NATIONAL RESEARCH LABORATORIES

Ottawa, Canada

REPORT

Division of Mechanical Engineering

Hydraulics Laboratory

Pages - Preface - 3
Text - 9
Figures - 14

LIMITED
Report: MH-78
Date: 30 October 1958
Lab. Order: 12781A
File: M2-17-14. P-5

For: Department of Public Works, Harbours & Rivers Engineering Branch, Hunter Building, Ottawa.

Reference: Letter of 3 March 1958 from General H.A. Young.

Subject: SAINT JOHN HARBOUR SURVEY - PRELIMINARY REPORT

Prepared by: H. A. Neu

Submitted by: W. D. Baines
Head
Hydraulics Laboratory

E. S. Turner
Head
Hydrodynamics Section

Approved by: D. C. MacPhail
Director

SUMMARY

Several preliminary designs for the improvement of Saint John Harbour, based on the observations obtained during the hydrographic survey in the summer of 1958, are presented. These proposals should be considered as a basis for discussions and detailed engineering and economic studies for improving and developing the harbour.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SAINT JOHN HARBOUR SURVEY - PRELIMINARY REPORT

1.0 DESCRIPTION OF HARBOUR

The harbour of Saint John, New Brunswick, is located at the mouth of the Saint John River about midway along the north shore of the Bay of Fundy. Just above the harbour, the river is constricted by a rocky ledge which forms the well-known "Reversing Falls". Above the falls, the river widens and deepens and, together with the Kennebecasis River and Grand Lake, forms a tidal waterway having an area of about 260 square miles, as far as Fredericton (Fig. 1).

The relationship between the water levels in the river and the sea permits sea water to flow upstream when the tide is between one-half flood to one-half ebb. The outward flow of the combined sea water and river water during the rest of the cycle causes high currents in the harbour and its approaches. The tide in the Bay of Fundy is of the anomalistic type, having a mean range at Saint John of about 20.9 ft. with 28 ft. maximum and 16 ft. minimum.

The harbour, at a minimum depth of 28 ft., requires dredging among the wharves of the west harbour, in Courtenay Bay, and in the approach channels, as shown in Figure 3. The quantity of material dredged annually is between 500,000 and 600,000 cu. yd. which is removed in hopper barges and dumped off Black and Mispek Points. Further deepening of the harbour under present conditions is expensive owing to the rapid accretion. The port is therefore limited to its present depth and cannot attract ships with deeper drafts and lower transportation rates. Owing to the trend to construct larger ships, only a relatively small portion of the world fleet will be able to enter the harbour in the not too distant future.

2.0 HYDROGRAPHIC SURVEY

The survey carried out by the National Research Council during the summer of 1958 was intended to determine the properties and movement of the water masses due to the action of the tides and the discharge from the river. A number of stations were established, as shown in Figures 4 and 5, and at each station the following measurements were taken over a full tide cycle:

(a) Velocity of current from surface to bed

(b) Direction of current

(c) Temperature of water

(d) Density of water

(e) Concentration of suspended sediment.

Because of the dredging problem in Courtenay Bay, the survey points were located closer together in this area. Owing to the lack of information on the river, a tide gauge was installed at Indiantown, above the Reversing Falls, and velocity measurements were made in the Saint John River and Kennebecasis River (Fig. 6).

3.0 RESULTS

Although the data obtained during the survey have not been analysed in detail, a general picture of the action of the tides and river has been obtained.

Measurements show that the velocity of the ebb current along the north shore of the Bay of Fundy is higher in a south-westerly direction than the opposite flood current. This indicates the probability of a counter-clockwise circulation in the Bay of Fundy, caused by the Coriolis acceleration.

During flood tide there is a relatively strong current into Saint John Bay. Half of the water entering the Bay flows through the harbour into the Saint John River system. Owing to the very large area of this system an inward flow of 150,000 to 200,000 c.f.s. is required to raise its surface level 1.5 ft. per tide. This large quantity of water carries sediment into Saint John Bay where it is deposited. Despite the discharge into the river, the current velocities in this Bay are lower than in the Bay of Fundy and the Bay acts therefore as a large stilling basin.

