are needed, or when the local crew is not large enough for periodic or emergency maintenance.

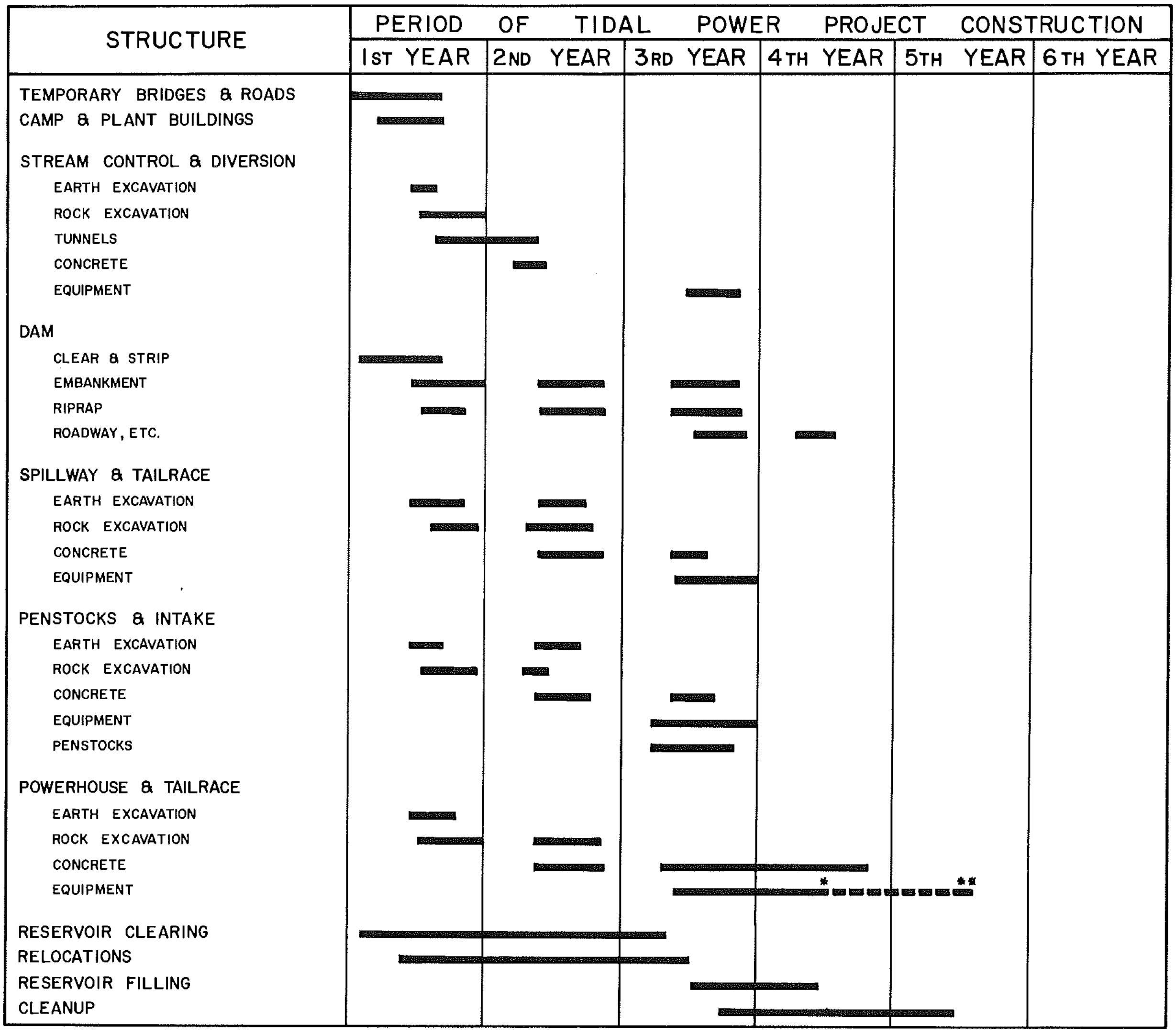
Downstream Projects

The existing Beechwood and Grand Falls hydroelectric projects on the Saint John River are located in New Brunswick, downstream from the Rankin Rapids site. The Beechwood plant is owned and operated by The New Brunswick Electric Power Commission, and the Grand Falls plant has been operated by the Commission since May 1, 1959. Both plants would benefit by the flow regulation achieved by Rankin Rapids auxiliary. In addition, several other sites are available on the Saint John River in New Brunswick where hydroelectric projects could be built. These plants would also benefit from regulation by Rankin Rapids. The value of Rankin Rapids regulation to the existing and potential downstream power plants is discussed in chapter IX.

DIGDEGUASH PUMPED-STORAGE AUXILIARY

After a study of several sites for pumped-storage reservoirs, a site on the Digdeguash River in New Brunswick was selected. Specific designs for the Digdeguash pumped-storage auxiliary were then carried to the same degree of refinement as the design of the Rankin Rapids river hydro auxiliary.

CONSTRUCTION SCHEDULE



* 2 Units in operation
** 8 Units in operation

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

RANKIN RAPIDS DEVELOPMENT

CONSTRUCTION SCHEDULE

International Passamaquoddy Engineering Board

AUGUST 1959

Dwg. No. TG7-255

Site Development

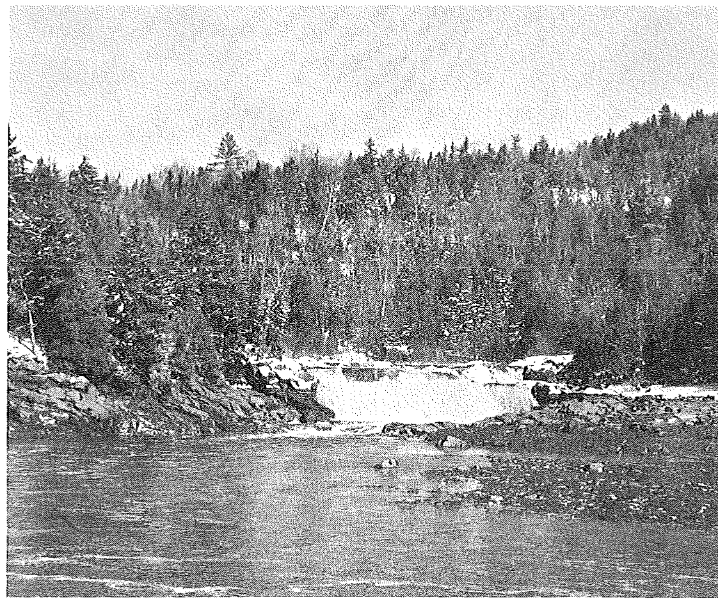
The Digdeguash River flows into Passamaquoddy Bay from the north. The reservoir would be formed in Dumbarton and St. Patrick Parishes, Charlotte County, New Brunswick, by damming the river at a location about 1,000 feet from tidewater where the stream bed is at el. 30. A channel excavated from the powerhouse to tidewater would provide much of the rock required for a rock-fill dam with an earth core. Other sites closer to tidewater, or located on the tidewater portion of the Digdeguash River, were studied and found to be more costly to develop.

Sea water stored in the reservoir between els. 140 and 180 could generate 28 million kw.-hr. of energy. This storage would be sufficient to permit full use of the combined output of the tidal plant and the pumped-storage plant in a normal market. These pool levels would provide favorable heads for efficient operation of the pumped-storage plant without inundating the town of Rolling Dam or Rolling Dam Station during the maximum possible flood. Three small saddle dams would be required. Two on the east side would be located almost entirely above the maximum normal pool level at el. 180.

The damsite is located in a narrow valley in bedrock with thin overburden. The powerhouse would be constructed in a deep excavation in the left abutment immediately downstream from the dam (plate 40). The reservoir would be connected to the powerhouse by an excavated approach channel, an intake structure, short high-level tunnels, and short steel penstocks above ground. A gated spillway in the right abutment would be a concrete overflow section of the dam with a short paved apron discharging into a small ravine leading to the tidewater portion of the Digdeguash River.

Power

The Digdeguash pumped-storage auxiliary would use surplus energy from the tidal plant to pump water from Passamaquoddy Bay to the reservoir. The stored water would be used to generate power when the tidal plant output is less than the load. This energy interchange for a typical 3-week period of operation is shown by the crosshatched areas on plate 13.



Falls on Digdeguash River at pumped-storage dam site

For an average annual generation of 1,843 million kw.-hr. at the tidal plant, 1,443 million kw.-hr. would fit under the normal load pattern. The remaining 400 million kw.-hr. would be used to pump sea water into the Digdeguash reservoir. When this sea water is passed through the turbines, it would generate 286 million kw.-hr. at an overall efficiency of 71.6 percent. The total annual output of the Digdeguash plant would be increased, however, by an additional 30 million kw.-hr. from fresh water inflow from the Digdeguash River. The net annual energy output to the load would be 1,443 million kw.-hr. from the tidal plant and an output of 316 million kw.-hr. from the pumped-storage plant, or a total of 1,759 million kw.-hr. during an average year. Total values would be 1,650 and 1,844 million kw.-hr. for minimum and maximum years.

The dependable generating capacity of the Digdeguash pumped-storage plant was selected as 228,000 kw. In combination with the tidal plant, total dependable capacity would be 323,000 kw. The ratio of average output to dependable capacity of this combination would be 62.2 percent in an average year, 58.3 percent in a minimum year, and 65.2 percent in a maximum year.

The Digdeguash reservoir could generate, without replenishment, about 28 million kw.-hr. from the sea water in storage. Of this amount, 14 million kw.-hr. would be required to compensate for the hourly, daily, and weekly variations in the load pattern and tidal plant output. The remaining storage would be sufficient to regulate the monthly average output at a constant amount. This storage would not be great enough, however, to regulate for month-to-month variations in the total system load.

Embankment

The main dam and saddle dams would be constructed of rockfill with an earth core. The crests at el. 190 would not be overtopped by wave runup above the maximum still-pool level. The embankments are designed to make maximum use of the materials available from construction excavation. Rock for the dams, including riprap, would be obtained mainly from excavation from the tailrace and the powerhouse. The impervious core would be composed of glacial till available from the valley walls and floor of the reservoir. Details of design would follow standard practice.

Care of Water During Construction

In order to place the impervious core material of the dam in the dry, the Digdeguash River would be diverted through a low-level tunnel in bedrock on the left side of the stream. This tunnel would not have to be converted into a low-level outlet because the power intakes are relatively low and because flow from the Digdeguash drainage area into the reservoir would be small in comparison with the turbine capacity. The 12- by 14-foot tunnel would be plugged with concrete after diversion.

Spillway

The gated spillway would pass the maximum possible flood with a maximum pool level at el. 184.5 and a spillway discharge of 75,000 c.f.s. Three 25- by 40-foot taintor gates would be provided with the top at el. 180. The concrete crest structure would be a gravity dam with an ogee shape (crest el. 155). From the toe of the dam, a short chute would direct the flow to a ravine. The chute would be constructed in bedrock lined with concrete for about 150 feet from the toe of the dam. The shallow overburden would be removed from the ravine so that the spillway discharge would not carry this material into the tidal portion of the Digdeguash River.

Main Power Units

The powerhouse would contain four dual-purpose units. Each unit would function as a turbine-generator to generate electrical power and as a pump-motor to pump water into the reservoir. The runners would be rated at 110,000 hp. at maximum operation as turbines. The pump-turbines would be of the recently developed feathering-blade Francis type installed at the Sir Adam Beck Station No. 2 at Niagara Falls, Canada. The speed of rotation would be 100 r.p.m. The blades on these turbines can be feathered so that flow is virtually closed off. For this reason, the turbines would not be equipped with conventional wicket gates. Because the blades overlap when fully feathered, they cannot be fully reversed. Therefore, the runner rotation must be reversed when changing from pumping to generating or back to pumping. This feathering capability, however, permits changeover from pumping to generating without evacuating the water from the draft tube.

The reversible motor-generators would be rated at 84,300 hp. as motors, and at 68,300 kv.-a. as generators. They could be operated continuously at 115 percent of the nominal rating either as a motor or a generator at a speed of 100 r.p.m.

Power Intakes

A reinforced concrete intake tower would be provided for the emergency headgates and trashracks at the reservoir end of each of the four power tunnels. The towers would be separate structures founded on bedrock, connected with each other and with the reservoir shore by a bridge.

Each intake would be equipped with two 7- by 24-foot, wheeled, emergency head gates. The gates would be operated by individual hoists, remotely controlled from the powerhouse. Each passage would also be equipped with a 14-foot-wide by 32-foot-high trashrack panel. Air vents downstream from the head gates would prevent negative pressures from accumulating in tunnels and penstocks during emergency closure of the gates.

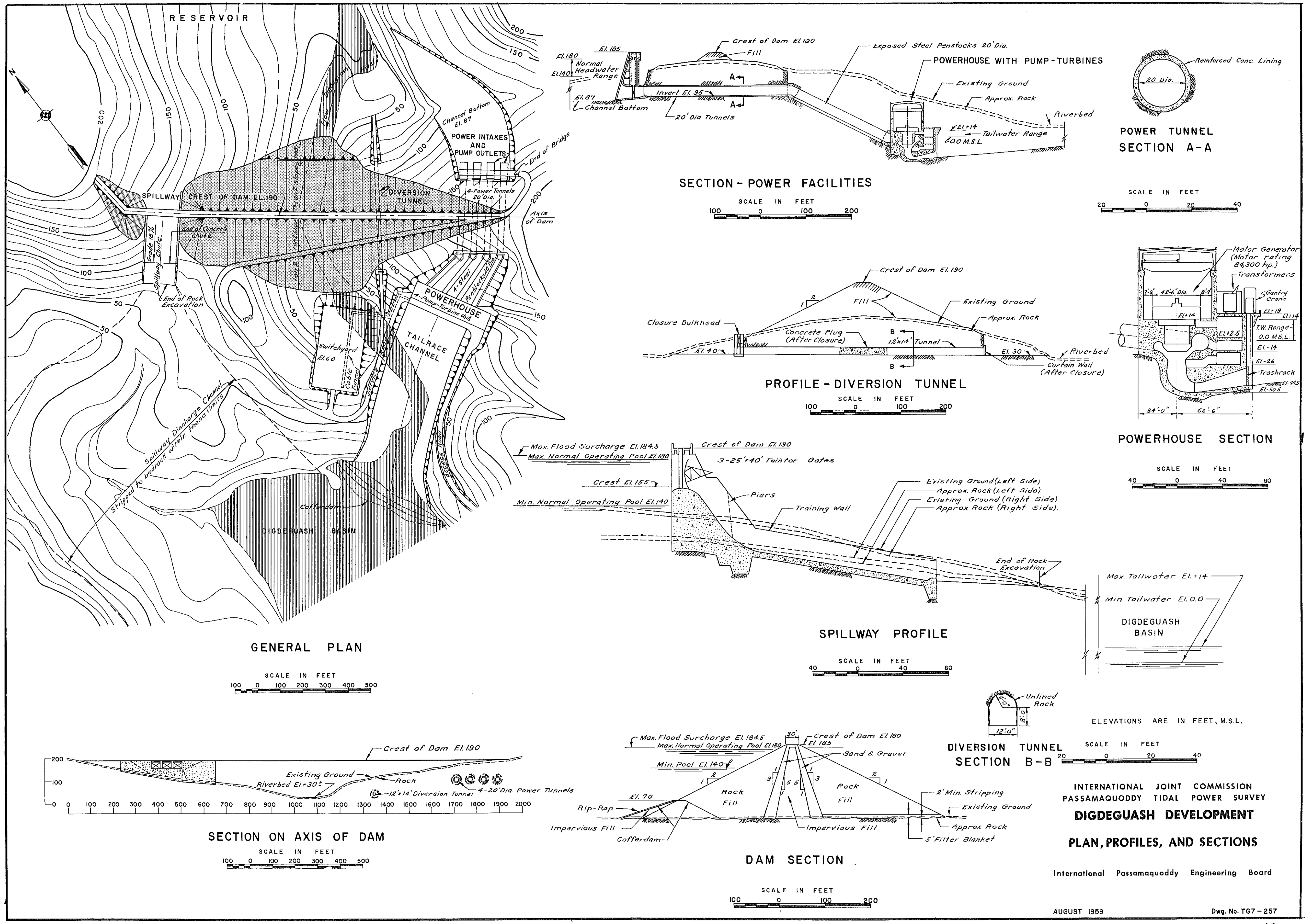

RESERVOIR
SPILLWAY
CREST OF DAM EL. 190
DIVERSION TUNNEL
Channel Bottom El. 87
POWER INTAKES AND PUMP OUTLETS
End of Bridge
4-Power Tunnels 20' Dia.
Axis of Dam
End of Concrete chute
Grade 18% Spillway Chute
End of Rock Excavation
POWERHOUSE 4-Pump-Turbine Units
4-Steel Penstocks 20' Dia.
TAILRACE CHANNEL
Switchyard El. 60
Cable Tunnel
Access Road
Spillway Discharge Channel Stripped to bedrock within these limits
Cofferdam
DIGDEGUASH BASIN
GENERAL PLAN
SCALE IN FEET
100 0 100 200 300 400 500
Crest of Dam El. 190
El. 195
El. 180
Normal Headwater Range
El. 140
El. 87
Channel Bottom
Fill
Invert El. 35
20' Dia. Tunnels
Exposed Steel Penstocks 20' Dia.
POWERHOUSE WITH PUMP-TURBINES
Existing Ground
Approx. Rock
Riverbed
El. +14
Tailwater Range
0.0 M.S.L.
SECTION - POWER FACILITIES
SCALE IN FEET
100 0 100 200
Reinforced Conc. Lining
20' Dia.
POWER TUNNEL SECTION A-A
SCALE IN FEET
20 0 20 40
Crest of Dam El. 190
Fill
Existing Ground
Approx. Rock
Closure Bulkhead
Concrete Plug (After Closure)
12'x14' Tunnel
El. 40
El. 30
Riverbed
Curtain Wall (After Closure)
PROFILE - DIVERSION TUNNEL
SCALE IN FEET
100 0 100 200
Motor Generator (Motor rating 84,300 hp.)
Transformers
Gantry Crane
42'-6" Dia.
El. +14
El. +2.5
T.W. Range 0.0 M.S.L.
El. -14
El. -26
Trashrack
El. -50.5
34'-0"
66'-6"
POWERHOUSE SECTION
SCALE IN FEET
40 0 40 80
Max. Flood Surcharge El. 184.5
Max. Normal Operating Pool El. 180
Crest of Dam El. 190
3-25'x40' Tainter Gates
Crest El. 155
Piers
Min. Normal Operating Pool El. 140
Training Wall
Existing Ground (Left Side)
Approx. Rock (Left Side)
Existing Ground (Right Side)
Approx. Rock (Right Side).
End of Rock Excavation
Max. Tailwater El. +14
Min. Tailwater El. 0.0
DIGDEGUASH BASIN
SPILLWAY PROFILE
SCALE IN FEET
40 0 40 80
Unlined Rock
12'-0"
8'-0"
DIVERSION TUNNEL SECTION B-B
SCALE IN FEET
20 0 20 40
ELEVATIONS ARE IN FEET, M.S.L.
Crest of Dam El. 190
Existing Ground
Riverbed El. +30±
Rock
12'x14' Diversion Tunnel
4-20' Dia. Power Tunnels
SECTION ON AXIS OF DAM
SCALE IN FEET
100 0 100 200 300 400 500
Max. Flood Surcharge El. 184.5
Max. Normal Operating Pool El. 180
Min. Pool El. 140
30'
Crest of Dam El. 190
El. 185
Sand & Gravel
Rock Fill
El. 70
Rip-Rap
Impervious Fill
Cofferdam
2' Min. Stripping
Existing Ground
Approx. Rock
5' Filter Blanket
DAM SECTION
SCALE IN FEET
100 0 100 200
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
DIGDEGUASH DEVELOPMENT
PLAN, PROFILES, AND SECTIONS
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-257

PLATE 40

The intake structures would serve as intakes during power generation and as outlets during pumping. For efficient pumping, the water passages on the reservoir side of the gates would be longer and more gradually flared than the usual intake designed for power use without pumping. The twin passages in each intake would be joined downstream from the head-gate slots in a power tunnel 20 feet in diameter.

Tunnels and Pipe Lines

Each pump-turbine would be connected to the reservoir by a separate penstock 20 feet in diameter. The upper section would be a reinforced concrete-lined tunnel in the rock abutment. This section would be 320 feet long with the invert at el. 95. Exposed steel penstocks 230 feet long on a 60 percent grade would connect the tunnel with the powerhouse. No special provision against freezing would be needed. Penstocks may be drained to prevent freezing if a unit is out of service for an extended period. The penstocks would be short and no surge tanks would be needed.

Powerhouse

The concrete powerhouse would be of the conventional indoor type. Each of the four generators would be set in a unit bay 74 feet long. With an 83-foot service bay located at the east end, the whole structure would be 379 feet long. The main generator floor would be at el. 14. The erection area in the service bay, the deck above the draft tubes, and the road servicing these areas would be at el. 19. A structure over the draft tubes would include vaults for two main transformers, the powerhouse control room, equipment rooms, and office space. A 365-ton traveling bridge crane would erect the main generating units during construction of the powerhouse. The crane would be used later to maintain the main power units and to untank the transformers.

Main Transformers and Switchyard

Two main power transformers would be provided for the four main power units. Each would be rated 157,000 kv.-a., 3-phase, and have a high tension voltage of 138 kv. The transformers would be located on the deck on the tailrace side of the powerhouse. Overhead lines would connect the transformers to the switchyard on the right bank of the tailrace. The switchyard would contain six line bays and two transfer bays. Two lines would connect with the distribution system in the United States and the tidal project switchyard. Two other lines would connect with the distribution system in Canada.

Corrosion Prevention

The problem of corrosion prevention at the Digdeguash pumped-storage auxiliary would be essentially the same as at the tidal power plant and the same preventive measures would be used. Estimates of cost are based on the following provisions:

(1) Pump-turbine blades, the hub, runner cone, discharge ring, and the top 4 feet of the draft tube liner would be stainless steel of AISI type 316.

(2) All other metal in the pump-turbine would be carbon steel. All surfaces exposed to sea water, including inner and outer head cover, and stay and guide vanes, would be protected with six coats of vinyl paint. The outer two coats would be an antifouling composition. An impressed voltage cathodic protection system would also protect the carbon steel in case of damage to the vinyl coat.

(3) The penstock, scroll case, and draft tube liner would be constructed of carbon steel plate, coated on the water side with a six-coat, antifouling vinyl paint. The penstock exterior would be given a four-coat vinyl painting, omitting the antifouling coats. The interior would also be protected by an impressed voltage cathodic protection system.

(4) Powerhouse intake gates, intake and draft tube trashracks, and spillway gates would be made of carbon steel and painted with a prime coat of coal-tar enamel. Guides and seal plates for powerhouse trashracks and intake gates would be corrosion-resistant alloy cast iron (Ni-Resist). The gate slots could be unwatered, but the lower part of trashrack guides would be accessible for repair only with great difficulty. Spillway gate seals and stoplog guides would be of carbon steel. The gates could be unwatered, and the stoplog guides would be periodically accessible for maintenance when pool levels are low. The

embedded metals would all be coated on the exposed surfaces with six coats of vinyl paint with antifouling top coats. Impressed voltage cathodic protection would also supplement the protective coatings at all locations.

Lands and Damages

The Digdeguash pumped-storage dam and reservoir would be located in Charlotte County, New Brunswick, north of Passamaquoddy Bay. The powerhouse and dam would be located just above Digdeguash basin, a small salt water bay. The reservoir would extend up the river about 12 miles to include the village of Elmsville, but not Rolling Dam nor Rolling Dam Station (plate 41). The valley is rolling country, partly wooded, with the remainder in farmland. The area is thinly populated and is classified as rural-residential with some small farming and woodlots.

The area to be acquired for the reservoir and dam comprises 6,842 acres in about 67 ownerships. Approximately 180 people live in the area, which includes 32 homes, 14 vacant houses, 13 camps, and 2 churches. The principal economic activities are farming and woodlot operations, which seem to be decreasing as rural residents find employment in cities and towns. It does not appear that the use of the land will change.

The area was surveyed by an experienced appraiser under contract to the Department of Public Works, Canada. Most land was classified from aerial photographs and visually checked on the ground. Buildings were inspected from the outside and estimated values were checked with local assessors. The value of growing timber is included in the value of land. The estimates are based on compensation paid for acquisition of comparable properties by government agencies, not on sale prices in the local area.

No mineral rights or water rights are known to be outstanding. No crop damage is estimated since there is no farmland at the damsite and since other farmland can be acquired to allow for harvesting. Severance damages are included in the estimate where the land holding would be divided by the taking line, the contour at el. 180.

The estimated cost of lands and damages for the proposed Digdeguash pumped-storage auxiliary power project is based on the price level of January 1958. In accordance with Canadian practice, where lands are expropriated for public projects, an allowance of 10 percent above basic value is included for forceful taking of inhabited areas.

Relocations

The principal road in the vicinity of the pumped-storage plant runs generally parallel to the Digdeguash River from Route 1 near Passamaquoddy Bay and crosses the reservoir area at Elmsville. The relocations would provide a similar road, on each side of the reservoir, which would be gravel surfaced and comparable to the existing road, except that modern standards of grade and alignment would be used where new right-of-way is needed. On the northeast side of the Digdeguash reservoir there would be about 10.2 miles of road relocation and of this length 0.8 mile would be on new right-of-way. On the southwest side of the reservoir approximately 3.7 miles of road relocation would be required, of which 3.3 miles would be on new right-of-way. These road relocations are shown on plate 41.

About 16.6 miles of power distribution lines of The New Brunswick Electric Power Commission lie within the area which would be flooded. Because these lines would not be needed after the project is build, they would not be relocated. An allowance is made, however, in the project cost under relocations for the residual value of the line. The line of the Eastern Telegraph and Telephone Company, however, which crosses the area of the tail-race and spillway channel, would be relocated.

Two cemeteries, one in the town of Elmsville and the other on the east ridge near the east saddle dams, containing a total of 200 graves, would be relocated.

Service Facilities

The Digdeguash development, although relatively close to the tidal power plant, would be self-sufficient in all operating and most maintenance functions. A small amount of assistance would be provided for

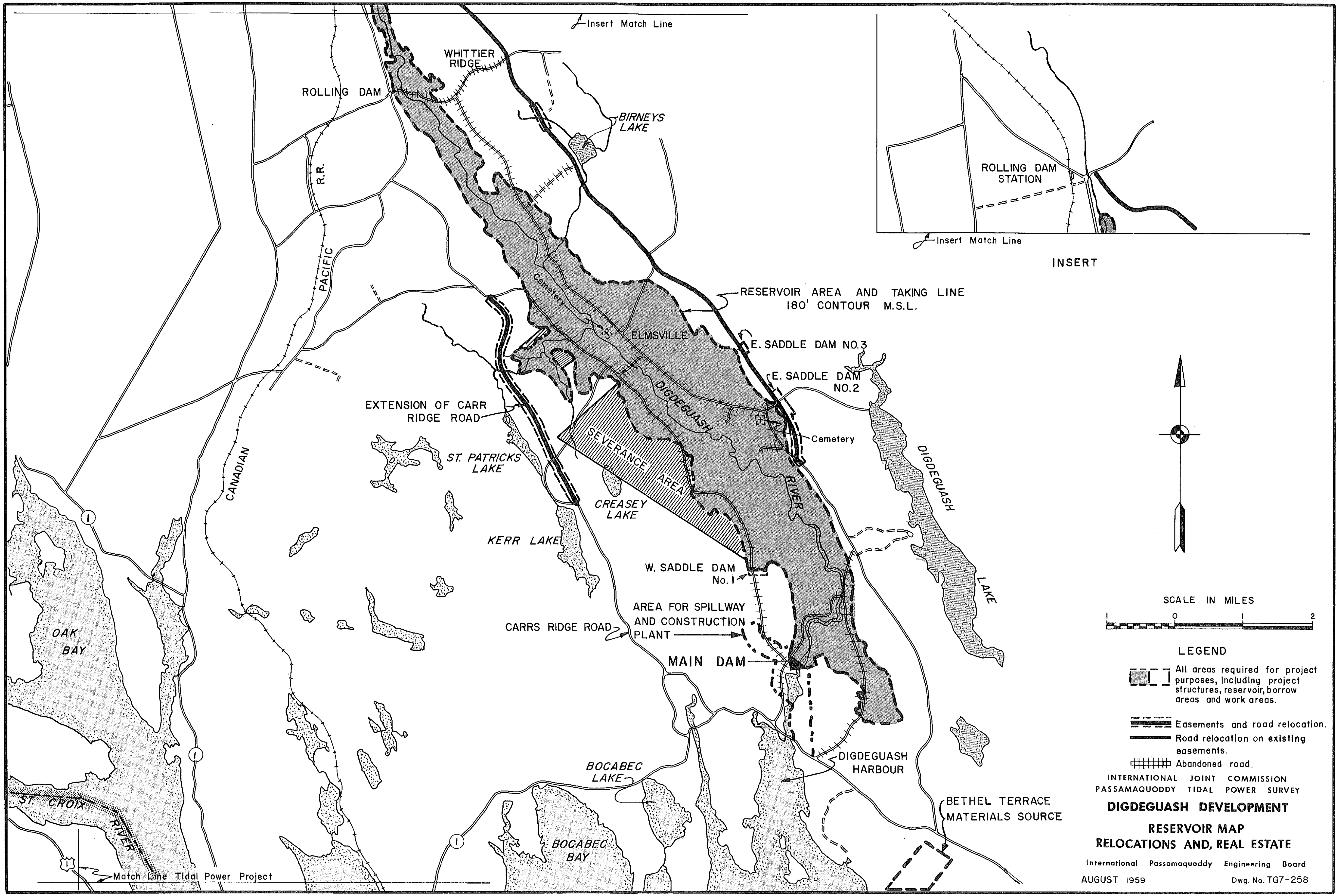

Insert Match Line
WHITTIER RIDGE
ROLLING DAM
BIRNEYS LAKE
R.R.
PACIFIC
CANADIAN
Cemetery
ELMSVILLE
RESERVOIR AREA AND TAKING LINE
180' CONTOUR M.S.L.
E. SADDLE DAM NO.3
E. SADDLE DAM NO.2
Cemetery
DIGDEGUASH
RIVER
SEVERANCE AREA
EXTENSION OF CARR RIDGE ROAD
ST. PATRICKS LAKE
CREASEY LAKE
KERR LAKE
W. SADDLE DAM No. 1
AREA FOR SPILLWAY AND CONSTRUCTION PLANT
CARRS RIDGE ROAD
MAIN DAM
DIGDEGUASH HARBOUR
DIGDEGUASH LAKE
OAK BAY
BOCABEC LAKE
BOCABEC BAY
ST. CROIX RIVER
Match Line Tidal Power Project
BETHEL TERRACE MATERIALS SOURCE
ROLLING DAM STATION
Insert Match Line
INSERT
SCALE IN MILES
0
1
2
LEGEND
All areas required for project purposes, Including project structures, reservoir, borrow areas and work areas.
Easements and road relocation.
Road relocation on existing easements.
Abandoned road.
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
DIGDEGUASH DEVELOPMENT
RESERVOIR MAP
RELOCATIONS AND, REAL ESTATE
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-258

PLATE 41

heavy maintenance by personnel and equipment from the tidal plant. The Digdeguash development would be equipped with maintenance shops, vehicle storage, warehousing, employee housing for key personnel, and land and marine plant necessary for normal operation and maintenance. Specialized equipment such as truck cranes, work barges, and special heavy-duty trucks would be obtained from the tidal power plant when needed.

Construction Schedule

Completion of the pumped-storage project would be scheduled at the same time as the tidal power project. Accordingly, construction would be started during the third year of the tidal project construction. Excavation for the powerhouse, spillway, and diversion tunnel would also be started in the third year (plate 42). The tunnel would be completed by the fourth spring. Stream closure, dam embankment, and the spillway would be completed by the end of the fourth year and the first power unit would be completed by the end of the fifth year. The remaining three units would be installed by the end of the sixth year, at which time the tidal power plant would also be ready for operation.

Operation and Maintenance

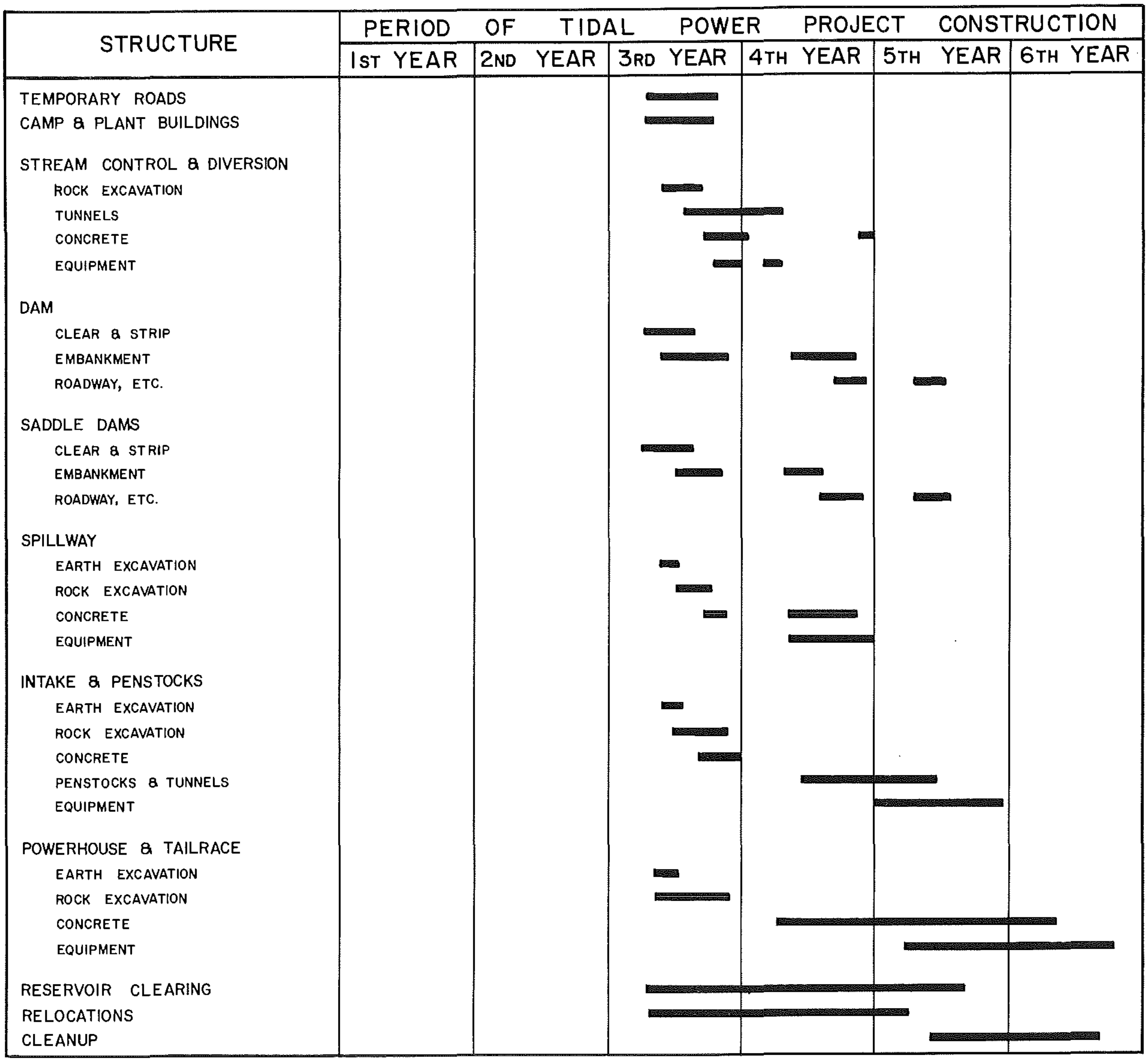
The Digdeguash project would be operated by 29 employees, including a project superintendent who would report to the project engineer at the tidal power project. He would be supported by an administrative assistant and a clerk.

The operating staff would consist of 10 men, enough to have 2 men on duty at all times. The senior operator would direct and control all operations from the powerhouse control room. The assistant would work on the generator room floor where he would do switching when instructed, and oversee the physical condition of the operating equipment. The assistant would also periodically visit the intakes, spillway, and switchyard to check their condition.

A high degree of automatic control and switching would be provided so that the plant may be operated by two men on each shift. The operation of the pumped-storage plant would be coordinated closely with the tidal plant in order to match the constantly varying output of the tidal plant and the load. Carrier telephone and telemetering systems would be provided for this purpose.

A 16-man maintenance force would be provided for the pumped-storage project. This crew would normally handle all preventive maintenance without assistance. Additional men would be assigned from the tidal project when needed for periodic or emergency maintenance.

CONSTRUCTION SCHEDULE



INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

DIGDEGUASH DEVELOPMENT

CONSTRUCTION SCHEDULE

International Passamaquoddy Engineering Board

AUGUST 1959

Dwg. No. TG7-259

PLATE 42

CHAPTER VI

DEVELOPMENT OF COSTS

The preparation of designs for the tidal power project and auxiliaries required a search for the least expensive methods of construction. When these methods were found, they were incorporated into the design. In this sense the following paragraphs describe only one phase of the process of determining project costs and apply only to the specific designs described in chapters IV and V.

CRITERIA

Project first costs were estimated on the basis of United States currency and cost levels prevailing in the United States in January 1958. United States costs were used because investigation showed that the lower labor costs in Canada were offset by higher costs for equipment and by other factors, resulting in the conclusion that a project would cost approximately as much in Canada as in the United States.

Quantities

Quantities for the estimate of project cost were determined in the conventional way for the designs described in chapters IV and V. Check lists and bid schedules for other large projects were reviewed for items not designed or laid out in the current studies. The cost estimates, therefore, include an allowance for these items.

Unit Prices

Unit prices developed are those which a contractor would be expected to bid, including direct costs, an allowance for indirect costs, and 10 percent profit. Unit costs for important phases of the work were built up rationally from equipment rental costs, equipment production, labor rates, and other factors.

Direct costs are those associated specifically with the construction of a part of the tidal project or its auxiliary, such as the powerhouse and filling gates, for example. Direct costs include labor, materials and supplies, equipment, and plant.

Labor costs were based on an 8-hour day and a 6-day workweek. It was assumed that the hourly wage rate for the sixth day is one and a half times that for the first 5 days. The wage rates used were those prevailing in the Bangor and Portland area in Maine in January 1958. A few representative hourly rates are as follows:

Carpenter	$2.75
Electricians	2.90
Laborers	1.85
Plumbers and steam fitters	2.85
Bulldozer operators	3.50
Power shovel operator	3.50
Specialized earth moving equipment operator	2.25

An allowance of 10 percent of the labor costs was added for insurance, taxes, and fringe benefits in all classifications, except for a 15 percent allowance for dredging operations.

Material and equipment prices were obtained from manufacturers, dealers, contractors, available records, and trade magazines. All material and equipment used in the project are assumed exempt from sales taxes. For the purpose of estimating costs of an international project, equipment originating in United States and Canada was assumed free of import duties. A 15 percent import duty was assumed in comparing the cost of equipment from other countries.

Charges for the construction plant were based on rental rates and average annual costs to contractors owning and maintaining construction equipment. This information is published by the Associated General Contractors of America, Inc., Washington, D.C. The cost of small tools, estimated at 5 percent of the labor cost of the item, was included as a plant cost.

Indirect costs are made up of distributive and overhead costs which, by nature, cannot readily be charged directly as a cost against a payment item. Indirect costs must, therefore, be distributed as a general cost against all payment items of a particular feature. In order to compute unit costs, all indirect costs were estimated separately and summarized for distribution as a percentage.

Distributive costs were computed separately and added to overhead costs to arrive at the total indirect costs. Distributive costs, estimated at 5 percent of the direct costs, consist of the following:

(a) Mobilization and demobilization of equipment.
(b) Mobilization and demobilization of personnel.
(c) Field office buildings.
(d) Shops and warehouses.
(e) Construction roads and maintenance.
(f) Utilities.
(g) Maintenance of temporary construction facilities.

Contractor's overhead costs, estimated at 12 percent of the direct costs, consist of the following:

(a) Supervision, including salaries of supervisors, engineers, timekeepers, purchasing agents, clerks, etc.
(b) Transportation of supervisory and office personnel during the construction period.
(c) Office supplies and communications.
(d) Interest on capital invested (payrolls, materials and equipment).
(e) Home office expense.
(f) Bonds.

Contingencies

An allowance for contingencies is commonly made in estimating project costs to account for unforeseen conditions which may be encountered during construction. The greatest uncertainty lies in the structure foundations. The foundation conditions become fully visible and known only when excavation is complete and the whole foundation area is exposed. It is common practice to vary the allowance for contingencies according to the status of planning. A preliminary examination may carry contingencies as high as 50 percent, while only a 5 percent allowance would be made for a project for which construction plans and specifications have been completed. Since the cost of the tidal project powerhouse is known more accurately than the costs of the dams, different allowances for contingencies for these items might be considered. Instead of differentiating between these items, however, an overall average allowance of 15 percent was made in the estimate of project cost. This percentage is applied to the sum of direct, indirect, distributive, and overhead costs.

Engineering, Design, Supervision, and Administration

An allowance for the construction agency of 9 percent is made for engineering, design, supervision, inspection of construction, and overhead. This percentage is applied to the sum of the construction costs and contingencies. Total project first cost, therefore, includes the 9 percent allowance.

Current Survey

The cost of the current survey is not included in the allowances described in the previous paragraph. The omission is in accordance with practices prevailing in both countries in January 1958.

TIDAL POWER PROJECT

The general process of computing unit costs by the rational method from equipment rental rates, production rates, labor costs, and so forth, was followed for all major construction items for both the tidal project and auxiliaries. For the relatively unprecedented features of the tidal project, such as dams and cofferdams, computation of unit costs was doubly important because these costs could be derived in no other way.

The tidal power project and its auxiliary would be used extensively for recreation. The project first cost developed in the following paragraphs does not, however, include facilities specifically for recreation.

Dams

The tidal dams, plates 4 through 9 and 19, would be built of locally available materials, most of which would come from excavation required for the powerhouse, gates, locks, and their channels. The quantities and the type of material available from required excavation, and from required borrow are as follows:

	Volume in cubic yards	
	Total	From borrow
Rock	36,200,000	12,800,000
Sand and gravel	7,100,000	5,300,000
Clay	7,500,000	22,000
Riprap	2,250,000	2,250,000
Total	53,050,000	20,372,000

These quantities include an allowance for loss in handling, particularly by dumping in deep water. About 2.2 million cu. yd. of the 17.2 million cu. yd. of clay excavated from the powerhouse forebay in Carryingplace Cove would be used in cofferdams. The remaining 7.5 million cu. yd. would be wasted.

Sand and gravel borrow would be obtained principally from Campobello Island, New Brunswick, in the area inland from Friar Bay. Most riprap material would be obtained from a new quarry at Man-of-War Head on Campobello Island. The rock is a diabase and breaks out in large sizes. The smaller particles from the quarry would be processed for concrete aggregate at a plant to be installed near the quarry.

The construction of the dams is divided into three tiers; the tier below el. -125, the tier between els. -125 and -25, and the tier above el. -25. Only three dams (those at Letite Passage, Head Harbour Passage, and Western Passage) extend below el. -125 for a total length of about 2,900 feet, about 8 percent of the total length of tidal dams. In these depths, the design incorporates a sand and gravel core flanked by rockfills as shown on plate 19.

Deep sections of the dams would be built early in the construction program so that tide currents would be as favorable as possible. Even so, currents during construction would reach momentary peaks of 6 feet per second. Under these conditions, and because the depths reach nearly 300 feet, it would be necessary to place the sand and gravel with special, large bottom-dump buckets 25 to 80 cu. yd. in capacity to avoid washing out the fines upon which the watertightness of the core depends. About 3.7 million cu. yd. of the sand and gravel would need to be placed with this bucket. The cost estimates of this work were based on using an anchored scow rigged to fill, lower, and raise the bucket rapidly. In this operation, other scows would be used to ship sand and gravel fill to the placing scow.

Rock for the outer fill would be placed by standard bottom-dump scows towed by large tugs. The rock would be placed at the same time as the core. The outer rockfill would be kept higher than the center core to protect the core from the tidal currents.

In the middle tier, between els. -125 and -25, all material would be placed by bottom-dump scows. Clay from the powerhouse headrace would be excavated and loaded on the scows by dipper or clamshell dredges. Sand and gravel would come from borrow. Since sand and gravel would be used for a transition zone, and since the loss of fines would be no problem, there would be no need for the expense of placing it by bucket. All materials would be placed concurrently, although placing would be delayed during extreme spring tides when the currents become too rapid.

The fact that the fill is under water and cannot be seen makes necessary an unusual method of keeping track of the construction progress. It is planned that this be done with a boat equipped with a sonic sounder and possibly a radio position finder. This equipment would probably operate continually during construction of the dams. Periodic measurements of the velocities across the unfinished dams would also be necessary to control the scheduling of the remaining construction.

The upper tier of the dam, from el. -25 to el. 25, top of dam, is above the level where scows can operate effectively, because of the lack of depth or because of rapid currents. For this reason, a mound of rock, shown on plate 19, would be end-dumped by trucks working outward from the shore. The top of the mound would be at el. 15 in order to clear high tide. The top surface would be about 40 feet wide to provide ample space for operating the trucks. This mound-building operation would restrict the flow of the tides, and the tidal currents would increase in velocity as the remaining gap becomes smaller. Final closure, with all the gates open, would be against a head of about 5 feet for an average tide. This operation would require larger rock than ordinary excavating methods would produce, and thus the rock would be specially quarried.

Construction of the remainder of the section shown on plate 19 would follow closely the construction of the rock mound. The mound would provide a working platform for large cranes with long booms to swing clamshell buckets. Clay, sand and gravel, and rock would be placed in successive layers to form the remainder of the section. The materials would be delivered for these operations by scow or truck depending on the dam and the source of material.

The contractors would require work areas at many locations, including the abutment areas of all the dams. It is expected that the dam building operations would be based in the powerhouse area northwest of Eastport, Maine, which has both rail and highway connections. Furthermore, much of the material destined for the dams would originate from this area.

It is expected that the construction of the dams would progress during both summer and winter until the work is completed. An allowance was made in both the construction schedule and estimate of cost for the delay caused by bad weather and storms. Where material must be excavated for other parts of the tidal project, the cost of placing the material was charged only to dams. Where material is borrowed for the dams, all associated costs are charged to dams.