During ebb tide a strong outward flow occurs from the Saint John River system due to the volume of tidal storage and the natural discharge of the river. The river water carries a considerable amount of colloidal material in suspension which, when mixed with salt water, flocculates and is deposited. It appears that this very fine material binds together the larger material brought into the Bay by the tidal currents.

During the quiet seasons of the year, silt appears to accumulate approximately uniformly over the entire Bay and outer reaches of the harbour. The east side of the inner harbour is kept reasonably clear by the discharge from the river. Under the action of the autumn and winter storms the entire area of the Bay is violently agitated and the bed material placed in suspension. The flood tide currents then carry the material into the harbour area.

According to a Courtenay Bay survey, from December 1942 to June 1944, 72 percent of the silt is deposited during the fall and winter storm period from October to March, 22 percent during river freshet, and only 6 percent during the summer months.

4.0 DISCUSSION OF RESULTS

Several important features of the movement of the water masses are immediately evident from the preliminary analysis of the data obtained during the 1958 survey.

One is that the evidence of a counter-clockwise circulation in the Bay c Fundy may have an important bearing on the problems arising along its shores. Consideration should be given to relocating the dumping grounds off Black and Mispek Points, because it is probable that the dredged material is carried back into the Bay by the tidal currents.

The double quantity of salt water entering the harbour and Saint John Bay is due to the very large tidal area in the Saint John River system. This causes not only high currents in the harbour but brings sedimentary material int the Bay.

The fresh water discharged by the river carries with it colloidal material which flocculates on mixing with salt water. This takes place over the entire Bay but chiefly in the vicinity of the harbour. The sediment settles in areas protected against currents of river and tide and against wave action, i.e. Courtenay Bay, among the wharves, and at greater depths in Saint John Bay.

5.0 PROPOSED SOLUTIONS

It is evident that a satisfactory solution of the problem can be found c when major changes are made which affect basic conditions. The proposals off for consideration therefore are designed

(a) to reduce the suspension load of the sea water entering the Bay of Sa John from the Bay of Fundy,

(b) to remove currents created by density difference,

(c) to avoid the colloidal flocculation in the harbour and bay areas which place by mixing colloidal-laden fresh water with sea water,

(d) to protect the harbour area from waves which put material on the bo of the Bay into suspension.

6.0 PROPOSAL I - DIVERTING SAINT JOHN RIVER

This proposal consists essentially of constructing a dam at the Reve Falls and diverting the river through an outlet at South Bay to the Bay of Fund (Fig. 7, 8).

6.1 Effect on Harbour

Closing off the river would have the following effects on the harbou bay:

(a) The currents on both flood and ebb tides would be reduced to less t half their present value since only the bay area would be subject to variation.

(b) Currents and turbulence would be reduced since there would be no density difference.

(c) Colloidal fresh water would be excluded from the harbour and bay.

The quantity of silt entering the harbour with the flood tide would be reduced to a small amount since the intensity of the current and the volume of water passing into the harbour would be reduced to less than half. The kinetic energy would be one-quarter its present value. A further reduction would be due to the absence of density difference.

Diverting the river would thus divert the colloidal flocculation which amounts to 15 to 20 percent of the silt deposit.

These improvements would only partially solve the problem as long as no breakwater protects the bay from sediment of a more sandy nature which would still be carried into the bay by autumn and winter storms.

Figure 8 illustrates a proposed arrangement of breakwaters to protect the bay from wave action, thus providing a safe anchorage in storms and reducing the possibility of bringing bed material into suspension. The area protected would be approximately 3.6 square miles and would contain salt water only. Dredged depth would be maintained. The currents at the ends of the breakwaters would be low since only the harbour would be subject to tides. A marine dredging plant may be required to transfer littoral drift across the entrance of the harbour.

Behind the proposed breakwater, harbour facilities could be developed which would handle all sizes of ships. A model investigation would be suggested to study the effect of the breakwater in detail.

6.2 Effect on River System

At present the deep channels in the Saint John and Kennebecasis Rivers are permanently salty, while mixed conditions occur near the Reversing Falls. A diversion dam at the Reversing Falls would prevent salt water from entering the Saint John River system, and in time the entire system would become fresh, thus improving conditions for marine life. This could include a navigation lock to make the entire Saint John River system available for navigation, thus opening a large internal waterway for the transport of bulk cargoes. By raising the water level to the normal flood water level, the waterway would be suitable for deep draft ships (25 to 27 ft.) over a very long distance. Close to the City of Saint John, a harbour, with no tidal effects, could be developed.

6.3 River Diversion

The distance between South Bay, a few miles upstream from the Reversing Falls, and Manawagonish Cove at the Bay of Fundy is approximately 10,000 ft. A ridge 150 ft. high and 1000 ft. wide lies between the low marshland of Manawagonish Creek to the south and a valley leading to South Bay in the north. A cut through this ridge and small excavations in the valley and marshland would open, for the river water, a short and straight outlet to the sea. At the coast, Manawagonish Cove, is an excellent natural estuary opening straight into the Bay of Fundy. River water would mix intensively with sea water and the colloidal fallout would be swept away from the harbour area because of the dominant anti-clockwise current in the Bay of Fundy.

6.4 Channel Properties

A trapezoidal channel, 300 ft. wide at the bottom with shoulders sloped 1:1, is proposed. Two layouts are shown in Figure 7; the one to be chosen depends on geology, amount of excavation, etc. The easterly route requires 6 to 7 million cu. yd. of excavation. The material is probably alluvial as gravel pits in the surrounding area would indicate.

The velocity in a channel lined with gravel should not exceed 5 ft./sec. The maximum discharge of the channel at 34-ft. depth is therefore:

$$\text{Max. } Q = 11,360 \text{ (ft.}^2\text{)} \cdot 5 \text{ (ft./sec.)} = 56,800 \text{ c.f.s.}$$

During April and May the discharge of the river exceeds this amount, as shown in Figure 9, by more than 80,000 c.f.s. The flood wave may be partly stored in the huge river basin; however, 11 percent of the total annual discharge must still pass into the harbour through the dam at the Reversing Falls. Colloidal siltation at present, with the full discharge of the river passing through the harbour, amounts to 15 to 20 percent of the total. In the proposed scheme this would be reduced to 1 to 2 percent which could be considered negligible.

6.5 Control Structure

To regulate the huge storage lake and to prevent sea water from entering the river system, a control structure into the channel would be required. It would be located at the downstream side of the ridge. Considering the head available at the structure, it is natural to consider development of hydro power. A powerhouse would then replace the control structure.

6.5.1 Power Development

Preliminary estimates show that the head pond represented by the 260 square miles of river system could be raised to an elevation of at least 24 ft. above mean sea level. This could be attained without difficulty since the spring floods of 20 to 25 ft. above sea level have prevented shoreline development. Little agricultural land would be flooded. With this head the maximum power available would vary between 52,000 and 170,000 h.p. Considering monthly means, between 40,000 and 116,000 h.p. would be available.

On Figure 10 the available head, discharge at powerhouse, and power production are plotted. The yearly energy, based on 39 years of monthly means of discharge, is 384 million K. W. H. Considering the powerhouse only, the cost of power should be less than that of steam power.

The power plant could be operated as a continuous load station, but its real value would be as a peak load power station with huge storage capacity. Water could be drawn or stored for weeks without appreciably affecting the level of the reservoir.

6.5.2 Tidal Effect on Power Production

The tailwater of the powerhouse would rise and fall with the tide. During the flood season in April and May, the channel would carry continuously the maximum discharge of 56,800 c.f.s. The power produced during a tidal cycle would therefore be sinusoidal, fluctuating between 52,000 h.p. at high tide and 170,000 h.p. at low tide, as shown in Figure 11. From June to March, discharge would be regulated to 24,000 c.f.s. The power production could be sinusoidal by constant discharge, constant by varying discharge (Fig. 12), or a combination of these plans.

The average power produced by varying discharge would be 45,000 h.p. If this were reduced, peak power could be produced as shown in Figure 11; the limits depending on the tide, i.e. at high tide 52,000 h.p., and at low tide 170,000 h.p.

As the demand for peak load power increases, consideration should be given to providing pump storage in high level lakes near the powerhouse to take care of peak loads at high tide. Furthermore, consideration should be given to raising the level of the river system above elevation 24.0 so that more of the spring flood could be stored.

6.6 Structures Required for Proposal I

A. Without Power Development

Structures required for river diversion:

1. 600-ft. long and 40-ft. high dam, and flood spillway at Reversing Falls.
2. 300-ft. wide and 10,000-ft. long diversion channel, excavation approximately 7 million cu. yd.
3. Regulation structure in diversion channel.
4. Two highway and two railway bridges.