Looking west at powerhouse site at Carryingplace Cove

The cost of each of the 13 dams (exclusive of contingencies, engineering, design, supervision, and administration) is tabulated below:

Letite Passage, north	$494,000
Letite Passage, south	4,034,000
McMaster Island to Jameson I.	602,000
Jameson Island to New Island	1,526,000
New Island to Pendleton Island	96,000
Pendleton Island to English I.	299,000
English Island to Deer Island	266,000
Head Harbour Passage, east	25,824,000
Head Harbour Passage, west	14,668,000
Indian River	5,149,000
Western Passage	20,017,000
Carryingplace Cove	701,000
Quoddy Roads	6,585,000
Total	$80,261,000

Power Plant

The cost estimate of the power plant includes the powerhouse, located between Mathews and Moose Islands, Maine (plate 8), excavation for the forebay, structure and tailrace, cofferdams and their unwatering, and the switchyard. The powerhouse includes the structure, turbines and generators, and all auxiliary mechanical and electrical equipment. The turbines, generators, cranes, and certain other electrical and mechanical equipment which would normally be purchased directly by the constructing agency rather than the constructing contractor, were estimated on this basis. The constructing contractor would install this equipment.

Eastport, Maine, located southeast of the powerhouse site, is served by a single-track line of the Maine Central Railroad and Maine State Highway No. 190. A permanent railroad spur would be constructed to the powerhouse. Temporary sidings from this spur would be used for unloading equipment and materials. Access highways would be built to connect the powerhouse area with the existing public highway system and other parts of the tidal project.

Excavation for the forebay, powerhouse, and tailrace would include about 18 million cu. yd. of earth, of which 17 million are clay, as well as about 8.6 million cu. yd. of rock. Most of the earth would be dredged and nearly all of the rock would be excavated in the dry within the cofferdams. About 10 million cu. yd. of the earth and nearly all of the rock would be used to build the dams and cofferdams. The total cost of excavation was charged against the power plant. The additional cost of placing the excavated material in the dams was charged against the dams.

The powerhouse would require about 685,000 cu. yd. of concrete, for which 1.3 million tons of aggregate would be used. Aggregate up to 3 inches in size would be quarried from Shackford Head just west of Eastport, Maine, and hauled 1 mile to a processing plant and storage area at the powerhouse site. About 430,000 tons of the aggregate, having a maximum size of 6 inches, could not be secured from Shackford Head because this rock breaks down to a smaller size. The larger aggregate would be towed from Man-of-War Head on Campobello Island, where a quarry for large rock and an aggregate processing plant would be set up.

A central concrete mixing plant would be set up at the powerhouse near the aggregate stockpile. The concrete would be delivered by trucks to the construction area where it would be placed by cranes as required. Other phases of the powerhouse construction would also use conventional methods.

The major items of cost of the power plant (exclusive of contingencies, engineering, design, supervision, and administration) are summarized as follows:

Cofferdams	$10,898,500
Excavation and backfill	31,756,700
Powerhouse	37,508,700
Intake gates	2,777,800
Draft tube gates	1,038,000
Turbines and governors	28,650,000
Generators, exciters, etc.	26,934,800
Accessory electrical equipment	5,095,600
Miscellaneous power plant equipment	1,961,400
Power transformers	1,504,600
Switchyard	2,909,400
Total	$151,035,500

Letite Passage Filling Gates

The 40 filling gates in Letite Passage would abut on Thum Cap and Dry Ledge, as shown on plate 4. A cofferdam would enclose the gate structure area and adjacent locations where excavation for the gate approach and discharge channels would be required. The cofferdam would consist mainly of cells of steel sheet piling filled with local materials. Nearly all excavation, amounting to 420,000 cu. yd. of earth and 1,780,000 cu. yd. of rock, would be done in the dry within the cofferdam. Most of the excavated material would be used in the dams in the area. Only the excavating and loading costs are charged to the gates.

Contractor's housing, warehouses, shops, central concrete plant, aggregate and cement storage, and other work facilities would be located on the islands north of the structure site and on the adjacent New Brunswick mainland. Most of the material for construction of the gates would be delivered to the site by water. Some equipment and materials would be shipped by rail to St. George, New Brunswick, and then hauled 9 miles by truck to the site over a two-lane road which is mostly hard surfaced.

The gate structures would require placing of about 145,000 cu. yd. of concrete. All aggregate for the concrete would be shipped by water from the quarry and aggregate plant on Man-of-War Head on Campobello Island. The contractor could establish a central concrete mixing plant with storage for aggregates and cement in his work area. Mixed concrete would be hauled to the structure by trucks and placed by cranes.

The estimate of the cost of the Letite Passage filling gates (exclusive of contingencies, engineering, design, supervision, and administration) is summarized as follows:

Cofferdams	$7,440,000
Excavation and backfill	5,487,400
Concrete	8,100,100
Gates and machinery	7,507,300
Operations building	56,000
Remaining items	217,500
Total	$28,808,900

Western Passage Filling Gates

As shown on plate 7, 50 filling gates would be located at Deer Island Point, Deer Island, New Brunswick, in an area which is now dry land. Thus, some excavation can be done before the cofferdam for the protection of the excavation of the approach and discharge channels is required. Steel sheet piling cells filled with material trucked from local sources would be used. The setting of the cofferdams would require some underwater excavation since it was found to be cheaper to use a small amount of expensive underwater excavation than to increase the depth of the cofferdams to the point that all excavation would be in the dry. About 300,000 cu. yd. of earth and 4,550,000 cu. yd. of rock would be excavated. Nearly all of this material would be used in the dams.

The area immediately north of the gate site was planned for the contractor's work area, including housing, warehouses, shops, storage and erection areas, aggregate and cement storage, and the concrete mixing plant. Equipment and materials for construction would be delivered to the site by water, except for shipment by truck of local materials from Deer Island.

About 158,000 cu. yd. of concrete would be needed for the structure. All aggregate would be shipped from the aggregate plant at Man-of-War Head on Campobello Island, New Brunswick. The estimates have assumed that the contractor would establish a central mixing plant from which mixed concrete would be trucked to the structures and placed by a crane.

The cost of the Western Passage filling gates (exclusive of contingencies, engineering, design, supervision, and administration) is summarized in the following table:

Preparation of site	$131,300
Cofferdams	4,308,900
Excavation	12,370,000
Concrete	9,349,400
Gates and machinery	9,292,000
Operations building	55,100
Remaining items	269,700
Total	$35,776,400

Head Harbour Passage Emptying Gates

As shown on plate 6, the 70 emptying gates would be located in Head Harbour Passage between Pope and Green Islets, New Brunswick. The site would be unwatered by about 7,500 feet of cofferdam. This cofferdam would also encircle Sandy Ledge and other areas in which excavation is required for both the approach and discharge channels. Where the bottom is above el. -45, the cofferdam would be steel sheet piling cells. Where the bottom is deeper, an embankment with a clay core and rock outer fills would be constructed.

Fill material for the cofferdams would come largely from the excavation for the Western Passage filling gates and the power plant. Most of the emptying gate excavation would be in the dry inside the cofferdam. The remainder, about 6 percent of the total, would be in the wet after the cofferdams are removed. This method is planned to avoid deeper cofferdams, which would increase total costs more than the use of expensive underwater excavation. Total excavation would be about 410,000 cu. yd. of earth and 2,320,000 cu. yd. of rock, all of which is scheduled for use in the dams.

Most of the contractor's housing, warehouses, shops, and other facilities would be on Campobello Island, New Brunswick, located as near as possible to the gate site. The concrete mixing plant and aggregate stock piles would be located on Pope Islet and on a westerly extension constructed of fill. All materials and equipment would be delivered to the site by water.

About 343,000 cu. yd. of concrete would be needed for the emptying gates. The aggregates would be shipped by water from the plant on Man-of-War Head. The mixed concrete would be trucked from the mixer on Pope Islet to the structure and placed in the forms with cranes.

The most unprecedented construction is that needed for the embankment cofferdam. The section is similar to that selected for the dams and would be built in the same way. The cofferdam foundations are all above el. -120, and a clay core would be used to the full depth. Construction of the steel sheet piling cell cofferdams is at about the present limit of experience, particularly in view of the tidal velocities which would peak at about 6 feet per second at the site during a spring tide.

The cost of the Head Harbour Passage emptying gates (exclusive of contingencies, engineering, design, supervision, and administration) is summarized below:

Cofferdams	$21,737,200
Excavation and backfill	7,757,500
Concrete	17,138,400
Gates and machinery	14,011,000
Operations building	57,300
Remaining items	406,900
Total	$61,108,300

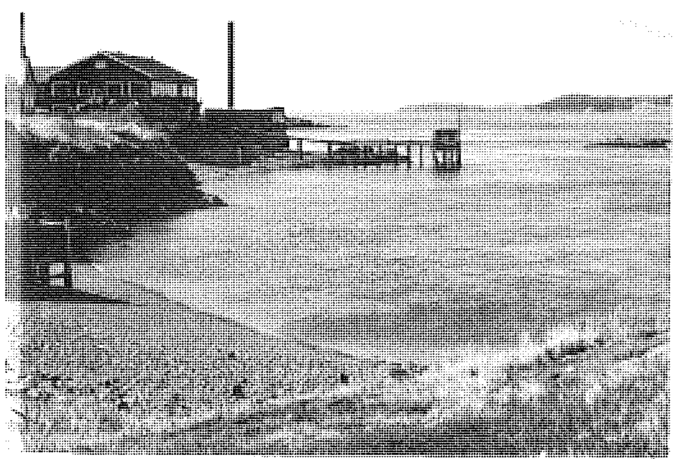
Navigation Locks

Four navigation locks would be built as components of the tidal power project at locations shown on plates 4, 6, 7, and 9. These locks would have the following clear dimensions at mean low water:

Head Harbour Passage lock	415' x 60' x 21'
Western Passage lock	415' x 60' x 21'
Little Letite Passage lock	95' x 25' x 12'
Quoddy Roads lock	95' x 25' x 12'

Structures for the larger locks would be located on land and could be constructed without extensive cofferdams. The approaches, however, would require cofferdams mainly of steel cells. Less excavation would be required for the smaller locks and could be accomplished within low cofferdams of the timber-crib type. Excavation at each site is summarized below:

Looking northwest at Western Passage lock site



	Excavation in cubic yards	
	Earth	Rock
Head Harbour Passage lock	25,000	960,000
Western Passage lock	300,000	580,000
Little Letite Passage lock	0	72,000
Quoddy Roads lock	0	20,000

Contractor's work areas would be located adjacent to the locks. Equipment and materials for the Head Harbour Passage lock would be shipped by water, except for concrete aggregates, which would be trucked from the Man-of-War Head aggregate producing area. The Western Passage lock would be served by truck and railroad. Most of the aggregate would come from Shackford Head to the west of Eastport, Maine, and would be processed at a plant near the powerhouse site. The 6-inch aggregate would come from the Man-of-War Head plant on Campobello Island, New Brunswick. All aggregate for the Little Letite Passage lock would be shipped by water from the Man-of-War Head plant. The aggregate for the Quoddy Roads lock would be hauled by truck from Man-of-War Head. The following table summarizes the concrete requirements for each of the locks:

	Concrete cu. yd.
Head Harbour Passage lock	54,000
Western Passage lock	57,000
Little Letite Passage lock	14,000
Quoddy Roads lock	17,000

The cost estimates were based on a centrally located concrete plant from which the mixed concrete would be trucked to the work area and placed in the forms by cranes.

The estimate of cost of each of the locks (exclusive of contingencies, engineering, design, supervision, and administration) is summarized as follows:

Item	Head Harbour Passage	Western Passage	Little Letite Passage	Quoddy Roads
Preparation of site	$39,800	$3,600	0	0
Cofferdams	1,674,400	2,178,800	$211,600	$1,231,200
Excavation and backfill	3,165,100	1,903,100	497,500	225,200
Concrete	2,274,800	2,341,200	748,900	860,800
Gates and machinery	955,900	933,900	407,800	403,600
Operations building	15,900	15,900	15,900	15,900
Remaining items	24,100	24,100	8,100	10,400
Total	8,150,000	7,400,600	1,889,800	2,747,100

Fishways

The two fishways planned for the tidal project, one located at the emptying gates and the other at the powerhouse, were estimated on the basis that they would be built at the same time as the rest of the project. If this were not done, separate and highly expensive cofferdams would be required. The estimated cost of these fishways (exclusive of contingencies, engineering, design, supervision, and administration) is as follows:

Powerhouse fishway	$646,700
Emptying gate fishway	272,400
Total	$919,100

Lubec Channel

Dredging Lubec channel to a width of 520 feet at el. -30 would involve 515,000 cu. yd. of gravelly clay and would cost $633,500 (exclusive of contingencies, engineering, design, supervision, and administration). The channel enlargement is included in the plan of development to improve the hydraulic efficiency of the channel and consequently the effectiveness of Quoddy Roads as a part of the lower pool.

Service Facilities

Maintenance shops, warehouses, employee housing, utilities, access roads, floating plant, motor vehicles, and other facilities needed after completion of construction for the maintenance and operation of the tidal project would cost $1,870,000 (exclusive of contingencies, engineering, design, supervision, and administration).

Relocations, Lands, and Damages

Relocations required in the United States for the tidal power project would amount to $3,815,000, and in Canada to $99,000, a total cost of $3,914,000 (exclusive of contingencies, engineering, design, supervision, and administration).

Lands and damages for the tidal project would amount to $1,032,000 in the United States, and to $827,000 in Canada, a total cost of $1,859,000 (exclusive of contingencies, engineering, design, supervision, and administration).

Summary of Project Cost

The costs of the various components of the tidal power project are summarized below. Contingencies, allowance for engineering, design, supervision of construction, and administration were applied to determine the total first cost of the tidal power project.

Dams	$80,261,000
Power plant	151,035,000
Filling gates at Letite Passage	28,809,000
Filling gates at Western Passage	35,776,000
Emptying gates	61,108,000
Head Harbour Passage lock	8,150,000
Western Passage lock	7,401,000
Little Letite Passage lock	1,890,000
Quoddy Roads lock	2,747,000
Fishways	919,000
Lubec channel	634,000
Service facilities	1,870,000
Relocations	3,914,000
Lands and damages	1,859,000
Subtotal	386,373,000
Contingencies	57,627,000
Subtotal	444,000,000
Engineering, design, supervision, and administration	40,000,000
Total first cost for tidal project alone	484,000,000

RANKIN RAPIDS HYDRO AUXILIARY

The same general methods used to estimate construction costs of the tidal project were also applied to the Rankin Rapids hydro auxiliary. All construction operations for the hydro auxiliary, however, would be conventional, and thus presented no unusual problems of design or cost estimating.

Access

Access to the dam site is presently made by Maine State Highway 161 extending upstream on the right bank of Saint John River from St. Francis, Maine. The Bangor and Aroostook Railroad now terminates at St. Francis. The project plans include construction of approximately 3 1/2 miles of single-track railroad spur to the damsite, for delivery of equipment and materials. This spur would have a number of sidings for construction use and would extend into the powerhouse for delivery of heavy equipment. A temporary construction bridge for vehicles would be built downstream from the site for access to the left bank of the river.

Work Areas

Areas for the contractor's warehouses, shop facilities, offices, and work facilities would be located on the gently sloping right bank of the river downstream from the site, where they would be served by both the highway and the railroad.

Concrete

Nearly 400,000 cu.yd. of concrete are required for the river hydro auxiliary. The 800,000 tons of aggregate needed for the concrete would be secured from DeBoullie Mountain about 16 road miles to the south. A quarry would be opened there and an aggregate processing plant set up. In addition, 2 miles of new road would be built and about 14 miles of existing roads improved for hauling the material to the damsite. The cost estimates were based on the assumption that one centrally located concrete mixer and aggregate and cement storage system would be used, and that the mixed concrete would be delivered to the construction area by truck, where it would be placed in the forms by cranes.

Earthwork

About 4,070,000 cu.yd. of rock would be excavated. All of the rock would be used in the dam as it is excavated and would occupy 5,690,000 cu.yd. About 5,040,000 cu.yd. of earth would be excavated and used in the dam. In addition, the following materials would be borrowed from local sources:

Impervious Material	9,240,000 cu.yd.
Pervious Material	12,900,000 cu.yd.
Riprap	221,000 cu.yd.
Gravel filter	55,000 cu.yd.

All the materials can be borrowed within 3 miles of the site, except gravel for the filter which must be hauled 10 miles.

The total fill amounts to 33 million cu.yd.

Clearing

The reservoir would be cleared to 5 feet below the limit of drawdown in accordance with the practice at Corps of Engineers reservoirs in the United States. This amount of clearing also conforms to the requirements of the state laws of Maine. It is expected that this clearing can be done in exchange for the saleable timber and pulpwood in the reservoir area. For this reason, there is no item in the estimate for clearing.

Estimate of Cost

The estimate of cost of the entire Rankin Rapids project is summarized as follows:

Lands and damages	$4,449,000
Relocations	130,000
Dams	81,706,600
Power plant	28,439,300
Access roads and railroad	1,088,500
Buildings, grounds, and facilities	728,600
Subtotal	116,542,000
Contingencies	17,458,000
Subtotal	134,000,000
Engineering, design, supervision, and administration	12,000,000
Total first cost using all of Rankin Rapids as auxiliary	146,000,000

INCREMENTAL CAPACITY ONLY AS AUXILIARY

The following estimate applies to the alternative study which includes incremental capacity only at Rankin Rapids as auxiliary to the tidal power project:

Intake, penstocks, and surgetanks	$12,500,000
Power plant	12,620,000
Subtotal	25,120,000
Contingencies	3,770,000
Subtotal	28,890,000
Engineering, design, supervision, and administration	2,610,000
Total first cost using incremental capacity only at Rankin Rapids	31,500,000

DIGDEGUASH PUMPED-STORAGE AUXILIARY

The pumped-storage project on the Digdeguash River, which empties into Passamaquoddy Bay from the north, is of conventional design and presented no construction difficulties to complicate the problem of estimating costs.

Access

The site is located about 1 mile from the Canadian Highway 1, a two-lane, hard-surfaced, all-weather road. St. Andrews, New Brunswick, is about 9 miles to the west on Highway 1, and St. George, New Brunswick, about 9 miles to the east. Both of these towns are served by the Canadian Pacific Railway. A heavy-duty road would be constructed along the left bank of the Digdeguash River from Highway 1 to the site for access and delivery of equipment and materials.

Work Areas

The contractor's housing, warehouses, shops, offices, and other work facilities would be located on the left bank of the river downstream from the site on a relatively flat area next to the access road.

Earthwork

The material needed for the dams is summarized as follows:

Rock from required excavation	1,333,000 cu.yd.
Rock from borrow	21,000 cu.yd.
Impervious fill from required excavation	186,000 cu.yd.
Impervious fill from borrow	119,000 cu.yd.
Gravel for filter from borrow	222,000 cu.yd.
Total	1,881,000 cu.yd.

Rock and impervious material may be borrowed within 2 miles of the embankment. Gravel for the filters would be borrowed from a glacial outwash terrace near Bethel, New Brunswick, about 3 1/2 miles from the site.

Concrete

About 130,000 cu.yd. of concrete would be required for the project. The aggregate for the concrete would be processed at the site from the basalt and rhyolite rocks which can be obtained in adequate quantity at the site. The cost estimates were based on a centrally located mixing plant and appurtenances from which the mixed concrete would be trucked to the construction area and placed in the forms by cranes.

Clearing

The reservoir would be cleared to 5 feet below minimum drawdown. Similar to Rankin Rapids, clearing would be done in exchange for the saleable pulpwood and timber in the reservoir area. Thus no item for the cost of clearing is given in the estimate.

Estimate of Cost

The cost of the pumped-storage auxiliary is summarized as follows:

Lands and damages	$523,000
Relocations	326,000
Dams	8,260,500
Power plant	17,674,500
Access roads	223,400
Buildings, grounds, and facilities	447,000
Subtotal	27,454,400
Contingencies	4,145,600
Subtotal	31,600,000
Engineering, design, supervision, and administration	2,900,000
Total first cost of Digdeguash pumped-storage auxiliary	34,500,000

MAJOR EQUIPMENT

Some of the hydraulic and electrical equipment at the tidal project and each of the auxiliaries considered would require replacement during the project amortization period. The annual allowance for these interim replacements is usually based on the first cost of the major hydraulic and electrical equipment which, including engineering, design, supervision, and administration, is tabulated below for the tidal project and the auxiliaries:

Tidal power project	$77,500,000
Rankin Rapids river hydro auxiliary	15,300,000
Incremental capacity only at Rankin Rapids as auxiliary	8,600,000
Digdeguash pumped-storage auxiliary	11,400,000

OTHER POSSIBLE PROJECT FUNCTIONS

The tidal power project and its auxiliary, if authorized for construction, could serve functions other than power if facilities specifically for these functions were added. Funds in addition to the project first costs, discussed in the previous paragraphs, would be required for these added facilities. The possible other functions include navigation and public highways. The added facilities which could be built and the cost involved is given in the following paragraphs for information only.

Possible Future Lock for Ocean Shipping

Should predictable traffic by large vessels in the future justify a large lock, this lock could be built in the Little Letite Passage area as shown on plate 5. The lock would provide access only to the upper pool and to the adjacent United States and Canadian shores. The cost of a lock at this location, not charged to power, was estimated using clear dimensions of 800 by 80 by 30 feet. A larger lock, however, can be built at this site.

The large lock could be built at the time the tidal power project is built, in which case the small Letite Passage lock would not be required. Since only the small lock is charged to power, the cost of the tidal power project would not change. However, only the increase in cost of the large lock would be charged to navigation. The large lock could also be built after the tidal power project is completed if it becomes apparent that traffic into Passamaquoddy Bay warrants it. In this event, two locks would occupy the Little Letite Passage area, and the entire cost of the larger lock would be borne by navigation. This latter procedure was selected to estimate the cost of the possible future lock because there is no evidence that the large lock would be required, and because delaying the construction of the large lock could easily reduce interest costs to such an extent that delaying construction would be the most economical procedure.

The contractor's work areas would be located on Jameson Island, which would be accessible at that time by roads over the tidal project dams from Eastport, Maine, and from St. George, New Brunswick, both of which are served by rail.

The lock site and the high pool approach are almost entirely in the dry on Jameson Island, and the excavation and construction can be done largely without cofferdams. The ocean approach would cross the south end of Parker Island and would require extensive cofferdams of rockfill and steel cells. Much of this could be built of excavation made in the dry on Jameson and Parker Islands. The excavation required would include 113,000 cu.yd. of earth and 2,180,000 cu.yd. of rock.

About 133,400 cu.yd. of concrete would be required for the lock. It was assumed that the concrete would be mixed in a central plant and trucked to the construction area to be placed in the forms by cranes. Aggregate would be trucked from the vicinity of Northwest Harbour on Deer Island.

The cost of the possible future lock is summarized below:

Preparation of site	$26,300
Cofferdams	2,896,100
Excavation and backfill	5,849,900
Concrete	4,999,700
Gates and machinery	1,580,100
Operations building	16,000
Miscellaneous items	42,000
Subtotal	15,410,100
Contingencies	2,309,900
Subtotal	17,720,000
Engineering, design, supervision, and administration	1,580,000
Total first cost of possible future lock	19,300,000

Possible Public Highways

The dams and structures of the tidal power project would afford a good opportunity to connect the various islands with the mainland by public highways, thus providing direct routes from Lubec and Eastport, Maine, to St. George, New Brunswick, as discussed in chapter VII. The estimate of the land portions in Canada was made using a construction rate per mile for similar construction in New Brunswick. The construction needed on the dams, over the gate structures, and as replacements for required access roads were made on the basis of estimated construction quantities and unit costs. Since the public highway would not be charged to tidal power, separate estimates were made for the construction required in United States and in Canada. The cost of this highway system, including contingencies, engineering, design, supervision, and administration is as follows:

United States	$957,000
Canada	7,473,000
Total first cost of public highways	8,430,000

CHAPTER VII

ECONOMIC EFFECTS OF PROJECT

The Passamaquoddy tidal project, constructed with or without an auxiliary plant, is a unique power project, and its construction would produce significant economic effects in the State of Maine and the Province of New Brunswick. Therefore, in consonance with the comprehensive scope of the survey and for economic analysis of the tidal power project, economic surveys were conducted in Maine and New Brunswick. The objectives of these surveys were to determine if the economies of Maine and New Brunswick would be able to absorb the power produced by the tidal project and its auxiliary and to determine the effect, if any, on the economy of the region. Separate economic studies were made of Maine and New Brunswick.

ECONOMY OF MAINE

The site of the tidal power project (plate 43) lies on the eastern tip of the coast of Maine. From the project site, Maine extends southwest about 220 air miles along the coast, to the west about 200 miles, and to the northwest about 180 miles. Augusta, the state capital, is 180 road miles southwest of the site. Maine has a total area of 33,215 square miles, including 2,175 square miles in inland water. Approximately 86 percent of the total land area of the State is in forest.

Population and Employment

In 1950 the population of Maine was 914,000, and it is expected to increase to at least 1,008,000 by 1970. Maine has a higher percentage of rural population than other sections of New England or the United States as a whole. The State also has a high record of educational achievement. However, due primarily to the migration of younger people, the rate of population growth in Maine has been low in the last several decades. The fact that some of the younger workers seek employment elsewhere brought about local and state-wide efforts to diversify industry more widely and to expand employment opportunities in all segments of Maine's economy.

Forty-eight percent of Maine's population live in rural areas, as compared with 36 percent for the United States. There are two metropolitan areas in the State. The largest includes Portland, South Portland, Westbrook, and adjacent residential towns and contains 13 percent of the State's population. The other area is the Auburn-Lewiston area. The principal cities in Maine, with populations of 10,000 or more, and their 1950 populations are:

Portland	77,634
Lewiston	40,974
Bangor	31,558
Auburn	23,134
South Portland	21,866
Augusta	20,913
Biddeford	20,836
Waterville	18,287
Sanford	15,177
Westbrook	12,284
Brunswick	10,996
Bath	10,644

In 1950 the total labor force in Maine numbered 345,000, or 38 percent of the total population. Native ingenuity, versatility, and educational level make this labor force readily adaptable to new employment opportunities in the growing economy of Maine. Of the total non-agricultural employment in 1956 of 281,700, thirty-nine percent were employed in manufacturing, a higher proportion than in the United States as a whole. The next largest employed group is engaged in wholesale and retail trade, followed by agriculture, fisheries, recreation, and professional and related services.

Manufacturing

Manufacturing is the largest income-producing and power consuming segment of the economy of Maine. In 1957 nearly 2,700 million kilowatt-hours of electricity were consumed by the industries of the State, or nearly two-thirds of all electric power generated. Utilities supplied approximately 43 percent of these requirements, and the remainder was furnished by power plants operated by the industries themselves. The utility share of the industrial load has been increasing steadily over a long period of years. Past growth of manufacturing and its prospects for the future are of particular importance, therefore, in evaluating the future power markets of the State.

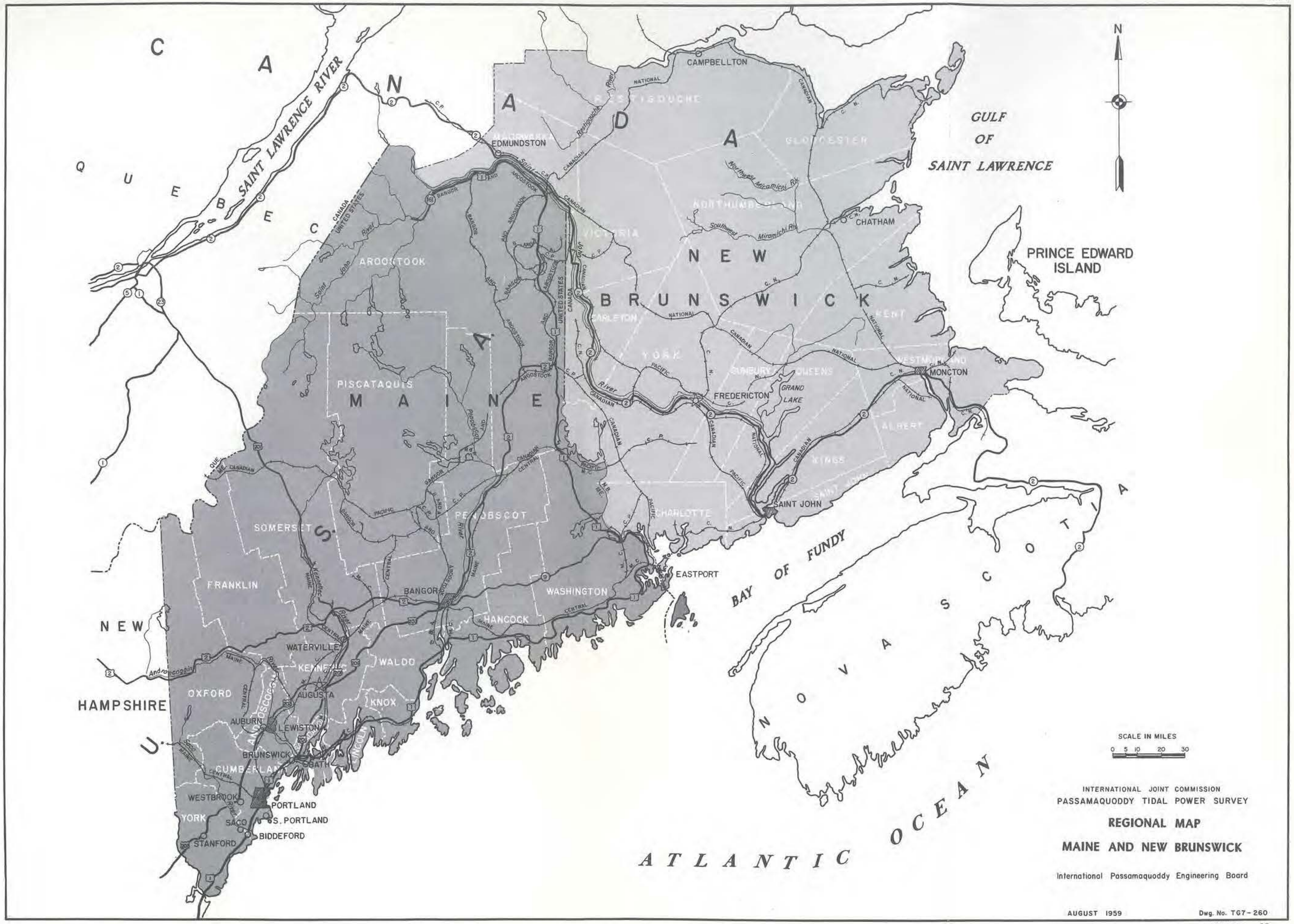
The five leading manufacturing industries of Maine are paper and allied products, food and kindred products, leather and leather products, textiles, and lumber and wood products. As shown in the table below, these five manufacturing industries in 1958 accounted for 80 percent of Maine's total manufactured value, 70 percent of all manufacturing wages paid, and 74 percent of all manufacturing employment.

The manufacturing industries of Maine have a long record of development and adjustment to changing economic and technological conditions. The significant characteristic of manufacturing in Maine is the wide diversity of its long-established industries. At the same time, relatively few new fields of industrial production have located in the State in recent years. Other important factors affecting industry are the dependence of many of the State's industries on imported raw materials as well as on distant markets. However, important as proximity to raw materials and to markets may be to economic growth, many states under similar conditions have reached and maintained high levels of industrial development.

The record of manufacturing production and employment in Maine in the last several years indicates that certain changes are taking place in this sector of the State's economy. The pulp and paper industry has shown sustained growth in recent years and the outlook for the future is favorable. The same is true of the lumber and wood products industries, which are also based on the State's extensive forest resources. The textile industry in Maine has been undergoing readjustments in the past several years which in the long run may prove beneficial to the State's economic future, just as similar developments proved to be in New Hampshire and Massachusetts. The apparel industry, fairly new in the State, has grown rapidly and is likely to continue its growth. The long-established leather and leather products industry is maintaining its economic position. The same is true of the food processing industry, which has long been of major importance to the economy of Maine.

Thus far, few of the newly developed industries such as electronics, plastics, and others have located in the State. Maine offers many advantages to these and other industries that seek locations for new enterprises. Among these advantages are: availability of suitable industrial sites; abundant supplies of high-quality fresh water for domestic and industrial use; availability of cold sea water for industrial cooling purposes; seaports for ready access to overseas raw materials and markets; favorable and cooperative local governments and business organizations; high-grade labor and management resources; and proximity to the largest academic, professional, and research centers in the country and to concentrations of capital resources available for investment.

	Value of product (millions)	Gross wages (millions)	Total workers (thousands)
All manufacturing	$1,344	$369	100.9
Paper	364	84	16.7
Food	248	34	11.4
Leather	197	59	20.8
Textiles	162	41	13.7
Lumber and Wood	110	36	11.9
Total	1,081	254	74.5
Percent of all manufacturing	80	70	74



C A N A D A
QUEBEC
SAINT LAWRENCE RIVER
GULF OF SAINT LAWRENCE
PRINCE EDWARD ISLAND
NEW BRUNSWICK
MAINE
U. S.
NEW HAMPSHIRE
NOVA SCOTIA
BAY OF FUNDY
ATLANTIC OCEAN
CAMPBELLTON
EDMUNDSTON
CHATHAM
FREDERICTON
MONCTON
SAINT JOHN
EASTPORT
BANGOR
WATERVILLE
AUGUSTA
AUBURN
LEWISTON
BRUNSWICK
BATH
WESTBROOK
PORTLAND
S. PORTLAND
SACO
BIDDEFORD
STANFORD
AROOSTOOK
PISCATAQUIS
SOMERSET
PENOBSCOT
FRANKLIN
WASHINGTON
HANCOCK
WALDO
KNOX
OXFORD
CUMBERLAND
YORK
GRAND LAKE
N
SCALE IN MILES
0 5 10 20 30
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
REGIONAL MAP
MAINE AND NEW BRUNSWICK
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-260

PLATE 43

Under these favorable conditions it is reasonable to assume that many new industries will take the place of those now declining and that these industries ultimately will provide a wider diversification, which will be accompanied by an ever-expanding demand for electric power.

By far the most important single element in the manufacturing economy of Maine, at the present time, is its forest products industry. The prominence of this industry arises from the fact that 86 percent of the total land area of Maine is in forest. Approximately 11.6 million acres are classed as commercial forest land. The forest products industry falls into two broad classifications: logging and lumbering, and pulp and paper manufacturing. In 1956 the forest products industry accounted for nearly 40 percent of the value added by manufacture and 30 percent of all production workers.

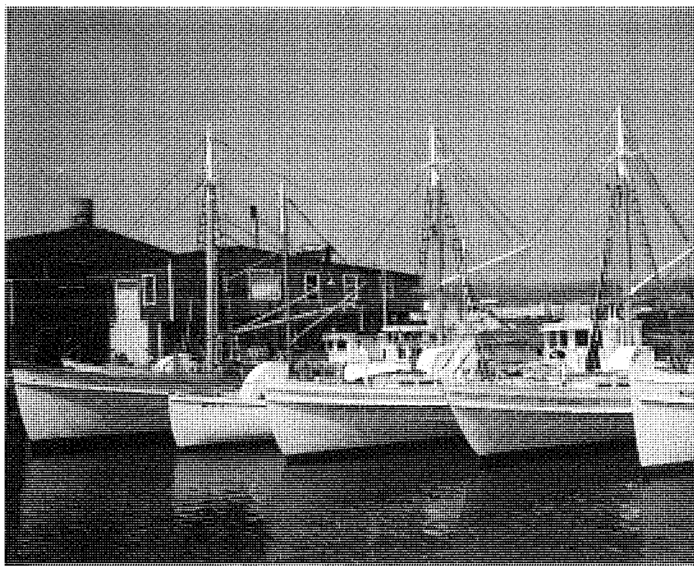
Maine is one of the country's three leading producers of white pine, which comprises more than half of the State's lumber output. However, the extensive stands of hardwood timber in the northern half of the State are becoming an increasingly important segment of the lumber industry. Since 1940 the lumber industry has expanded greatly due to exploitation of hardwood stands, and in 1956 annual production reached 550 million board feet.

Maine ranks fifth among the states as a producer of pulp, with an annual production of about 1.5 million tons. In paper and paperboard production Maine ranks seventh, with a yearly output of 1.6 million tons. A high proportion of Maine's pulp is used in the manufacture of kraft paper in the western part of the State. The value of pulp, paper, and allied products grew from $206.1 million in 1949 to $381.5 million in 1957, an increase of 85 percent.

The long-term prospects of Maine's forest products industry is favorable, particularly in the production of pulp and paper.

Fishing and Fish Processing

The fishing industry has long been an important segment of Maine's economy. In recent years higher personal income has increased the demand for more expensive fish.



White-hulled carriers from the Maine sardine fleet

Total fish landings have increased with population growth, and this trend is expected to continue. Landings of commercial fish and shellfish in Maine in 1956 totalled 277.8 million pounds valued at $17 million to the fishermen. These landings represented an increase of nine percent in volume and five percent in value over 1955 landings. In terms of value the ranking was first lobster, then ocean perch, herring, groundfish, and clams.

In 1955, fishing employed 715 fishermen on vessels and 8,925 on boats. Maine fish wholesaling and processing establishments employed a seasonal average of 7,034 persons. In 1957, the value of manufactured fishing products, dominated by canned sardines, was $18.7 million. Production of fresh and frozen ocean perch fillets is second in importance among manufactured fish products, followed by processed clams. The groundfishing industry in Maine is expected to show little expansion, although it should not fall behind its present position.

Losses in the sardine industry have been somewhat offset by growth of the lobster industry, which has benefited from the increased demand for more expensive products. Growing constantly since 1939, the lobster catch reached a high of 22.7 million pounds in 1955, valued at $8,716,000, an increase of 242 percent in weight over the 1939 catch.

Minerals

The value of mineral production in Maine, which presently consists of bulky, low-per-ton value materials such as stone, peat, and feldspar, is a relatively small segment of the economy of Maine. In 1956 the total value of all mineral production was $12,179,000. In an effort to stimulate mineral surveys and prospecting, the State has revised its mineral and mining laws to facilitate further discovery and development of mineral resources particularly of base-metal deposits which are believed to exist similar to those recently discovered in the Newcastle-Bathurst area of New Brunswick. Until important discoveries are reported, however, there is no evidence on which to forecast significant changes in the mining economy of Maine.

Agriculture

Agriculture provides 6 to 8 percent of the total personal income in Maine. In the past, the State's agriculture has been dominated by the potato crop of Aroostook County. In the face of rising output in other parts of the country, Maine has maintained its position as the leading potato-producing state because of great increases in yields on a reduced acreage, improved seed, development of high-yielding varieties, heavier use of fertilizer, and improved techniques of controlling insects and disease. Maine's yields have risen from 250 bushels per acre in 1921-25, when the national average was less than 100 bushels, to an average of 380 bushels per acre in 1951-55. The development of improved marketing and processing techniques have also contributed to the success of maintaining Maine's eminence as the leading producer in the nation. With rising standards of living, the shift toward ready-to-use potato products offers new opportunities for the establishment of potato-processing facilities in proximity to the potato-raising areas of Maine.

Potato harvesting in Aroostook County, Maine

One of the encouraging recent developments in Maine agriculture has been the growth of the production of poultry and poultry products into the leading source of farm income. Maine broilers have successfully invaded the Boston and New York metropolitan markets. It is expected that in the future Maine poultry farmers will continue to find an expanding market for their broilers.

An important development in Maine's agriculture in recent years has been the gradual transition from subsistence to commercial farming and the resulting increase in the average size and value of farms. In 1954, half of Maine's commercial farms each sold products worth more than $5,000, while only 39 percent of all U.S. commercial farms had sales of $5,000 or more.

Cash receipts from farming in Maine totalled $180,842,000 in 1956. The outlook for Maine agriculture appears favorable. Output will be further concentrated on larger and more efficient farms, while marginal and subsistence farms continue to decline. It is estimated that cash receipts from farm marketing will rise over the $200 million level between 1960 and 1970 and that net income per farm will continue to be above the national average.

Recreation

The nation's increasing population, income, leisure time and personal mobility, are bringing about a rapid growth in the recreation industry throughout the country.

These national trends are important to Maine because its vacation and tourist business depends largely on out-of-state visitors. Maine is richly endowed as a vacation center and its recreation industry has long been an important factor in economy of the state.

The rapidly growing use of the State's recreational resources is shown by the 1956 visitor attendance at Acadia National Park of 735,000, an increase of 80,000 over the previous year and an increase of 100 percent over 1946. In state parks alone, which provided recreation for nearly 500,000 visitors in 1955, visitor use has been increasing at the rate of 30,000 to 40,000 a year. The gross income of Maine's vacation business rose from $135 million in 1950 to $272 million in 1957. It has been estimated that income from this source is about 10 percent of the State's total income.

Expected population growth in northeastern United States has led the Maine State Park Commission to estimate that accommodations for more than one million visitors a year, or more than twice the 1956 total, will be needed in the state parks by 1966. This is a measure of the expected continuing growth of the recreation industry in Maine.

Transportation

The transportation systems in Maine are generally adequate for present needs. The State is well served by railroads and has an extensive highway system that is being constantly improved. Forest products, paper and paper products, potatoes, and petroleum products account for a high proportion of all rail traffic within the State. Rail passenger service has been curtailed during the past few years, as in the United States as a whole and other New England states. Scheduled air service connects eight of Maine's principal cities with Boston and other metropolitan areas. Portland, one of the finest deep-water harbors on the eastern coast of the United States, has a land-locked ice-free harbor with a channel depth of 35 feet at mean low water. The possibility exists of future development of increased waterborne commerce in the many deep-water harbors of Maine. These ports are relatively close to Europe and close to major ports along the east coast of the United States and Canada and to United States and Canadian trade centers recently opened by the St. Lawrence seaway.

Fishing for recreation in Maine

Washington County

In 1950, the population of Washington County, in which part of the Passamaquoddy tidal power project would be located, was 35,000, a decrease of 3,000 from 1940. About 78 percent of the people live in rural areas.

The economy of Washington County depends primarily on fishing and related industries. From 1949 through 1956, products manufactured from herring, alewives, and trash fish averaged over $13 million in annual value and represented about 75 percent of the value of all products manufactured in the county. Of the nine municipalities in the county, Calais, Eastport, and Lubec produce the bulk of the manufactured products.

Washington County's contribution to Maine's forest-products industry, about 6 percent of the total, is commensurate with its share of the state's forest resources. The St. Croix Paper Company maintains a pulp and paper factory in Washington County on the St. Croix River in Woodland. The company obtains a portion of its pulp supply from Washington County and the remainder is imported from Canada.

In 1951, twelve percent of the county's area was farmed and 419 of the county's 1,120 farms were classed as commercial. About half of these farms had incomes of more than $2,500 each.

With more than 130,000 acres of lakes, excellent fishing streams, 1.5 million acres of woodland for camping and hunting, and a picturesque coastline, Washington County is well endowed with recreational resources. In 1957 income from the tourist business was estimated at $4,380,000. The recreation industry of Washington County can be expected to show considerable growth in the future, particularly if the international Passamaquoddy tidal power project is constructed.

The Maine State Park Commission has outlined a long-range program for expanding the system of public parks and recreation facilities in an effort to meet the rapidly increasing needs for non-urban recreation in Maine. While the greatest emphasis has been given to the establishment of new recreation areas in southwestern Maine, where most of the State's population is concentrated and the tourist traffic is heaviest, the plan also provides for the development of additional areas in the east, including two state parks in Washington County. Development of these and other areas within easy reach of U.S. Highway No. 1 would provide an important additional attraction for tourists considering a visit to the Passamaquoddy project.

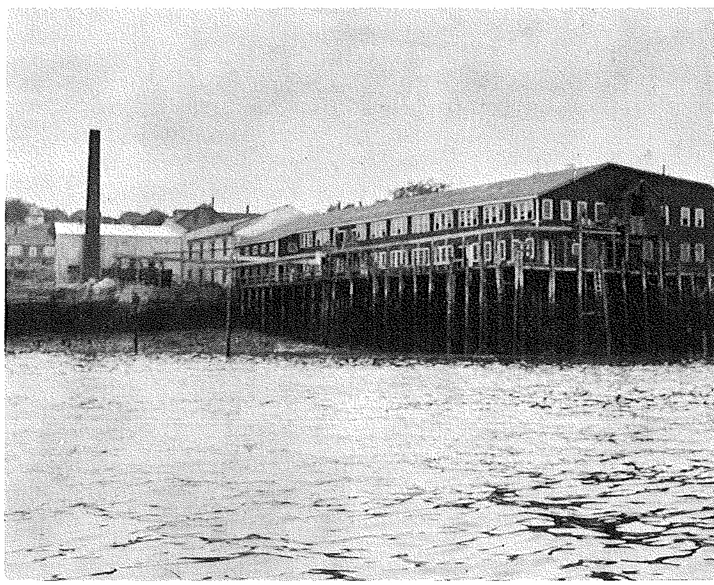
Effect of Tidal Project

Construction of the Passamaquoddy tidal power project with an auxiliary power plant would have a favorable impact on all segments of the economy of Maine. The accompanying growth in the demand for electricity, which is fully discussed in the next chapter, could readily absorb the United States' share of the output of the tidal power plant and its auxiliary. In addition to supplying an important block of power to assist in meeting the needs of the growing power markets, the construction and operation of the tidal power project and its auxiliary would serve also as a catalytic agent in the regeneration of the economy of Maine, particularly in Washington County.

Construction of the tidal power project and the Rankin Rapids auxiliary would also produce an important short-term economic impact on the economy of Maine. During the six-year construction period of the tidal power project alone, total investment outlays in Maine, and to a major degree in Washington County, would amount to approximately $100 million or more. This investment would generate an additional $100 million of expenditures, increasing total income in Maine by at least $200 million. This additional income would exert an important upward pressure on the construction industry and on wholesale and retail trades.

In addition to long-term beneficial economic effects, the economy of Washington County would be transformed during construction of the project by the influx of several thousand workers and the generation of substantial new income in wages alone.

Fish-processing plant in Eastport, Maine



ECONOMY OF NEW BRUNSWICK

The site of the tidal project lies at the southernmost point of the Province of New Brunswick. In area, the Province extends from the project site about 150 air miles to the east and 200 miles to the north. Somewhat smaller in area than Maine, New Brunswick has a total area of 27,985 square miles, with 512 square miles of inland water. The capital city of the Province, Fredericton, has a population of 18,303, and is located on the Saint John River about 110 miles by road to the north. The population of New Brunswick is concentrated in the east along the shore of the Gulf of St. Lawrence, in the south along the shore of the Bay of Fundy, and in the west along the valley of the Saint John River.

Population, Labor Force, and Gross Provincial Product

According to the 1956 census, the population of New Brunswick was distributed as follows:

Municipality	1956 population	Percent of total population
Saint John	52,491	9.5
Moncton	38,479	6.9
Fredericton	18,303	3.3
Lancaster	12,371	2.3
Edmundston	11,997	2.1
Campbellton	8,389	1.5
Cities subtotal	142,030	25.6
19 Towns	56,956	10.3
2 Villages	2,079	0.4
Urban subtotal	201,065	36.3
15 Counties	353,551	63.7
Total population	554,616	100.0

As shown in the above table, more than 60 percent of New Brunswick's population, in 1956, was located outside incorporated urban municipalities, while more than one-quarter lived in six cities.

The population of New Brunswick was 547,000 in 1955 and is expected to grow to 825,000 in 1980. Substantial though this growth is, the projected increase of 51 percent is well below the population growth of 71 percent for Canada as a whole as predicted by the Royal Commission on Canada's Economic Prospects. In projecting New Brunswick's population it was assumed that Provincial economic performance in the future will exhibit reasonably high levels of demand and employment. It was also assumed that expenditures on all levels of government will be maintained and, on some levels, increased. The factors that control population growth (birth, death, marriage, fertility, reproduction, and net emigration rates) were analyzed for the 1926-55 period and projected to 1980. In 1955, the labor force of about 171,000 was 31 percent of the Provincial population; in 1980 the projected labor force of 247,500 is estimated to be about 30 percent of the Provincial population.

Gross Provincial Product (GPP) measures the at-market value of all goods and services produced in a year and is thus the most comprehensive index of economic performance available. Estimates of New Brunswick's GPP were made for the period 1936-55, and were then projected to 1980 in constant (1955) dollars. Provincial output figures were thus deflated in order to eliminate variations due to price movements from year to year and to show the growth of Provincial output in real terms. For the purpose of illustrating the behaviour of each part of Provincial economy, the following eight sectors were analyzed: minerals, pulp and paper, lumber and wood-using industries, fishing and fish processing, primary agricultural operations, secondary manufacturing, construction, and services. The first four sectors constitute the resource-based industries, each of which contains the entire run of production from primary operations through processing and manufacturing stages. Secondary manufacturing includes all manufacturing other than mineral, forest, and fish processing. Construction and services are treated as separate sectors.

The projected growth of New Brunswick's economy from 1955 to 1980 is summarized in the following table, with the Gross Provincial Product (GPP) in 1955 Canadian dollar values:

Project Growth of New Brunswick's Economy

Sector	1955 Employment (thousands)	1955 GPP (millions)	1980 Employment (thousands)	1980 GPP (millions)	Percent increase Employment	Percent increase GPP
Minerals	2.2	$11	4.8	$26	118	136
Pulp and paper	9.9	49	18.8	117	90	139
Lumber and wood	7.6	27	9.0	33	18	22
Fishing	12.6	11	12.5	20	- 1	82
Agriculture	23.2	35	16.8	44	-28	26
Secondary manufacturing	11.2	53	13.5	88	21	66
Construction	19.5	79	20.6	111	6	41
Commodity production	86.2	265	96.0	439	11	66
Services	74.7	265	136.5	596	83	125
Total	160.9	530	232.5	1,035	45	95

In addition to the employment indicated in the tabulation, the estimated unemployed was 10,000 in 1955 and will be 15,000 in 1980. Total labor force estimates are 171,000 in 1955 and 247,500 in 1980.

The long-term economic growth of New Brunswick is expected to be most pronounced in resource-based industries that manufacture for export and attract large capital investment. The future labor requirements of the Province in such sectors as minerals, pulp, and paper will depend mainly, therefore, on growth of the export market. The growth of employment in construction is anticipated to be small, largely because of the abnormally heavy construction boom in 1955. As a result of technological changes, the number of workers in agriculture and fisheries is expected to decline. The projected growth of the labor force in commodity production and construction is much smaller than the increase in service employment, a trend similar to that predicted for Canada as a whole by the Royal Commission on Canada's Economic Prospects.

Whereas the projected growth of total employment is only 45 percent, the increase of GPP from 1955 to 1980 is 95 percent. The share of GPP contributed by different sectors indicates a much greater dependence on mineral, pulp and paper, and fisheries development than on growth in secondary manufacturing, lumbering, and agriculture. By 1980, the income generated in the 4 resource-based sectors is estimated at 45 percent of all income from commodity production. The comparable ratio in 1955 was only 37 percent. Again, there are strong indications that the relative value of services in the economy will increase during the next two decades.

Minerals

Nonmetallic minerals, especially structural materials, are produced in New Brunswick to meet local requirements. A cement plant has supplied the maritime regional market for a number of years. Limestone is produced in several areas for agricultural purposes. The coal mining industry is located in the Minto-Chipman area near Grand Lake and supplies mainly the provincial market, with some exports. New Brunswick coal is bituminous and has an average of 11,500 B.t.u. per pound. In recent years coal mining has become increasingly mechanized with stripping operations predominating. On the basis of a market survey, the output of New Brunswick's coal industry is expected to increase by 10 percent between 1955 and 1980.

The discovery of lead, zinc, copper, and silver in the Bathurst-Newcastle area is of major economic importance. Large deposits of high-grade ore, suitably located near tidewater, resulted in a sizeable investment of external capital. The interested companies to date have spent an estimated $25 million in prospecting and development, and one 1,500-ton-per-day concentrating mill has been built and operated. Plans for further base-metal concentrators have been announced, but these plans have been temporarily halted due to the recent softening of metal prices.

In addition to base-metal deposits, some 200 million tons of low-grade manganese ore, in six ore bodies, are located near the U.S. border in Carleton County. There are indications that the main problems of upgrading these ores have been resolved. A ferromanganese smelter, to be developed in 3 stages during the next 12 years, is accordingly projected in this survey.

Although recent market developments imposed a short-term curtailment of provincial metal development, the longrun prospects of New Brunswick's mineral industry remain optimistic. With Canadian exports of minerals expected to increase four times by 1980, it is predicted that zinc output will be doubled, copper production increased by two-thirds, and lead by one-half. The New Brunswick industry should share in this general expansion. The Government of Canada has undertaken to provide enlarged harbor facilities at Bathurst, on condition that the mining companies proceed with their announced production schedules. The federal and provincial governments have contributed to the cost of constructing rail lines, roads, and bridges to assure movement from mine to tidewater at a low unit cost.

For the entire mineral sector, including structural materials and coal, the gross value of products is expected to increase from $17 million in 1956 to approximately $100 million in 1980. By 1980, an estimated 4,800 workers will be engaged in mineral production.

Pulp and Paper

The pulp and paper industry of New Brunswick owes its existence and development to several important factors. The Province has vast timber resources. Reproduction and growth rates of softwoods suitable for the industry are relatively high. The United States permits newsprint over a certain size to enter duty free, but other types of paper products are normally subject to prohibitive tariffs. Canada's domestic market for pulp and paper products is growing rapidly, while market prospects in the United Kingdom and western Europe appear to be equally favorable. A recent study shows that the domestic supply of pulp could be doubled immediately, without recourse to extraprovincial supplies, by using sawmill waste, redirecting current pulpwood exports to Provincial mills, and by absorbing the anticipated decline in fuelwood production. Although the pulp and paper industry is economically the most important in New Brunswick, it employs only about 19 percent of the total labor force. In 1955, the gross value of pulp and paper products amounted to $94 million and the industry employed 10,000; in 1980 the estimated gross value of output is $251 million, with an anticipated labor force of approximately 19,000.

Accumulation of pulp wood at paper mill in Saint John, New Brunswick

Lumber and Wood-Using Industries

The prospects for lumber and wood-using industries are less favorable than for pulp and paper. The products manufactured in this sector generally require a larger market than can be reached economically. Certain conditions have restricted the ability of producers to retain their markets in central Canada, while international currency and trade limitations have seriously hindered exports to traditional British and European markets. In addition, the small-scale operations in use have retarded the utilization of waste wood. Few operations, in fact, are of sufficient size to warrant secondary by-products. In 1955, the gross value of lumber products was $49 million and the primary and secondary operations of the industry employed just over 7,000. The gross value of lumber production is expected to reach over $70 million by 1980, while employment should increase to 9,000.

Fishing and Fish Processing

About 35 commercial fish species are produced in New Brunswick. Shellfish constitute a substantial part of total marketed value, lobsters being the most valuable single species. Sardines, herring, cod, and smelt are also of importance. Haddock, clams, oysters, and salmon, together with a variety of other species, make up the rest. The annual catch ranges from 200 to 250 million pounds and has recently been increased sharply through mechanization.

Sardine-canning plant on Campobello Island

The structure of the fishing industry has gradually changed over the years. Traditional salting, drying, and smoking operations have declined, and there is now much greater emphasis on fresh and frozen groundfish production. An additional dynamic element in the industry is the rapid growth of by-product utilization, especially fish meal and various marine oils. The future growth of the fishing industry will depend on the following: domestic and foreign demand growth; availability of raw materials; government policies, especially the tariff policies of foreign consumer nations; the degree of international competition both for markets and materials; and finally, the impact of technical innovations.

A study of future requirements indicates that the gross value of fishery products should rise from $20 million in 1955 to about $35 million by 1980. Implicit in this projection is the belief that technological advances will continue, but at a somewhat slower pace than during the postwar decade. Thus, a small decrease is anticipated in fisheries employment as a whole, a decrease resulting from large employment losses in primary operations combined with small increases in employment at the processing stage.

Agriculture

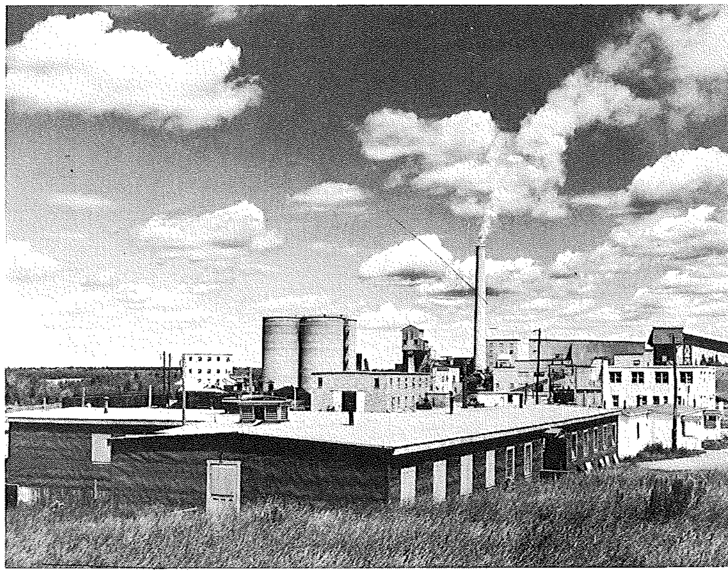
New Brunswick soils are generally thin, low in both organic matter and fertility, and highly acid. Good useable agricultural land is scattered in small pockets, thus making efficient farming operations difficult. There are some notable exceptions, particularly in the upper Saint John River valley, the Grand Lake and Sussex areas, and the southeastern marshlands. The agricultural industry is unable to provide the Province's domestic food requirements. With the exception of such commodities as potatoes, apples, and strawberries, New Brunswick is deficient in all agricultural products. According to the last major census (1951), 71 percent of all farms reported annual cash income from the sale of farm products of less than $1,200. These unproductive farms accounted for only 22 percent of total farm sales.

No basic change in the structure of Provincial farming is foreseen during the next 20 years. The longrun downward trend in farm acreages should continue through 1980. These losses will continue to result from the abandonment of small-scale, unproductive or subsistence farms. These trends should be accompanied by an increase in the number of productive farm units, greater land use, and larger farms. The total agricultural labor force, which declined by one-half between 1931 and 1956, should be stabilized at about 16,000 by 1980. The gross value of farm products is expected to increase from $55 million in 1955, to $68 million in 1980.

Secondary Manufacturing

Manufacturing in areas other than mineral, forest, and fish processing is not highly developed in New Brunswick. Great interest by the Maritime Provincial Governments, and the Maritime Boards of Trade, in attracting additional industries to area led to formation of the APEC, "Atlantic Provinces Economic Council." The effort of this Council should greatly assist the development of secondary industries in New Brunswick. The availability and dependability of the labor force in New Brunswick are great assets to prospective industry intending to locate in the province.

Nearly 60 percent of the value in secondary manufacturing is in food and beverage production. Historically, the rate of growth in food and beverage industries has lagged behind the rate of population increase. This trend should continue in the future. In secondary manufacturing, other than food and beverages, there is reason to anticipate moderate growth. Because of its many locational disadvantages, however, this sector of the Provincial economy will continue to expand at a rate well below the national average of 4.5 percent annually as predicted by the Royal Commission on Canada's Economic Prospects. The gross value of secondary manufacturing production is expected to increase from $142 million in 1955 to $240 million at the end of the forecast period. During this time, employment should likewise increase from 11,000 to 13,500.



Cement plant at Havelock, New Brunswick

Transportation

The transportation systems in New Brunswick have been improving in the last few years. The Province is served by two railroad systems, the Canadian Pacific Railway and Canadian National Railways, which provide both freight and passenger service throughout the Province. New public highways are being built and the existing highways improved, providing easy access to all parts of the Province. The construction of the Trans-Canada Highway has opened up the center of the Province to a large movement of traffic. Air service is provided from the three civilian airports near Moncton, Saint John, and Fredericton. Water transportation in the inland waterways of New Brunswick includes log driving, towing of pulpwood and logs in booms, and oil shipments by small tankers. These rivers are a potential source of cheap transportation for products of future industrial development.

Saint John is the most important harbor in New Brunswick. It is located on the southern coast in the Bay of Fundy and is one of the large ice-free winter ports in the Maritime Provinces. The port is served by highways and railroads, and exports products from upper and western Canada to overseas markets. World-wide shipping calls at Saint John to discharge cargoes destined for all points in Canada. Saint John is also a winter terminus for the Canadian Pacific Railway and Cunard passenger liners.

Several ports are situated on the north and east coasts of New Brunswick, including Campbellton, Dalhousie, Bathurst, and Newcastle, which are used mainly for export of pulpwood and paper, and lumber products. These harbors are also potential ports for the shipping of ores recently discovered in the Bathurst-Newcastle area.

Construction

In 1955, New Brunswick experienced an unprecedented construction boom. Growth as pronounced as that between 1954 and 1955 cannot be expected to continue over a long period. However, a 50 percent growth in construction between 1955 and 1980 is anticipated. In conformity with national trends, a moderate increase in productivity and a continuing replacement of labor by machinery is assumed for the forecast period. The gross value of construction is expected to rise from $154 million in 1955 to $227 million by 1980, while the construction labor force should grow by more than 1,000.

Services

Services are defined as all activities resulting in invisible products rather than in physical objects. Services thus include transportation, communication, and other utilities; wholesale and retail trade; finance, insurance, and other commercial operations; personal, professional, business, and recreation services; and government at all levels.

In 1955, nearly 47 percent of the Provincial labor force was engaged in service operations, while the share of services in gross Provincial product stood at 50 percent. The Royal Commission on Canada's Economic Prospects anticipates a vigorous growth in services by 1980. The growth factors in the Commission's estimates range from 2.5 to 3.5 for the period of forecast. While the possibilities of an expansion of services in New Brunswick are more modest than those for Canada, it is nevertheless expected that Provincial service activities will more than double between 1955 and 1980. The growth of services will thus keep pace with such dynamic sectors as pulp, paper, and minerals. As a consequence, the ratio of income and employment in services to income and employment in commodity production will change considerably during the forecast period. The output of electricity will contribute substantially to the increased product of Provincial services, since the main growth industries in New Brunswick are heavy consumers of electric energy. Other dynamic elements within the services sector include government and recreation.

Recreation

New Brunswick's unique location, adjoining Quebec and the State of Maine attracts a great number of visitors each year. The Province is well endowed with natural beauty, with 80 percent of its area in forest and many lakes and world-famous salmon and trout-fishing streams. The coastline stretches for a length of 600 miles and varies from the picturesque rocky coastline of the Bay of Fundy to the gently sloping beaches of the Northumberland Strait.

The tourist industry is recognized as a growing segment of New Brunswick's economy, income from which is estimated to be from 30 to 40 million dollars annually. A total of 1,370,000 people visited the Province in 1958.

The Fundy National Park is located in New Brunswick, extending 8 miles along the shore of the Bay of Fundy and covering an area of 80 square miles. The park, which opened in 1949, has expanded its accommodation facilities from the original 26 chalets to a present total of 70. More than 130,000 people visited the park in 1958. Plans are being made to improve the existing facilities for the growing number of visitors.

The Provincial Government maintains throughout the Province 52 picnic sites, 80 percent of which are adapted for trailer and tenting parks. The facilities are planned to be increased 7 percent in capacity for 1959. Several travel bureaus are operated in order to direct people to the many natural phenomena and historical sites.

Great interest is now being shown in the potential of New Brunswick rivers and shoreline in the development of pleasure-boating facilities. Boating to date in New Brunswick has lagged behind the rapid development elsewhere, but now shows every indication of following the trend.

New Brunswick is well known for its wildlife and the opportunities for fishing and hunting. In 1958, 49,000 combined hunting licenses for deer and birds and 20,000 licenses for birds were issued. Of these, approximately 5,000 were nonresident licenses. Upwards of 20,000 deer and 117,000 game birds were killed in 1958.

Charlotte County

In recent years there has been a notable absence of growth in the economy of Charlotte County. County population and employment in agriculture has declined steadily. Primary operations in forestry and fishing have provided the principal income in the rural economy. Manufacturing is relatively undeveloped and recently suffered a setback due to the closing of the Milltown textile plant. The fish processing industry, which now constitutes 40 percent of county manufacturing, paid an average of only $1,190 per employee in 1955. Thus, workers in this important segment of the county economy receive incomes which approximate only one-third the average income per employee in Canadian manufacturing. The long-term prospects for Charlotte County will depend on more intensive use of forest resources, greater development in fisheries, and an expansion of recreational facilities.

Effect of Tidal Project on Charlotte County

As a result of the construction of the Passamaquoddy project, the short-term benefit to the county economy would be substantial. The current high unemployment would be fully absorbed. The new income from wages alone would have a marked effect on county retail trade. The effect of this new income would be largely exhausted at the retail level, however, since few consumption goods are produced in Charlotte County. If an undertaking as extensive as the Passamaquoddy project should proceed, the county lumber and other industries would likewise experience a considerable impetus. At the same time, it is possible that the large short-term demand for construction labor could affect the local labor market to some extent. If a significant number of workers ordinarily engaged in primary fishing and woods operations were attracted to construction employment on the project because of the higher wages offered, supplies of raw fish and wood to the county's processing establishments could be reduced substantially.

Finally, an additional small but continuing benefit would accrue from the maintenance labor and expenditures associated with the operation of the Passamaquoddy system, and also from the estimated 800,000 annual visitors to the tidal power project.

Effect of Tidal Project on the Province of New Brunswick

The power from the tidal project would be absorbed into the transmission system of The New Brunswick Electric Power Commission and would have the same effect on the general economy of the Province as any other block of power of similar size and cost developed to satisfy the growing load demand.

Approximately $100 million would be spent in New Brunswick for building supplies such as lumber, cement, hardware, etc. The spending of this money would probably generate another $100 million which would have a beneficial effect on the Provincial wholesale and retail trade.

EFFECTS ON FISHERIES

The Passamaquoddy tidal project, the Rankin Rapids hydro auxiliary, and the Digdeguash pumped-storage auxiliary each affect the fisheries in the waters they control. The International Passamaquoddy Fisheries Board studied the effects that the tidal project would have on the fisheries in the Bay of Fundy and within the tidal project in Passmaquoddy and Cobscook Bays. The findings of the Fisheries Board considered in this report include only those damages measurable in dollars which might affect the economic justification of the project.

Tidal Project

The usefulness of two lobster pounds at North Harbour on Deer Island, New Brunswick, may be damaged and might require relocation at an estimated cost of $365,000. Construction of fishways at the powerhouse and at the emptying gates was included in the project design at the request of the Fisheries Board. These facilities, estimated to cost $919,000, are necessary to prevent damage which would otherwise result from blocking migration of anadromous fish. These two costs are included in the estimated total cost of the tidal project.

The remedial works incorporated into the tidal power project would not alleviate all the losses which the fisheries of the region would sustain if the tidal power project were built. The remaining annual losses are tabulated below:

	United States	Canada
Increased cost of maintaining fish weirs in the upper pool	$2,000	$8,000
Reduced groundfish catch from project pools	3,000	0
Reduced harvest of clams from project pools	17,000	87,000
Totals	22,000	95,000

The following annual gains to the fisheries compensate for part of the losses:

	United States	Canada
Increased smelt production	Slight	0
Increased scallop production	2,000	12,000
Totals	2,000	12,000

The net annual value of the above to both countries amounts to a loss of $103,000.

The following additional losses would occur in the local economy:

Relocation of 6 weirs from construction sites	$33,000
Reconstruction of 82 weirs due to changed water levels	96,000
Cessation of clam processing	100,000
Total	229,000

At a 6 percent interest rate the annual losses would be about $14,000.

The aggregate fisheries' losses remaining after incorporating remedial facilities into the tidal power project amount to $117,000 a year. This amount is too small to affect the benefit-cost ratios of the project and, accordingly, was not included in the computation of the ratio. Other secondary factors such as recreational benefits which have a higher annual value also were not included in the computation of the benefit-cost ratio.

Rankin Rapids Project

The Rankin Rapids project would flood substantial reaches of the Allagash and Saint John Rivers in Maine which now support an important sport trout fishery, particularly on the Allagash River. The Bureau of Sport Fisheries and Wildlife of the United States Department of the Interior considered the problem and recommended that remedial measures be taken if the project is built. These measures are listed in chapter II. No economic evaluation has been placed on damage to existing fisheries resulting from the construction of the Rankin Rapids project.

Digdeguash Project

The Digdeguash River now supports a small run of Atlantic salmon which would be destroyed by construction of the pumped-storage auxiliary. Methods of restoring this run were not determined. No economic evaluation has been placed on damages to existing fisheries resulting from construction of the pumped-storage auxiliary.

RECREATION

Population growth, greater per capita income, leisure time, and the greater personal mobility are resulting in a rapid growth of the recreation and tourist busines at Federal dams and reservoirs, national parks and forests, and privately-owned installations throughout United States and Canada. In Maine, the recreation industry has long been an important buttress of the economy of the State. The uniqueness of the tidal project and the greater accessibility to the upper Saint John River areas afforded by the proposed reservoir auxiliary would make substantial contribution to the recreation industry by attracting great numbers of visitors.

Tidal Project

Construction of the Passamaquoddy tidal power project would be an important added attraction for tourists from both United States and Canada. The project would increase the tourist business in New Brunswick and in the areas along the entire coast of Maine northeast of Penobscot Bay. It is estimated that a total of at least 800,000 persons from the two countries would visit the project area each year, increasing annually at a rate of 5 percent.

It is the current policy of the U.S. Army Corps of Engineers to credit a water resource project with benefits from $0.50 to $1.50 per visitor day. Using a median value of $1.00 a day, and assuming that each visitor spends one day at the project, the recreation benefits would be at least $800,000 each year. However, these benefits, in spite of the conservative estimate and the surging increase in recreational activity, were not credited to the tidal power project to increase the benefit-cost ratio or to reduce the cost of power.

In addition to the recreation benefits described above, other benefits would result from the increased local economic activities due to a greater number of visitors. Many additional restaurants, motels, and other facilities would be developed and thereby benefit the economy of the area, particularly during the vacation season.

Rankin Rapids Project

The Rankin Rapids river hydro auxiliary would flood the lower reaches of the Allagash River which, in addition to being a sport trout fishery, is a well-known wilderness, white-water canoe route. While annual statistics are not available, the Great Northern Paper Company reports that only 409 people used the lower Allagash River between June 10 and November 29, 1958. Of these, 213 were local people with camps in the area. Almost all the rest were canoe groups from boys' camps. A large dam and reservoir built at Rankin Rapids would change the type of attraction and make more of the area accessible to a greater number of people. That the reservoir site would be used by a great many more people than now use the white-water area is supported by the rapidly growing number of people visiting water resource projects in the United States and Canada. A total of nearly 95 million visits were made to U.S. Army Corps of Engineers' projects alone in 1958, a twenty-fold increase over 1946. While not as great as for the U.S. Army Corps of Engineers projects, visitors to other United States reservoirs, parks, and forests have increased greatly over the same period.

NAVIGATION

The barrier dams of the tidal power project would block the access to Passamaquoddy and Cobscook Bays. The project plan includes locks at four locations to maintain access to both high and low pools by vessels somewhat larger than those now using the area. The cost of these locks was included in the estimate of tidal power project cost. A large lock can be built in the Little Letite Passage area, if justified, to allow access to the high pool should industrial development occur along the pool shores, and should the need for access by large oceangoing ships arise. The cost of this future lock is not included in the tidal power project cost.

High Pool

Construction of the tidal project would modify the normal tide cycles in the high pool. The rising tide would last only 2 to 3 hours instead of the 6 hours of the natural tide. During spring tides the pool would rise only 4 to 5 feet instead of the normal 24 feet. Maximum water level in the high pool would be more than 1 foot lower than natural high tide, and the falling cycle would be 9 to 10 hours long and much more gradual than the natural tide. More important as a benefit to navigation are the pool levels which would prevail after construction of the project. These levels are compared with natural levels below:

	Elevation in feet, m.s.l.	
	Present conditions	With tidal project
Maximum	+13.9	+12.2
Average	0	+ 6.3
Minimum	-13.4	+ 3

The controlling navigation depth in the St. Croix River at Calais, Maine, and St. Stephen, New Brunswick, would be increased from the present 7 feet at mean low tide to about 22 feet. At extreme low tide, the controlling depth would be increased from 2.5 to 19 feet. Thus, by decreasing the tidal range, access to the waterfront areas of Calais, Maine, and St. Stephen and St. Andrews, New Brunswick, would be considerably improved. Smaller ports like St. George and Fairhaven, New Brunswick, and Robbinston and Red Beach, Maine, would also benefit from increased controlling depths.

Low Pool

Water levels in the low pool would be affected in somewhat the same way as water levels in the high pool, except that the low pool would remain below mean sea level and the range between high and low levels would be greater than in the high pool. During operation of the tidal project, the level of the lower pool would fall for 3 to 4 hours, followed by a rising cycle of 8 to 9 hours. During a 24-foot spring tide, the lower pool would fall only 10 feet from el. -2 to el. -12. Minimum levels in the low pool would be about 6 inches higher than low tide. Levels of the lower pool compared with natural tide levels are as follows:

	Elevation in feet, m.s.l.	
	Present conditions	With tidal project
Maximum	+13.9	0.0
Average	0	- 5.0
Minimum	-13.4	-12.9

The low pool would have adequate depths for navigation except in areas near the shore. The elimination of tides above mean sea level would make it impossible to use water-front facilities where vessels cannot now tie up at low water. An allowance for extending the piers to deeper water was included in the cost of the tidal power project.

In two restricted channels in the low pool, the Falls Island area and the Lubec Channel, high tidal currents occur during most stages of the tide. If the tidal project is built, tidal currents in these areas would be approximately the same as at present during the 3- or 4-hour drawdown of the low pool. During the remaining 8 or 9 hours while the low pool is filling, however, the currents would be considerably decreased, thus affording improved navigation at these locations.

HIGHWAYS

The project first cost includes the cost of restoring permanently the service of public highways disrupted by construction of the tidal project and its auxiliary. Maine State Highway No. 190, which serves Eastport, Maine, is the only major highway relocation required. This highway would be cut by the powerhouse headrace channel. Service would be maintained by relocating the highway on a bridge across the channel. The bridge would also carry a single track of the Maine Central Railroad and several utility lines. The first cost of the pumped-storage auxiliary also includes the cost of relocating roads flooded by the Digdeguash reservoir. No highway relocations would be required for the Rankin Rapids auxiliary.

The 7 miles of tidal dams would also afford an opportunity to connect the Canadian coastal highway at St. George, New Brunswick, with the United States coastal highway, at Eastport and Lubec, Maine. The cost of this highway is given in chapter VI, and general routes are shown on plate 44. In the layout of this highway the possibility that an international bridge will be built from Lubec, Maine, across the narrow Lubec Channel to Campobello Island, New Brunswick, was considered. At the writing of this report, this bridge is in the planning stage by the Governments of Maine and New Brunswick.

Although the monetary benefits of this highway were not estimated, the desirability of such a highway is evident. Access to Deer Island is now made by ferry from Letite, New Brunswick, and from Eastport, Maine. Access to Campobello Island from Lubec is also made by ferry. A highway system built on the tidal dams would replace the ferries and would provide an additional direct road between Deer and Campobello Islands. In addition to saving the cost of maintaining and operating the ferries, the island residents would benefit in many ways, including a greater tourist trade.

DEFENSE PLANNING

The defense agencies of both the United States and Canada concluded that construction of the tidal power project would have no effect on defense planning. Of importance to both nations, however, is that the Passamaquoddy tidal power plant requires no fuel, and in combination with the Rankin Rapids auxiliary, would save 1,280,000 tons of coal or 5,700,000 barrels of oil a year.

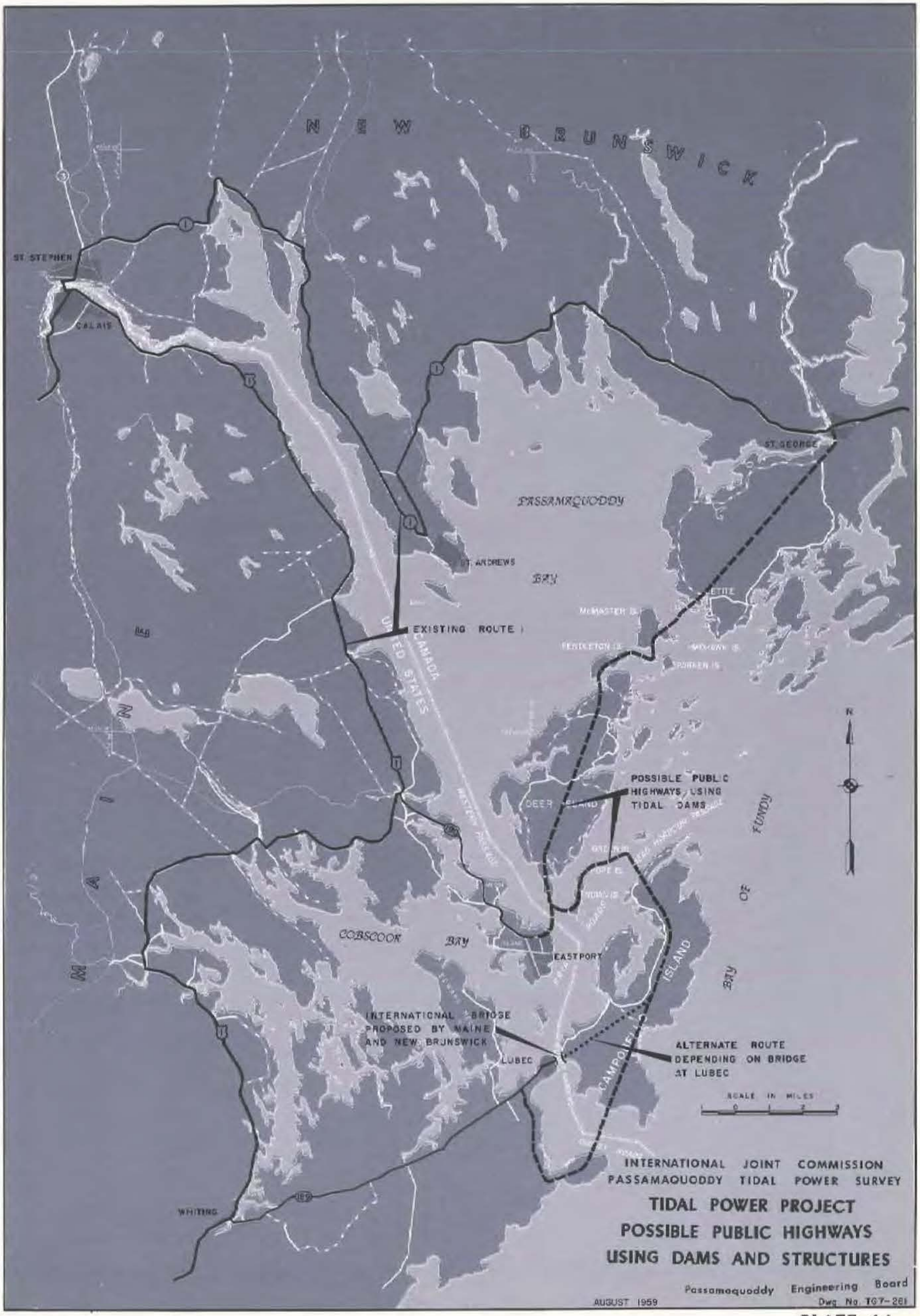

N E W B R U N S W I C K
ST. STEPHEN
CALAIS
ST. GEORGE
PASSAMAQUODDY
BAY
ST. ANDREWS
McMASTER IS.
PENDLETON IS.
EXISTING ROUTE 1
UNITED STATES
CANADA
POSSIBLE PUBLIC
HIGHWAYS USING
TIDAL DAMS
DEER ISLAND
FUNDY
OF
BAY
COBSCOOK
BAY
EASTPORT
CAMPOBELLO ISLAND
INTERNATIONAL BRIDGE
PROPOSED BY MAINE
AND NEW BRUNSWICK
LUBEC
ALTERNATE ROUTE
DEPENDING ON BRIDGE
AT LUBEC
SCALE IN MILES
0 1 2 3
M A I N E
WHITING
N
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
POSSIBLE PUBLIC HIGHWAYS
USING DAMS AND STRUCTURES
Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-261

PLATE 44

CHAPTER VIII

POWER UTILIZATION

The goods or services produced by a project have value only to the extent that a need and demand for the product exists. With this principle as a guide, studies were made of the markets in Maine and New Brunswick which would use the power from the tidal project and its auxiliary. It was found that the total capacity and energy that can be generated can be absorbed over a number of years by the normal growth of the combined market. It was assumed in this study that the United States and Canada would share equally the power output of the project. The power market studies and the studies of the required transmission lines are summarized in this chapter.

POWER MARKETS

The project would serve the growing power markets of Maine and New Brunswick for which additional generating capacity will be required in the future. The markets fall into the following three general categories:

First and most important is the market consisting of farm, nonfarm domestic, commercial, industrial, and other users of electric energy which are supplied by utility systems. As customer requirements expand, the utilities obtain additional supplies of power either by constructing new generating facilities or by purchase.

The second market, which is also a fairly large power market in Maine and New Brunswick, is that supplied by power plants owned and operated by industrial establishments. This type of power supply is used by pulp, paper, textile, and other industries when power costs can be reduced by combining the production of required process steam with electric power generation, or by the use of by-product fuels. Any growth of industrial power requirements which can be supplied more advantageously by industry-owned generating plants has not been considered as a utility market. On the other hand, industrial requirements supplied by energy purchased from utilities are a component of the utility market.

A third market would develop if new, large power-consuming industries which would be served directly by the tidal project were to locate in the vicinity of the project in Maine. A detailed examination of all economic and locational factors indicated that the magnitude and characteristics of basic materials industries which might be attracted into the project area in the future cannot be determined adequately at the present time. It is assumed, nevertheless, that the construction and operation of the tidal project would stimulate development in the immediate vicinity of the project in Maine of a diversified market capable of absorbing at least 25,000 kw.

Characteristics of Utility Power Markets

The growth of utility power markets in Maine and New Brunswick, as in the rest of United States and Canada, is influenced by a number of economic and technological factors. Among these factors are the growth of population and households; expansion of industrial production; growth of activities associated with service, trade, and professional establishments; greater application of known processes and devices using electricity; and the development and introduction of new uses for electricity in the home, industry, and other fields. Under the impact of these influences, the utility markets have grown steadily over a long period. Except for unforeseeable national or regional deterrents, the growth of these markets can be expected to continue in the future.

The principal classes of utility service and the factors affecting the growth of their power requirements are as follows:

(1) Farm Service. Farm service includes the requirements of utility customers living in rural areas who depend on agriculture for the major portion of their income.

Farm customers use electricity in their homes as well as in some of their farming operations. Electrification of the farm homestead brought to the farming population many comforts and conveniences, including labor-saving devices, entertainment, education, improved sanitary conditions, and many other advantages. Under favorable economic conditions in the future, farm use of electricity will continue to grow, particularly in farming operations and processing of the products of agriculture.

(2) Nonfarm Residential Service. Nonfarm residential service includes by far the largest number of customers, most of whom live in urban and suburban areas. They use electricity for lighting, heating, cooking, refrigerating, and for operating numerous devices and appliances. The number of customers is in direct proportion to the number of households in the market area. The annual use per customer has been increasing steadily. Many domestic appliances have been in use for many years and have reached high levels of saturation. Others have come into use only recently and will take some time to find wide acceptance. Still others are in the development stage and will stimulate domestic use at some time in the future. Generally, this class of service is least affected by adverse economic conditions. Combined, the farm and nonfarm domestic service group is sometimes identified as the rural and residential class.

(3) Commercial. Commercial energy sales include deliveries to wholesale and retail trade enterprises, professional and personal service establishments, places of recreation, financial institutions, and other business concerns. More commercial energy is used as population increases. Better lighting has proved highly effective in stimulating the business of service and trade establishments. Air conditioning is fast becoming essential to the operation of department stores, theaters, restaurants, and other competitive enterprises. Electrification of the office, store, and shop equipment results in higher efficiency, labor savings, and lower operating costs. Under these influences, commercial service can be expected to continue its expansion in the foreseeable future.

(4) Industrial. The industrial class of service includes all energy sold to manufacturing and mining establishments. Estimates of the growth of energy use by industrial establishments are based upon the assumption that favorable economic conditions will prevail and that short period fluctuations in business conditions would not cause material changes in long-term trends. Electricity has proved effective in expanding industrial production, lowering costs, increasing efficiency, and raising the productivity of labor. Under these assumptions, industrial power requirements will increase as existing industries expand their operations and as new industries find it advantageous to locate in these areas.

(5) All-Other. The "all-other" classification includes sales to government establishments, public schools, hospitals, libraries, other municipal buildings, military camps and depots, government warehouses, water supply systems, street and highway lighting, railways and railroads, and various miscellaneous customers not included in other classifications. The activities of government establishments will expand with population growth and with the need for increased public services. Better lighting and electrification of service equipment in public buildings can also be expected. Growth of population brings about greater demands for water and increased use of energy for pumping. With higher densities of population, improved street lighting for safety and crime prevention will be promoted. Highway lighting also will expand as networks of roads become more extensive and complex. All of these factors will contribute to increased energy sales under the "all-other" class of service.

Utility Market in Maine

There are at present 32 electric utility systems operating in the State of Maine. Almost 90 percent of the utility market is served by three utility companies, the Central Maine Power Company, the Bangor Hydro-Electric Company, and the Maine Public Service Company. The remaining utilities are small municipally or privately owned systems that buy all or most of their power from the three large companies.

The Central Maine Power Company serves the major portion of western and central Maine. Its transmission and distribution facilities extend over 14 counties and handle over 70 percent of the State's utility load. Included in its service area are such industrial centers as Auburn, Augusta, Bath, Biddeford, Brunswick, Lewiston, Portland, Saco, Sanford, South Portland, and Waterville (plate 43).

The Bangor Hydro-Electric Company operates in eastern Maine, and markets over 10 percent of all utility energy distributed in the State. The system operates in the counties of Hancock, Penobscot, Piscataquis, Waldo, and Washington, including the industrial centers of Bangor, Millinocket, and Old Town.

In the northern portion of the State, the Maine Public Service Company serves most of Aroostook and part of Penobscot Counties.

The distribution of the electric utility load in Maine corresponds with existing concentrations of population and industrial activity, the larger cities and their surrounding areas forming the principal load centers. Plate 45 shows the location of the principal generating stations and transmission lines in the State.

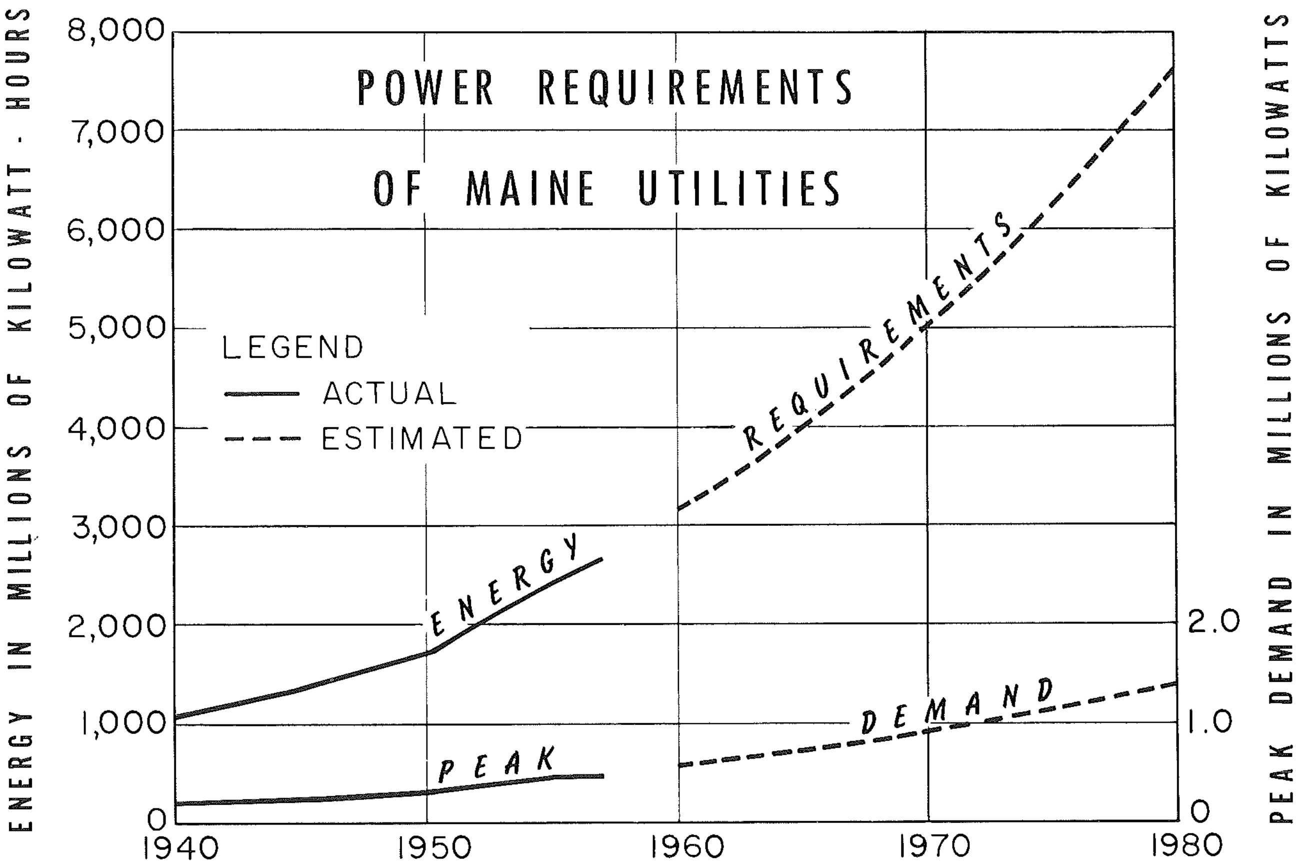
Electric utility service in Maine, as in most other parts of the nation, has grown from modest beginnings in the early part of the 20th century. The first systems were small, with limited transmission and distribution facilities. With growth in demand for electric power and progress in the technology of power generation and transmission, electric utility service spread over wider areas. Interconnections between individual systems were followed frequently by mergers and consolidations to form the large utility systems of the present time.

In 1940 the utilities of Maine supplied their customers with a total of 1,108 million kw.-hr. of electrical energy. By 1957, their requirements increased to 2,682 million kw.-hr., representing an overall growth of 142 percent in 17 years. In the same period of time, the combined noncoincident peak demand of the utilities increased from 209,000 to 493,000 kw. It is estimated that utility energy requirements in Maine will increase to 4,020 million kw.-hr. in 1965 and to 7,630 million kw.-hr. in 1980. The corresponding peak demand will be 740,000 and 1,390,000 kw. The past and estimated future power requirements of the utility market in Maine over the 1940-1980 period is tabulated below and illustrated on the growth curve. The load factor (ratio of average to peak load) is estimated to average about 62 percent during this period.