Structures to prevent siltation in storm season:

5. Breakwater between Partridge Island and Red Head.

Structure for navigation in river system:

6. Lock at Reversing Falls.
7. Relocation of one highway and one railway bridge at Reversing Falls.
8. Development of deep sea harbour, excavation approximately 8 million cu. yd.

B. With Power Development

A powerhouse would replace the regulating structure in the diversion channel.

7.0 PROPOSAL II - BAY ENCLOSED BY DAM

This proposal consists of a watertight dam to close off the bay. Navigation would enter and leave the bay through a sea lock near Partridge Island and the river would discharge into the sea between Partridge Island and Negro Point (Fig. 13).

7.1 Effect on Harbour

The bay closed off by the dam would be filled with river water only. Practically no siltation would take place since the sea water, which carries sediment and causes colloidal flocculation by mixing with river water, would be prevented from entering the bay. Currents caused by tides and density differences would be avoided and only currents caused by the river flowing through the bay would remain.

The water in the bay, not subject to tidal variation, would be controlled to the elevation of high tide which is approximately 22 ft. above low water. While in Proposal I extensive dredging would be required to establish a deep sea harbour behind the breakwater; in this scheme 40 to 50 ft. depth would be available in most of the bay without dredging.

7.2 River Control

The location of the spillway between Partridge Island and Negro Point was chosen so that mixing of river and sea water would take place as far as possible from the lock entrance.

The spillway and floodgates must be so designed that spring floods up to 300,000 c.f.s. could be discharged. In the flood control a brief critical time occurs during the freshet when the head between the bay and sea at high tide would be insufficient to drain the flood. To prevent flooding the harbour and structures during a spring tide, a flood channel in the Reversing Falls must be excavated to enable the river system to store the flood water for a short time until drainage is obtained again.

7.3 Effect on River System

The still water in the bay, controlled to the elevation of high tide, would submerge the rock ledge of the Reversing Falls 30 ft. and raise the water level in the river system 10 ft. This would provide a waterway suitable for ships with draft of 25 ft. over a distance of 80 miles with no additional locks. With the exception of a few days during serious river floods, the river system would be accessible from the harbour at all times.

7.4 Siltation Outside of Dam

The dam would change the configuration and hydraulic conditions of the Bay of Saint John fundamentally but a prediction of how currents would be affected is very difficult without model studies.

The colloidal material would flocculate and settle where conditions are favourable. However, it is probable that strong tidal currents in the Bay of Fundy would keep clear the area around Partridge Island and the entrance to the lock.

7.5 Power Development

Should power development be considered, the water level in the bay would have to be kept as high as possible to ensure power production most of the time. The minimum head at mean high tide would be 4.5 ft. However, this could be reduced to 1.5 ft. by a spring tide. This reduction in power during each cycle may make power development uneconomical.

In Figure 14, the head between mean sea level and the harbour, the annual discharge, and the annual power production, are plotted. The energy available would be 300 million K.W.H. per year.

7.6 Structures Required for Proposal II

1. 11,000-ft. cellular cofferdam.
2. Sea lock with filling and emptying gates.
3. Spillway and floodgates for river control.
4. Flood channel at Reversing Falls.

8.0 PROPOSAL III

A further proposal, which deserves some thought, is to close the Reversing Falls against the entrance of sea water so that only river water would flow through the harbour. A dam or powerhouse across the Falls and floodgates for spring flood would be required.

Sea water entering the bay would be half its present amount. The effect on siltation would be that the silt carried by the currents of the flood tide would be reduced and the colloidal flocculation by mixing river and sea water decreased.

A further improvement may be a breakwater to prevent fresh water from violently mixing with sea water.

9.0 PROPOSAL IV

The basic ideas in Proposal II could be applied to Courtenay Bay only. The structures would consist of a watertight dam to close Courtenay Bay and create a still water basin filled with fresh water. The basin would be independent of the river and tide. A cell dam, 6500 ft. long, and a sea lock would be required. Two creeks and Little River would compensate for losses of water during locking. The rest of the harbour would remain in its present state.

10.0 SYNOPSIS

Modifications contained in the proposals would tend to improve conditions basically.