Utility Power Requirements in Maine, 1940-80

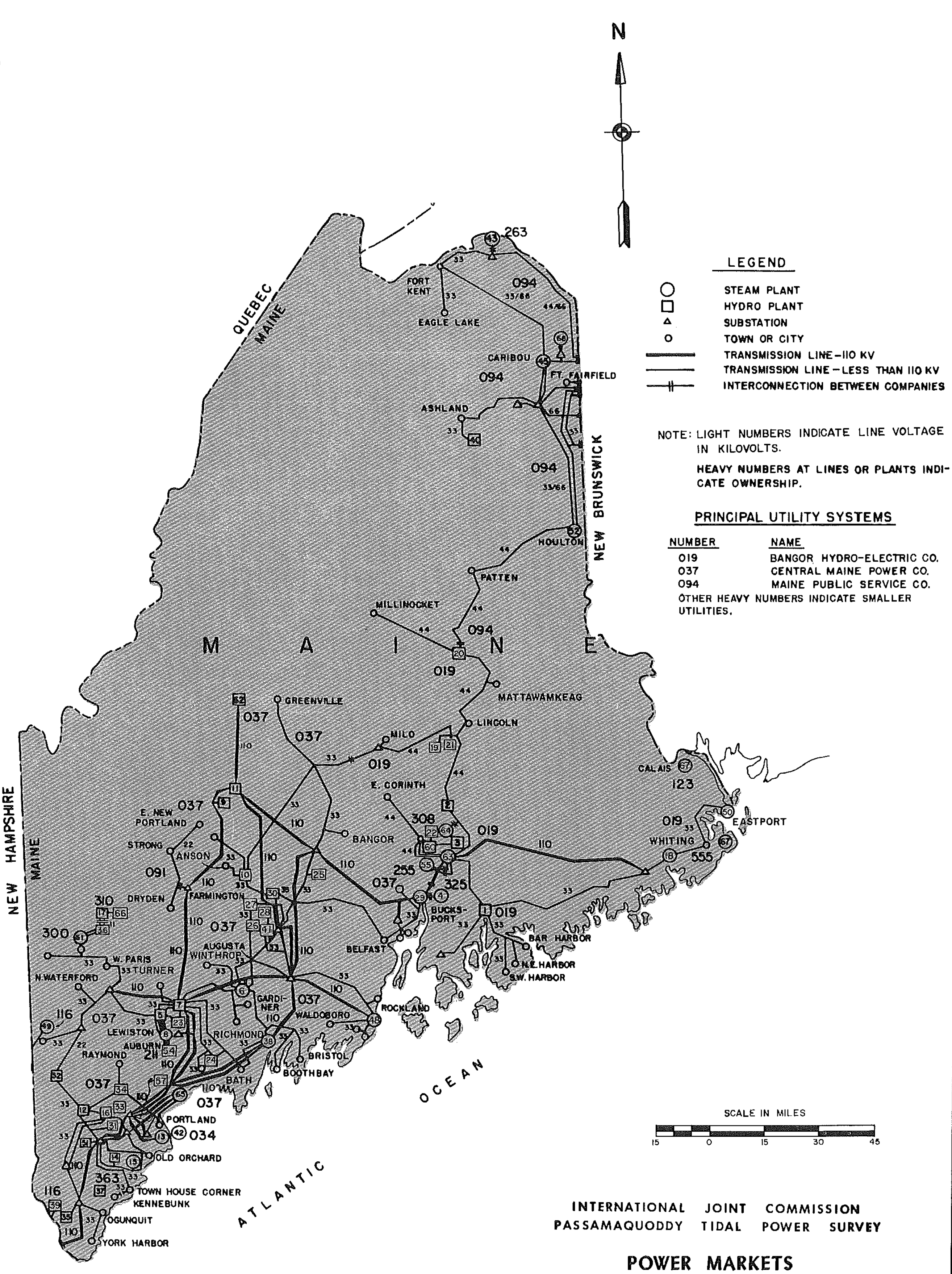
Year	Energy for load (million kw.-hr.)	Peak demand (thousand kw.)	Load factor (percent)
1940	1,108	209	60.3
1945	1,386	251	63.0
1950	1,737	334	59.5
1955	2,449	483	57.9
1957	2,682	493	62.1
1960	3,160	585	61.7
1965	4,020	740	62.0
1970	5,020	920	62.3
1975	6,210	1,135	62.4
1980	7,630	1,390	62.6

1940-1957 - Actual
1960-1980 - Estimated



Of the 32 utilities in Maine, 16 operate power-generating facilities to produce all or part of their requirements. The distribution of total utility capacity and generation in Maine, by type of prime mover in 1957, is as follows:

	Capacity		Net Generation	
	Kw.	Percent	Million kw.-hr.	Percent
Hydroelectric	347,288	50.4	1,467	59.0
Steam-electric	287,500	41.7	941	37.9
Internal combustion	54,894	7.9	77	3.1
Total	689,682	100.0	2,485	100.0



INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

POWER MARKETS
PRINCIPAL POWER GENERATING STATIONS AND TRANSMISSION LINES, MAINE

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-262

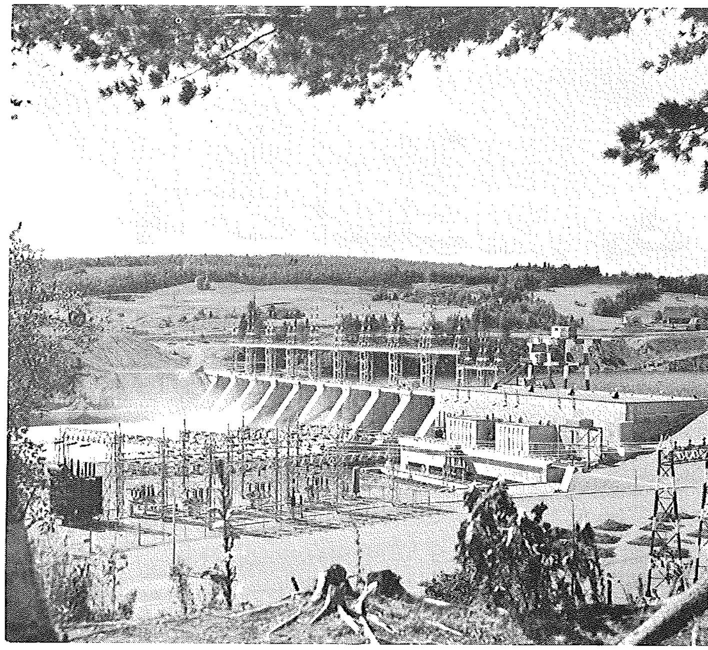
Fuel-burning plants of the utilities in Maine were used in the past primarily to meet peak loads and to firm hydroelectric capacity. More recently, steam-electric plants have been built to take over increasing portions of the utility base load. Diesel- and gas-turbine power plants are used by the larger utilities mainly for peaking and standby service.

The utility plants in Maine vary in size over a wide range. The largest hydroelectric power plants are owned and operated by the Central Maine Power Company, including the 75,000-kw. Harris and 72,000-kw. Wyman plants, both located on the Kennebec River. The Central Maine Power Company also owns and operates the 139,000-kw. Mason steam-electric plant at Wiscasset. A new plant at Yarmouth has an initial installation of two 44,000 kw. units. The plant is expected to have an ultimate capacity of 500,000 kw.

Extensive networks of 33-, 44-, and 110-kv. lines are used by the utilities of Maine to interconnect their systems within the State and also to interconnect with systems in neighboring New Hampshire and New Brunswick. These high-voltage facilities also interconnect the utility generating stations with the principal load centers.

Utility Market in New Brunswick

In New Brunswick the leading utility is The New Brunswick Electric Power Commission, which serves directly or indirectly more than 90 percent of the people in the Province. Several municipal systems purchase all their requirements from the Commission and resell the energy to ultimate consumers. Adjacent to the international border, the Maine and New Brunswick Electrical Power Company, Limited, operates a small utility system. Other municipal systems in Edmundston and Campbellton own power generating facilities and also purchase power from neighboring utilities. Plate 46 shows the principal power plants and transmission lines in New Brunswick.



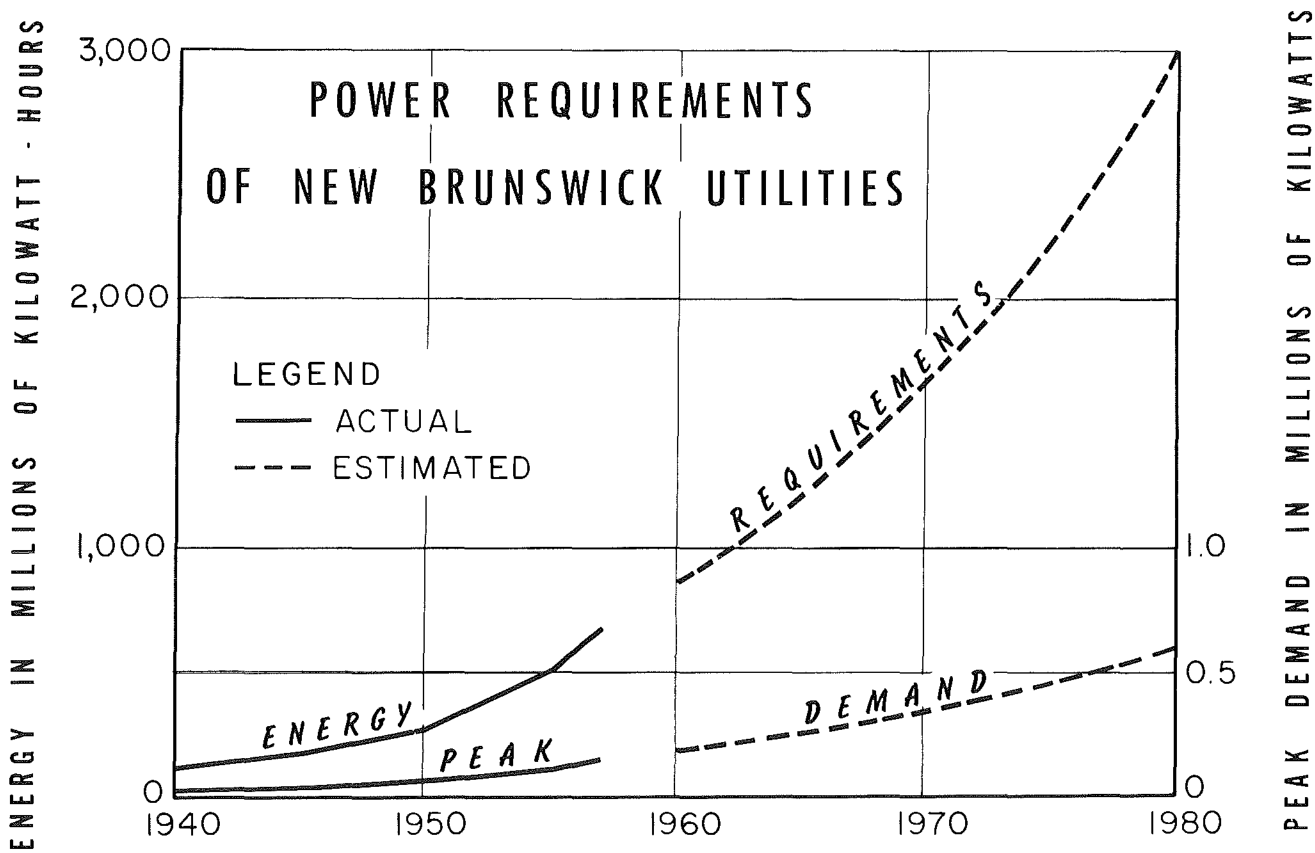
The Beechwood station of The New Brunswick Electric Power Commission

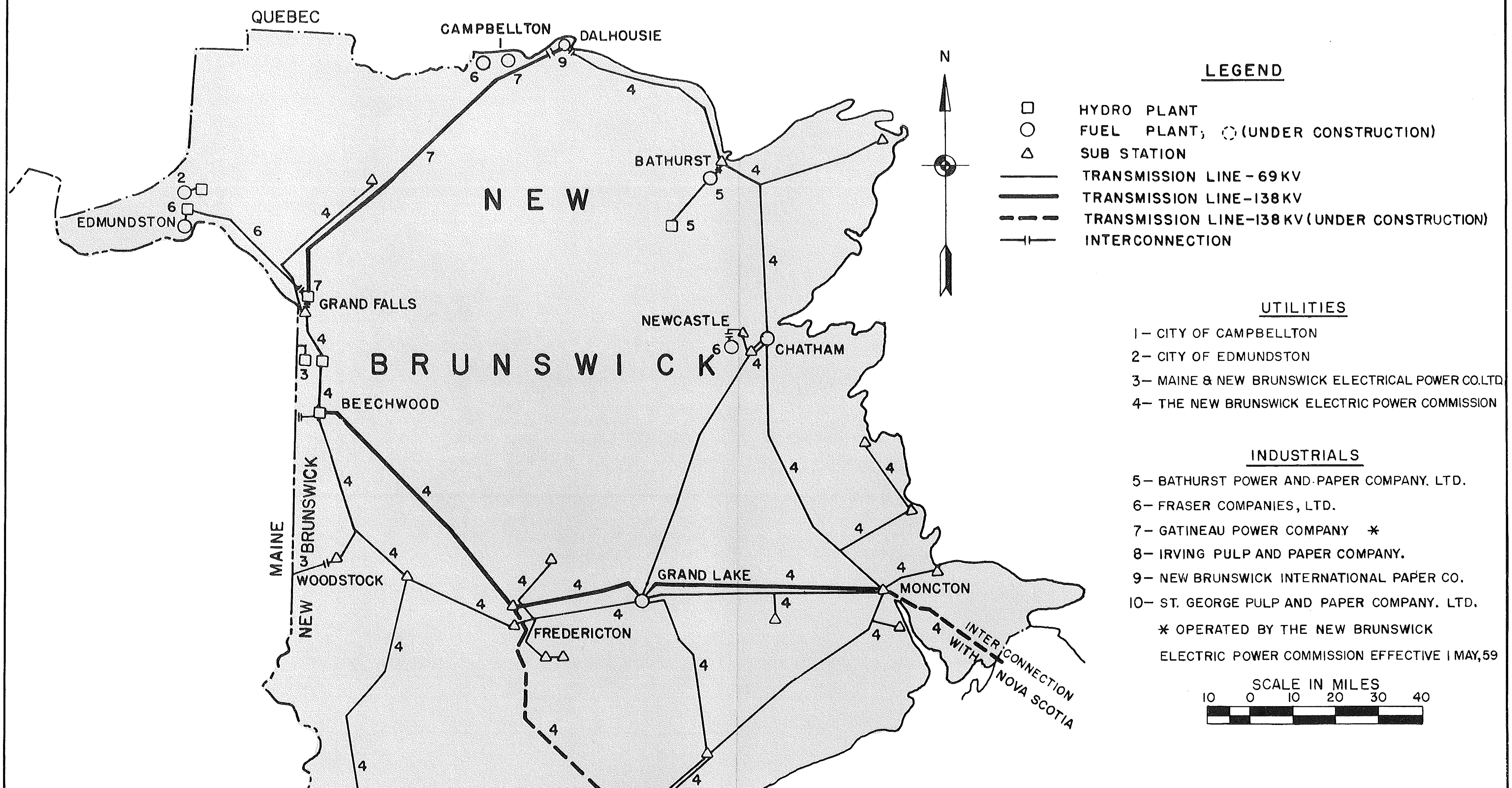
The record of past energy requirements in New Brunswick is one of spectacular growth. Between 1940 and 1957 the utility market increased some 450 percent, accompanied by a substantial improvement in load factor. In 1957 the utility requirements in New Brunswick amounted to 680 million kw.-hr., with an annual peak demand of 152,000 kw. and a load factor of 51.2 percent. Further growth can be expected as the known uses of energy find wider acceptance and new fields of industrial activity are developed, particularly in the exploitation of the area's mineral resources. The energy requirements of the utility market in New Brunswick are estimated at 1,220 million kw.-hr. in 1965 and at 3,040 million kw.-hr. in 1980. The corresponding peak demand will be 260,000 and 600,000 kw. The load factor is expected to increase from 51.2 percent in 1957 to 58.0 percent in 1980. The past and estimated future utility power requirements in New Brunswick from 1940 through 1980 are tabulated below and illustrated on the growth curve.

Utility Power Requirements in New Brunswick, 1940-80

Year	Energy for load (million kw.-hr.)	Peak demand (thousand kw.)	Load factor (percent)
1940	120	29	46.9
1945	179	40	50.9
1950	276	66	47.9
1955	511	110	52.8
1957	680	152	51.2
1960	865	190	52.3
1965	1,220	260	53.7
1970	1,680	350	55.1
1975	2,240	455	56.5
1980	3,040	600	58.0

1940-1957 - Actual
1960-1980 - Estimated





INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

POWER MARKETS
PRINCIPAL POWER GENERATING STATIONS
AND TRANSMISSION LINES, NEW BRUNSWICK

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-264

In late 1958, sixteen utility generating plants were in operation in New Brunswick. Six were hydroelectric plants with a total installed capacity of 112,694 kw., 5 were steam-electric plants with a combined capacity of 94,250 kw., and 5 were internal combustion stations with 7,392 kw. of capacity.

The largest hydroelectric station is the 72,000-kw. Beechwood plant and the largest steam-electric plant is the Chatham station of 34,500 kw. The New Brunswick Electric Power Commission expects to start a 50,000-kw. steam-electric unit in its new Saint John plant by July 1961.

A network of high-tension transmission lines interconnects the principal generating stations and load centers of The New Brunswick Electric Power Commission. Recently constructed 138-kv. lines connect the Beechwood plant and a station at Grand Lake to the load centers at Fredericton and Moncton. Another 138-kv. line is now under construction between Saint John and Fredericton and will be completed in July 1960. A 138-kv. line is being built to interconnect the Commission's system with the electric utility systems of Nova Scotia. The remainder of the Commission's system is interconnected by 69-kv. lines. Surveys have been completed for approximately 125 miles of additional 138-kv. lines between Grand Lake and Bathurst to serve the Newcastle-Bathurst area.

Future Capacity Requirements

Requirements for generating capacity are determined usually by the magnitude of the peak demand and the reserves required to maintain continuity of service. The reserve requirements of the utilities of Maine are estimated at 14 percent of the expected demand. Considered in this estimate are the wide dispersion of the utility service, the size of generating units, the degree of interconnection and coordination among systems, and other factors. The New Brunswick Electric Power Commission estimates its reserve requirements at 12.5 percent of peak demand.

Data on retirements of utility facilities indicate that 40 years is a representative period of service for fuel-electric capacity, and that no specific period is used in connection with hydroelectric installations. For the purpose of this study it was estimated that in the 1960-1980 period, a total of 79,000 kw. of fuel-electric capacity would be retired in Maine and New Brunswick and replaced by more modern and efficient units.

Additional capacity definitely scheduled for installation by utilities in the United States are reported periodically to the Federal Power Commission. The latest reports indicate that in the 1958-1962 period, the utilities of Maine expect to install a total of 63,000 kw. of fuel-electric capacity. As stated previously, The New Brunswick Electric Power Commission expects to operate a new 50,000-kw. unit at its new Saint John plant in 1961.

The generating capacity that must be added by utilities in Maine and New Brunswick between 1960 and 1980 to meet growing needs is summarized below. By 1975 a total of 908,000 kw. of dependable capacity must be added to existing facilities in order to meet the anticipated demand with adequate reserves. This added capacity is much greater than the dependable capacity that could be provided by the tidal power project and its auxiliary. In the following 5 years, from 1975 to 1980, utilities in Maine and The New Brunswick Electric Power Commission in New Brunswick must install an additional 474,000 kw. of new capacity at an average rate of 95,000 kw. a year.

Additional Dependable Capacity Required to Supply
Estimated Future Utility Load in Maine and New Brunswick, 1960-80

(Thousands of kilowatts)

	1960	1965	1970	1975	1980
Estimated requirements					
Estimated peak demand	775	1,000	1,270	1,590	1,990
Reserve requirements	104	138	174	217	270
Total capacity requirements	879	1,138	1,444	1,807	2,260
Capacity available for load					
Existing fuel-electric capacity, 1957	461	461	461	461	461
Scheduled additions to fuel-electric capacity	50	113	113	113	113
Estimated retirement of fuel-electric capacity	10	47	53	58	79
Net fuel-electric capacity	501	527	521	516	495
Existing hydroelectric capacity, 1957	383	383	383	383	383
Total available capacity	884	910	904	899	878
Additional dependable capacity required	---	228	540	908	1,382

Future requirements for additional capacity in Maine and New Brunswick, compared with the capacity of the tidal project, with and without an auxiliary, shows whether tidal power can be absorbed readily by the combined markets. The tidal project alone could provide 95,000 kw. of dependable capacity. The tidal project with the pumped-storage auxiliary at Digdeguash could provide 323,000 kw., and the tidal project with incremental firming capacity at Rankin Rapids could provide 355,000 kw. With the entire installation at Rankin Rapids combined with the tidal plant, a dependable capacity of 555,000 kw. would be available. It is evident, therefore, that the output of the tidal project, with or without an auxiliary, could be readily absorbed by the utility markets of Maine and New Brunswick.

TRANSMISSION LINES

Because the electric utility markets are distant from the tidal project and its auxiliary, extensive transmission lines would be needed. The required lines were designed for each of the four tidal project - auxiliary combinations analyzed for economic justification. The designs are based on market conditions expected in 1980, and thus cannot be considered as a proposal for construction. The transmission lines are not included in the project first cost. The annual cost of transmission lines was estimated and subtracted from the market value to obtain the at-site value of power. This at-site value of power is the power benefit not including downstream benefits.

Points of Delivery

The Central Maine Power Company's Winslow substation near Waterville and Gulf Island substation near Lewiston would be suitable delivery stations for power from the tidal power project and auxiliary. Both substations are on the 110-kv. network of this system. For delivery to the Bangor Hydro-Electric Company, a suitable point would be the Veazie substation near Bangor which, it was assumed, would be on a 110-kv. network by 1980 instead of the present 44-kv. network. The Maine Public Service Company would receive project power at Presque Isle, but only if the tidal project were combined with a full development of Rankin Rapids. For all other combinations of tidal project and auxiliary, it would be uneconomical to transmit the small block of power which the system could use over the 160-mile distance between the tidal project and Presque Isle.

The total Canadian share of the project power would be delivered to the 138-kv. network of The New Brunswick Electric Power Commission at the Saint John and Beechwood substations. The following tabulation shows the assumed points of delivery of the at-site firm capacity of the tidal project, with or without an auxiliary, to the utility systems of Maine and New Brunswick.

Basis of Design

Each combination of tidal project and auxiliary requires a separate layout of lines, substations, and other facilities for delivering the output to market. Transmission voltages, the number of circuits, the size and material of conductors, and the type of supporting structures were determined for each set of transmission facilities, considering the amount of power to be transmitted, distances and present-day utility practices. The same factors determined selection of transformers and all other equipment at receiving and sending substations.

Assumed Use of At-Site Dependable Capacity for Loads In Maine and New Brunswick

(Thousands of kilowatts)

Utility system	Point of delivery	Tidal project alone	Tidal project and auxiliary: All of Rankin Rapids	Tidal project and auxiliary: Incremental capacity only at Rankin Rapids	Tidal project and auxiliary: Digdeguash pumped-storage
Maine					
Central Maine Power Co.	Winslow	--	65.0	60.0	65.0
Central Maine Power Co.	Gulf Island	--	122.5	92.5	31.5
Bangor Hydro-Electric Co.	Veazie	22.5	40.0	--	40.0
Maine Public Service Co.	Presque Isle	--	25.0	--	--
Vicinity of Tidal Project		25.0	25.0	25.0	25.0
Subtotal		47.5	277.5	177.5	161.5
New Brunswick					
The New Brunswick Electric Power Commission	Saint John	47.5	47.5	47.5	161.5
	Beechwood	--	230.0	130.0	--
Subtotal		47.5	277.5	177.5	161.5
Total dependable capacity		95.0	555.0	355.0	323.0

The estimated capital costs of the transmission layouts for service in Maine are based on cost data furnished to the Federal Power Commission by electric utilities. Annual fixed charges in Maine were computed on the basis of federal financing at a 2 1/2 percent interest rate. Operation and maintenance expenses were estimated on the basis of current utility experience in Maine. The estimated capital and annual costs in New Brunswick were based on data furnished by The New Brunswick Electric Power Commission, and fixed charges were based on an interest rate of 4 1/8 percent. All costs and interest rates are at price levels of January 1958.

Tidal Project Alone

As shown on plate 47, the transmission system in Maine for the tidal project alone would consist of two 230-kv. lines extending about 85 miles west and south to Bangor, and two 115-kv. lines extending from Bangor 60 miles to Waterville. Provision was made for serving a 25,000-kw. load about 15 miles from the tidal plant. To serve New Brunswick, two 138-kv. lines would extend about 85 miles around the north end of Passamaquoddy Bay to Saint John. The lines to both the Maine and New Brunswick markets are of sufficient size to carry half the peak output of the tidal power plant of 345,000 kw., which is considerably larger than the dependable capacity of 95,000 kw.

Tidal Plant and All of Rankin Rapids

As shown on plate 48, the lines leading from the tidal plant would be similar to those used for the tidal plant alone. From Rankin Rapids, three 230-kv. lines 55 miles long would extend to Presque Isle, Maine, splitting to two 230-kv. lines 130 miles long to Bangor, Maine, and two 138-kv. lines 90 miles long to Beechwood and Fredericton. At Bangor, the lines from Rankin Rapids would join the lines from the tidal project. Two 230-kv. lines would extend to Waterville and Lewiston, a total distance of 110 miles. In New Brunswick, a single 138-kv. line 30 miles long would connect Fredericton with Grand Lake. In the transmission system shown on plate 48, Rankin Rapids is connected to the tidal power project through transmission lines extending to the market areas of both Maine and New Brunswick. This indirect connection was selected because it was found to be more economical than a direct connection from the tidal project to the auxiliary.

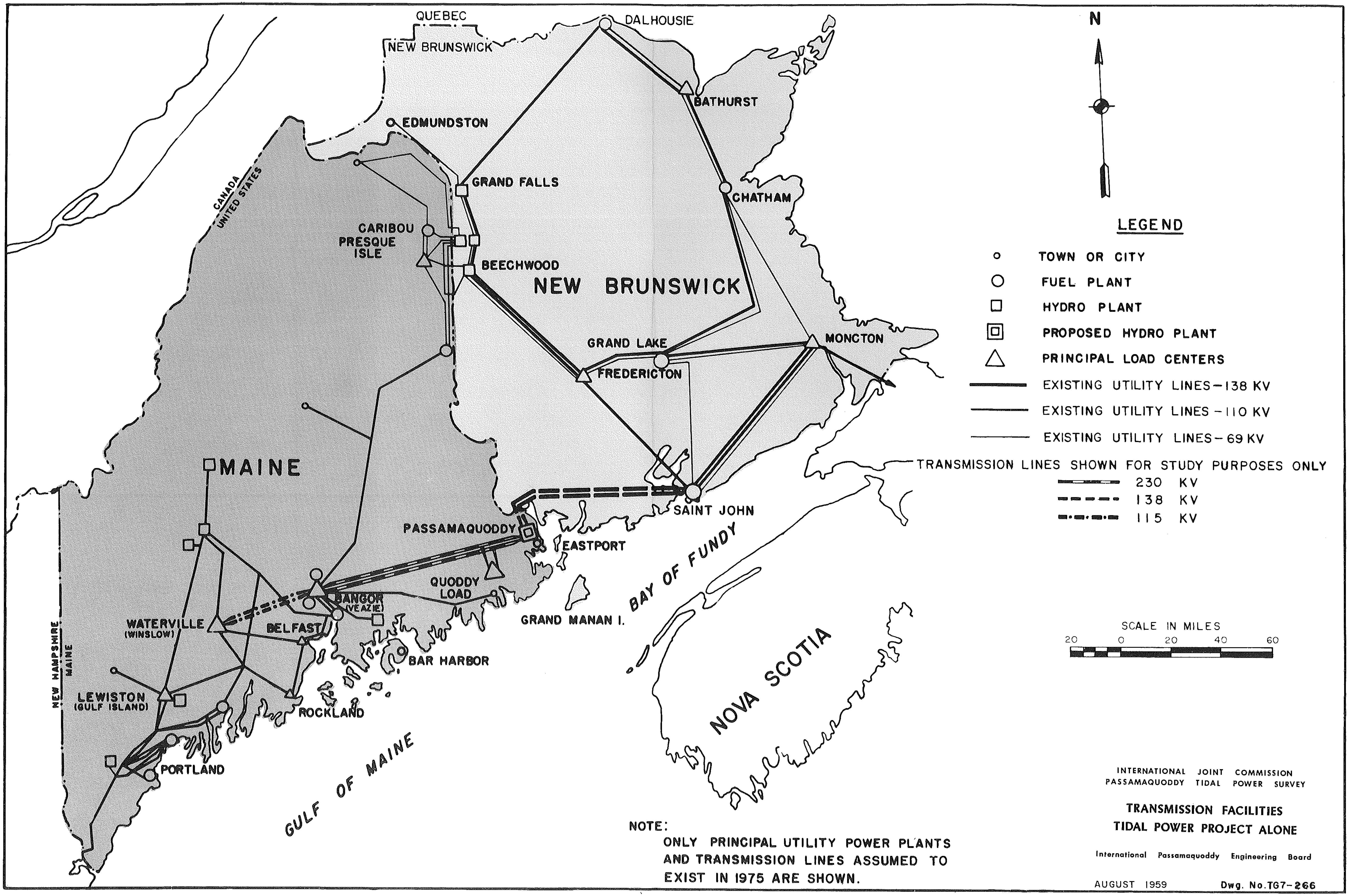
Tidal Project and Incremental Capacity only at Rankin Rapids

As shown on plate 49, the transmission lines leaving the tidal project would be similar to those shown on the previous two plates. Of the 460,000 kw. of dependable capacity available at Rankin Rapids, 200,000 kw. and all energy that would be produced at this site was assumed to serve loads in Maine. Only 260,000 kw. at Rankin Rapids would be used as firming capacity for the tidal power project, and this capacity would be transmitted 55 miles by two 230-kv. lines to Presque Isle. At that point, one-half of the capacity would go to Bangor over two 230-kv. lines 130 miles long to join with power from the tidal project. From Bangor, a 230-kv. line 110 miles long would carry the combined tidal energy and Rankin Rapids firming capacity to Waterville and Lewiston. The Canadian half of the Rankin Rapids firming capacity would go 20 miles from Presque Isle to Beechwood over two 138-kv. lines, and on to Fredericton and Grand Lake.

Tidal Project and Pumped-Storage Auxiliary

The transmission system of the tidal project and the pumped-storage auxiliary on the Digdeguash River in south New Brunswick, as shown on plate 50, would be somewhat similar to that for the tidal project alone. In New Brunswick, however, the output from the Digdeguash switchyard would be inserted into the two 138-kv. lines from the tidal project to Saint John. In Maine, one 110-kv. line would carry the power beyond Waterville 50 miles to Lewiston.

Power in the two 138-kv. lines between the tidal project and the auxiliary could flow



NOTE:
ONLY PRINCIPAL UTILITY POWER PLANTS AND TRANSMISSION LINES ASSUMED TO EXIST IN 1975 ARE SHOWN.

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

TRANSMISSION FACILITIES
TIDAL POWER PROJECT ALONE

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-266

PLATE 47

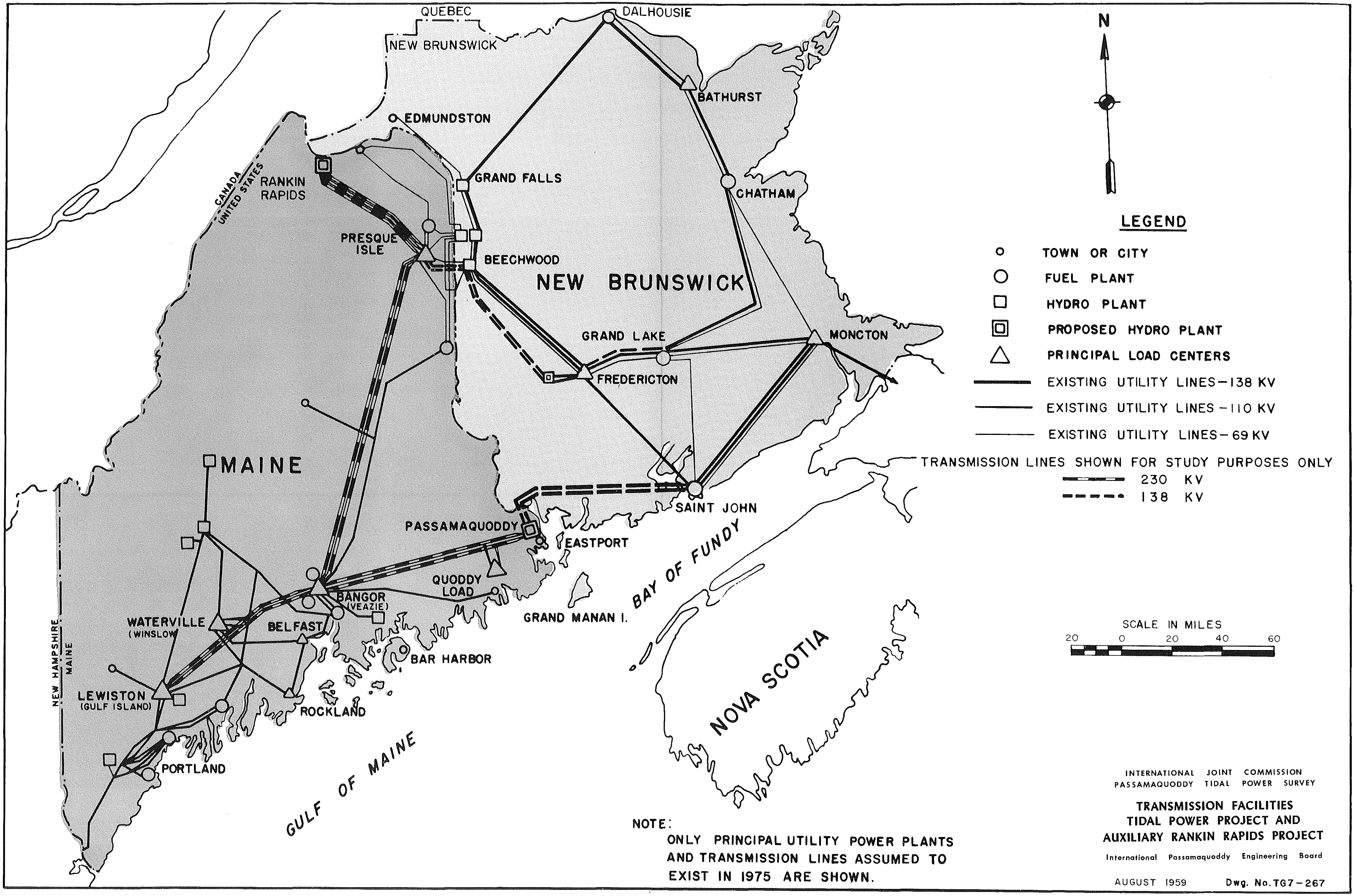

QUEBEC
NEW BRUNSWICK
DALHOUSIE
BATHURST
EDMUNDSTON
GRAND FALLS
CHATHAM
CANADA
UNITED STATES
RANKIN RAPIDS
PRESQUE ISLE
BEECHWOOD
NEW BRUNSWICK
GRAND LAKE
MONCTON
FREDERICTON
MAINE
SAINT JOHN
PASSAMAQUODDY
EASTPORT
QUODDY LOAD
BANGOR (VEAZIE)
WATERVILLE (WINSLOW)
BELFAST
GRAND MANAN I.
BAY OF FUNDY
BAR HARBOR
NEW HAMPSHIRE
MAINE
LEWISTON (GULF ISLAND)
ROCKLAND
PORTLAND
GULF OF MAINE
NOVA SCOTIA
N
LEGEND
TOWN OR CITY
FUEL PLANT
HYDRO PLANT
PROPOSED HYDRO PLANT
PRINCIPAL LOAD CENTERS
EXISTING UTILITY LINES—138 KV
EXISTING UTILITY LINES—110 KV
EXISTING UTILITY LINES—69 KV
TRANSMISSION LINES SHOWN FOR STUDY PURPOSES ONLY
230 KV
138 KV
SCALE IN MILES
20 0 20 40 60
NOTE:
ONLY PRINCIPAL UTILITY POWER PLANTS AND TRANSMISSION LINES ASSUMED TO EXIST IN 1975 ARE SHOWN.
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TRANSMISSION FACILITIES
TIDAL POWER PROJECT AND
AUXILIARY RANKIN RAPIDS PROJECT
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-267

PLATE 48

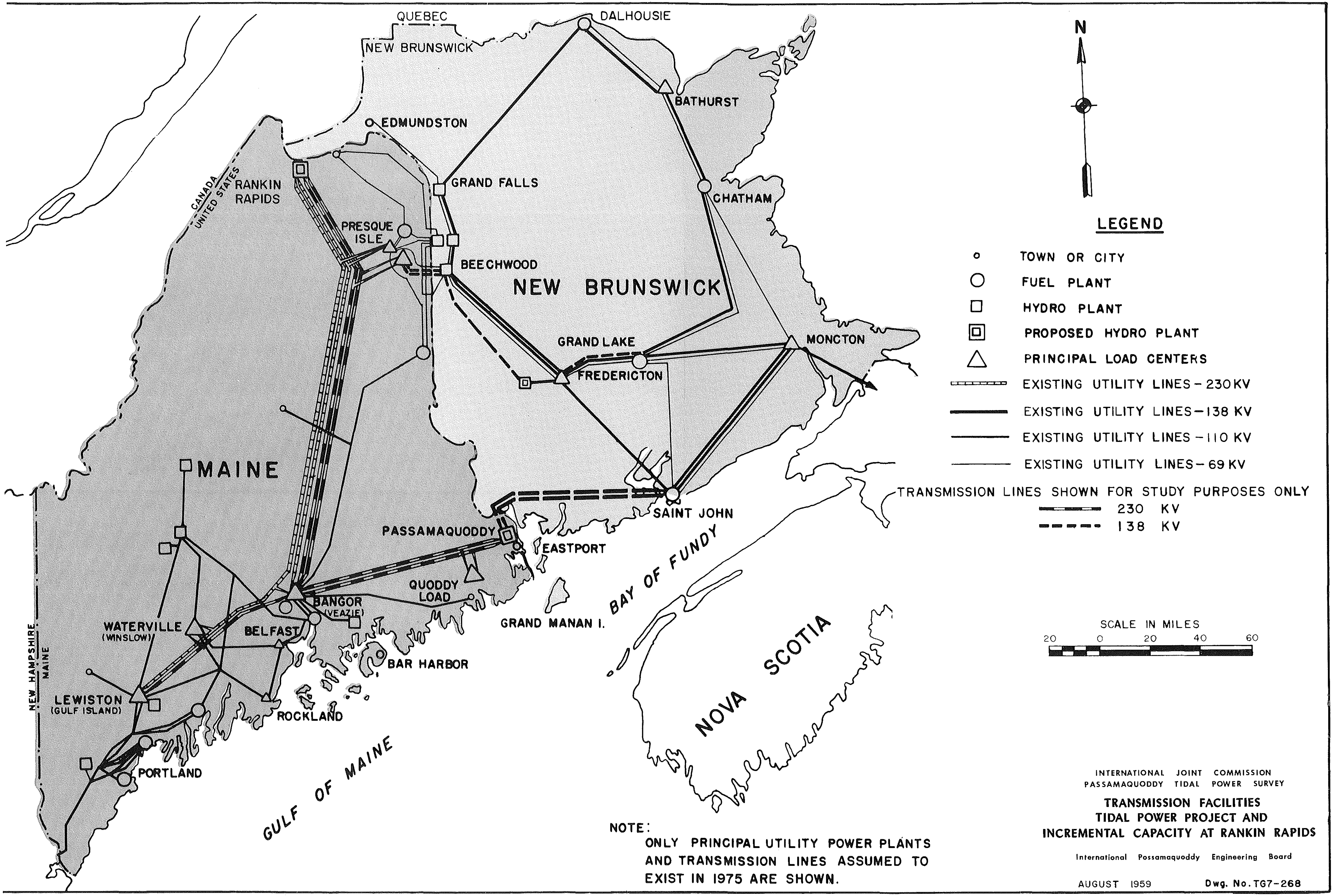

QUEBEC
NEW BRUNSWICK
DALHOUSIE
BATHURST
EDMUNDSTON
CANADA
UNITED STATES
RANKIN RAPIDS
GRAND FALLS
CHATHAM
PRESQUE ISLE
BEECHWOOD
NEW BRUNSWICK
GRAND LAKE
FREDERICTON
MONCTON
MAINE
SAINT JOHN
PASSAMAQUODDY
EASTPORT
BAY OF FUNDY
QUODDY LOAD
BANGOR (VEAZIE)
GRAND MANAN I.
WATERVILLE (WINSLOW)
BELFAST
BAR HARBOR
NEW HAMPSHIRE
MAINE
LEWISTON (GULF ISLAND)
ROCKLAND
NOVA SCOTIA
PORTLAND
GULF OF MAINE
N
LEGEND
TOWN OR CITY
FUEL PLANT
HYDRO PLANT
PROPOSED HYDRO PLANT
PRINCIPAL LOAD CENTERS
EXISTING UTILITY LINES - 230 KV
EXISTING UTILITY LINES - 138 KV
EXISTING UTILITY LINES - 110 KV
EXISTING UTILITY LINES - 69 KV
TRANSMISSION LINES SHOWN FOR STUDY PURPOSES ONLY
230 KV
138 KV
SCALE IN MILES
20 0 20 40 60
NOTE:
ONLY PRINCIPAL UTILITY POWER PLANTS AND TRANSMISSION LINES ASSUMED TO EXIST IN 1975 ARE SHOWN.
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TRANSMISSION FACILITIES
TIDAL POWER PROJECT AND
INCREMENTAL CAPACITY AT RANKIN RAPIDS
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-268

PLATE 49

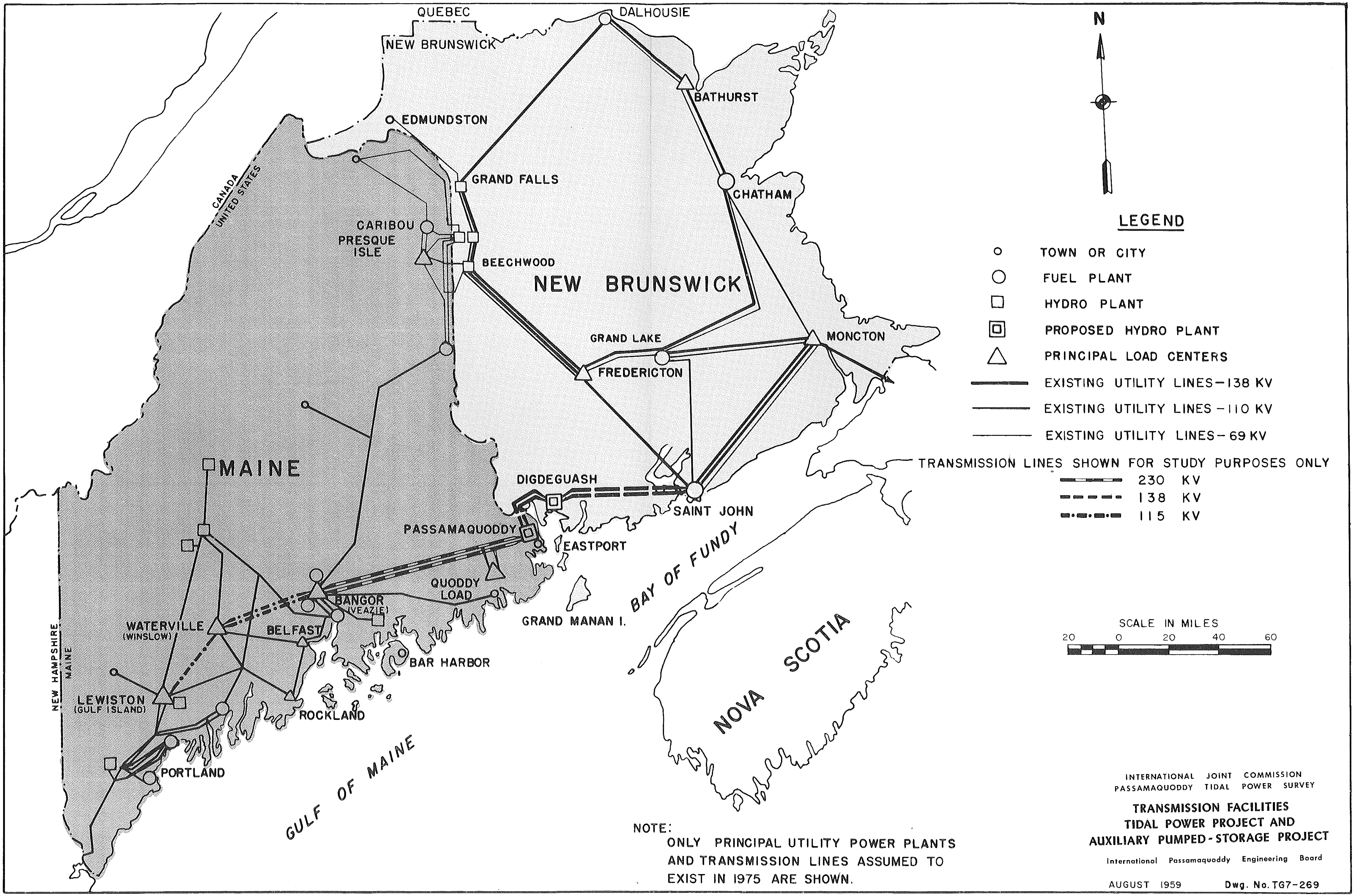

QUEBEC
NEW BRUNSWICK
DALHOUSIE
BATHURST
EDMUNDSTON
GRAND FALLS
CHATHAM
CANADA
UNITED STATES
CARIBOU
PRESQUE ISLE
BEECHWOOD
NEW BRUNSWICK
GRAND LAKE
MONCTON
FREDERICTON
MAINE
DIGDEGUASH
SAINT JOHN
PASSAMAQUODDY
EASTPORT
QUODDY LOAD
BANGOR (VEAZIE)
WATERVILLE (WINSLOW)
BELFAST
BAR HARBOR
GRAND MANAN I.
BAY OF FUNDY
NOVA SCOTIA
NEW HAMPSHIRE
MAINE
LEWISTON (GULF ISLAND)
ROCKLAND
PORTLAND
GULF OF MAINE
N
LEGEND
TOWN OR CITY
FUEL PLANT
HYDRO PLANT
PROPOSED HYDRO PLANT
PRINCIPAL LOAD CENTERS
EXISTING UTILITY LINES—138 KV
EXISTING UTILITY LINES—110 KV
EXISTING UTILITY LINES—69 KV
TRANSMISSION LINES SHOWN FOR STUDY PURPOSES ONLY
230 KV
138 KV
115 KV
SCALE IN MILES
20 0 20 40 60
NOTE:
ONLY PRINCIPAL UTILITY POWER PLANTS AND TRANSMISSION LINES ASSUMED TO EXIST IN 1975 ARE SHOWN.
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TRANSMISSION FACILITIES
TIDAL POWER PROJECT AND
AUXILIARY PUMPED-STORAGE PROJECT
International Passamaquoddy Engineering Board
AUGUST 1959
Dwg. No. TG7-269

PLATE 50

in either direction, depending on the size of the load and whether the auxiliary was pumping or generating. Auxiliary power would be stepped up to 230 kv. for delivery to Maine by an autotransformer in the tidal project switchyard.

Transmission Costs

The capital and annual costs of transmission facilities which were assumed for each tidal project and auxiliary combination, are summarized in the following table.

Capital and Annual Costs of Transmission Facilities for Various Project Combinations

Project combination	Dependable capacity (kw.)	Capital costs		Annual costs	
		Maine	New Brunswick	Maine	New Brunswick
Tidal project alone	95,000	$11,360,000	$3,310,000	$661,000	$229,000
Tidal project and all of Rankin Rapids	555,000	30,810,000	13,580,000	1,720,000	919,000
Tidal project and incremental capacity only at Rankin Rapids	355,000	23,750,000	10,550,000	1,341,000	670,000
Tidal project and Digdeguash pumped-storage auxiliary	323,000	14,170,000	3,330,000	781,000	206,000

CHAPTER IX

PROJECT EVALUATION

In order to determine the economic justification of the international Passamaquoddy tidal power project, annual benefits and costs were computed for each of the four project combinations selected as first described in chapter II. It is assumed that the criterion of economic justification is met when power needed to meet expected power requirements can be produced at a cost no greater than that of the alternative source of power most likely to be used. The degree of economic justification is measured by the ratio of annual benefits to annual costs.

It was assumed that the first costs of the project would be shared equally by the United States and Canada, just as the power output would be shared. Owing to differences in interest rates and differences in other economic factors between the two countries, separate analyses of economic justification were made for the United States and Canada.

VALUE OF POWER

The value of the output of a hydroelectric power project delivered to its market is measured by the cost of producing an equivalent supply of power at a suitable alternative source and of delivering this power to the same market. The alternative power supply used in this comparison is generally a modern, conventional steam-electric plant with generating unit sizes and design features appropriate to the future power requirements of the selected market. The growing utility power requirements of Maine and New Brunswick constitute the markets for power from the tidal project and its auxiliary power source. The utility systems of both areas presently operate substantial amounts of steam-electric capacity, and more is planned to meet future power needs. For the present study, therefore, steam-electric capacity is taken as the most likely source of alternative power.

The cost of the alternative steam-electric power was computed in accordance with common practice in each country. In Maine, the alternative power would be privately financed, and in New Brunswick, publicly financed. For this reason, separate analyses of the power benefits were made for the two countries.

Power Benefits

At-market values of tidal project power are obtained by estimating the costs of producing an equivalent supply of power from alternative steam-electric plants, adding to this cost the cost of transmission to selected load centers, and finally by applying adjustments for hydro-steam differentials that may exist. The resultant at-market values are then reduced by the costs of transmitting the output of the proposed project to the same or to comparable load centers, thus yielding the at-site values or benefits. The at-site benefits are compared with at-site costs to determine economic justification.

Project power values, or benefits, are usually expressed in terms of two components: (1) capacity value in dollars per year per kilowatt of dependable capacity; and (2) energy value in mills per kilowatt-hour of average annual energy.

Hydro-Steam Power Value Adjustments

The hydro-steam power value adjustments consist of a capacity credit and energy credit or debit, applied to the at-market cost of power from the alternative steam-electric source.

Hydroelectric power needs fewer reserves and possesses greater operating flexibility, service availability, and other advantages over fuel-electric power. Tidal power has additional advantages which are of importance in the economic analysis of the project. Although only 95,000 of the proposed total of 300,000 kw. installed would be classed as dependable, the time and magnitude of the remaining 205,000 kw. are predictable with certainty. This would afford a definite advantage in coordinating operations of the tidal plant with existing utility systems in the market areas. The transmission facilities that would deliver the power output of the tidal and auxiliary projects would form a high-voltage, large-capacity network between the utilities of Maine and New Brunswick, only lightly tied at present. Such an interconnection would have many benefits. Among these benefits are savings in reserve requirements, use of larger generating units, more advantageous scheduling of capacity additions, diversity in peak demands between Maine and New Brunswick because of their different time zones, and the possibility of interchange of low-cost energy between the two areas. In view of these benefits, the capacity value credit of the tidal development is estimated at 7 percent of the at-market cost of alternative power.

An energy value adjustment is usually made when the average annual plant factor of the hydro projects differs materially from the average annual plant factor of the alternative steam plant. However, because the plant factors of the tidal power development and the alternative steam plant do not differ significantly, no energy value adjustment is necessary.

Location of Alternative Plants

Distribution of the output of the tidal project and its auxiliary among the principal utility load centers in Maine and New Brunswick is determined by estimated future power requirements at the load centers, the output of each combination of tidal and auxiliary projects, and transmission distances. The selection of corresponding alternative steam-electric plants was made on the same basis. Other conditions that influenced the selection of suitable sites for the alternative steam-electric plants were the availability of a suitable supply of condensing water and of waterborne fuel. The location of the alternative plants and related load centers are tabulated below. No transmission distance to load center is indicated where alternative steam-electric plants would be located on utility high-voltage networks and would therefore not require the construction of additional transmission facilities.

Market area	Alternative power plant	Load center	Transmission distance (miles)
Maine	Eastport	Passamaquoddy area	15
	Caribou	Presque Isle	--
	Belfast	Bangor	30
		Waterville	35
	Yarmouth	Lewiston	30
New Brunswick	Saint John, Bathurst	The New Brunswick Electric Power Commission System	

Size and Cost of Generating Units

Many factors influence the size and cost of the turbine-generator units selected for a steam-electric plant. Operating economy is achieved when units as large as possible are employed that are consistent with system load, reserve requirements, and existing facilities. Construction costs of steam-electric stations expressed in dollars per kilowatt of installed capacity vary widely, depending on the size of generating units, plant location, site conditions, design criteria, and other factors.

Each of the alternative steam-electric stations used for evaluating the proposed tidal project and its auxiliaries is of conventional design and consists of three generating units with one boiler per unit. Average yearly operation of 4,500 hours is assumed. The unit sizes for the selected alternative power plants in Maine and New Brunswick, together with their estimated capital costs as of January 1958, are as follows:

Market	Plant location	Net capability (kw.)	Capital cost ($/kw.)
Maine	Eastport	12,500	240
	Caribou	25,000	225
	Belfast	75,000	210
	Yarmouth	75,000	210
New Brunswick	Saint John	100,000	155
	Bathurst	100,000	155

The costs shown in the above table are based on information supplied by the U.S. Federal Power Commission and The New Brunswick Electric Power Commission.

Annual Costs of Steam-Electric Plants

It is customary in the analysis of steam-electric power costs to separate the total annual costs into fixed and variable components. Annual fixed costs consist of fixed charges on plant investment, interest on investment in reserve fuel supply, fixed components of total production expense (fuel and operation and maintenance), and administrative and general expenses. The remaining costs of power generation consist of the variable components of fuel consumption and of operation and maintenance expenses. These items are also known as incremental energy costs.

Fixed charges are those elements of annual cost that are a direct function of the capital investment in a facility. These are made up of interest, depreciation or amortization, interim replacements, insurance, and taxes.

Since the principal utility systems in Maine are privately owned, the cost of money for construction and system expansion will depend generally on the competition for available capital and the investment risk. For projects built by public agencies, like The New Brunswick Electric Power Commission, investment risk is usually less, and interest rates are lower due to governmental support.

Annual costs are a function of the assumed life of the project and the interest on the invested capital being depreciated or amortized. Because the sinking-fund method of depreciation, or amortization, used in economic studies does not take into account property elements having a life span less than the life of the project as a whole, provision for interim replacements is included in the fixed charges.

Private utilities carry insurance against catastrophe and accidental damage to system properties. The yearly cost of this protection is part of the expenses of system operations. On the other hand, publicly financed developments undertaken by agencies, such as The New Brunswick Electric Power Commission, are considered self-insured. The provision made for the cost of self-insurance is somewhat less than the cost to a private enterprise of equivalent insurance.

The privately owned utilities in Maine are subject to taxation by federal, state, and local governments. Taxes fall into three general classifications: federal income, federal miscellaneous, and state and local taxes. Only property taxes are directly related to plant investment. However, in most power studies it is convenient to relate all taxes to plant investment. Because there is no simple method of computing taxes as a percent of capital costs, provision for taxes is based on studies of actual taxes paid. In general, publicly owned systems are exempt from taxation, as is The New Brunswick Electric Power Commission.

The estimated average annual fixed charges as a percent of capital investment, as of January 1958, for steam-electric plants located in Maine and New Brunswick are summarized as follows:

	Maine (private)	New Brunswick (public)
Cost of money	6.00	4.125
Depreciation (35-year sinking fund)	0.90	-
Amortization (35-year sinking fund)	-	1.324
Interim replacements	0.35	0.350
Insurance	0.25	0.100
Subtotal	7.50	5.899
Total taxes	4.44	-
Total fixed charges	11.94	5.899

To assure uninterrupted operation of fuel-electric generating stations, it is common procedure among operating utilities to maintain adequate reserves of fuel. The amount of protection sought varies with company policy and experience. Fuel reserves for about 100 days of normal operation appear representative for the utilities in Maine and New Brunswick. The annual cost of the investment in reserve fuel is part of the cost of producing power.

The fixed and variable components of annual production expenses are subject to wide variation and are, for this reason, difficult to relate directly to plant characteristics. The values considered applicable to plan‧ ‧n Maine and New Brunswick are based ‧ ‧stations of three units, operating at an average of 4,500 hours per year throughout their useful service life, with a distribution of fixed and variable components in the order of 65 and 35 percent. The fixed and variable components of operation and maintenance expenses, exclusive of fuel, for oil-burning units in Maine and coal-burning units in New Brunswick are as follows:

	Unit capability (kilowatts)	Operation and maintenance expenses, exclusive of fuel: Fixed ($/kw./yr.)	Operation and maintenance expenses, exclusive of fuel: Variable (mills/kw.-hr.)
Maine	75,000	2.40	0.28
	25,000	3.65	0.43
	12,500	4.35	0.52
New Brunswick	100,000	2.10	0.25

The fuel consumed annually by a steam-electric plant may also be separated into two components - fixed and incremental. Fixed fuel is that part of the total fuel burned to maintain the plant during no-load periods and the fuel equivalent to spinning reserve requirements during load carrying periods. All other fuel consumption is the incremental component, and varies directly with net generation of the station. Studies indicate that the fixed fuel component represents approximately 10 percent of total fuel consumed in coal-burning stations and 9 percent in oil-burning stations.

The type of fuel used by a utility in the production of electric energy depends in general on availability and cost of the fuel as compared to other types. In recent years, oil has been the only fuel used for generation of electricity in Maine. As of January 1958, it was assumed that alternative steam-electric plants in New Brunswick would use coal mined in the Maritime Provinces.

Administrative and general expenses are allocated generally to the various phases of utility operation. These expenses include salaries and wages of officers and office employees, cost of office supplies, legal expenses, and welfare and pension funds. A representative allocation of these expenses to production of steam-electric power in the United States is 25 percent of the fixed operation and maintenance costs, not including fuel, and 20 percent of these costs in New Brunswick. The annual cost of power, at the bus bar, of the alternative steam-electric plants is shown below.

Estimated Bus-bar Cost of Steam-electric Power

Maine and New Brunswick, January 1958

Item	Unit	Maine: Yarmouth and Belfast	Maine: Caribou	Maine: Eastport	New Brunswick: Saint John and Bathurst
Annual capacity cost					
Fixed charges	$/kw./yr.	25.07	26.87	28.66	9.14
Interest on reserve fuel investment	$/kw./yr.	0.36	0.59	0.49	0.24
Fixed operating costs					
Fuel	$/kw./yr.	2.03	2.67	2.67	2.16
Operation and maintenance	$/kw./yr.	2.40	3.65	4.35	2.10
Administrative and general	$/kw./yr.	0.60	0.91	1.09	0.42
Total		5.03	7.23	8.11	4.68
Total annual capacity cost					
Calculated	$/kw./yr.	30.46	34.69	37.26	14.06
Use	$/kw./yr.	30.50	34.70	37.30	14.10
Variable operating costs					
Incremental fuel	Mills/kw.-hr.	4.55	6.00	6.00	4.32
Operation and maintenance	Mills/kw.-hr.	0.28	0.43	0.52	0.25
Total Cost					
Calculated	Mills/kw.-hr.	4.83	6.43	6.52	4.57
Use	Mills/kw.-hr.	4.8	6.4	6.5	4.6

The required annual outputs of the alternative power plants are determined by the amount of power available from each combination of tidal and auxiliary projects, the assumed distribution of this power among various load centers, and the losses incurred in transmission over the facilities of the proposed projects and of the alternative steam-electric plant. The required annual generation, adjusted for losses, at the alternative plants for the various combinations of projects studied is shown below.

Transmission Facilities for Alternative Plants

The at-market cost of alternative power includes, in addition to the cost of generation, all costs of transmitting the alternative plant output to the principal load centers. The amount of power transmitted, distances, transmission voltages, and conductor sizes are economically interrelated. Since the alternative power plants used for evaluation of the tidal project and its auxiliaries would be located reasonably close to the load centers, or on existing high-tension networks of the utilities, the transmission lines and substations for these plants would be considerably smaller than those needed for the tidal project and its auxiliary.

Substations needed to step up the voltage of power transmitted from alternative power plants to load centers vary widely in design and costs. Substation design depends upon the purpose and relative importance of the substation in the power supply system and upon company policy. The major items of cost of substation construction are power transformers, high-voltage switchgear, metering, and protective equipment. Estimates of substation costs in Maine, as of January 1958, range from $11 to $15 per kv.-a. of capacity, depending on transformer size and voltage levels; in New Brunswick, a 330,000-kv.-a., 138-kv. substation at Saint John is estimated to cost less than $6 per kv.-a. Substation service lives are estimated at 35 years in Maine and 30 years in New Brunswick.

Although design and construction of transmission lines are highly standardized, the capital costs of lines of similar design may differ widely, depending on cost of rights-of-way and construction difficulties. For a given operating voltage, conductor size, and number of circuits, the total capital investment required varies as the length of the line. In Maine, a service life of 35 years is used for wood-pole and 50 years for steel-tower lines. A 40-year life is used for both types in New Brunswick.

Required Annual Generation at Alternative Steam-electric Plants

Project combination	Maine				New Brunswick
	Yarmouth	Belfast	Eastport	Caribou	Saint John and Bathurst
Tidal project alone					
Capacity, kw.	-	22,600	25,200	-	46,700
Energy, million kw.-hr. (1)	-	796	122	-	901
Tidal project and all of Rankin Rapids					
Capacity, kw.	118,500	102,700	25,200	24,600	255,000
Energy, million kw.-hr.	700	564	122	124	1,452
Tidal project and incremental capacity only at Rankin Rapids					
Capacity, kw.	88,300	57,500	25,200	-	166,200
Energy, million kw.-hr.	471	308	122	-	885
Tidal project and Digdeguash pumped-storage auxiliary					
Capacity, kw.	29,600	102,600	25,000	-	153,800
Energy, million kw.-hr.	180	563	121	-	857

(1) Includes energy equivalent to nonfirm energy from tidal project.

Unlike the costs of steam-electric plants, the total annual costs of system transmission facilities are fixed costs. These costs consist of fixed charges on the transmission investment, operation and maintenance expenses, and an allocated portion of total administrative and general expenses.

Fixed charges on the investment in transmission facilities are made up of the same cost components indicated previously for the alternative power plants. These are cost of money, depreciation or amortization, interim replacements, insurance, and taxes. No separate allowance for interim replacements and insurance is made by The New Brunswick Electric Power Commission. Investment capital would be privately financed in Maine and publicly financed in New Brunswick. Being an agency of the Province, The New Brunswick Electric Power Commission would pay no taxes.

The annual expenses of operating and maintaining system transmission facilities do not vary with the amount of power transmitted and are, therefore, fixed costs. In general, substation operation and maintenance charges depend on the size of the station. The cost on a unit basis varies inversely with capacity. Transmission line operation and maintenance expenses are evaluated on a cost-per-mile basis.

A charge equal to 20 percent of the operation and maintenance expenses of transmission facilities is adopted as an estimate of the share of total administrative and general expenses allocated to this function.

The total capital and annual costs of transmission facilities for each of the alternative steam-electric plants used for comparison with the tidal power and auxiliary combinations investigated are shown in the following table.

Capital and Annual Costs of Transmission Systems
Associated with Alternative Power Plants
(Thousands of dollars)

Plan of development	Maine					New Brunswick
	Yarmouth	Belfast	Eastport	Caribou	Total	Saint John and Bathurst
Tidal project alone						
Capital cost	---	$720	$971	---	$1,691	$460
Annual cost	---	108	156	---	264	40
Tidal project and all of Rankin Rapids						
Capital cost	2,758	3,052	971	367	7,148	2,100
Annual cost	423	461	156	65	1,105	189
Tidal project and incremental capacity only at Rankin Rapids						
Capital cost	2,649	1,443	971	---	5,063	1,400
Annual cost	402	212	156	---	770	126
Tidal project and Digdeguash pumped-storage auxiliary						
Capital cost	1,099	3,052	971	---	5,122	1,250
Annual cost	163	461	156	---	780	112

Notes: a. Fixed charges included in annual costs for Maine are based on private financing.
b. Fixed charges included in annual costs for New Brunswick are based on public financing.
c. The capital and annual costs shown for the tidal project alone represent that portion of total costs applicable to firm power.

At-Market Value of Power

Preceding paragraphs of this chapter set forth data on (1) the amount of power required from the alternative steam-electric plants to match the several plans of tidal project development considered in this investigation; (2) the cost of alternative power; and (3) the costs of transmitting this power to market. With these data, the total annual at-market capacity and energy value of alternative steam-electric power can be derived readily. By applying the hydro-steam capacity adjustment factor to the at-market capacity cost, the at-market capacity value of power from tidal and auxiliary project can be derived. Since there is no basis for using an energy differential, the at-market hydro energy value is equal to the at-market steam-electric energy cost. If the tidal project is built without an auxiliary, a considerable amount of non-firm, or secondary power, will have energy value only.

The at-market values of power from the tidal project, with or without an auxiliary source of supply, are as follows:

Project combination	Total annual value of power at market	
	Maine	New Brunswick
Tidal project alone	$6,638,000	$4,892,000
Tidal project and all of Rankin Rapids	17,974,000	10,729,000
Tidal project and incremental capacity only at Rankin Rapids	11,120,000	6,713,000
Tidal project and Digdeguash pumped-storage auxiliary	10,500,000	6,383,000

At-Site Value of Power

In order to obtain at-site values, it is necessary to subtract from the at-market values developed previously the annual costs of transmission for each tidal project development. The transmission costs, together with a detailed description of the facilities in Maine and New Brunswick, are given in chapter VIII. The derivation of the annual at-site values is shown in the following table:

Project combination	Total annual power values at market	Total annual cost of transmission	Total annual power values at site
Maine			
Tidal project alone	$6,638,000	$661,000	$5,977,000
Tidal project and all of Rankin Rapids	17,974,000	1,720,000	16,254,000
Tidal project and incremental capacity only at Rankin Rapids	11,120,000	1,341,000	9,779,000
Tidal project and Digdeguash pumped-storage auxiliary	10,500,000	781,000	9,719,000
New Brunswick			
Tidal project alone	4,892,000	229,000	4,663,000
Tidal project and all of Rankin Rapids	10,729,000	919,000	9,810,000
Tidal project and incremental capacity only at Rankin Rapids	6,713,000	670,000	6,043,000
Tidal project and Digdeguash pumped-storage auxiliary	6,383,000	206,000	6,177,000

DOWNSTREAM BENEFITS

The Rankin Rapids river hydro auxiliary would have 2.8 million acre-feet of storage which would be used to regulate the river flows. A part of the high spring freshet flows would be held over to supplement the low flows of late summer and winter and to provide storage for years of exceptionally low runoff. For example, at the existing downstream plant on the Saint John River at Beechwood, New Brunswick, the low flow would be increased from about 2,000 c.f.s. to over 5,000 c.f.s. On the average, this regulation of stream flows by the Rankin Rapids project would result initially in a substantial increase in energy generation at existing downstream plants and a small increase in dependable capacity. An increase in installed capacity at existing plants or development of other potential sites on the lower Saint John River would result in additional benefits.

Full evaluation of the ultimate benefits of regulation by the Rankin Rapids project would require the designing and estimating of several potential downstream hydro plants and of possible additions to existing plants, as well as detailed power studies, and distribution of benefits and costs upstream and downstream.

Since all this work is clearly outside the intent of the Reference for the survey of the tidal power project, the estimates of power benefits downstream on the Saint John River were computed considering only the existing installations at Grand Falls and Beechwood hydroelectric power plants. On the basis of this limited study, the downstream benefits attributable to the tidal project--Rankin Rapids combination would be 180 million kw.-hr. of energy. The existing installations at Grand Falls and Beechwood would limit possible capacity benefits to 5,000 kw.

The downstream power described above was assumed divided equally between United States and Canada in the evaluation of project justification. Unit power values used to determine the monetary value of the downstream benefits are the at-site values of energy and capacity determined for the tidal power project. These are as follows:

	United States	Canada
Capacity $/kw./yr.	31.20	11.40
Energy Mills/kw.-hr.	5.0	4.4

ANNUAL COST CRITERIA

The cost of tidal power project, with or without an auxiliary, is based on the annual cost of maintaining and operating the projects and the financing charges. Project first costs are as follows:

Tidal project alone	$484,000,000
All of Rankin Rapids	146,000,000
Incremental capacity only at Rankin Rapids	31,500,000
Digdeguash pumped-storage auxiliary	34,500,000

Because the tidal power project with its auxiliary would be an international project of considerable magnitude, it was assumed in the analysis of economic justification that the project would be built with funds furnished by the two countries.

Interest Rates

Interest on the United States investment in the proposed project is computed at the rate of 2 1/2 percent a year. This rate has been specified by the United States Bureau of the Budget for evaluating water resources projects. The Canadian interest rate was established as 4 1/8 percent, which is the interest rate used by the Government of Canada in January 1958 for loans to crown corporations and provincial governments.

Interest during Construction

Interest during construction on the United States share of the project was computed on the basis of an interest rate of 2 1/2 percent for one-half of the construction period. Interest during construction on the Canadian share was computed on the basis of 4 1/8 percent. The tidal project is treated separately from the auxiliary sources, as are the costs of United States and Canadian interest during construction. The initial investment is the sum of interest during construction and the project first cost.

Salvage

Net investment to be amortized is often considered the initial investment less the salvage value of the project at the end of the amortization period. The salvage value of the tidal project and the auxiliary would amount to the value of the land. The land required for the tidal project is of small value, and the resale value of the auxiliary reservoir area would also be small because the area would be cleared of its timber. Therefore, salvage value was not used in this study.

Amortization Period

Project evaluation was made using amortization periods of both 50 and 75 years. Fifty years represents the period commonly used in both the United States and Canada for recovering investment from water resources projects. In the United States, water resources projects are sometimes amortized over longer periods, the upper limit being 100 years. On this basis, amortization of the tidal project over 75 years was also examined.

Interim Replacements

Mechanical and electrical equipment may have to be replaced in whole or in part before the end of the amortization period of the project. Based on general experience with this type of equipment, it is estimated that about 25 percent of the major items of mechanical and electrical equipment would require replacement after 30 years of operation, not including replacement of minor parts and components as part of ordinary maintenance. Using this estimate, the deferred costs of major replacement items were computed on an annual basis over the amortization period of the project.

The cost of major mechanical and electrical equipment is as follows:

Tidal project	$77,500,000
All of Rankin Rapids	15,300,000
Incremental capacity only at Rankin Rapids	8,600,000
Digdeguash pumped-storage auxiliary	11,400,000

Self-Insurance

An allowance was included in the annual costs for self-insurance to provide for accidents. The annual allowance made for this purpose is 0.05 percent of the first cost. This self-insurance is in addition to the allowance for major replacements.

Operation and Maintenance

Annual operation and maintenance costs, including labor, supplies, and contract services estimated for the tidal project, the river hydro auxiliary, and the pumped-storage auxiliary, are summarized below:

Feature	Annual operation and maintenance cost
Tidal power project	$874,000
Rankin Rapids auxiliary power project	230,000
Digdeguash pumped-storage auxiliary power project	178,000

The use of incremental capacity only at Rankin Rapids as auxiliary power for the tidal power project was charged with only part of the operation and maintenance cost of the entire Rankin Rapids project. Since none of the energy, and only incremental capacity, is considered auxiliary, one-quarter of the total annual cost shown above, or $57,500, was selected as a representative sum.

Tax Reductions

It is assumed that land acquired in the United States and Canada for the tidal project, in United States for the Rankin Rapids auxiliary and in Canada for the Digdeguash pumped-storage auxiliary, would be acquired and held by a quasi-government agency which would not pay taxes on these lands to local political subdivisions. Withdrawal of these lands from local tax rolls would represent a loss of income to the local subdivisions. However, these losses would be too small to influence the computation of benefits and costs.

Taxes Foregone

If the tidal project and auxiliary are not built, the utility companies of Maine and The New Brunswick Electric Power Commission would have to construct equivalent alternative facilities to meet the requirements of the growing power load. The private utility corporations in Maine would pay taxes on these facilities. On the other hand, the tidal project and its auxiliary, assumed to be quasi-governmental, would pay no taxes. Similar to the land acquired for the project, this represents a loss in revenue to the people of the United States. Evaluation of United States water resources projects customarily includes an item for taxes foregone in the annual economic cost of a project. However, this problem does not exist in Canada because The New Brunswick Electric Power Commission does not pay taxes. It was concluded, therefore, that because the tidal development is an international project, taxes foregone in Maine would not be included.

RECREATION AND COMMERCIAL FISHERIES

Recreational benefits and the losses to commercial fisheries were considered economic effects of a secondary nature.

Construction of the Passamaquoddy tidal power project would give added impetus to the growing recreation industries of Washington County, Maine, and Charlotte County, New Brunswick, by creating new recreation benefits amounting to $800,000 a year or more. These recreation benefits were not credited to the tidal power project to improve the benefit-cost ratio or to reduce the cost of power.

The tidal project, by itself, would damage commercial fisheries in Passamaquoddy and Cobscook Bays. Part of these damages would be compensated by (a) construction of fishways to provide access to both bays and to the St. Croix River system for anadromous fish, and (b) relocation, if necessary, of the lobster pounds on Deer Island, New Brunswick. Other one-time losses, such as the cost of reconstructing existing sardine weirs in the high pool, are not considered compensable and are not included in project first cost. These losses were considered, however, in the economic analysis by reducing them to an annual basis and adding them to other residual annual fisheries losses such as the diminished groundfish and clam catch in the tidal project pools. As discussed in more detail in chapter VII, the total residual loss to the fisheries amounts to $117,000 a year. This amount is too small to affect the benefit-cost ratios of the project and, accordingly, was not included in the computation of the ratio.

COMPUTATION OF ECONOMIC JUSTIFICATION

The results of the computation of economic justification are summarized on plate 51 for a 50-year amortization period and on plate 52 for a 75-year amortization period.

PROJECT COMBINATION FOR ECONOMIC EVALUATION

	Tidal project alone		Tidal project with all of Rankin Rapids as auxiliary		Tidal project with incremental capacity only at Rankin Rapids		Tidal project with Digdeguash pumped-storage auxiliary	
	United States	Canada	United States	Canada	United States	Canada	United States	Canada
INVESTMENT (millions of dollars)								
Tidal project first cost	242.0	242.0	242.0	242.0	242.0	242.0	242.0	242.0
Interest during construction	18.2	29.9	18.2	29.9	18.2	29.9	18.2	29.9
Auxiliary project first cost	0	0	73.0	73.0	15.8	15.7	17.3	17.2
Interest during construction	0	0	3.6	6.0	.8	1.3	.9	1.4
Total investment	260.2	271.9	336.8	350.9	276.8	288.9	278.4	290.5
ANNUAL POWER BENEFITS (millions of dollars)								
At-site value of power	5.977	4.663	16.254	9.810	9.779	6.043	9.719	6.177
Value of downstream power benefits	0	0	.528	.425	0	0	0	0
Total annual power benefits	5.977	4.663	16.782	10.235	9.779	6.043	9.719	6.177
ANNUAL COSTS (millions of dollars)								
Interest, 2-1/2 percent U.S. and 4-1/8 percent Canada	6.505	11.216	8.420	14.475	6.920	11.917	6.960	11.983
Amortization 50 years	2.680	1.740	3.469	2.246	2.851	1.849	2.868	1.859
Major replacements	.163	.136	.195	.162	.181	.151	.187	.156
Self insurance, 0.05 percent per year	.130	.136	.168	.175	.138	.144	.139	.145
Operation, maintenance and supplies	.437	.437	.552	.552	.466	.466	.526	.526
Total at-site annual cost	9.915	13.665	12.804	17.610	10.556	14.527	10.680	14.669
BENEFIT – COST RATIO	0.60	0.34	1.31	0.58	0.93	0.42	0.91	0.42
POWER								
Installed capacity, kw.	150,000	150,000	350,000	350,000	263,000	263,000	280,000	280,000
Dependable capacity, kw.	47,500	47,500	277,500	277,500	177,500	177,500	161,500	161,500
Average annual generation (million kw.-hr.)	922	922	1,532	1,532	922	922	880	880
AT-SITE UNIT COST OF ENERGY (mills per kw.-hr.)	10.8	14.9	8.4	11.5	11.5	15.8	12.2	16.8

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

BENEFITS AND COSTS
50-YEAR AMORTIZATION PERIOD

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-270

PROJECT COMBINATION FOR ECONOMIC EVALUATION

	Tidal project alone		Tidal project with all of Rankin Rapids as auxiliary		Tidal project with incremental capacity only at Rankin Rapids		Tidal project with Digdeguash pumped-storage auxiliary	
	United States	Canada	United States	Canada	United States	Canada	United States	Canada
INVESTMENT (millions of dollars)								
Tidal project first cost	242.0	242.0	242.0	242.0	242.0	242.0	242.0	242.0
Interest during construction	18.2	29.9	18.2	29.9	18.2	29.9	18.2	29.9
Auxiliary project first cost	0	0	73.0	73.0	15.8	15.7	17.3	17.2
Interest during construction	0	0	3.6	6.0	0.8	1.3	.9	1.4
Total investment	260.2	271.9	336.8	350.9	276.8	288.9	278.4	290.5
ANNUAL POWER BENEFITS (millions of dollars)								
At-site value of power	5.977	4.663	16.254	9.810	9.779	6.043	9.719	6.177
Value of downstream power benefits	0	0	0.528	0.425	0	0	0	0
Total annual power benefits	5.977	4.663	16.782	10.235	9.779	6.043	9.719	6.177
ANNUAL COSTS (millions of dollars)								
Interest, 2-1/2 percent U.S. and 4-1/8 percent Canada	6.505	11.216	8.420	14.475	6.920	11.917	6.960	11.983
Amortization 75 years	1.223	.571	1.582	.737	1.300	.607	1.308	.610
Major replacements	.202	.163	.241	.195	.224	.181	.231	.187
Self insurance, 0.05 percent per year	.130	.136	.168	.175	.138	.144	.139	.145
Operation, maintenance and supplies	.437	.437	.552	.552	.466	.466	.526	.526
Total at-site annual cost	8.497	12.523	10.963	16.134	9.048	13.315	9.164	13.451
BENEFIT - COST RATIO	0.70	0.37	1.53	0.63	1.08	0.45	1.06	0.46
POWER								
Installed capacity, kw.	150,000	150,000	350,000	350,000	263,000	263,000	280,000	280,000
Dependable capacity, kw.	47,500	47,500	277,500	277,500	177,500	177,500	161,500	161,500
Average annual generation (million kw.-hr.)	922	922	1,532	1,532	922	922	880	880
AT-SITE UNIT COST OF ENERGY (mills per kw.-hr.)	9.3	13.7	7.2	10.6	9.9	14.5	10.5	15.4

INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY

BENEFITS AND COSTS

75-YEAR AMORTIZATION PERIOD

International Passamaquoddy Engineering Board

AUGUST 1959 Dwg. No. TG7-271

DISCUSSION

Additional factors that influence the economic justification of the project, but which are not accounted for in the computation summarized on plates 51 and 52, are discussed below.

Effect of Taxes Foregone

Taxes foregone, if used, would increase the annual economic cost of the United States half of the project by about $9 per kw. of dependable capacity. This would reduce the benefit-cost ratio for the United States to the following values:

	Amortization Period 50 years	75 years
Tidal project alone	0.58	0.67
Tidal project and all of Rankin Rapids	1.10	1.25
Tidal project and incremental capacity only at Rankin Rapids	0.80	0.92
Tidal project and Digdeguash pumped-storage auxiliary	0.80	0.92

Downstream Benefits

With ultimate development of the Saint John River below Rankin Rapids, preliminary estimates of gains indicate that the monetary value of the benefits would be increased substantially over the estimate used in the benefit-cost analysis in the present study. However, these increases in downstream values would not raise the Canadian benefit-cost ratio to unity, nor would it raise the United States ratio significantly above the 1.3 - 1.5 range shown on plates 51 and 52.

Financing by United States Alone

Examination of plates 51 and 52 show that the international Passamaquoddy tidal power project - Rankin Rapids combination is economically justified if built entirely by the United States at an interest rate of 2 1/2 percent and if all the power is used in Maine. The growth of the power market in Maine is such that all of the power output of the combination may not be absorbed during the early years of the project combination life. This early excess probably could be sold to the New Brunswick or other markets. A combined project of this type would remain international because the high pool of the tidal project would be located partly in Canada, and because the Rankin Rapids project in the United States would regulate the flow of Saint John River in Canada. The nature of the agreement required for this plan was not examined.

CHAPTER X

CONCLUSIONS

The conclusions of the survey of the international Passamaquoddy tidal power project are summarized as follows:

(1) A tidal power project using the waters of Passamaquoddy and Cobscook Bays can be built and operated. The two-pool type of project is best suited for the site conditions in the area and the power markets it would serve. The tidal project arrangement selected makes best use of the site conditions.

(2) The first cost (construction cost) of the tidal power project by itself would be $484 million. With interest during construction, the investment would be $532.1 million. The tidal power project would have an installed capacity of 300,000 kw. and a dependable capacity of 95,000 kw. Average annual energy would be 1,843 million kw.-hr. However, for maximum power benefits, the tidal power project would have to be combined with an auxiliary power source.

(3) The most favorable project combination is the tidal power project operated in conjunction with a river hydroelectric auxiliary built at the Rankin Rapids site on the upper Saint John River in Maine. The combined cost of the tidal project and the Rankin Rapids auxiliary is $630 million. With interest during construction, the investment would be $687.7 million. The dependable capacity of this combination would be 555,000 kw. and average annual generation would be 3,063 million kw.-hr.

(4) Construction of the tidal project - Rankin Rapids combination would increase low flows in the lower Saint John River by a considerable amount, thus increasing substantially the usefulness of the river for downstream generation of power. Downstream benefits accruing to existing power plants were included in the economic evaluation.

(5) The combination of the tidal power project, and the installation and use of 260,000 kw. of capacity only at Rankin Rapids for firming up the output of the tidal power project, would cost $515.5 million. With interest during construction, the investment would be $565.7 million. This combination would provide a total dependable capacity of 355,000 kw. and an average annual generation of 1,843 million kw.-hr.

(6) The tidal power project and the Digdeguash pumped-storage auxiliary would cost $518.5 million. With interest during construction, the investment would be $578.9 million. The dependable capacity would be 323,000 kw. and average annual generation would be 1,759 million kw.-hr.

(7) The total output from the tidal power project and Rankin Rapids hydroelectric plant can be absorbed readily by the growing utility markets of Maine and New Brunswick.

(8) Because of differences in interest rates prevailing in the two countries, and because of different values of alternative power, it was necessary to compute separate benefit-cost ratios for United States and Canada. Economic evaluations, assuming 50-year and 75-year amortization periods, and assuming that power and project first costs would be equally divided between United States and Canada, are tabulated below.

Benefit-Cost Ratios and Cost of Power

	50-year amortization		75-year amortization	
	Benefit-cost ratio	Cost per kw.-hr. (mills)	Benefit-cost ratio	Cost per kw.-hr. (mills)
Tidal project alone				
United States	0.60	10.8	0.70	9.3
Canada	0.34	14.9	0.37	13.7
Tidal project and all of Rankin Rapids				
United States	1.31	8.4	1.53	7.2
Canada	0.58	11.5	0.63	10.6
Tidal project and incremental capacity only at Rankin Rapids				
United States	0.93	11.5	1.08	9.9
Canada	0.42	15.8	0.45	14.5
Total project and Digdeguash pumped-storage auxiliary				
United States	0.91	12.2	1.06	10.5
Canada	0.42	16.8	0.46	15.4

(9) The inclusion of taxes foregone with project costs is not the practice in the economic justification of public projects in Canada, and due to the international nature of the project, such taxes have not been applied to United States' costs. However, if they were included in United States' costs, the benefit-cost ratio of the most favorable project combination would be reduced to 1.10 for the 50-year amortization period and to 1.25 for the 75-year period.

(10) By including appropriate remedial measures in the design of the tidal power structures, the construction, maintenance, and operation of the tidal power project would have only a minor residual effect on the fisheries of the region.

(11) Considerable annual recreation benefits would grow out of the construction and operation of the tidal power project. However, the monetary value of these benefits was not included in the economic evaluation.

(12) Assuming an equal division of power output and of first costs between United States and Canada, construction of the tidal power project with all of Rankin Rapids as auxiliary is not an economically justified project for Canada.

(13) The Passamaquoddy tidal project and Rankin Rapids combination, if built entirely by the United States, at an interest rate of 2 1/2 percent, is economically justified.

INDEX

D = Digdeguash River auxiliary pumped-storage project
P = Passamaquoddy tidal power project
R = Rankin Rapids auxiliary hydro project on Saint John River

---

D = Digdeguash River auxiliary pumped-storage project
P = Passamaquoddy tidal power project
R = Rankin Rapids auxiliary hydro project on Saint John River

---

D = Digdeguash River auxiliary pumped-storage project
P = Passamaquoddy tidal power project
R = Rankin Rapids auxiliary hydro project on Saint John River

---

D = Digdeguash River auxiliary pumped-storage project
P = Passamaquoddy tidal power project
R = Rankin Rapids auxiliary hydro project on Saint John River

---

D = Digdeguash River auxiliary pumped-storage project
P = Passamaquoddy tidal power project
R = Rankin Rapids auxiliary hydro project on Saint John River

INTERNATIONAL PASSAMAQUODDY FISHERIES BOARD

Ottawa, Ontario
Washington, D. C.

October 1, 1959

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

Gentlemen:

The International Passamaquoddy Fisheries Board has the honour to submit the accompanying report in accordance with instructions of the International Joint Commission issued on October 3, 1956.

Forecasts of the effects of the proposed Passamaquoddy tidal power project on commercial fisheries are based on the results of co-ordinated investigations of the oceanography, biology, and fishing economy of the area along with engineering details of the construction and operation of the proposed project. Although time did not permit the desired stage of completeness for some aspects of the studies, it is believed that the opinions expressed are sound.

It is pointed out that the Board has limited its efforts to consideration of the effects of the tidal power project on the fisheries of the Passamaquoddy area and has not commented on the effects of associated projects on the fisheries of the Saint John River system.

In presenting its report, the Board wishes to record its commendation of the efforts of its Research Committee in proposing and carrying out an effective field program, analysing results, and framing the report.

Respectfully submitted,

Canadian Members	United States Members
J. L. Hart	D. L. McKernan
Fisheries Research Board of Canada	Bureau of Commercial Fisheries
A. L. Pritchard	M. B. Pike
Department of Fisheries	Holmes Packing Corporation

PASSAMAQUODDY FISHERIES INVESTIGATIONS

INTERNATIONAL PASSAMAQUODDY FISHERIES BOARD

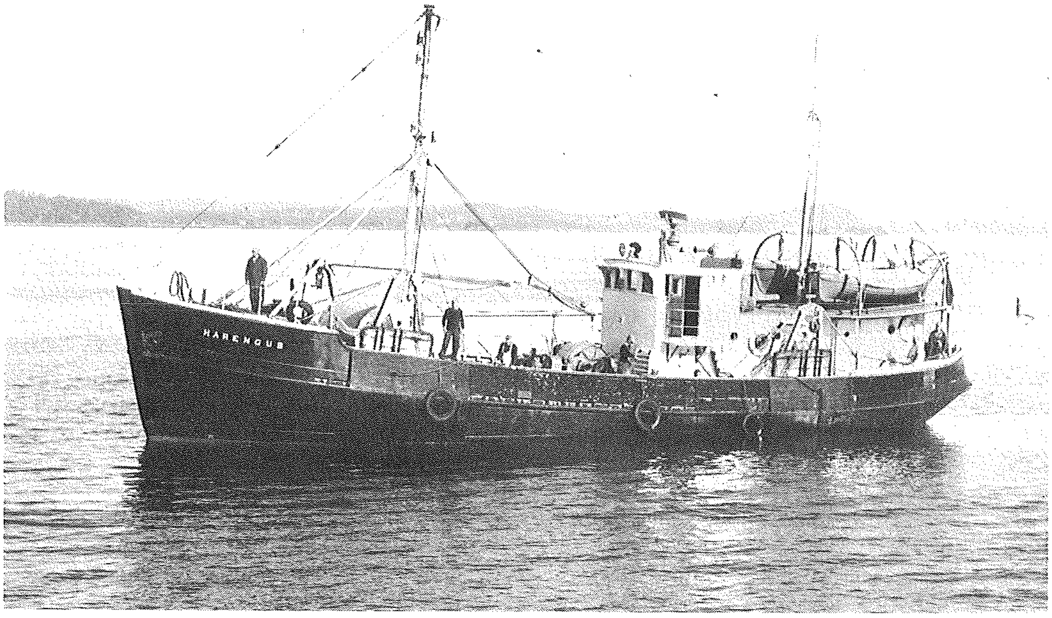
Report to

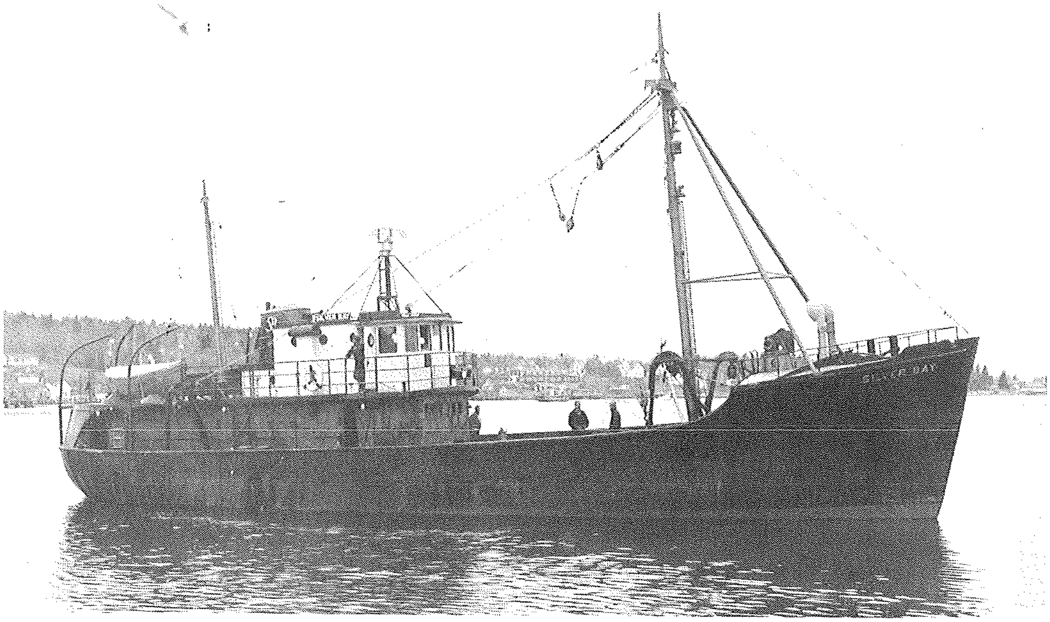
INTERNATIONAL JOINT COMMISSION

October 1959

INTERNATIONAL PASSAMAQUODDY FISHERIES BOARD

CANADA	UNITED STATES
Members	
J. L. Hart, Chairman A. L. Pritchard	A. J. Suomela, Chairman (to August 30, 1957) D. L. McKernan, Chairman (from August 30, 1957) M. B. Pike
Special Advisors	
	H. H. Eckles J. L. McHugh
Secretaries	
L. R. Day	H. W. Graham (to March 3, 1958) B. E. Skud (March 3, 1958 to August 28, 1958) J. E. Watson (from August 28, 1958)
Research Committee	
S. N. Tibbo, Chairman L. R. Day R. W. Trites R. A. McKenzie (from August 30, 1957) W. F. Doucet (from August 28, 1958)	L. W. Scattergood, Chairman H. W. Graham C. J. Sindermann D. F. Bumpus (from August 30, 1957) B. E. Skud (to August 28, 1958) J. E. Watson (from August 28, 1958)





Two of the vessels used for Passamaquoddy investigations (upper) Canadian research vessel M. V. *Harengus*, (lower) United States chartered vessel M. V. *Silver Bay*.

FOREWORD

The International Passamaquoddy Fisheries Board expresses its indebtedness to the Fisheries Research Board of Canada and to the United States Bureau of Commercial Fisheries, whose staffs and consultants have played leading parts in developing its research program. The respective staffs have carried out much of the research and have coordinated investigations by others. Of cooperating agencies, the most prominent were the Markets and Economics and the Conservation and Development Services of the Canadian Department of Fisheries, the Hydrographic Service of the Canadian Department of Mines and Technical Surveys, the Economics Department of Bowdoin College, the Maine Department of Sea and Shore Fisheries, the Atlantic Sea-Run Salmon Commission, and the Woods Hole Oceanographic Institution.

The Board's special gratitude is expressed to members of the Research Committee, named on page ii, who have worked competently and faithfully.

NOTE.--The findings of the research group were transmitted through the International Passamaquoddy Fisheries Board to the International Joint Commission in October 1959. The appendices listed in the table of contents have been submitted to the International Joint Commission but are not reproduced here. These individual units of research supporting this publication will appear separately in various United States and Canadian journals as numbered papers in the International Passamaquoddy Fisheries Board, 1956-59, Scientific Report (IPFBSR) series. This document, slightly edited, has also appeared in the U. S. Fish and Wildlife Service's Special Scientific Report--Fisheries No. 360 (August 1960).

CONTENTS

FIGURES

LIST OF APPENDICES

APPENDICES (continued)

GPO 905573

PASSAMAQUODDY FISHERIES INVESTIGATIONS, 1957-1958

by

International Passamaquoddy Fisheries Board

INTRODUCTION

In 1956, the Governments of Canada and the United States asked the International Joint Commission to determine whether the tidal forces of Passamaquoddy and Cobscook Bays could be used to produce hydroelectric power, and to appraise the effect of powerdam construction on the important fish and shellfish industries of the area. Two Boards were established on October 3, 1956: the International Passamaquoddy Engineering Board, which was charged with a study of the engineering aspects of the proposed project, and the International Passamaquoddy Fisheries Board, which was made responsible for a study of fisheries that might be affected by the project. The specific reference to the International Passamaquoddy Fisheries Board was--

> . . . to determine the effects, beneficial or otherwise, which such a power project might have on the local and national economies in the United States and Canada, and, to this end, to study specifically the effects which the construction, maintenance, and operation of the tidal power structure proposed might have upon the fisheries in the area. . . (Cf., I. J. C. Docket 72, October 3, 1956.)

The first regular meeting of the Fisheries Board took place on November 16, 1956. Thereafter regular meetings were held semiannually. Informal meetings were also held immediately before International Joint Commission hearings in April and October each year.

The Board appointed a research committee of Canadian and United States scientists to develop plans and to conduct the necessary research on the fisheries of the Passamaquoddy Region.

A joint engineering and fisheries committee of the Engineering and Fisheries Boards was set up in accordance with directions from the International Joint Commission dated October 4, 1957. The Joint Engineering and Fisheries Committee assured that no aspects of the Passamaquoddy problem would be overlooked, established an appropriate and practicable line of demarcation between the work of the two Boards, and attempted to obtain uniformity in measuring benefits and damages.

At its second meeting, held in Boston, Mass., on March 6, 1957, the Board approved a research program to provide as much pertinent information about the area and its fisheries as could be expected within the time limits imposed and the money appropriated. It recognized, however, that such short-term studies could not answer all of the questions that had been raised.

The research program considered not only the "sardine" herring fishery, but also the fisheries for cod, haddock, flounder, redfish, hake, pollock, salmon, alewives, clam, smelt, scallops, and lobsters. All of the fisheries were certain to be affected in some way by the proposed structures. The principal problems concerned the sources of fish, method of transport to the fishing grounds, the environmental conditions within Passamaquoddy and Cobscook Bays and their approaches, and the commercial value of recent catches.

The investigations extended to all parts of the Bay of Fundy and the Gulf of Maine

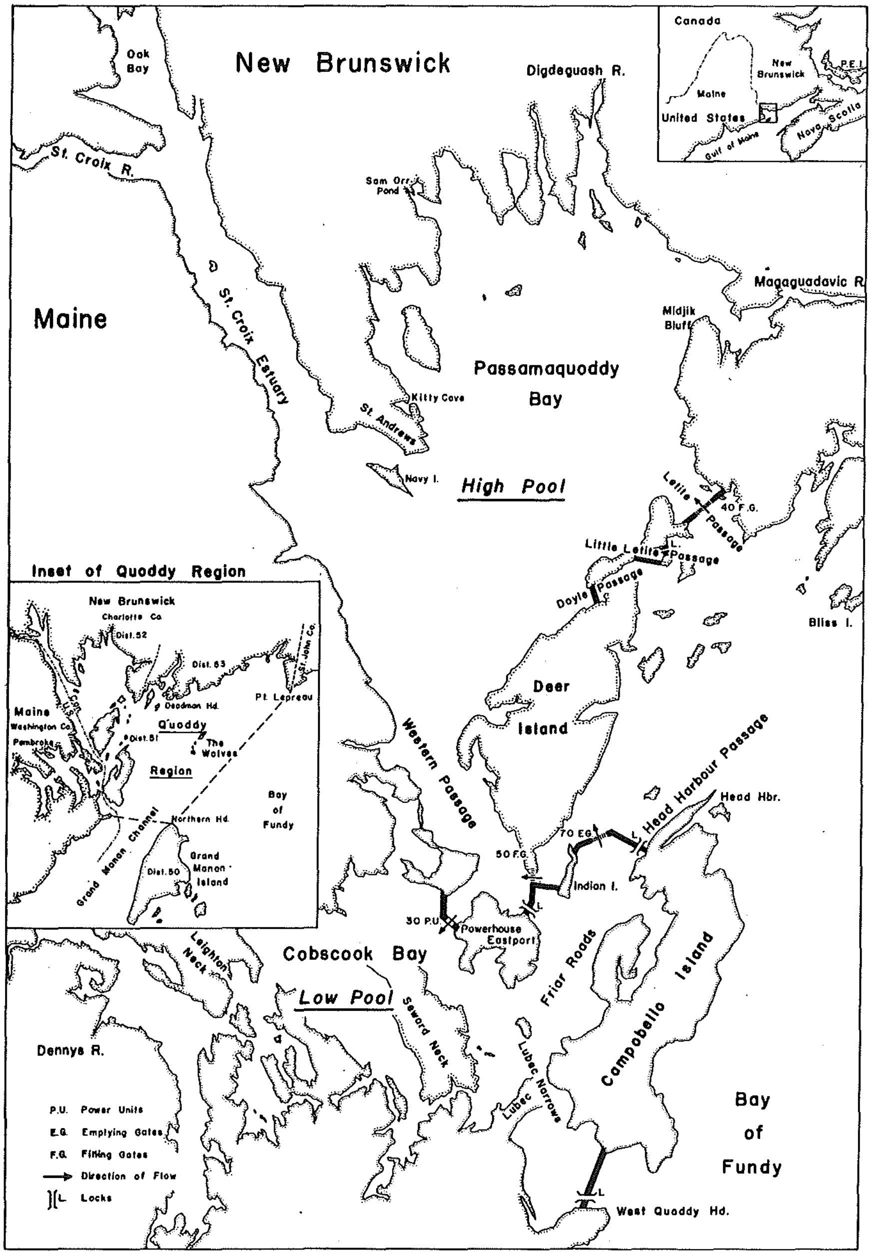


Figure 1.--Map showing location of high pool, low pool, filling gates, emptying gates, and powerhouse. The Quoddy Region is shown in inset.

where proposed structures might reasonably be expected to affect fish populations. Particular emphasis, however, was placed on the Quoddy Region, which was defined as the area inside a line drawn from Point Lepreau, N. B., to Northern Head, Grand Manan, N. B., thence to West Quoddy Head, Maine. The Region was divided by the proposed dams into high-pool, low-pool, and outside areas on the basis of information received from the International Passamaquoddy Engineering Board in October 1957. A study of the gross features of the Kennebecasis Bay area, near St. John, N. B., was made because it had certain physical aspects which were similar to those that would be imposed upon the Passamaquoddy area if power dams were constructed.

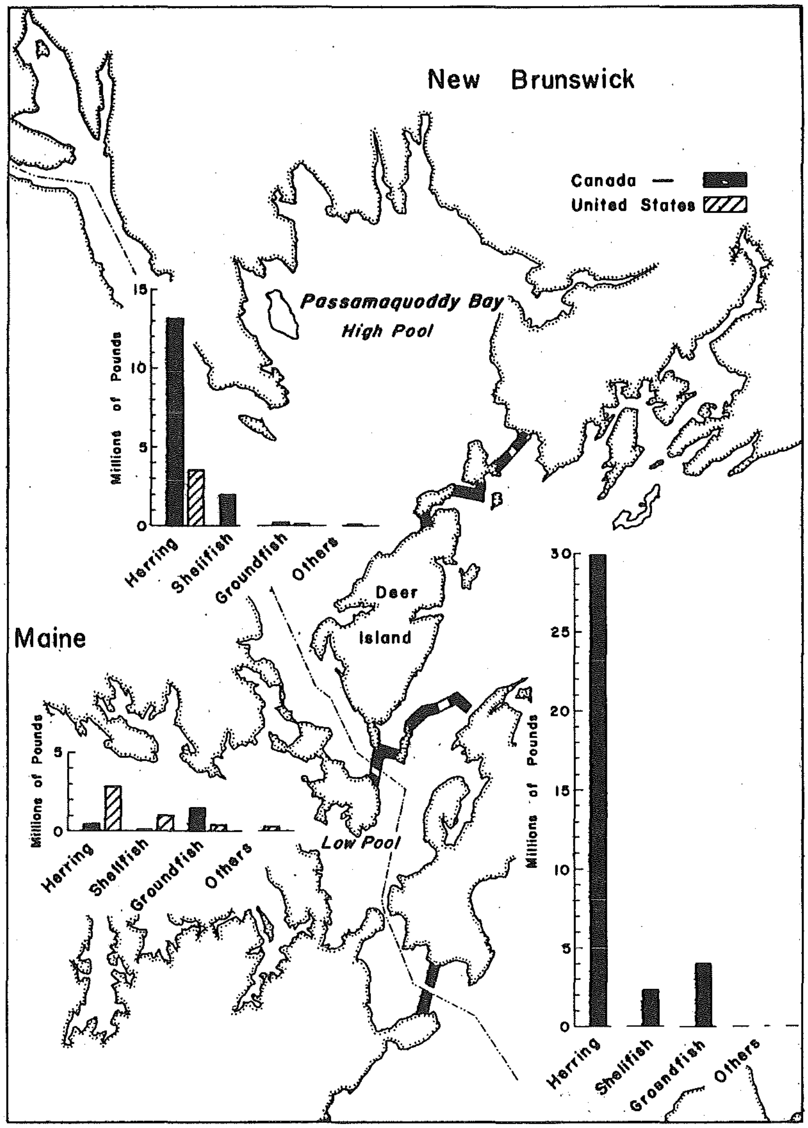


Figure 2.--Average annual landings of herring and other species in the Quoddy Region. High-pool, low-pool, and outside-area landings are superimposed in their respective positions.

Construction of an hydraulic model for hydrographic studies and for studies related to fish behavior was considered, but was ruled out because the anticipated additional information would not justify the cost. Special attention was given to the problem of assuring facilities for passage of anadromous fishes from the open sea to their spawning grounds in the rivers and lakes.

To establish a basis for prediction of the effects of the dams on fisheries, the present oceanographic, biologic, and economic features of the area and its fisheries were studied. Temperature, salinity, tides, and tidal currents in the bays, in the approaches, and outside the bays were studied. Biological studies were made of fish populations, breeding grounds, nursery areas, food and feeding habits, and the interrelationship of fish and their environment. Economic studies of the capital value of fishing and processing equipment, of fishing receipts and costs, and of the general economic environment of the area were also undertaken.

The research program was carried on as a cooperative effort by the Fisheries Research Board of Canada and the United States Bureau of Commercial Fisheries.

Some projects within the program were assigned to other organizations. Studies of herring behavior, migrations, length, age, vertebral counts, spawning areas and seasons, distribution of larvae, explorations, and compilations of catch statistics were carried out both at St. Andrews, N. B., and at Boothbay Harbor, Maine, laboratories. Parasitological and serological projects were done at the Boothbay Harbor laboratory; plankton and correlation projects, at the St. Andrews laboratory. Specialists from Canada and the United States were consulted on the biology of other species. A survey of fish-passage needs was carried out by fishery engineers of the Canadian Department of Fisheries and the United States Bureau of Commercial Fisheries.

The Atlantic Oceanographic Group of the Fisheries Research Board of Canada carried out studies of circulation and distribution of physical properties in the Quoddy Region and an oceanographical and biological reconnaissance of the Kennebecasis area. The study of nontidal drift in the Bay of Fundy and the Gulf of Maine was the responsibility of the Woods Hole Oceanographic Institution, which operated under a contract with the United States Bureau of Commercial Fisheries. The tide and tidal-current project was done jointly by the Atlantic Oceanographic Group and the Hydrographic Service of the Department of Mines and Technical Surveys of Canada.

Economic surveys of herring and lobster fisheries in southern New Brunswick were carried out by the Economics Service of the Department of Fisheries of Canada. The United States Bureau of Commercial Fisheries, assisted by economists from Bowdoin College, made an economic survey of the Maine "sardine" fishery. The Fisheries Research Board of Canada provided assessments of probable effects on other species in the Canadian area. The Maine Department of Sea and Shore Fisheries, under a United States Bureau of Commercial Fisheries contract, provided a comparable service for the United States.

REVIEW OF LITERATURE

Comprehensive and valuable information on the Passamaquoddy area and its fisheries is contained in the literature. This information was carefully considered, particularly during the planning and final-assessment stages of the present investigations.

One of the earliest systematic oceanographic surveys in the Bay of Fundy consisted of tidal-current measurements by Dawson (1908). Extensive data have been collected since that made possible a general description of the nontidal circulation and the spatial and temporal distribution of temperature and salinity. Copeland (1912), Craigie (1916), Vachon (1918), Hachey (1934b), Watson (1936), and Bailey (1957) dealt with certain oceanographic aspects of Passamaquoddy Bay. Studies of oceanographic features of the Bay of Fundy were published by Craigie and Chase (1918), Mavor (1922, 1923), Hachey (1934a, 1935), Watson (1936), Fish and Johnson (1937), McLellan (1951), MacGregor and McLellan (1952), Ketchum and Keen (1953), and Bailey *et al.* (1954). Hachey (1957) reviewed oceanographic requirements relative to the sardine fishery in the Passamaquoddy area.

Studies of the effects of dams on the fisheries of the Passamaquoddy area were first conducted during the late 1920's and early 1930's. In February 1928, Dr. A. G. Huntsman, Director of the Atlantic Biological Station at St. Andrews, N. B., testifying before a Royal Commission on Maritime Fisheries, predicted considerable damage, particularly to herring, clam, and pollock fisheries. Huntsman (1928) predicted the elimination of the important fisheries of Passamaquoddy Bay and serious effects on fisheries of neighboring areas as far away as Digby County in Nova Scotia and along the coast of Maine.

On June 2, 1928, at a meeting of the North American Council on Fishery Investigations, the question of the effects of the Passamaquoddy project on international fisheries was raised, and a resolution passed urging the Governments of the two countries to carry out detailed investigations. The International Passamaquoddy Fisheries Commission was set up in 1931 to carry out necessary studies. Field work was completed during the summer of 1933, and in October of the same year a final report was presented.

The conclusions given in the report were as follows:

> The physical effects of the present mixing mechanism appear to be local and although the construction of the dams would influence the hydrographic conditions in the passages, it is not expected that their influence would extend far into or beyond the Outer Quoddy Region.
>
> The influence of this local mixing on the supply of nutrient salts in the surface layers, where they are available for plant production, is almost entirely confined to the Quoddy Region. The conditions existing over the greater part of the Bay of Fundy appear to result from other factors, which would not be influenced by the dams. It is not considered that the construction of the dams would have an appreciable effect upon the production of plant life outside the Quoddy Region.
>
> The rich fishery in the Quoddy Region is not due to a localized abundance of zooplankton. The zooplankton supply which supports the herring population outside of Passamaquoddy Bay in summer (and is found within the bay in winter) is considered to be mainly produced in areas beyond the influence of the Quoddy mixing mechanism and transported passively by ocean circulation into the region. Any influence of the proposed dams upon this supply would probably be insignificant.
>
> A sure forecast of the effect of the proposed dams on the fishery requires more comprehensive and more detailed knowledge of the biology of the herring than is available at present. The researches do, however, lead to some relevant conclusions.
>
> The herring population is produced beyond the influence of local mixing and no way has been foreseen by which the dams would render the Outer Quoddy Region or the Bay of Fundy less favorable to the existence of herring arriving from elsewhere.
>
> The effect upon the availability of herring is likely to be considerable. Many changes in the set of tidal streams may be expected, and probably every little change would have an effect on the fishery of nearby weirs. Some weirs would be made richer, some poorer. It cannot be foretold whether the total effect of disturbance of tidal streams on capture outside of the dams would be deleterious or not.
>
> There appears little probability of the proposed dams affecting the sardine fishery along the coast of Maine or even seriously at Grand Manan.
>
> The herring fishery inside of Passamaquoddy Bay would almost certainly be reduced to negligible proportions. (North American Council on Fishery Investigations, Proceedings 1931-1933, No. 2, 1935, pp. 6-7.)

Other biological investigations in the Bay of Fundy and adjacent areas included studies of herring spawning areas and seasons by Perley (1852), and Bigelow and Schroeder (1953). Graham (1936), and Fish and Johnson (1937) discussed the distribution of herring larvae. Moore (1898), Battle (1935), Battle et al. (1936), and Johnson (1940) described the food and feeding habits of herring. Huntsman (1934, 1952, 1953), Battle et al. (1936), and Graham (1936) considered the influence of environmental conditions on the movements and catches of herring. Leim (1956) prepared an annotated bibliography of Bay of Fundy herring and Scattergood (1957) published a bibliography of Atlantic and Pacific herring.

RESULTS OF INVESTIGATIONS, 1957-1958

The reference from the International Joint Commission specified that an economic assessment be made of any changes in the fisheries which might result from the proposed tidal power project. Such an assessment depends on a forecast of the probable effects on abundance and availability of fish and other organisms. This, in turn, depends on prediction of changes in the physical environment. Hence, the logical sequence for presenting the results of investigations is (1) oceanography, (2) biology, and (3) economics.

OCEANOGRAPHIC STUDIES

The Quoddy Region and contiguous areas of the Bay of Fundy and Gulf of Maine were studied to determine present circulation, tides, distribution of properties, and controlling or relating factors, and to predict changes that may occur if dams are installed. To assess present conditions, extensive measurements and observations were made during 1957 and 1958, together with data gathered from the region over a period of 50 years prior to 1957.

Oceanographic features of the Bay of Fundy are determined by tide-producing forces, the earth's rotation, river discharge, meteorological conditions, and bottom configuration. Due to strong tidal currents (up to 8 feet per second) vertical mixing proceeds vigorously; hence, seasonal fluctuations in temperature and salinity are much reduced. Circulation in the main portion of the Bay is anticlockwise. Inflowing waters hold close to the Nova Scotia coast. Outflowing waters pass along the southeastern coast of Grand Manan, thence along the coast of Maine or across the mouth of the Bay to Nova Scotia.

Temperature and salinity

Mean annual ranges in temperature and salinity of the surface layer in the Quoddy Region are approximately 34° to 54° F. and 30 to 33 parts per thousand. Seasonal variations in inshore areas and in Passamaquoddy Bay are slightly greater than in offshore areas. During 1957 and 1958, 43 cruises were completed in the Quoddy Region. They covered a network of stations, in which temperature and salinity were observed and drift bottles released.

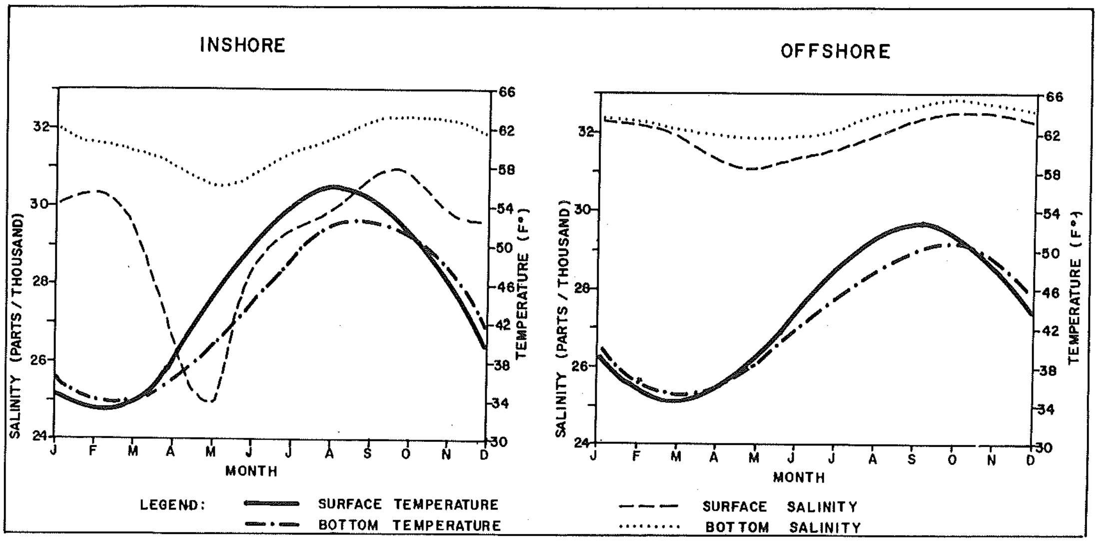


Figure 3.--Seasonal variations in temperature and salinity of surface and bottom waters in the inshore and offshore areas of the Quoddy Region.

Oceanographic features in the 2 years were very different. This difference has been related, in part, to abnormal river runoff, which was well below normal in 1957 and well above normal in 1958. The flushing time (i.e., the average length of time required to remove 1-day's contribution of river water) for Passamaquoddy Bay varied from about 8 to 20 days, with the more rapid flushing rate occurring during high river discharge.

Tides and tidal currents

Currents were measured at 60 stations in Passamaquoddy Bay and the Bay of Fundy during the summers of 1957 and 1958. This project was carried out jointly by the Canadian Hydrographic Service of the Department of Mines and Technical Surveys and the Atlantic Oceanographic Group of the Fisheries Research Board of Canada. The program was aimed at determining the tidal and nontidal water movements in Passamaquoddy Bay and its approaches and in part of the Bay of Fundy.

Tides in the Bay of Fundy are characterized by a predominant semidiurnal component. Tidal amplitude in the Quoddy Region varies from an extreme minimum of approximately 14 feet at neap tide to a maximum of nearly 28 feet at spring tide. The mean tidal range is approximately 20 feet. Tidal currents vary markedly throughout the Region. Maximum recorded speeds were found in Letite Passage where mean maximum speeds reached 8 feet per second (4.8 knots). In Passamaquoddy Bay, speeds were mostly less than 1 foot per second. Near the mouth of Cobscook Bay, mean maximum speeds were 5 feet per second. In the outside area, mean maximum speeds seldom exceeded 5 feet per second. Currents were usually maximum in the surface layer and decreased slowly with depth. Residual flows were mostly less than 2 miles per day in Passamaquoddy Bay, Cobscook Bay, and the approaches. In the Bay of Fundy, residual flows were variable and in some areas were as much as 10 miles per day.

Nontidal drift of surface waters

During 1957 and 1958, approximately 10,000 drift bottles were released in the

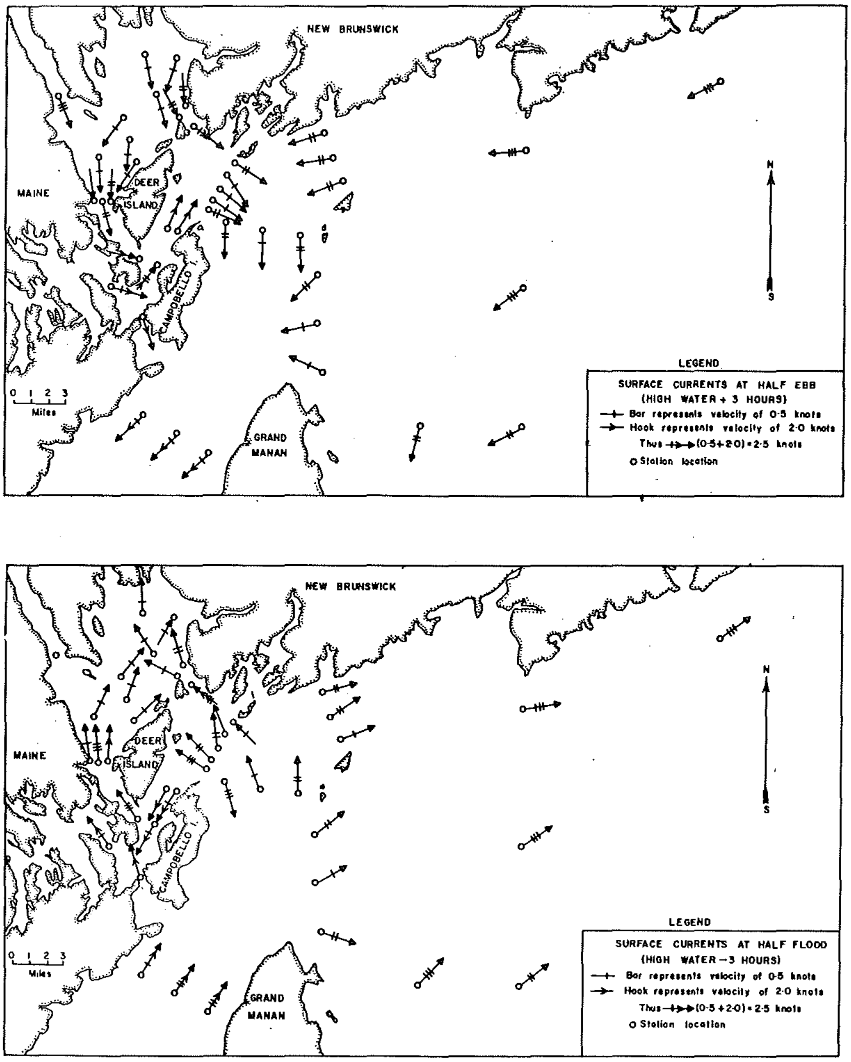


Figure 4.--Surface tidal currents in the Quoddy Region showing half-ebb and half-flood conditions.

Quoddy Region and about 25 percent were recovered. During the first 10 days, 9 percent were recovered, and during the first 30 days, 17 percent. Inside Passamaquoddy Bay, in Cobscook Bay, and in the Passages, the usual distance between release and recovery was of the same order of magnitude as the tidal excursions. Hence, it is difficult to infer net circulation in this area. Inside Passamaquoddy Bay, surface circulation on the average appeared to be counterclockwise; however, wind evidently modified this situation markedly. On the whole, wind action is very effective in moving the surface layer. In general, winds with a southerly component tend to confine surface waters to Passamaquoddy Bay, while winds from the north and west remove surface waters from the Bay. In each instance, there must be compensating flow at subsurface levels. No clear picture of net surface flow through Letite and Western Passages was established. There is some evidence that, on the average, net flow is outward through Western Passage and inward through Letite Passage. However, there are instances when net flow appears to be reversed. There also are times when surface flow is in the same direction in both passages with a compensating subsurface flow. Drift-bottle returns plotted on a monthly basis indicate marked changes in pattern of flow both seasonally and for the same month for the 2 years. A small percentage of the drift bottles leave the region; some move along the coast of Maine as far as Massachusetts, while others drift across the Bay of Fundy to Nova Scotia.

Flow through the passages

The electromagnetic induction method of measuring water transport was used in Western and Letite Passages, Lubec Narrows, and the Saint Croix estuary. The average duration of the flooding tide into Passamaquoddy Bay is approximately 6 hours, while the tide ebbs for nearly $6\frac{1}{2}$ hours. Tidal currents during the flood are slightly higher than during the ebb. In Western Passage, slack water occurs later than in Letite Passage. This phase lag varies from 15 to 50 minutes with some degree of periodicity. Evidence indicated that residual flow, while seldom very pronounced, was on the average outward through Western Passage.

Bay of Fundy and Gulf of Maine

Considerable attention was given to the oceanography of the Bay of Fundy and the Gulf of Maine. Returns from 35,000 drift bottles launched in the Gulf of Maine area since 1919 were examined to determine the sources of surface waters that enter the Bay of Fundy. The area from which drift bottles enter the Bay is restricted during January to the immediate approaches to the Bay. This area gradually expands during the spring to a maximum in early summer when it encompasses most of the Gulf of Maine and part of Georges Bank. The source area gradually retracts during autumn to the eastern side of the Gulf of Maine and northward away from Georges Bank. Thus, there is little likelihood that herring larvae spawned on Georges Bank in the autumn would drift into the Bay of Fundy. There is some evidence that a sudden increase in runoff gives impetus to increased circulation out of the Bay of Fundy and along the Maine coast to Massachusetts Bay. From January to March, 1958, there was marked movement down the coast of Maine; bottles reached Cape Cod in as little as 3 weeks after release in the Quoddy Region. This occurred during and following a period of high river runoff. During 1957, a period of drought, few drift bottles launched in Passamaquoddy Bay were recovered outside the Bay of Fundy.

Kennebecasis Bay, New Brunswick

A study was made of Kennebecasis Bay and the Saint John estuarial system, since physical and biological conditions in Kennebecasis Bay seemed similar to those expected in Passamaquoddy Bay if dams were installed. Results of the study showed a degree of similarity between Kennebecasis Bay and Passamaquoddy Bay when dammed. There are two important factors, however, that are markedly different for the two situations. One is that quantities and relative locations of fresh water discharged into the two areas differ. The other is that two sills separate the saline water of the Bay of Fundy from the deep water in Kennebecasis Bay, compared with one sill under the proposed conditions for Passamaquoddy Bay. Therefore, distribution of properties in Kennebecasis Bay represents a more extreme condition than is anticipated in Passamaquoddy Bay if power dams are installed. The results of this study are useful in estimating the extreme conditions probable in Passamaquoddy Bay after impoundment.

BIOLOGICAL STUDIES

The primary aim of biological studies was to provide information on abundance, distribution, habits, and reproduction of fish stocks in the Quoddy Region. Results apply particularly to herring, but consideration was given to other species of commercial importance in the region and ways they would be affected by the dams. Species not present in commercial quantities now, but which might increase under new conditions, were also considered as were species present in quantity but not of current commercial interest.

Herring

Fishery statistics.--Herring landing statistics for southern New Brunswick and eastern Maine are not available before the latter part of the 19th century when the fishery was chiefly for large, mature fish. Canadian landings of these fish declined from about 25 million pounds in the 1880's to less than 5 million pounds in the 1920's. Over the same period, catches of small, immature "sardine" herring increased from about 5 million pounds to nearly 70 million pounds. During the last 20 years, Canadian and United

States landings in the Quoddy Region have consisted almost entirely of sardine herring and, while there have been large year-to-year fluctuations, average landings have been about 55 million pounds annually.

Weirs are the most important method of capture, but stop seines and purse seines are becoming more popular and are accounting for increasing proportions of the total herring catch. The fishery is seasonal and most of the landings are made during the summer. Sardine canning is the major market for herring, but substantial quantities are canned as pet food and reduced to meal and oil. Pearl essence is an important and valuable byproduct.

A survey was made of the herring fishery in southern New Brunswick. Landings by counties and areas from 1920 to 1958 were examined. Annual and monthly landings by fishery statistical areas in southern New Brunswick for 1937 to 1958 were studied in detail. During 1957 and 1958, daily catch statistics were collected according to individual units of gear. Interviews with weir owners provided catch records for 1947 to 1957. Because the proposed dams will divide the Region into pools which will not coincide with existing fishery statistical districts, the data were used as a basis for allocating recent catches to the new pool areas.

The average annual herring landings in the high pool from 1947 to 1958 were 13,200,000 pounds; in the low pool, 500,000 pounds; immediately outside the dams (Head Harbour to Deadman Head) 13,400,000 pounds; in the remainder of the Quoddy Region, 16,400,000 pounds; and in the remainder of southern New Brunswick, 26,500,000 pounds.

In the Quoddy Region, west of Letite Passage, 70 to 75 percent of the catch is landed from June to September; however, east of Letite Passage where there is a large winter purse-seining fishery, about 54 percent of the landings are made during these months.

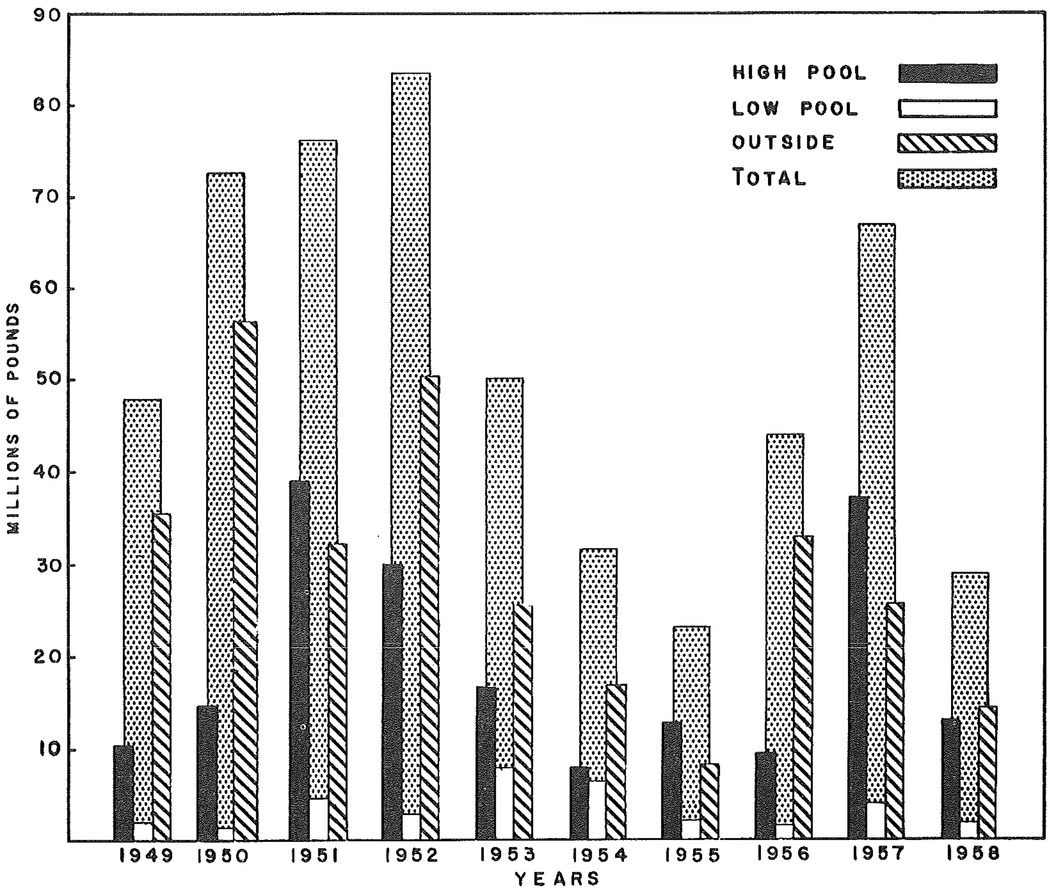


Figure 5.--Total (Canadian and United States) herring landings in the high and low pools and in the part of the Quoddy Region outside the proposed dams.

Before 1957, there were no detailed records of landings by gear. Though there are almost 1,100 registered weir sites in Charlotte and Saint John Counties, only a small proportion are licensed annually. During 1957 and 1958, weirs caught 70 to 85 percent of the catch in the two counties. The balance was made by drag or stop seines (5 to 7 percent) and purse seines (9 to 22 percent).

From 1947 to 1958, the number of weirs built and operated varied from 56 to 85 in the high pool, from 9 to 21 in the low pool, and from 111 to 205 in the remainder of the Quoddy Region. Over the same period, the average catch per weir was about 240,000 pounds in the two pools, while in the outside area it was approximately 130,000 pounds.

Detailed information on the Maine herring fishery was available from the daily catch records that have been collected since 1947. From these records, statistics of the fishery by weeks, months, areas of capture, and gear were compiled. Certain facts pertinent to the Passamaquoddy studies are evident. In the past 12 years, the total Maine catch varied from 75 to 200 million pounds, while that of the Quoddy Region varied from 2 to 11 million pounds or from 1 to 12 percent of the total. However, the processing industry does not depend solely on herring taken locally, but draws upon Canadian Quoddy and other areas of Maine, New Brunswick, and Nova Scotia.

Many marked fluctuations are noted from the statistics. For example, in 1947, the low-pool catch was 49,000 pounds, and the high-pool catch 6,273,000 pounds; in 1954, the low-pool catch was 6,369,000 pounds; and the high-pool catch 238,000 pounds. The average high-pool catch from 1947 to 1958 was 3,613,000 pounds, and the low-pool catch 2,878,000 pounds. In the high pool, weirs caught 82 percent of the herring landed; stop seines took the remainder. In the low pool, stop seines caught about 77 percent of the herring, and weirs about 23 percent. Since 1947, the number of weirs in operation in both pools has varied from 14 to 31. Weirs in the low pool have fluctuated markedly: from none to 16. In 1958, there were 10 weirs in the high pool and 4 in the low.

From 1947 to 1958, Maine herring landings immediately outside the dams (from West Quoddy Head to Cross Island) averaged 6,121,000 pounds, and the remainder of Washington County (from Cross Island to Gouldsboro) 28,134,000 pounds. In 1958, there were 59 weirs between West Quoddy Head and Gouldsboro and these accounted for 64 percent of the catch; stop seines took the remaining 36 percent.

The herring fishery is seasonal. Ninety percent of Maine landings and 94 percent of Washington County landings are made from June through October. Landings in the high pool are greatest from August through October and in the low pool, from September through October.

Populations.--Population studies included an analysis of data on length and age composition, year-class variation, and growth, collected in the Quoddy Region in 1957 and 1958. Studies of parasites and reactions of blood components were made from 1955 through 1958 including samples from the entire Atlantic area from Newfoundland to New Jersey.

Length and age analyses were based on 71,000 herring sampled for length and 23,000 fish sampled for scales. All samples were drawn from the commercial fishery for immature herring. Determinations of age and growth were made by length-frequency analysis because a high proportion of the scales were unreadable. The fishery is sustained by herring which grow to a length of between $4\frac{1}{4}$ and 5 inches in their first year of life and to a length of between $6\frac{1}{4}$ and $7\frac{1}{2}$ inches in their second year. This growth is in agreement with results of investigations made in 1915 (Huntsman 1919) and 1932 (Graham 1936).

Studies of parasites and serological reactions show that adult herring spawning off the Nova Scotia coast are distinguishable from those spawning on Georges Bank. Immature herring from the Gulf of Maine are distinguishable as two subgroups--"eastern" and "western"--with a zone of mixing in the vicinity of Penobscot Bay. The "eastern" subgroup showed greater serological similarity to southwest Nova Scotia adults than to Georges Bank adults. This similarity suggests that spawning off the Nova Scotia coast is principally responsible for eastern sardine stocks, including those of the Quoddy Region.

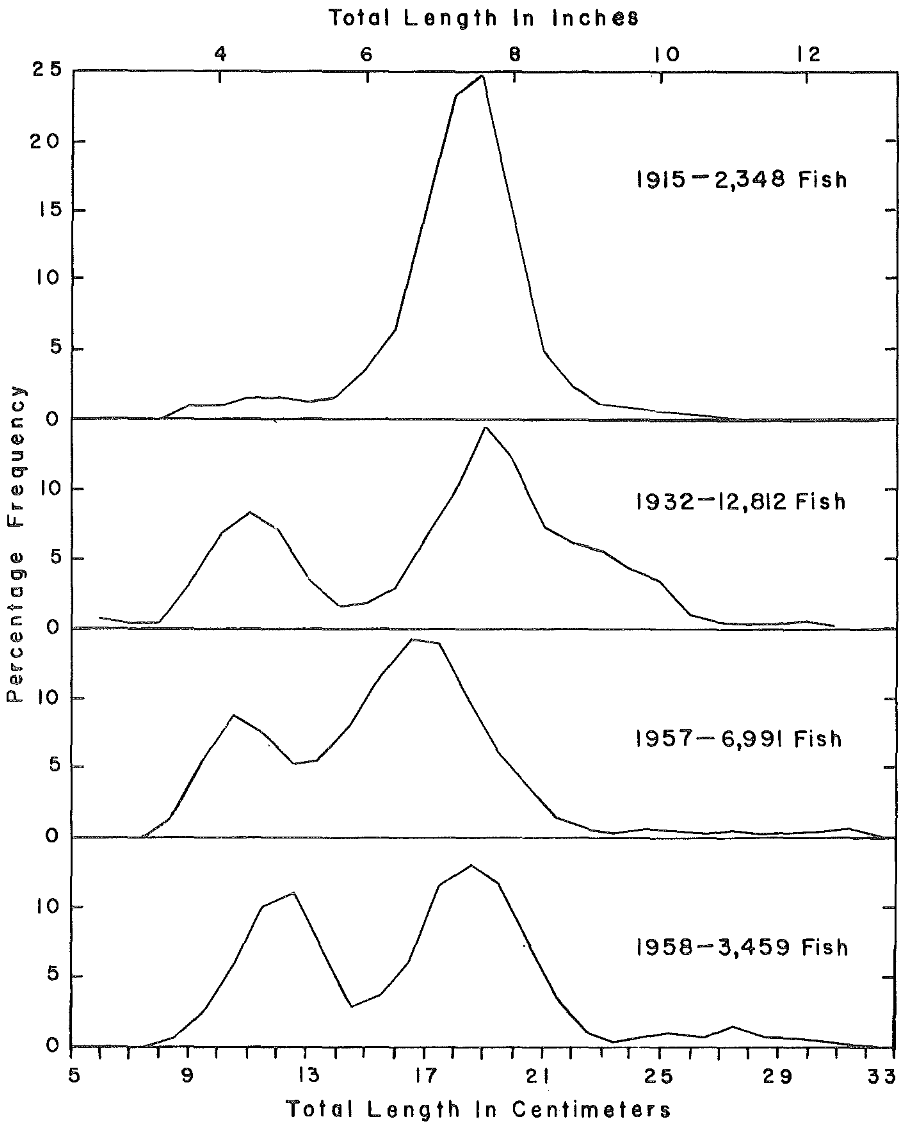


Figure 6.--Comparison of length-frequency distributions of herring samples collected in the Passamaquoddy Region during September in 1915, 1932, 1957, and 1958.

Migrations.--Movements of herring in and near the Quoddy Region were studied to discover the source and the fate of the herring in Passamaquoddy and Cobscook Bays. In 1957 and 1958, 59 taggings involved more than 137,000 herring. Recaptures from 1957 taggings totalled 792 (2.1 percent) while recaptures from 1958 taggings totalled 2,790 (2.8 percent).

Recaptures showed that herring move in and out of Passamaquoddy Bay from points as far east as Point Lepreau and as far south as southern Grand Manan. No recaptures from Passamaquoddy Bay taggings were made to the southwest along the coast of Maine. However, some fish tagged on the coast of Maine moved to Passamaquoddy Bay and beyond to Point Lepreau. The pattern of recoveries did not indicate clearly whether movements were via Letite or Western Passage, but there was some indication that both passages were used. Comparison of drift-bottle and tag recoveries indicated that herring do not always move in the same direction as the surface currents. While there is insufficient information to establish a pattern of herring migrations, there is a suggestion of random movement.

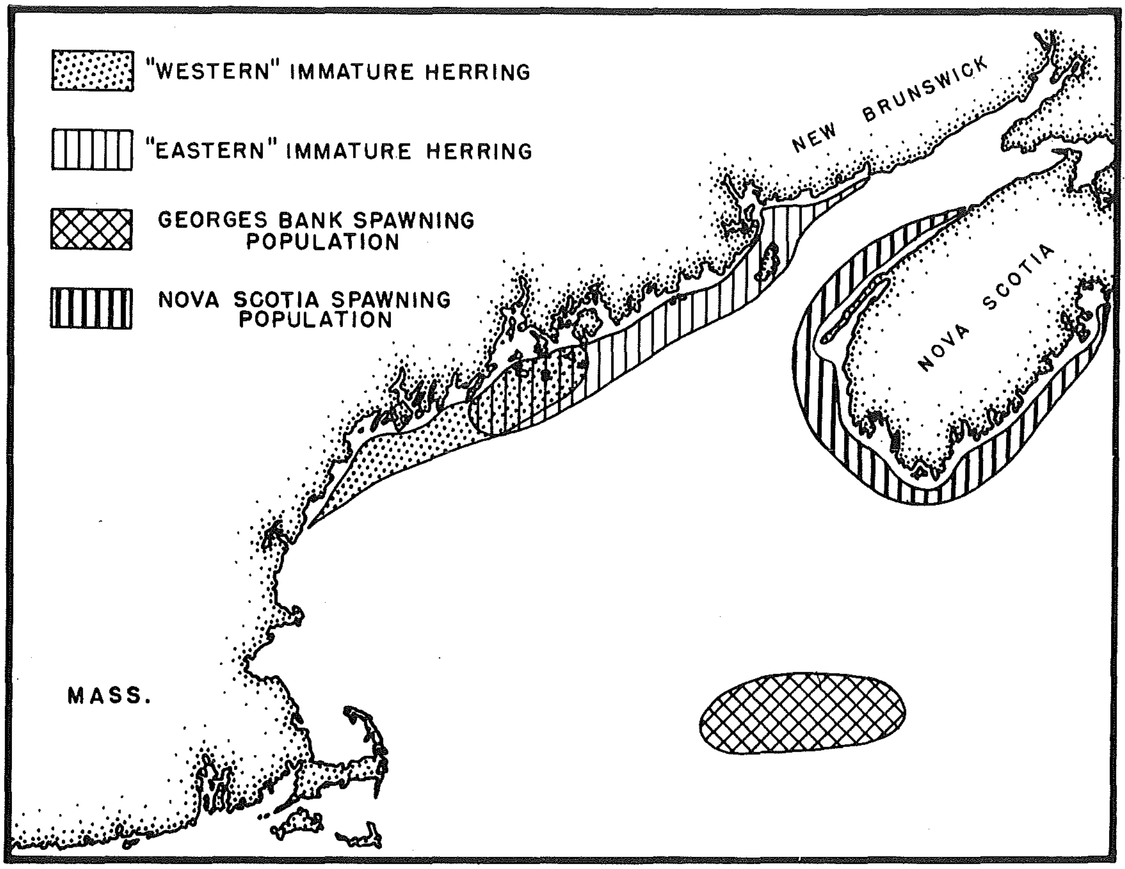


Figure 7.--Major Bay of Fundy and Gulf of Maine herring groups as determined by serological and parasitological methods.

Results demonstrate that there is no mass movement of herring away from the Quoddy Region from April to November. Because the tags remained on the fish for short periods, no information was obtained on movements into or away from the Region during the winter months.

Behavior.--To determine whether herring could withstand anticipated changes in hydrographic conditions in Passamaquoddy and Cobscook Bays, temperature, salinity, and pressure tolerances were investigated. The behavior of herring in currents, their swimming speeds, and depth distribution provide a basis for prediction of fish movements in the approaches to the dams and the turbines.

Mortalities of herring at various temperatures were determined for newly caught fish. Large herring were more acutely affected by high temperatures than were small herring. The temperature at which 50 percent of the herring would die in 48 hours was calculated to lie between 66° and 70° F. for $3\frac{1}{2}$- to 12-inch herring.

The tolerance of herring to various salinities was tested, and it was found that salinities as low as 5 parts per thousand are not injurious.

Resistance of herring to rapid changes in pressure was investigated to determine whether they could survive the pressure changes encountered during passage through the turbines. Sardine herring accustomed to surface pressure withstood an increase of 67 pounds per square inch (equivalent to a water depth of 150 feet) at a rate of 0.8 pounds per square inch per second. Sardines accustomed to a pressure of 20 pounds per square inch survived decompression at a rate of

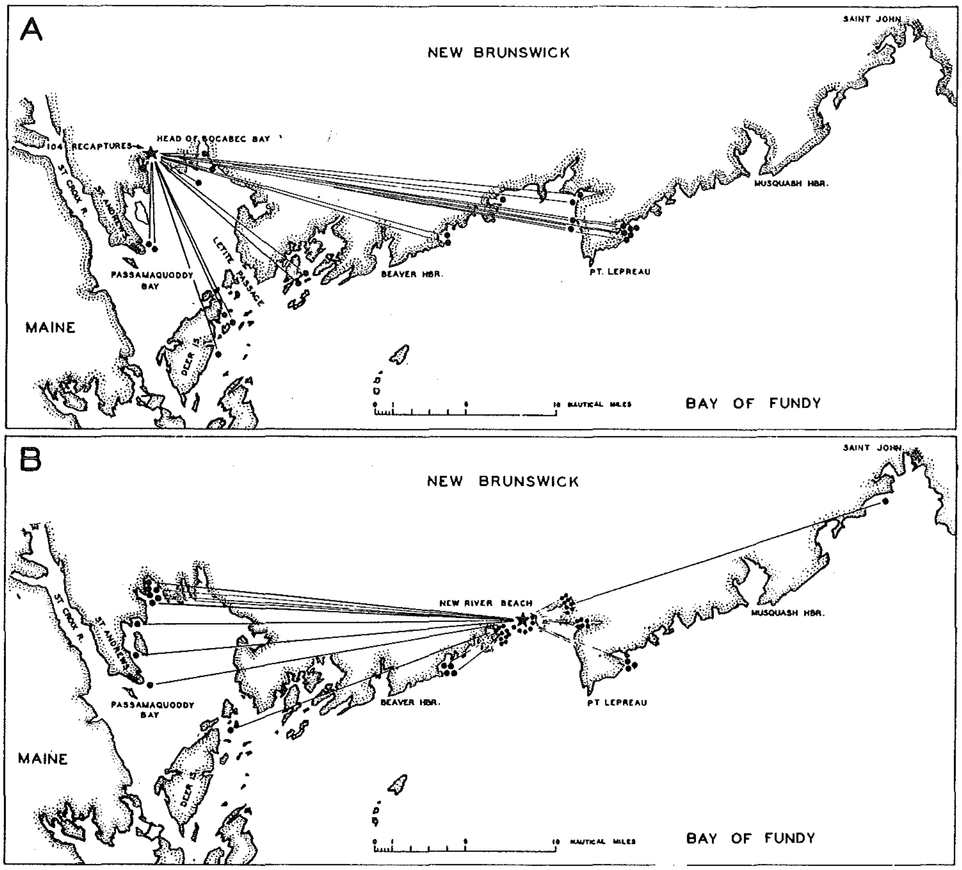


Figure 8.--Movements of herring as shown by tagging. The straight lines connect the areas of tagging to points of recovery but do not show lines of travel.

12.5 pounds per square inch per second. Predicted pressures and rates of pressure change between turbine intakes and exits are therefore within the limits which these fish can withstand. The effect of increase in pressure from the top of the draft tube to its lowest point was not investigated but anticipated pressure changes are unlikely to injure the fish.

Herring held in a large mesh-covered cage responded to the movement of water through the cage by heading into the current and swimming from side to side in the "upstream" direction. The response seemed to be based on visual stimuli, but its effectiveness was limited by the maximum swimming speed. With increasing water velocities, herring continued to swim against the current until forced backward, tail first. Swimming speeds increased with size of fish and ranged from 2.4 to 4.7 feet per second (1.4 to 2.8 knots) for herring with mean lengths of $2\frac{3}{4}$ to $10\frac{1}{2}$ inches. Swimming endurance also increased with size of fish. Herring $7\frac{3}{4}$ inches long were able to stem currents of 3.4 feet per second for a period of 13 minutes.

Examinations of echo-sounder records showed that during the fishing season from May to October the median depth of herring shoals varied from 26 to 35 feet during the day and from 17 to 23 feet at night.

Early Life History.--There were 33 cruises (1,404 plankton tows) from September 1956 to February 1959 throughout the Bay of Fundy and Gulf of Maine to study distribution and abundance of herring larvae as indicators of spawning grounds and nursery areas, and to discover survival, growth, and methods of transport of herring to the Passamaquoddy area. There were two main spawning grounds:

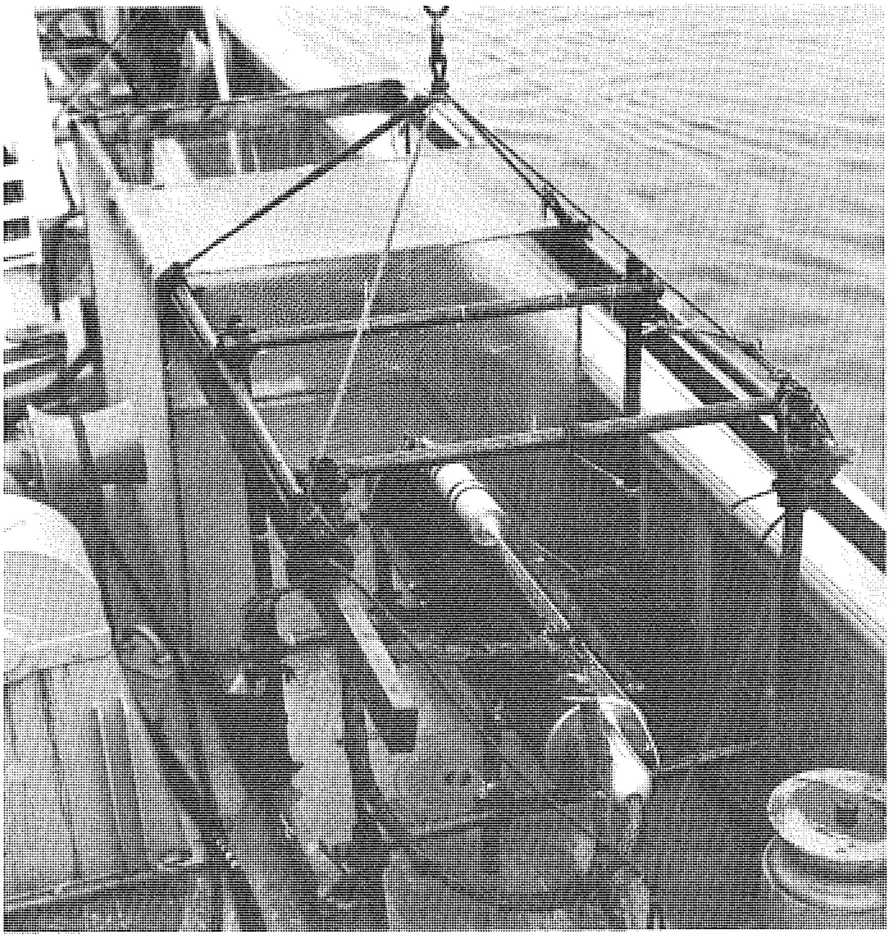


Figure 9.--Underwater television camera and holding cage used for herring behavior experiments.

the northern edge of Georges Bank and the southwest Nova Scotia coast. Catches of newly hatched larvae indicated small spawnings in Penobscot Bay, on Stellwagen Bank, on Nantucket Shoals and south of Grand Manan. There was no evidence of spawning inside Passamaquoddy or Cobscook Bays. Large numbers of herring larvae were found on Georges Bank and in the Bay of Fundy in September and October each year. Catches decreased sharply in November and were very small in December, January, and February except for one large catch in December 1956. Only occasional specimens were taken in other months.

The drift of larvae, as indicated by distribution of larger larvae and by nontidal surface currents in the Bay of Fundy and Gulf of Maine, suggested that southwest Nova Scotia spawnings are major contributors to commercial stocks of herring in inshore areas of southern New Brunswick and eastern Maine. Other spawnings, particularly those on Georges Bank, may also supply some herring to the area.

Plankton and food studies.--Data from 2,537 plankton tows in the Quoddy Region and data from herring stomach analyses were used to obtain information on food and feeding habits, and to test for a possible relation between plankton abundance and commercial catches of herring.

Studies of the composition, abundance, and distribution of zooplankton communities in the Passamaquoddy area showed that copepods dominate except at a few localities where occasionally the larvae of barnacles or other groups were abundant. Volumes of plankton in all tows were usually found to be four to five

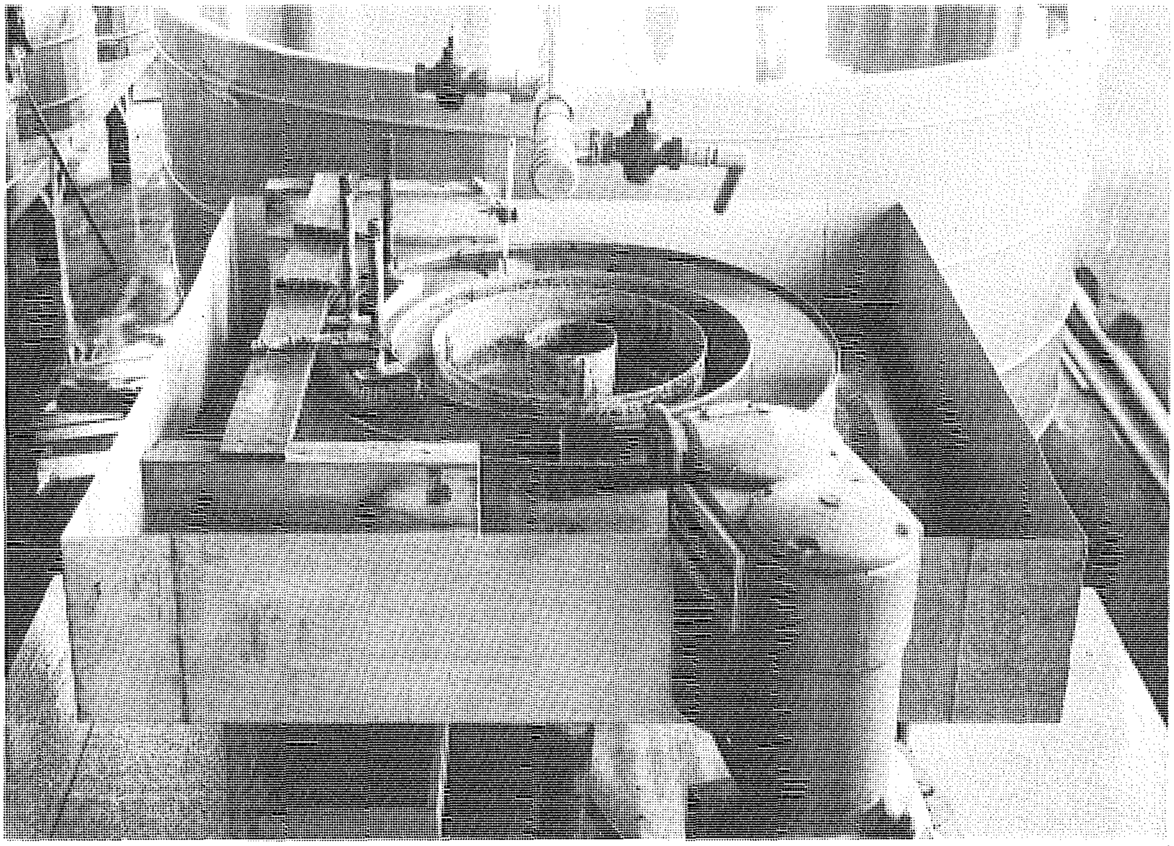


Figure 10.--Rotating tank used to measure the swimming speeds of herring.

times larger outside than inside Passamaquoddy Bay. The seasonal abundance of plankton varied greatly. The vernal crop of phytoplankton extended from late March to late June, while the largest volumes of zooplankton were taken during the summer months. Phytoplankton "bloom" ended abruptly in the summer while zooplankton populations decreased more slowly and were at their lowest ebb during the spring.

The stomachs of 1,696 herring taken in 1958 were examined for kinds and quantities of food organisms. The importance of plankton in the diet of the herring varied according to the availability of food in different localities. Copepods were the main food items, but the diet was quite diversified, and about 50 different organisms were identified. No correlation was found between standing plankton crop and feeding activity. A period of low feeding activity extended from March to August, while from September to November feeding activity was high. There was no apparent relation between plankton abundance and commercial catches of herring.

Exploratory fishing.--Exploratory fishing was carried on during 1957 and 1958 to provide additional information on the movements of herring, to supplement shore sampling program, and to locate unexploited herring populations. Electronic detection equipment and various kinds of fishing gear were used.

Exploratory fishing operations confirmed the presence of a large spawning population of herring on the northern edge of Georges Bank in the autumn and located small quantities of postlarvae in inshore areas of eastern Maine in the spring. Weekly sonic-sounder cruises during the summer months in 1957 and 1958 showed that, in general, the largest concentrations of herring in the Quoddy Region were in open waters where there are no weirs. Attempts to catch these fish with midwater trawls and gill nets were unsuccessful but large quantities were taken by commercial purse seiners. The species of fish taken in the Kennebecasis and Long Reach areas of the Saint John River were the same as those common to the Quoddy Region.

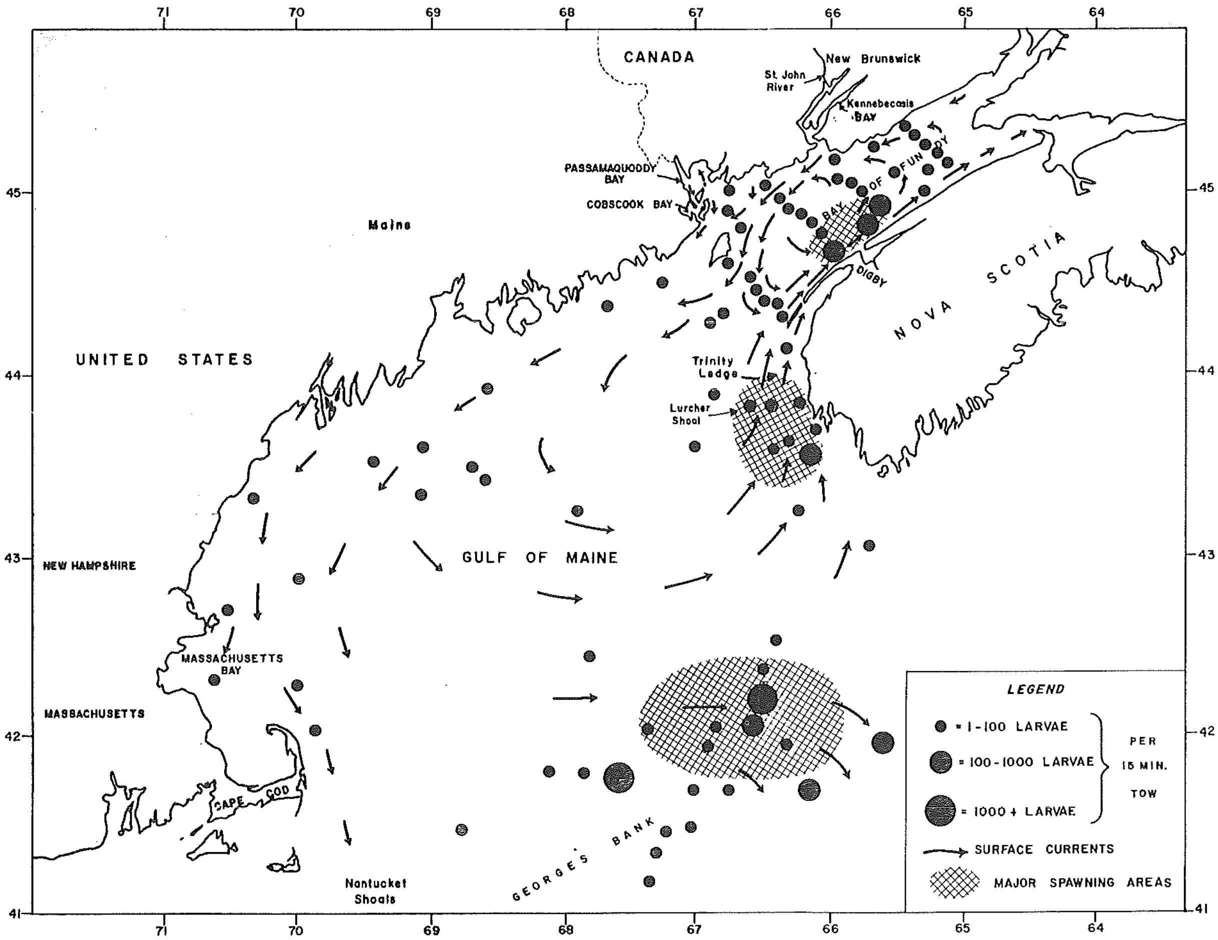


Figure 11.--Spawning areas, distribution, and abundance of herring larvae, and surface currents in the Bay of Fundy and Gulf of Maine during the autumn.

Correlation studies.--Correlation studies were undertaken because an understanding of the changes associated with present fluctuations in the herring catch might assist materially in predicting changes resulting from the dams. It was impossible, however, to establish any consistent correlation between catch and such factors as river discharge, wind speed and direction, air and sea temperatures, salinities at various depths, plankton, and cloud cover.

Other Species

Groundfish.--Commercially important species of groundfish in the Quoddy Region are pollock, haddock, cod, hake, and winter flounder. Hake and cod are scarce inside the proposed dam areas. Large catches of pollock are made in the low-pool area and small catches of haddock and winter flounder in the high-pool area. The present (1958) catch of all groundfish species in the Region is approximately 6 million pounds, of which approximately 2 million pounds (chiefly pollock) are taken inside the proposed dam areas. The haddock are fast-growing fish of the type caught off the New England States. Tagging studies show that they migrate south for the winter months and spawn outside the Region.

Mollusks.--Only two species of molluscan shellfish are harvested from the Quoddy Region in sufficient quantity to warrant consideration: soft-shell clams in the intertidal zone and sea scallops

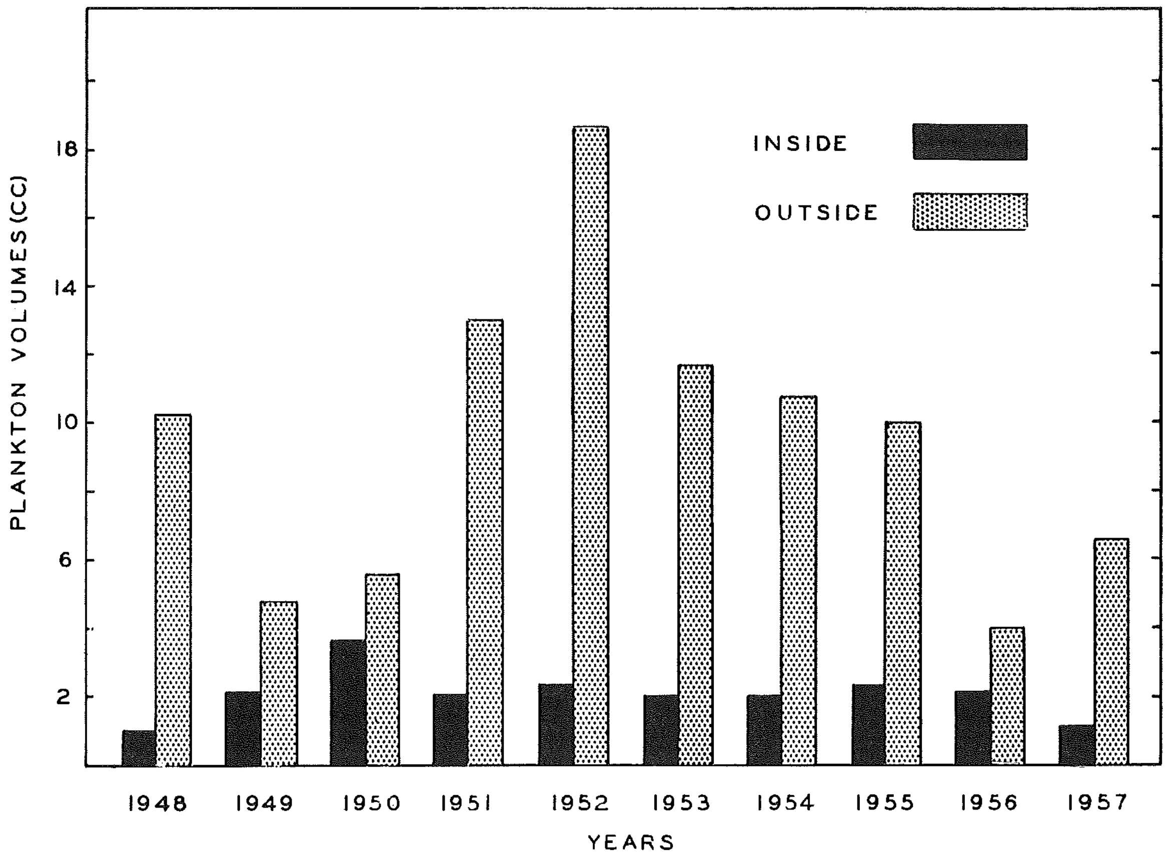


Figure 12.--Relative abundance of plankton inside and outside Passamaquoddy and Cobscook Bays. Only forms which constitute food for herring are included.

in deeper waters. In recent years the average annual landings inside the proposed dam areas have approximated 750,000 pounds of clam meats and 60,000 pounds of scallop meats. The abundance of both species has fluctuated widely and will continue to fluctuate with or without impoundment. Maintenance of scallop populations seems to depend on retention of the free-swimming larvae over their native beds until they mature and attach themselves. Evidence of shipworms, although not previously recorded from Passamaquoddy Bay, was found during this investigation in two tributary inlets--Kitty Cove and Sam Orr Pond. The species appeared to be *Teredo navalis*. Another wood borer *(Xylophaga)* is common in the offshore waters of New England and in recent years has invaded the inshore waters south and west of Mount Desert Island, Maine.

Lobsters.--From 1952 to 1958, lobster landings in the Quoddy Region averaged approximately 388,000 pounds. Of this amount, about 102,000 pounds were taken inside the proposed dam areas. Tagging has shown that adult lobsters do not move appreciably from one area to another, and hence the stocks are considered to be relatively separate and distinct.

Anadromous fishes.--Anadromous species with actual or potential economic value in the Quoddy Region include Atlantic salmon, trout, smelt, and alewives. The entire value of trout and most of the value of salmon lie in their fresh-water sport fisheries. The Dennys River is the most important salmon river and from 30 to 100 fish are angled there annually. The Digdeguash and Magaguadavic Rivers now have quite good populations of young salmon which probably contribute adult salmon to commercial catches over a wide area of the Atlantic coast. The St. Croix River has few naturally produced salmon due to obstructions and pollution.

The present sport fishery for trout is quite valuable but is based chiefly on fish which do not go to sea. Tomcod, shad, and striped bass are not fished commercially in the Quoddy Region but provide valuable fisheries in warmer, less saline estuaries. Smelt populations are probably localized and may stay within Passamaquoddy and Cobscook Bays, whereas alewives move into and out of these Bays.

Miscellaneous.--Marine worms, valued as bait for sport fishing, are harvested in small quantities in Cobscook Bay. Rockweed is a potentially valuable resource and is available in good supply. The gribble *(Limnoria)*, a crustacean wood borer, is common in the Quoddy Region, and damages caused by it are significant.

ECONOMIC STUDIES

Economic surveys of the principal fisheries of Charlotte County, N. B., and of the Passamaquoddy section of the State of Maine, were made for the years 1956 and 1957. The study assessed the investment and income position of the herring and lobster fisheries, including the herring-carrier fleet, and determined the value of investment in plant and equipment and the manufacturing costs of fish-processing establishments. Groundfish and shellfish, species of commercial importance, were not covered by the economic surveys but were studied from other statistical sources. The results provide a basis for evaluating the economic impact of any change in the primary and secondary fisheries of the Quoddy Region. The primary fishery includes all activities associated with catching fish and delivering them to the processing plants; the secondary fishery includes the fish-processing activities after delivery of the fish to the plant.

Canadian fisheries

The investigation of the primary fishery was conducted on a sample basis. For the secondary fishery, a complete coverage was made of processors from Blacks Harbour to the International Boundary.

Herring weir fishery.--Like most inshore fisheries, the Canadian herring weir fishery is decentralized and dependent upon intensive application of labor. It is organized in small enterprise units, consisting typically of one weir (with a crew of about four men per weir), in which the traditional "lay" (share) system of payment to labor and capital still prevails. About 50 percent of the weir workers are hired laborers--tendermen, so-called--who have no equity in the capital of the enterprise but tend and operate weirs for a predetermined share of the season's catch. Only in a few, isolated cases do these workers receive a stipulated money wage. Thus, owners are relieved of a great deal of risk and uncertainty; the risk is further reduced by the fact that equity capital in most weir enterprises is small and spread among several owners.

Despite a basic similarity in weir construction, considerable variation in weir investment exists within and between different parts of Charlotte County. This variation is due to differences in weir sizes and in topographic and oceanographic environment. Survey data obtained for 1956 and 1957 revealed an average weir investment (including associated weir gear) of about $5,500 inside Passamaquoddy Bay and of about $6,200 outside the Bay. Total investment in weir enterprises for the entire region was placed at $1.7 million. Approximately 1,100 men are engaged in the weir fishery.

Income derived from the weir fishery is largely a function of the success of the catch. Owing to the nature of the market, prices which fishermen receive are relatively inflexible. At the same time, operating expenditures are fairly stable and subject to little influence from variations in receipts. Consequently, fluctuations in catches within the region and from year to year can engender wide variations in earnings among fishermen, and a series of unsuccessful catches can leave the weirmen in rather poor circumstances.

Data obtained on 86 weir enterprises for 1956 and 1957 provided tangible evidence of this connection. In 1956, operating incomes of these enterprises ranged from $-1,671 to $15,565; in 1957, from $-1,653 to $16,117. Average net income per enterprise was $1,385 and $2,040,

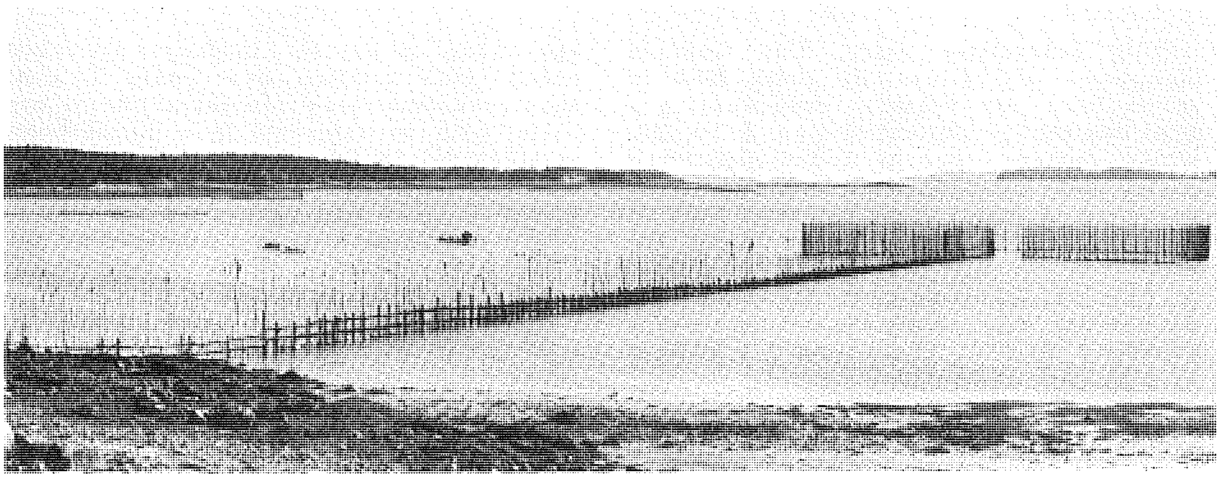


Figure 13.--Typical Canadian weirs. In the foreground, a simple weir without a parlor. In the background, a compound weir with a parlor in which herring are held alive awaiting sale.

respectively for 1956 and 1957. Average share to capital (before allowance was made for depreciation) was only $434 and $732. Despite such low and often discouraging returns, weir owners continue to maintain their investment in this operation and are generally opposed to the use of alternative methods of herring fishing.

Herring purse-seine fishery.--In contrast with the weir fishery, the Canadian herring purse-seine fishery is carried out by mobile, highly capitalized

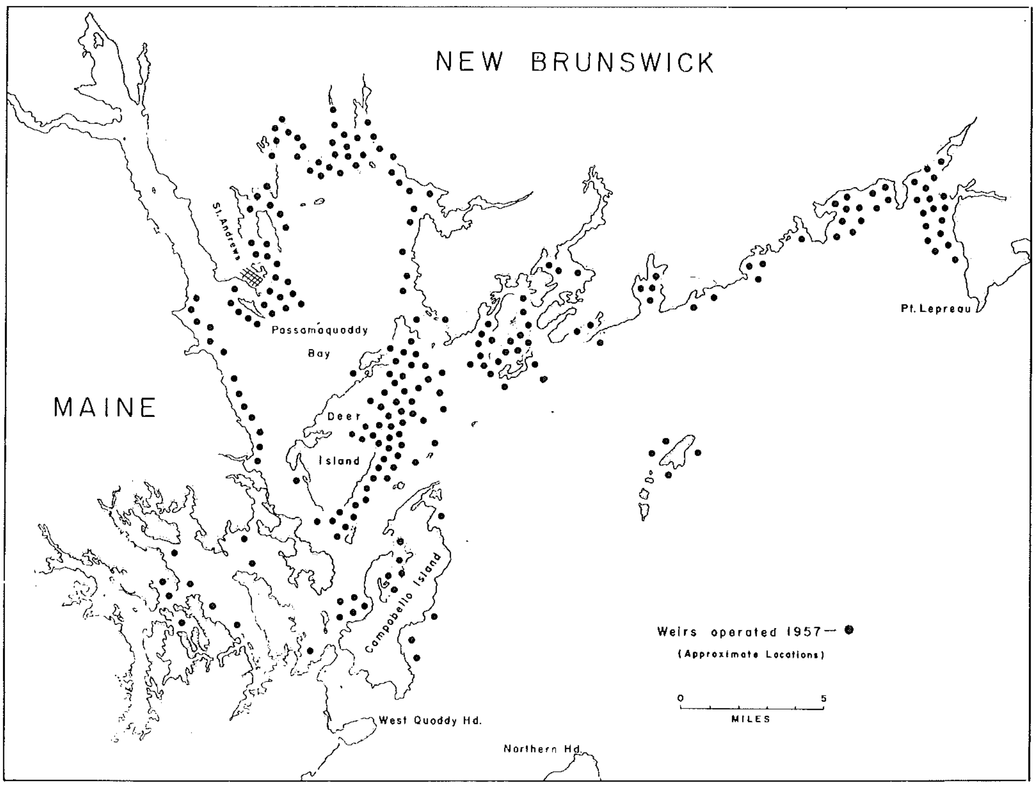


Figure 14.--Approximate locations of Canadian and United States herring weirs operated in the Quoddy Region in 1957.

fishing enterprise units. The fleet is composed of 17 vessels (with four to seven men per vessel), representing a total capital investment of about $170,000. While seiners operate under high fixed costs, their catching performance permits recovery of fairly high returns. Data on six seiners covering 1957 operations revealed an average net income per vessel of $26,445. Average crew earnings were $3,818 per man, while the net boat share averaged $4,172. There was a return of 22.4 percent on invested capital.

Notwithstanding this relatively good performance, the history of the seining fleet has been one of uneasy expansion and restricted operation. This situation has resulted from limited markets for fresh herring and local opposition to seining activity, particularly on the part of weir interests and lobster fishermen. Seiners have operated much like a fettered fleet: their movements have been restricted to certain distances from shore and from the sites of stationary fishing gear and their fishing effort has often been reduced, due to the inability of the market to absorb the catch. There is hope, however, that new channels of herring utilization will alter the existing supply-demand relationship and, thereby, reduce local opposition to the application of efficient capital in the herring fishing industry.

Herring carrier fleet.--This fleet is a necessary adjunct to the weir and purse-seining fisheries. Vessels vary greatly in size--from about 40 feet to 65 feet--and carry a crew of one to three men. In 1957, there were 57 independently operated vessels engaged in the carrying trade, representing an average capital investment of $6,496 (based on survey data covering 46 vessels). Values ranged from $350 to $21,650. Total net income from carrying operations--derived mainly from the herring trade--showed little change during the 2-year study. The average income per vessel was $4,072 in 1956 and $4,115 in 1957. This uniformity was due to the supply-demand relation for the commodity transported and to the constancy of both receipts and expenditures in the region as a whole.

Lobster fishery.--In the Quoddy Region this fishery is small compared with that in some areas of the Maritime Provinces. During the 10-year period ending in 1957, the value of lobster landings averaged about $0.5 million per year. Typical lobster enterprises consist of one or two men, with investments in a small boat, in about 150 lobster traps, and in a modest stock of shore equipment. A small capital outlay in gear and equipment for use in other fisheries usually accompanies the "lobstering assets." Total investment of lobster enterprises in Charlotte County is estimated at $659,000 representing an average of about $1,985 per enterprise. Investment varies among the several subdivisions of the area. In Grand Manan, in particular, lobster enterprises use more gear and are generally more heavily capitalized; net returns per man are higher. Operating expenditures in the lobster fishery are fairly inflexible and relatively independent of results of the catch. The net income, however, is subject to considerable variations from year to year in response to supply and price conditions. In 1957, the average net income of 22 lobster enterprises was $811.

Groundfish fishery.--In Charlotte County this fishery is pursued by approximately 350 men, fishing mainly on inshore grounds, using small motor boats and limited capital equipment. The value of their landings from 1948 to 1957 averaged about $270,000 annually. Since 1950, a trend toward modernization and expansion has developed. Largely through government assistance, mechanized vessels (chiefly draggers) have been introduced and have had appreciable success in improving fish landings and incomes of fishermen. A modern large-scale filletting and freezing plant was established in the area in 1957 and has greatly increased the local demand for groundfish.

Mollusk fisheries.--Clams, mussels, and scallops support the principal Canadian fisheries for mollusks in the area. There are an estimated 300 men engaged in these fisheries. Most of these men participate in other fishing activities. The income derived from shellfish landings averaged about $225,000 annually from 1948 to 1957. Clams constituted about three-quarters of the total value. Capital equipment associated with the shellfish fisheries in Charlotte County is negligible. Largely for this reason, the fisherman's expenditures are small; consequently, receipts from the sale of mollusks approximate a net reward for labor.

Fish-processing.--In Charlotte County the industry is dominated by sardine and lobster plants. A number of plants process other species on a small scale, principally groundfish and clams.

Investment in plant and equipment of all processors in the area was calculated for 1957 to exceed $7.0 million (based on replacement values). The direct influence of this industry upon the economy of the area can be measured, at least in part, in terms of the employment which it generates. This employment is largely seasonal in nature, reaching its peak during the summer months. In 1957, for example, the number of persons employed ranged from about 1,400 in July to 450 in December.

United States fisheries

The survey of the primary fisheries in the Quoddy Region of the State of Maine covered investments, operating costs, and net returns to fishermen for 1956 and 1957. Data on investments, operating costs, and gross stock of herring carriers were also collected. The survey of the secondary fisheries obtained, whenever possible, similar data from fish processors, such as smokers, sardine packers, fishmeal and oil producers, and pet-food canners. The primary fishery is concerned principally with herring. Other commercially important species are clams and scallops. Lobsters, groundfish, alewives, and smelts are of minor importance. Comparatively small catches of species other than herring and scallops involve limited gear investment, negligible operating costs, and small profits.

Herring weir fishery.--The United States fishery in the Quoddy Region is small compared with the Canadian fishery. Two types of weirs are used--the "beach

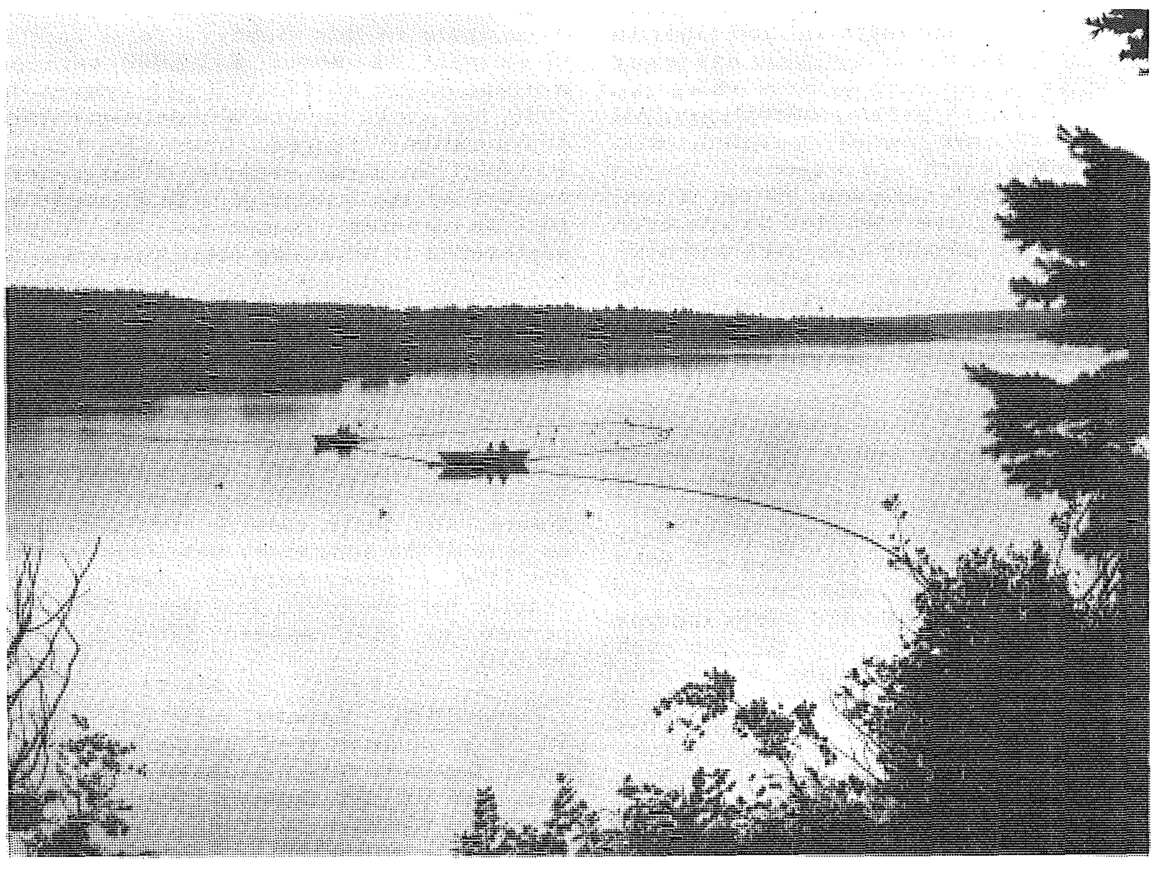


Figure 15.--A typical United States stop seine. In the background, note the pocket for removing the "sardine" catch.

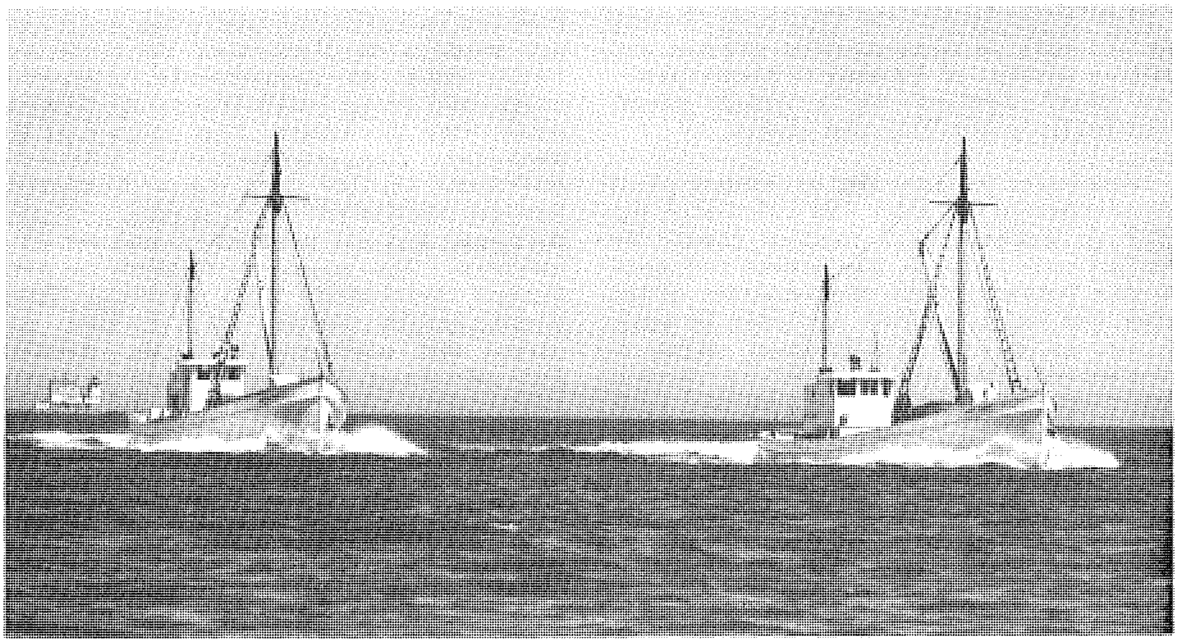


Figure 16.--United States herring carriers.

weir'' and the ''patent weir.'' The beach weir requires more material and labor to construct, while the patent weir has fewer and larger stakes with netting, which can also be used in stop-seine operations. All beach weirs are owner-operated, with the season's catch and expenses shared with one or two tendermen. Patent weirs, in most cases, are operated in conjunction with stop-seining activities and usually are not in operation unless herring are seen in the vicinity. They can be put into operation in 1 to 3 days, while the beach weir requires several weeks, both ashore and afloat.

There were 19 weir enterprises that operated 24 weirs inside the proposed impoundment area in 1957. Their total value was more than $133,000. Approximately 40 men were engaged in the weir fishery. Data obtained for 1956 and 1957 revealed an average weir investment of about $5,555. The average gross income per weir was $1,478 and the net cash return was $829. In 1956, the net income, before allowance for depreciation, ranged from $-660 to $7,059; in 1957, from $194 to $5,006. Income derived from the weir fishery depends on both catch and selling price, which vary according to availability of the fish.

Herring stop-seine fishery.--In the Quoddy Region, seven United States vessels (with two to five men per vessel) participate in this fishery. Total capital investment is about $107,000 with an average value of $15,000 per vessel. In 1956, the gross income per seiner, before depreciation, ranged from $1,035 to $12,502. On some vessels, a large percentage of the fishing gear is financed by sardine-canning companies to insure preference in obtaining their catches.

Herring carrier fleet.--In 1957, 15 United States herring carriers operated in the Quoddy Region. Their total value was more than $290,000. Carrier values ranged from $6,200 to $38,000. Nearly all have fish pumps, radar, and other electronic equipment. The carriers are owned and operated by eight sardine plants, and their owners consider them as part of the secondary industry. Profits for the herring-carrier fleet cannot readily be computed, but their total expenses in 1957 ranged from $924 to $8,558.

Groundfish fishery.--Annual United States groundfish (cod, haddock, and pollock) landings taken by hand line, trawl line, and lift net from the low-pool area average 400,000 pounds, worth about $6,000. Investments in equipment are generally small (about $100 per lift-net unit). The number of persons engaged in the fishery each year fluctuates widely from about 6 to more than 50.

Lobster fishery.--The low level of United States lobster landings--less than 1,000 pounds valued at less than $400--makes it a subsistence fishery only carried on by some 15 to 20 part-time fishermen. Lobster traps have a total value not exceeding $400.

Mollusk fishery.--Landings of mollusks (soft clams, scallops, and periwinkles) have averaged less than 300,000 pounds worth about $80,000 each year for the past decade. Clam landings have declined 100,000 pounds since 1957 and scallop production in 1958 dropped to less than 4,000 pounds, the lowest level since 1948. An average of 108 diggers were engaged in the clam fishery with investments in equipment not exceeding $3,000. Investments in locally owned scalloping equipment amounted to less than $5,000.

Fisheries for anadromous species.--Commercial landings of alewives and smelts in the United States averaged 280,000 pounds worth between $5,000 and $6,000 annually during the past decade. Investments in equipment do not exceed $1,000; not more than a ½-dozen fishermen are engaged in the alewife fishery and less than 50 in the smelt fishery.

Miscellaneous.--In 1958, sand worms were taken commercially for the first time in the Passamaquoddy area. Preliminary surveys indicate concentrations of probable commercial importance in Lubec, Pembroke, and Eastport.

Fish processing.--The survey of the secondary fisheries covered the herring-processing industry of the Quoddy Region for 1957. There were 11 sardine and 2 pet-food canneries, 6 smoke houses, and 9 fishmeal and pearl-essence plants. Total value of herring products was more than $11,000,000. Pet-food plants accounted for 49 percent of this value, compared with 37 percent for the "sardine" plants. Although the operation of "sardine" plants is seasonal in nature, employment in them accounts for about 80 percent of the total number (1,671) employed in the fish-processing industry. Reduction and pet-food plants employed more than 11 percent.

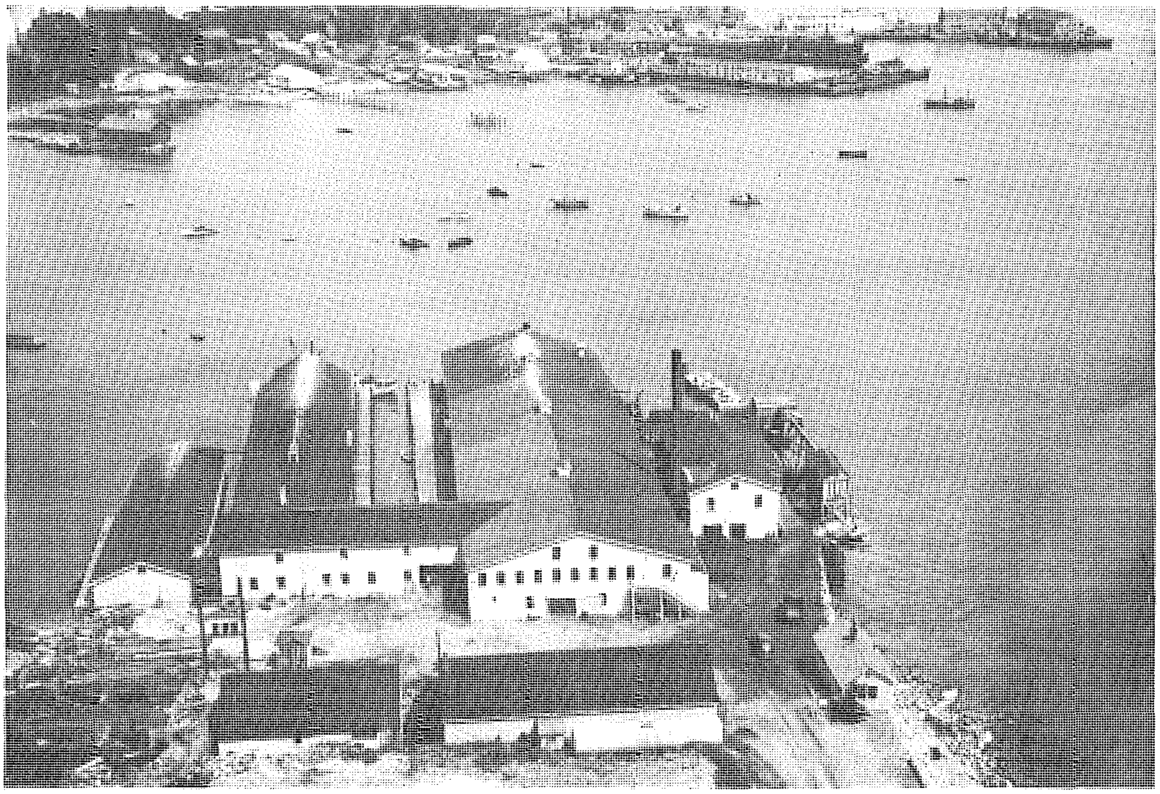


Figure 17.--A United States sardine cannery.

Predictions and Conclusions

The results of these investigations provide the basis for predicting effects which the proposed tidal power structures might have on the fisheries of the area. Consideration is given first to anticipated changes in oceanographic conditions if the dams are constructed. Changes in environment will then affect distribution, behavior, and abundance of fish stocks, and these in turn will affect the economic status of the fisheries in the area.

OCEANOGRAPHIC EFFECTS OF IMPOUNDMENT

Tides, circulation, and distribution of properties have been described in general, but only a qualitative evaluation of their relation to controlling factors has been possible. Without a quantitative relationship, precise predictions as to what will happen under a new set of controlling factors cannot be made. It should be borne in mind that the predictions given here can place only approximate limits on the changes anticipated.

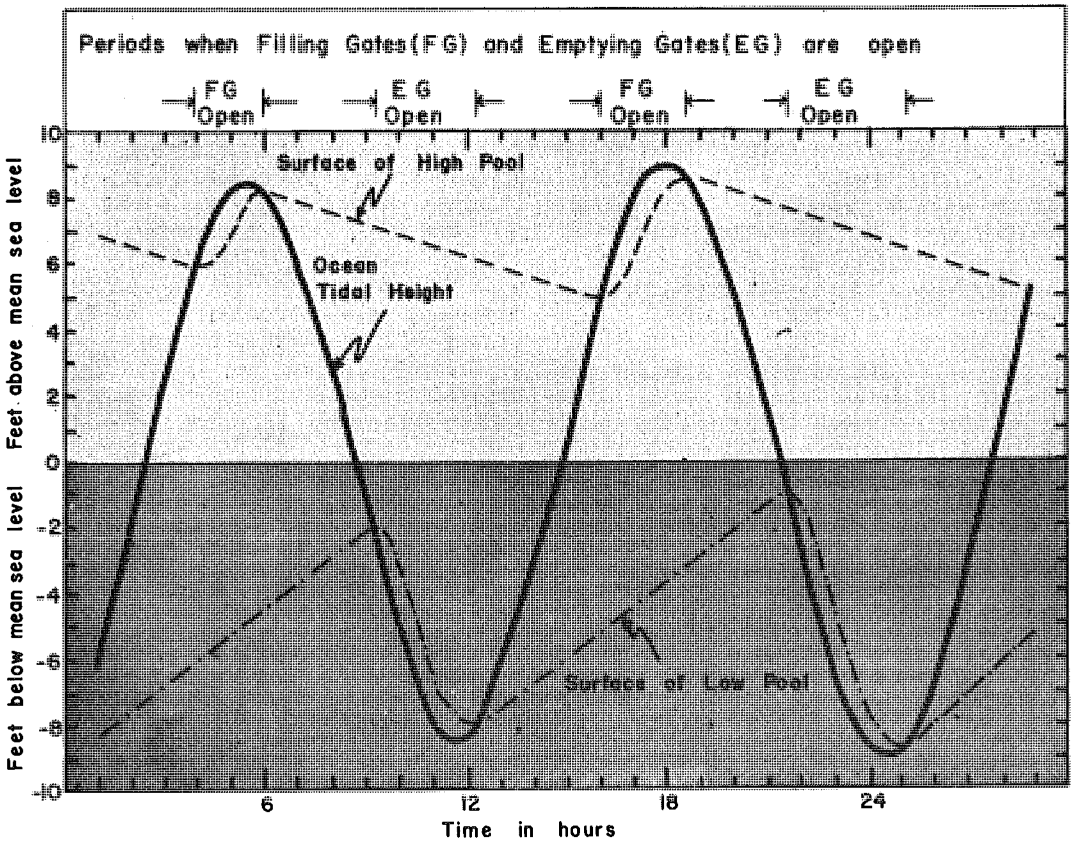


Figure 18.--Daily cycle of power-project operations showing the variation in water level for the high pool, low pool, and outside areas. Periods when filling and emptying gates are open are also shown.

It was instructive to consider pertinent aspects of other areas, e.g., Kennebecasis Bay, Oak Bay, Northumberland Strait, British Columbia inlets, in which certain oceanographic factors bear a degree of similarity to the anticipated conditions in the Quoddy Region. By making simplified assumptions about the nature of the mixing process expected under the proposed conditions for the Quoddy Region, distribution and accumulation of fresh water in the St. Croix and the Magaguadavic estuaries were computed. Flushing times of the high and low pools were estimated.

The following gross effects and tendencies can be expected in the high and low pools and in the outside area. Engineering details pertinent to the oceanographic predictions were supplied by the International Passamaquoddy Engineering Board.

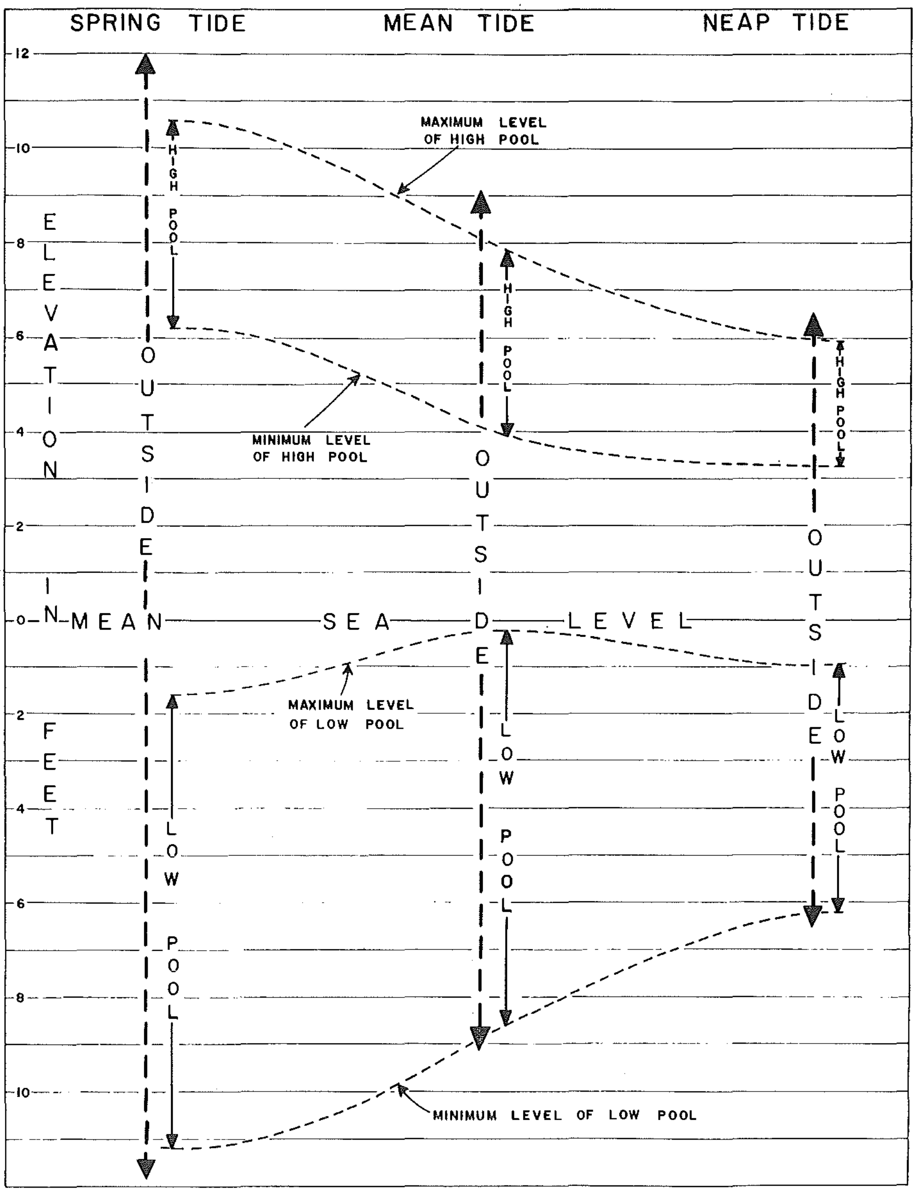


Figure 19.--Schematic illustration of elevations and ranges of water levels in the high pool, low pool, and outside areas for spring, mean, and neap tides.

Water levels

The mean level of the high pool will be raised about 6 feet with a tidal range averaging 4 feet. Minimum and maximum ranges will be $2\frac{1}{2}$ and $4\frac{1}{2}$ feet. Minimum elevation, which will occur during neap tides, and maximum elevation, which will occur during spring tides, will be 3 feet and 11 feet above mean sea level.

The mean level of the low pool will be lowered 5 feet with a "tidal" range averaging 8 feet. Minimum and maximum ranges will be $5\frac{1}{2}$ and $9\frac{1}{2}$ feet respectively. Maximum elevation, which will occur during mean tides, and minimum elevation, which will occur during spring tides, will be zero and -11 feet respectively relative to mean sea level.

Due to configuration, the tidal range of the Bay of Fundy may increase approximately 1 percent. The increase in maximum range will occur at the head of the Bay of Fundy and should be less than 1 foot.

Currents

For about $9\frac{1}{2}$ hours in a tidal cycle of $12\frac{1}{2}$ hours, the filling gates will be closed. Water will leave the high pool continuously through the turbines. While the filling gates are closed, the only motion will be towards Western Passage and will be contained mostly in the upper 45 feet. Mean velocities of the upper layer are expected to be about one-fifth of the present values. When the gates are open, velocities should be similar in most areas but slightly lower than at present. A residual counterclockwise circulation in the Bay will likely be more pronounced.

When the emptying gates are open, velocities in the low pool will be similar to present values at half-ebb. While the emptying gates are closed, the flow will spread in both directions from the low-pool side of the powerhouse. During this period, the velocities in Cobscook Bay should be less than one-third the present value west of the powerhouse and approximately one-fifth the present value between the powerhouse and the emptying gates. The vertical-longitudinal circulation in Cobscook Bay west of the powerhouse will be an inward movement of the deeper water and a seaward movement of the surface layer.

In the outside area there is little indication that significant changes in residual flow will extend much beyond the Head Harbour-Bliss Island Region. Tidal streams should be reduced in the approaches to the passages and increased in other areas of the Quoddy Region. The direction of tidal streams will be altered only slightly, and changes in speed are not expected to exceed 20 percent of their present value. For about 6 hours in $12\frac{1}{2}$, speeds inside the Head Harbour-Bliss Island line will be very small. When the filling gates are open, flow in the Bliss Island region should be similar to that at present, but reduced slightly in the Head Harbour region and increased in the channel between Indian Island and Deer Island. Most of the water entering the Western filling gates will be water that has drained from the low pool. Inflow through the Letite filling gates will be mostly "new" water from outside the dams. Residual flow, which will be more marked than at present, will be inward toward Letite Passage and outward from Head Harbour Passage. Wind speed and direction should play an important role in controlling the amount of water recirculated through the Letite gates.

Water temperature

Reduced velocities in the high pool will result in decreased vertical mixing, permitting increased stratification, and hence greater seasonal variations in the temperature of the surface waters. These variations will be minimum near the Letite filling gates (altered only slightly from present conditions) and maximum along the north shore of Passamaquoddy Bay and in the St. Croix estuary. Maximum summer temperatures at the surface are likely to be in the vicinity of 68° F. The surface layer will probably be less than 10 feet in depth most of the time, but on occasion may deepen to 30 to 50 feet. Below this depth, temperatures will be altered only slightly, with the expected range falling within 32° F. and 56° F. Ice cover is expected to occur over part of the Bay in winter.

Stratification will not be as marked in the low pool as in Passamaquoddy Bay, except in the upper reaches. Summer maximum at the surface in the inner part of the Bay may reach 68° F. The outer area is unlikely to exceed 60° F. Summer temperatures of the bottom water may increase by 4° to 5°, while winter temperatures will be lowered only slightly. Ice cover is likely to occur in the inner part of the Bay during the winter.

Little change is expected in the outside area except contiguous to the emptying and filling gates and mostly inside the Head Harbour-Bliss Island line, where a somewhat greater seasonal variation is expected.

Salinity

Mean surface salinity in the high pool will be lowered. Bottom salinities should be altered only slightly. During freshets, surface salinity may drop below 20 parts per thousand (normal sea water in the Bay of Fundy is approximately 33 parts per thousand). At other times of the year, surface salinity should be between 20 and 30 parts per thousand, except in the St. Croix estuary above St. Andrews and in the north part of Passamaquoddy Bay. Maximum surface salinity will occur just inside Letite filling gates and will exceed 30 parts per thousand. Fresh water is not likely to penetrate below 30 to 50 feet, and the bulk of it will be confined to the upper 5 to 15 feet. Flushing time is expected to be increased markedly.

All saline water will enter the low pool through the turbines and will carry with it the total fresh water discharged into Passamaquoddy Bay. Mean salinity should therefore be lowered. Decreases should not exceed 3 to 4 parts per thousand (i.e., salinity not less than 28 parts per thousand) except during peak runoff. Bottom salinities should not drop below 28 parts per thousand. Stratification should not be very marked except in the upper reaches of Cobscook Bay. West of Leighton Neck, however, a thin layer, probably not more than 3 feet thick, may be quite brackish and at times drop below 20 parts per thousand. Flushing time is expected to be increased substantially.

In outside areas, significant changes are expected only adjacent to the emptying gates and inside the Head Harbour-Bliss Island line. Reduction in salinity is unlikely to exceed a few parts per thousand.

Oxygen content

At present, due to vigorous tidal mixing, water in the Quoddy Region is nearly saturated with oxygen. Under proposed conditions, mixing will be decreased inside the impoundment and oxygen concentrations of water in the deep basins of Passamaquoddy and Cobscook Bays may be reduced. Rates of water renewal, and hence rates of oxygen supply to the deep water within the basins, will be minimal during periods of maximum fresh-water discharge into the Quoddy Region. However, oxygen concentrations are unlikely to fall below 50 percent saturation.

BIOLOGICAL EFFECTS OF IMPOUNDMENT

In the biological study, particular attention was given to herring, the most important commercial species in the Quoddy Region. This study included catch statistics, identification and origin of populations, food and feeding habits, behavior, and migrations. Catch statistics and published information on other species were evaluated. Anticipated changes in oceanographic conditions were considered in predicting changes that may take place in all commercially important species as a result of the proposed dams.

Herring

Herring stocks in the Quoddy Region are produced outside, probably in southwest Nova Scotia waters. Since environmental changes are anticipated only inside the bays and immediately outside the proposed dams, it is extremely unlikely that the abundance of herring will be affected. Most of the plankton that makes up the food of herring is also produced outside the Quoddy Region, and no major change in its abundance and distribution is anticipated.

Tagging experiments indicate that herring move freely in and out of Passamaquoddy and Cobscook Bays during the fishing season with some tendency to concentrate at the head of Passamaquoddy Bay. It is not expected that the installation and operation of the proposed dams will affect the movement of herring to the Quoddy Region, nor should the distribution of fish, except in the bays and immediately outside the dams, be affected. It has been predicted that significant changes are unlikely in oceanographic conditions outside the Quoddy Region beyond the Head Harbour-Bliss Island line. Herring should therefore arrive outside the passages as before. It has been concluded from behavior studies that herring will swim against a current only when they can see fixed objects such as the bottom. Most of the year, herring are in the upper-water layers and, hence, probably will be transported passively in the current. For most of the period when they are open, the current through the filling gates and for some distance outside will exceed 5 feet per second. This velocity exceeds the maximum swimming speed of herring and the fish will be carried into the high pool. Since the filling gates are open only for about 6 hours each day, movements of fish into Passamaquoddy Bay will be delayed. This short period during which the gates are open will affect the rate at which herring accumulate inside Passamaquoddy Bay. However, recaptures from tagging

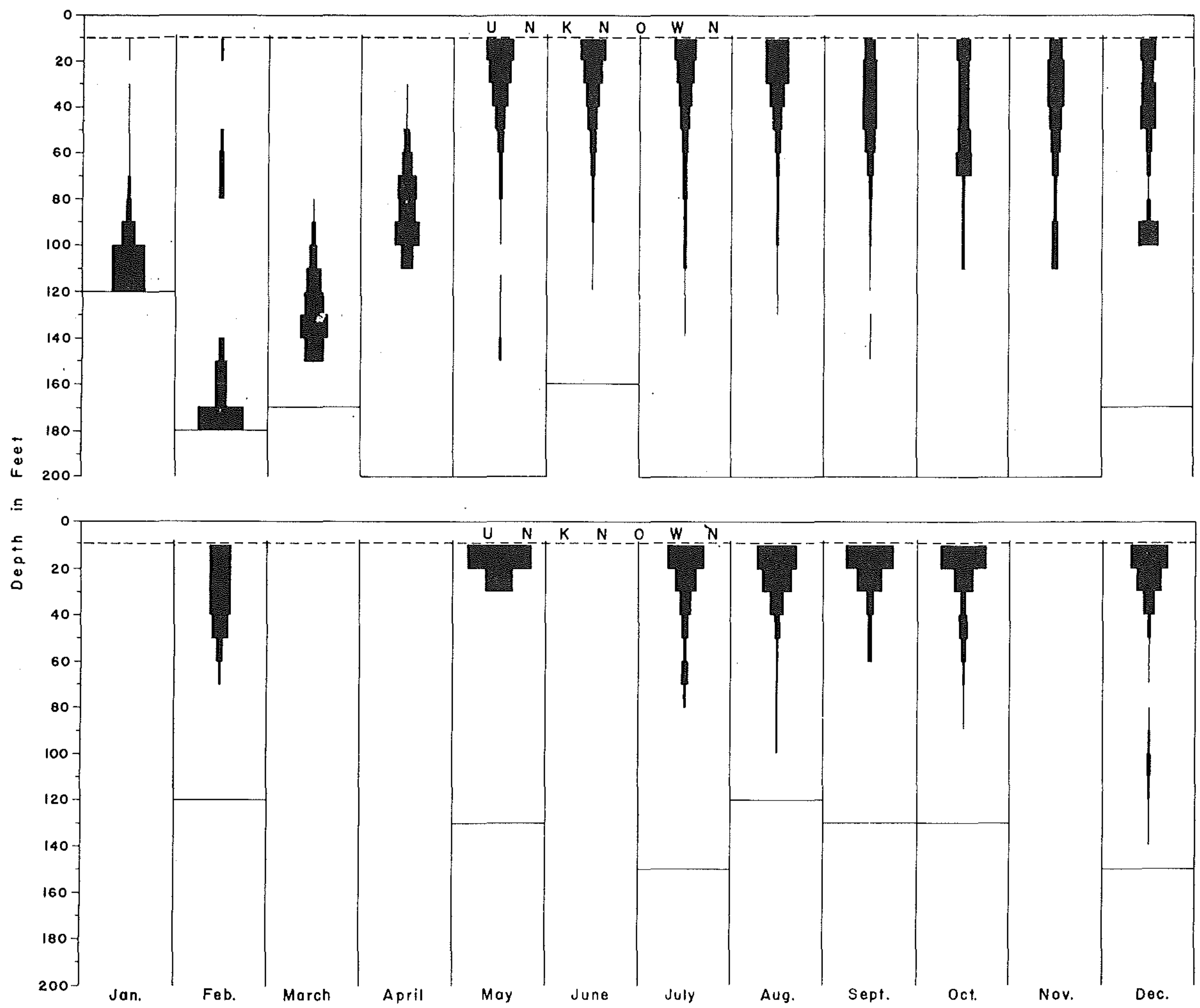


Figure 20.--Depth distribution of herring schools in Passamaquoddy Bay as determined by sonic-sounder recordings (upper) day, (lower) night.

and results of echo-sounder surveys suggest that fishing mortality is low, hence there should be no reduction in the abundance of herring inside the Bay.

Herring will be unable to enter Cobscook Bay directly from the outside except in insignificant numbers through the navigation locks and filling gates. Entry into Cobscook Bay and exit from Passamaquoddy Bay will be possible only through the turbines. As a result, movement into Cobscook Bay and away from both Bays will be altered both in time and direction. Most of the water entering the Western filling gates will have been discharged from the low pool, whereas inflow through the Letite filling gates will be mostly "new" water from outside the dams. Therefore, recruitment of herring to Passamaquoddy Bay is expected to be mainly through the Letite filling gates.

The predicted salinities of 20 to 30 parts per thousand in the upper (10 to 15 feet) water layers of the high pool during normal summer conditions are well within limits that herring can tolerate. If temperatures in this layer reach or exceed the predicted value of 68° F. and especially if they rise above 70° F., herring mortality might be high. Temperatures of this order may occur only in isolated or sheltered coves, and any mortality due to high temperature and low salinity should be limited in time and extent. It is possible that herring will avoid warmer, less saline water. In the low pool, herring should be able to survive the altered salinities and temperatures except for localized mortality if temperatures exceed 68° F. Predicted pressures and rates of pressure change between turbine intakes and exits are within limits that herring have been shown to withstand. In passing through the turbines, some fish will undoubtedly come in contact with the sides of the draft tubes and with the turbine blades. This contact may cause some abrasion with a resultant mortality, but the effect is expected to be insignificant.

Most of the herring are taken in weirs built close to shore. Analysis of weir catches shows no significant relation between average catches inside Passamaquoddy and Cobscook Bays and catches in outside areas for the same year. Weirs inside the bays are more efficient and catch about twice as many herring per weir as those outside the bays. This suggests that the bays act as a natural fish trap and tend to hold herring in a restricted area.

The only significant change expected is a time lag in the entry of herring into the bays resulting from closure of the filling gates for about 19 hours in every 25. However, the most significant point established from the results of investigations is that year-to-year variations both in individual weir catches and in total catches in the various statistical districts of the Quoddy Region are far greater now than any that can be forecast as resulting from the installation of dams.

Groundfish

No measurable change in groundfish landings is anticipated for the Quoddy Region, but there will be a change in the species composition of the fraction of the catch taken inside the dams. Winter flounders should increase in numbers since anticipated conditions will more closely resemble those to the south where there are important winter flounder fisheries. A larger commercial and sport fishery for winter flounder is visualized. The proposed structures will probably eliminate the haddock fishery inside the bays, but no effect is expected outside. Impoundment will deny fish direct access to the low pool and therefore sharply reduce the pollock fishery there.

Mollusks

It may be assumed that clam production will vary with the size of the intertidal zone. This zone will change in size and position if dams are installed. In the high pool, which yields roughly half the total clam production in the Quoddy Region, the present beds will be permanently submerged. Consequently, clam production will decrease drastically with impoundment. There will be no substantial clam production in the high pool until new beds are established at new intertidal levels and until the clams there have grown to marketable size. This should take from 6 to 10 years and even then production may be only 5 percent of its present volume. In the low pool, production should drop to 50 percent of the present small volume, but after 6 to 10 years it should rise to the present volume. In the outside area no changes are anticipated.

Impoundment is expected to increase scallop landings substantially in the Quoddy Region. In the high pool, flushing times may be doubled and hence conditions for retention of the pelagic larvae improved. In the low pool, improved conditions for feeding and survival should increase production slightly. In the outside areas there are likely to be no changes.

Turbidity and water temperature are important factors regulating shipworm distribution. The threshold temperature for spawning in *Teredo navalis* is 61° F. Because of the expected increase in water temperature in summer, a rapid spread of shipworms to all parts of both pools may be expected. The outside area will not be affected appreciably.

Lobsters

It is anticipated that only the stocks of lobsters inside the dams will be affected. The present fishery is carried out almost exclusively in Passamaquoddy Bay. If the bay becomes ice covered, the present winter fishery would be impossible but lobsters could be harvested equally well in another season. Predicted increases in surface temperatures during the summer should favor growth and survival of free-swimming larvae. Decreased water exchange between Passamaquoddy Bay and the Bay of Fundy should favor retention and settlement of larvae within Passamaquoddy Bay. Consequently, there may be a modest increase in the lobster catch.

Anadromous fishes

Anadromous fishes that have present or potential value in the Quoddy Region include Atlantic salmon, smelt, alewife, shad, tomcod, and sea-run trout. Of these, Atlantic salmon and alewives have the greatest potential value but their status after impoundment will depend upon the efficiency and adequacy of fish-passage facilities. With stream improvements, particularly in the St. Croix River, the total annual run of Atlantic salmon into the rivers of the Quoddy Region might be increased. Adequate management should increase alewife production. Warming of sea water and reduction in tidal amplitude may favor a sport fishery for trout. The smelt, shad, and tomcod populations should increase under the new conditions. Striped bass thrive in areas where summer waters are warm and of reduced salinity, but increases in their abundance within the impoundment cannot be predicted with any certainty.

Other species

Reduction in accessible beach areas may result in a decrease in the present small fishery for marine worms in both high and low pools. Supplies of rockweed may be reduced somewhat in the low pool, but no change is forecast for the high pool or outside. Damages caused by the gribble (*Limnoria*) may become more serious.

ECONOMIC EFFECTS OF IMPOUNDMENT

Results of oceanographic and biological studies indicate that the installation of dams will not affect the abundance of herring in the Quoddy Region substantially. Consequently, operation of herring processors and of men engaged in purse seining and the herring-carrying trade will not be disturbed. However, a number of weir fishermen will be affected; some will have to relocate a few weirs situated on or near the site of the proposed dams; others, more numerous, will have to re-position weirs or alter construction to suit the new oceanographic environment. The average cost of weir operation will likely rise. At the same time, a number of weirs may gain in efficiency. Groundfish and clam fisheries inside the proposed dams are expected to be substantially reduced. There will be a drastic reduction of the clam fishery in the high pool. Other species now taken commercially inside the proposed dams (lobsters, flounders, scallops) are expected to remain relatively unchanged in abundance, with the possibility of slight improvement.

The primary fishing industry

Direct damages attributable to the proposed power project are concerned chiefly with the herring fishery. Six weirs near the dams will be destroyed by the proposed project. The replacement value of weirs, including all associated gear, inside the proposed dams averages $5,500. Assuming that weir values in the vicinity of the dams do not differ from the area average, the replacement value to be considered amounts to $33,000.

Indirect damages as a result of changes in environmental conditions brought about by the construction of dams must be given due weight in an assessment of the economic effects on the weir fishery. Four factors deserve examination: water levels, wood borers, ice cover, and tidal scour.

On the basis of predicted oceanographic changes in the high pool, weirs in this area may not be operated at their present locations unless they are modified and altered in size to fish approximately 10 additional feet of water. In particular, weir stakes and nets will need to be larger to suit the new water levels. The average value of Canadian-owned weirs, including seines, in the area is about $4,600, and the cost of weir construction can be expected to rise by approximately $1,000 after the dams are installed. The average cost of annual maintenance and repair might also increase by about $100 per weir. In the United States section of the high pool, the average value of weirs is about $4,000, and the additional cost of construction can be expected to rise by about $1,200 per weir. The increased cost of annual maintenance and repair would be about $120 per weir.

There were 82 weirs in operation in the high pool in 1957--69 in Canada and 13 in the United States. Eleven additional Canadian weir sites were licensed but not operated that year. On the basis of these weir numbers, the initial increase in weir construction cost in this area could be expected to range from $84,600 to $95,600--$69,000 to $80,000 for Canadian weirs and $15,600 for United States weirs. The increase in total annual operating costs could range from $8,500 to $9,600--$6,900 to $8,000 for Canadian weirs and $1,600 for United States weirs.

Admittedly, some weir owners would have the alternative of relocating their weirs closer to shore or at sites farther distant. In a number of instances this might not be feasible, however, owing to the topography of the immediate environment or the unavailability of suitable sites elsewhere. In any event, it should be recognized that a certain element of disruption and, indeed, of cost, either for material or for labor, would be experienced by the majority of weir owners in the area designated as the high pool.

It is not expected that weir fishermen in the low pool would be seriously affected by the proposed project. Predicted oceanographic changes indicate, in a general way, the reverse of the water-level conditions forecast for the high pool. Weirs, therefore, could be fished at their present sites, although fishing in approximately 5 feet less water. In this event, the size of weir gear could be reduced to adjust to the new water levels. This would decrease construction and operating costs, although it might also result in a reduction of weir efficiency.

An alternative to the fishermen of the low-pool area would be to relocate their weirs, if suitable sites were to be found, in an attempt to employ existing gear to maximum potential efficiency. Such a course would entail additional costs, principally labor, in the first year of construction, but should not be significant.

On the basis of predicted changes in water temperatures following the construction of the dams, it is anticipated that the activity of wood borers will increase. While it is impossible to measure the extent of damage likely to result from this source, it should be recognized that the durability of wooden structures within the impoundment will be diminished. Thus, the life of untreated wood structures will be reduced, which will add to annual operating costs.

The temperature changes forecast lead to the conclusion that the shoreward fringes of Passamaquoddy and Cobscook Bays (except at and near the dams) will have an ice cover during the winter months after the dams are installed. In this event, weir fishermen will be faced with two alternatives: either to dismantle all structural weir material before the onset of winter for rebuilding in the spring, or to leave the structures to the hazards of winter and replace them each spring if necessary. Whatever course is followed will add to existing weir operating cost.

The construction of the dams will result in some reduction of tidal currents and wave actions, both of which now cause some damage to weirs. To some extent, this will reduce the increased costs arising from other environmental changes.

The interaction of the changes described is likely to result in an appreciable increase in average weir expenditures inside the dams. Considering the nature of the prevailing weir fishery--high, relatively inflexible costs, with correspondingly low returns--it is conceivable that weir owners will not continue to maintain their investment in weirs in the area. Should this happen, a capital investment of nearly $500,000 could eventually be displaced. A shift to alternative methods of fishing could be expected to maintain the fishery, at least at its present level.

Increased temperatures and reduced water exchange could favor the growth, survival, and retention of lobster larvae inside the dams. This might result in a modest increase in the commercial production of lobsters. Since quantitative estimates of the potential gain are not available, it is impossible to estimate the increase in income which might accrue to the fishing community from this source.

No measurable change in groundfish abundance is predicted for the Quoddy Region after the dams are built, although the species composition of the portion of the catch taken inside the dams will change. The overall effect on Canadian fishermen is expected to be negligible. However, United States fishermen will be forced to abandon the small lift-net pollock fishery in Eastport and Lubec, with a resultant loss of approximately $3,000 annually.

With present methods of fishing, clams may not be accessible to Canadian fishermen in the high pool for a period of 6 to 10 years; thereafter, the fishery should be developed at about 5 percent of its present size. In the United States section of this area, clam landings are expected to be reduced by 50 percent immediately and remain so for 10 years. The loss to the fishermen of both countries would be about $90,900 annually for 10 years ($86,000 for Canada and $4,900 for the United States). In the low pool, clam landings will decline 20 percent in Cobscook Bay and 50 percent in the Friar Roads area, and remain at these levels for a maximum period of 10 years. The fishery should be re-established at its original or slightly higher level thereafter. The total loss to fishermen would be about $13,000 annually for 10 years ($500 for Canada and $12,500 for the United States).

The reduction in water exchange due to the dams is expected to create a more favorable environment for scallop production. Substantial increases are predicted for the high pool, resulting in an annual increase of $12,000 to fishermen ($11,500 for Canada and $500 for the United States). In the low pool, a small gain of about $1,900 annually is estimated for United States fishermen.

At present, anadromous species are of little commercial significance in the Passamaquoddy Region. After the installation of dams, conditions may well be improved for species such as salmon, smelts, striped bass, shad, and alewives. To what extent the variety and abundance of anadromous species will improve is unknown, but it could be substantial if the needed improvements are made in the St. Croix River. Conceivably, the benefits could accrue to sport fishermen rather than to those who fish for commercial gain. However, as far as the economy of the Region is concerned, the income-generating features of an improved sport fishery could, in the long run, be quite beneficial. In an effort to preserve and help improve the sport fishery, principally salmon, the construction of fishways at the power dams is contemplated. The cost of this project, as estimated by fishery engineers, is expected to be in the neighborhood of $3.0 million.

The secondary fishing industry

It is believed that the proposed project would have immediate impact on the operations of lobster- and clam-processing plants in the Quoddy Region. Two sardine-processing plants will require relocation (Sunset Packing Co., West Pembroke, Maine, and the North Lubec Manufacturing Co., North Lubec, Maine).

Because of changes in water temperatures and salinity, the relocation of two lobster pounds and the refrigeration of sea water or an extension of water intake pipes for one lobster plant will be necessary. The costs have been assessed by the International Passamaquoddy Engineering Board at $450,000.

The predicted loss of clam supplies will create an excess of clam-processing capacity in the Canadian part of the Quoddy Region. More than one-half of the Charlotte County clam supplies from 1948 to 1957 were obtained from the proposed high pool. There is little reason to expect a change in the pattern of landings in the remainder of Charlotte County sufficient to compensate for this loss. The equipment used by clam processors is specialized and not suited to alternative uses. Assuming, therefore, no major change in clam supplies and in fishing intensity in the section of Charlotte County lying outside the proposed dam sites, it is estimated that about one-half of the existing clam-processing facilities will fall into disuse after the dams are built. Data on investment, employment, and income in clam-processing plants were not provided for inclusion in this report. However, it is believed that the capital which would be disengaged would not exceed $100,000.

RECAPITULATION

Approximate present oceanographic conditions

			High pool	Low pool	Outside
Levels (feet)	Mean level (sea)		0	0	0
	Mean range (spring & neap)		$\frac{+10}{-10}$ 20	$\frac{+9-1/2}{-9-1/2}$ 19	$\frac{+9}{-9}$ 18
	Min. max. elevation (spring range)		-14 to +14	-13 to +13	-13 to +13
Currents	Tidal (feet per second)		<1 to 8	<1 to 8	<1 to 6
	Non-tidal (miles per day)		Mostly <2	Mostly <2	Variable to 10
Temperature (degrees Fahrenheit)	Surface	Mean	45	45	45
		Range	32 to 57	32 to 55	34 to 54
	Deep	Mean	45	45	45
		Range	34 to 54	34 to 55	36 to 52
Salinity (parts per thousand)	Surface	Mean	31	32	32
		Range	24 to 32	29 to 33	30 to 33
	Deep	Mean	32	32	32
		Range	31 to 33	31 to 33	31 to 33

Probable oceanographic conditions after the dams are installed

			High pool	Low pool	Outside
Levels (feet)	Mean level		+6	-5	0
	Mean range		4	8	18
	Min. max. elevation		+3 to +11	-11 to 0	-13 to +13
Currents	Gates opened		as present	as present	as present
	Gates closed		speeds markedly reduced; flow toward Western Passage	speeds markedly reduced; flow spreads from turbines	speeds markedly reduced in immediate area; slight increase further away
Temperature (degrees Fahrenheit)	Surface	Mean	little change	little change	
		Range	<32 to 66	<32 to 61	Little change except in immediate area where somewhat greater seasonal variation will occur.
	Deep	Mean	little change	little change	
		Range	32 to 55	32 to 59	
Salinity (parts per thousand)	Surface	Mean	<25	approximately 25	
		Range	<20 to <30	<20 to approximately 30	
	Deep	Range	29 to 33	28 to 32	

Fisheries of the Quoddy Region - Present and Predicted
(average annual landings (pounds) within the period 1937 to 1958

	Present			Predicted
	High pool	Low pool	Outside	Quoddy Region
Species				
Herring	16,800,000	3,400,000	29,800,000	No change
Lobsters	71,250	30,750	286,000	Slight improvement inside dams. No change outside.
Groundfish	225,000	1,900,000	4,000,000	Substantial decrease inside dams. Compensating increase outside.
Clams (meats)	500,000	250,000	500,000	Drastic decrease inside dams. No change outside.
Scallops (meats)	31,000	30,000	31,000	Marked improvement inside dams. No change outside.
Alewives	---	270,000	---	No change
Smelt	500	9,000	---	Slight improvement
Salmon	100	600	---	No change
Others	---	18,200	---	Slight decrease

Economic evaluation of effects of the Passamaquoddy power project on the fisheries of the area

Species	Costs			Annual benefits
	Capital investment	Annual Maintenance	Annual income loss[a/]	
	$			
Herring				
Weir destruction	33,000	---	--- ---	---
Weir alteration	96,000	---	---	---
Weir maintenance	---	10,000	---	---
Teredo damage	---	Indeterminate	---	---
Ice damage	---	Indeterminate	---	---
Lobsters	450,000[b/]	---	---	Slight
Groundfish	---	---	3,000	---
Clams	100,000	---	104,000 (10 yr)	---
Scallops	---	---	---	14,000
Anadromous	3,000,000[b/]	---	---	Slight
Grand total	3,679,000	10,000	107,000	14,000
Total for Canada	663,000	8,000	87,000	12,000
Total for United States	16,000	2,000	20,000	2,000
Common to both countries	3,000,000	---	---	---

a/ In terms of landed fish values to fishermen.

b/ These are preliminary estimates and probably will differ from the detailed International Passamaquoddy Engineering Board estimates.

Summary

On August 2, 1956, the Governments of Canada and the United States referred to the International Joint Commission the responsibility for an investigation to determine the feasibility, desirability, and cost of developing hydroelectric power in Passamaquoddy and Cobscook Bays from tidal forces. On October 3, 1956, an International Passamaquoddy Fisheries Board was established and was given the following reference: "to study specifically the effects which the construction, maintenance, and operation of the tidal power structure proposed might have upon the fisheries in the Area" (cf. I.J.C. Docket 72, October 3, 1956).

A research committee composed of Canadian and United States scientists carried out oceanographic, biologic, and economic investigations in the Passamaquoddy area of southern New Brunswick and eastern Maine. Most of the work was done in the Quoddy Region which includes all of the area inside the line from Point Lepreau, N. B., to Northern Head, Grand Manan, N. B., thence to West Quoddy Head, Maine. The results of the investigations provide a basis for predicting the effects of the project on the fisheries.

It is expected that the construction of dams will change the oceanographic features of the Quoddy Region. Major changes are anticipated inside Passamaquoddy and Cobscook Bays and immediately outside the dams. Effects outside the Head Harbour-Bliss Island line will likely be insignificant.

The mean water level of Passamaquoddy Bay will be raised about 6 feet while the mean level of Cobscook Bay will be lowered about 5 feet. The mean "tidal" range in the high pool and low pool will be reduced to approximately 4 feet and 8 feet respectively. The tidal range of the Bay of Fundy may increase approximately 1 percent with a maximum increase at the head of this Bay of less than 1 foot.

Current patterns in Passamaquoddy and Cobscook Bays and in the approaches will be altered markedly since the emptying and filling gates will be closed for about 9 and $9\frac{1}{2}$ hours respectively during each tidal cycle of $12\frac{1}{2}$ hours. When the gates are open, velocities in most areas should be only slightly lower than at present. The residual counterclockwise circulation in Passamaquoddy Bay will likely be more pronounced. Tidal streams in the outer Quoddy Region will probably be altered by not more than 20 percent. No change in nontidal circulation is anticipated for the Bay of Fundy.

Reduced velocities in Passamaquoddy and Cobscook Bays will result in decreased vertical mixing, giving rise to increased stratification and hence to greater seasonal variations in surface-water temperature. The summer maximum is likely to be in the vicinity of 68° F. while in winter an ice cover is expected over part of the Bays. Outside, little change is expected adjacent to the emptying and filling gates where there will be slightly greater seasonal variation.

Mean surface salinities for both pools will be lowered but bottom salinities are likely to be altered only slightly. It is doubtful if fresh water will penetrate below 30 to 50 feet. Flushing time is expected to increase substantially. Outside, no significant change is expected except near the emptying gates where there will be a slight reduction in salinity.

Oxygen concentrations of the deep water inside the dams may be lowered somewhat, especially during periods of maximum fresh water discharge. However, it is unlikely to fall below 50 percent saturation.

The herring population is produced outside the Quoddy Region, probably off southwest Nova Scotia. The general abundance of herring in the Bay of Fundy and the Gulf of Maine is unlikely to be affected.

Echo-sounder records show that a large proportion of herring are in the open waters of Passamaquoddy Bay where no fishing takes place. Tagging experiments show that herring move freely throughout the Quoddy Region during the fishing season.

Since there are unlikely to be any significant changes in oceanographic conditions outside the dams, herring should arrive in this area as before. Little change is expected in current velocities in the approaches to the filling gates when open. Because velocities are well above the maximum sustained swimming speed of herring, the fish will be carried through the filling gates. Since the filling gates are open for about 6 hours each day, movement of herring into Passamaquoddy Bay is expected to be delayed. This is also true for Cobscook Bay where entry will be chiefly through turbines. Although the rate at which herring accumulate will be slower, there should be no reduction in overall abundance inside the Bays.

Predicted changes in temperatures and salinities are expected to make the areas inside the dams no less favorable for herring except in isolated areas where high temperatures and low salinities may cause some mortality. Predicted pressures and rates of pressure change between the turbine intakes and exits are within limits that herring can withstand.

No relation between herring landings and various meteorological and oceanographic conditions including surface drift, river discharge, wind speed and direction, zooplankton, temperatures, and salinities is apparent.

Long-term statistics of herring landings show year-to-year variations in individual weir catches and in total catches in various parts of the Quoddy Region. These are of far greater magnitude than the changes that can be forecast as resulting from the dams.

No measurable change in groundfish landings in the Quoddy Region is anticipated, but a change in species composition of the fraction of the catch taken inside the dams is expected. Inside the dams, winter flounder fisheries may increase while haddock and pollock fisheries may be greatly reduced. It is expected that clam fisheries will be greatly reduced for a period of 10 years and then become re-established at a lower level of production. Scallop stocks should increase substantially. Inside the dams, a modest increase in production of lobsters is anticipated. Conditions for anadromous species such as Atlantic salmon and alewives may be improved. Smelt, shad, and sea-run trout stocks should increase. Striped bass and tomcod thrive in areas where conditions of temperature and salinity are similar to those predicted for Passamaquoddy and Cobscook Bays. Some reduction is expected in the availability of marine worms and rockweed.

Six existing herring weir sites will be eliminated by the construction of dams. Other weirs must be relocated or altered to suit the new oceanographic environment. Weir stakes and nets will have to be increased in size to suit new water levels. The resultant fixed costs are estimated at $129,000. Wood borer activity is expected to increase. Ice will cause some damage to weir materials during the winter. The annual cost of weir operations will rise approximately $10,000. It is conceivable that weir owners may discontinue their investments in weirs inside the dams. A shift to other methods of fishing could be expected to maintain the fishery, at least at its present level.

Lobster fishermen are not expected to be adversely affected, but physical damages due to relocation of lobster pounds, refrigeration of water, or extension of intake pipes are expected to cost $450,000. Changes in the clam fishery may result in a loss of capital investment in plants valued at $100,000 and an annual loss in primary production of $104,000 for 10 years. The disappearance of some groundfish from inside the dams will result in an annual loss of approximately $3,000.

The installation of fish-passage facilities required for anadromous species was estimated by fisheries engineers to cost $3.0 million.

Literature Cited

BAILEY, W. B.
1957. Some features of the oceanography of the Passamaquoddy region. Fisheries Research Board of Canada, Manuscript Report Series (Oceanographic and Limnological) No. 2, 56 pp.

BAILEY, W. B., D. G. MacGREGOR, AND H. B. HACHEY.
1954. Annual variations of temperature and salinity in the Bay of Fundy. Journal of the Fisheries Research Board of Canada, vol. 11, No. 1, pp. 32-47.

BATTLE, HELEN I.
1935. Digestion and digestive enzymes in the herring (*Clupea harengus* L.). Journal of the Biological Board of Canada, vol. 1, No. 3, pp. 145-157.

BATTLE, HELEN I., A. G. HUNTSMAN, ANNE M. JEFFERS, G. W. JEFFERS, W. H. JOHNSON, AND N. A. McNAIRN.
1936. Fatness, digestion and food of Passamaquoddy young herring. Journal of the Biological Board of Canada, vol. 2, No. 4, pp. 401-429.

BIGELOW, HENRY B., AND WILLIAM C. SCHROEDER.
1953. Fishes of the Gulf of Maine. U. S. Fish and Wildlife Service, Fishery Bulletin, vol. 53, No. 74, viii + 577 pp.

COPELAND, G. G.
1912. The temperatures and densities and allied subjects of Passamaquoddy Bay and its environs. Their bearing on the oyster industry. Contributions to Canadian Biology 1906-1910. XVIII, pp. 281-294.

CRAIGIE, E. HORNE.
1916. Hydrographic investigations in the St. Croix River and Passamaquoddy Bay in 1914. Contributions to Canadian Biology 1914-1915, pp. 151-161.

CRAIGIE, E. HORNE, AND W. H. CHASE.
1918. Further hydrographic investigation in the Bay of Fundy. Contributions to Canadian Biology 1917-18, pp. 127-147.

DAWSON, W. B.
1908. Tables of the hourly direction and velocity of the currents and time of slack water in the Bay of Fundy and its approaches as far as Cape Sable. Department of Marine and Fisheries, 15 pp. Ottawa.

FISH, CHARLES J., AND MARTIN W. JOHNSON.
1937. The biology of the zooplankton population in the Bay of Fundy and Gulf of Maine with special reference to production and distribution. Journal of the Biological Board of Canada, vol. 3, No. 3, pp. 189-322.

GRAHAM, MICHAEL.
1936. Investigations of the herring of Passamaquoddy and adjacent regions. Journal of the Biological Board of Canada, vol. 2, No. 2, pp. 95-140.

HACHEY, H. B.
1934a. The replacement of Bay of Fundy waters. Journal of the Biological Board of Canada, vol. 1, No. 2, pp. 121-131.
1934b. Movements resulting from mixing of stratified waters. Journal of the Biological Board of Canada, vol. 1, No. 2, pp. 133-143.
1935. Tidal mixing in an estuary. Journal of the Biological Board of Canada, vol. 1, No. 3, pp. 171-178.
1957. Oceanographic factors relative to the sardine fishery of the Bay of Fundy area. Fisheries Research Board of Canada, Manuscript Report Biological Station No. 625, 25 pp.

HUNTSMAN, A. G.
1919. Growth of the young herring (so-called sardines) of the Bay of Fundy. Department of the Naval Service, Canadian Fisheries Expedition, 1914-1915, pp. 165-171. Ottawa.
1928. The Passamaquoddy Bay power project and its effects on the fisheries. The Telegraph Journal, Saint John, 45 pp.

1934. Herring and water movements. James Johnstone Memorial Volume, pp. 81-96.
1952. The production of life in the Bay of Fundy. Transactions of the Royal Society of Canada, vol. 46, ser. 3, sect. 5, pp. 15-38.
1953. Movements and decline of large Quoddy herring. Journal of the Fisheries Research Board of Canada, vol. 10, No. 1, pp. 1-50.

JOHNSON, W. H.
1940. Feeding of the herring. Journal of the Fisheries Research Board of Canada, vol. 4, No. 5, pp. 392-395.

KETCHUM, BOSTWICK H., AND D. JEAN KEEN.
1953. The exchanges of fresh and salt waters in the Bay of Fundy and in Passamaquoddy Bay. Journal of the Fisheries Research Board of Canada, vol. 10, No. 3, pp. 97-124.

LEIM, A. H.
1956. Review of literature on Bay of Fundy herring. Fisheries Research Board of Canada, Manuscript Report Biological Station No. 612, 65 pp.

MacGREGOR, D. G., AND H. McLELLAN.
1952. Current measurements in the Grand Manan Channel. Journal of the Fisheries Research Board of Canada, vol. 9, No. 5, pp. 213-222.

MAVOR, JAMES W.
1922. The circulation of the water in the Bay of Fundy. I. Introduction and drift bottle experiments. Contributions to Canadian Biology, N. S., vol. 1, No. 8, pp. 101-124.
1923. The circulation of water in the Bay of Fundy. II. The distribution of temperature, salinity, and density in 1919 and the movements of water which they indicate in the Bay of Fundy. Contributions to Canadian Biology, N. S., vol. 1, No. 18, pp. 353-376.

McLELLAN, H. J.
1951. A survey of water conditions in the Grand Manan Channel in September, 1950. Fisheries Research Board of Canada, Manuscript Report Biological Station No. 433, 19 pp.

MOORE, H. F.
1898. Observations on the herring and fisheries of the northeast coast, with special reference to the vicinity of Passamaquoddy Bay. Report of the U. S. Fish Commission, vol. 22, pp. 387-442.

NORTH AMERICAN COUNCIL ON FISHERY INVESTIGATIONS.
1935. Proceedings 1931-1933, No. 2, 40 pp.

PERLEY, M. H.
1852. Reports on the sea and river fisheries of New Brunswick. J. Simpson, Fredericton, 294 pp.

SCATTERGOOD, LESLIE W.
1957. A bibliography of the herring (*Clupea harengus* and *C. pallasii*). Maine Department of Sea and Shore Fisheries, Research Bulletin No. 26, 108 pp.

VACHON, A.
1918. Hydrography in Passamaquoddy Bay and vicinity, New Brunswick. Contributions to Canadian Biology for 1917-1918, pp. 294-328.

WATSON, E. E.
1936. Mixing and residual currents in tidal waters as illustrated in the Bay of Fundy. Journal of the Biological Board of Canada, vol. 2, No. 2, pp. 141-208.

GPO 89918