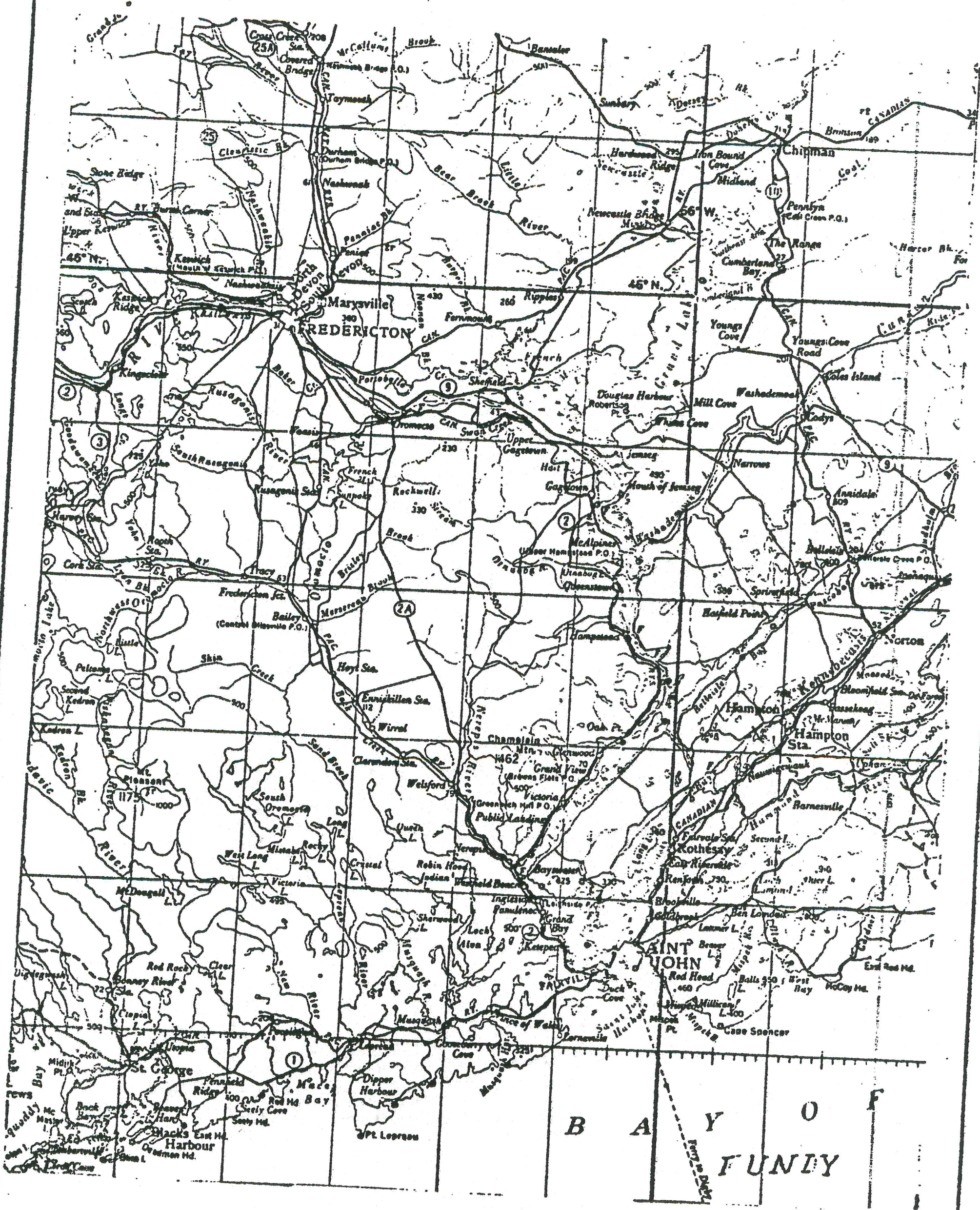
In Proposal I, the river, which causes most of the problem, would be diverted straight into the sea, thus keeping the colloidal silt out of the harbour. The proposed plan would also reduce silt carried in from the bay.

In Proposal II, the harbour bay would be sealed against sea water, and siltation inside the bay could not occur. Siltation might occur outside the dam near the entrance to the lock. A model study might be helpful in solving this problem.

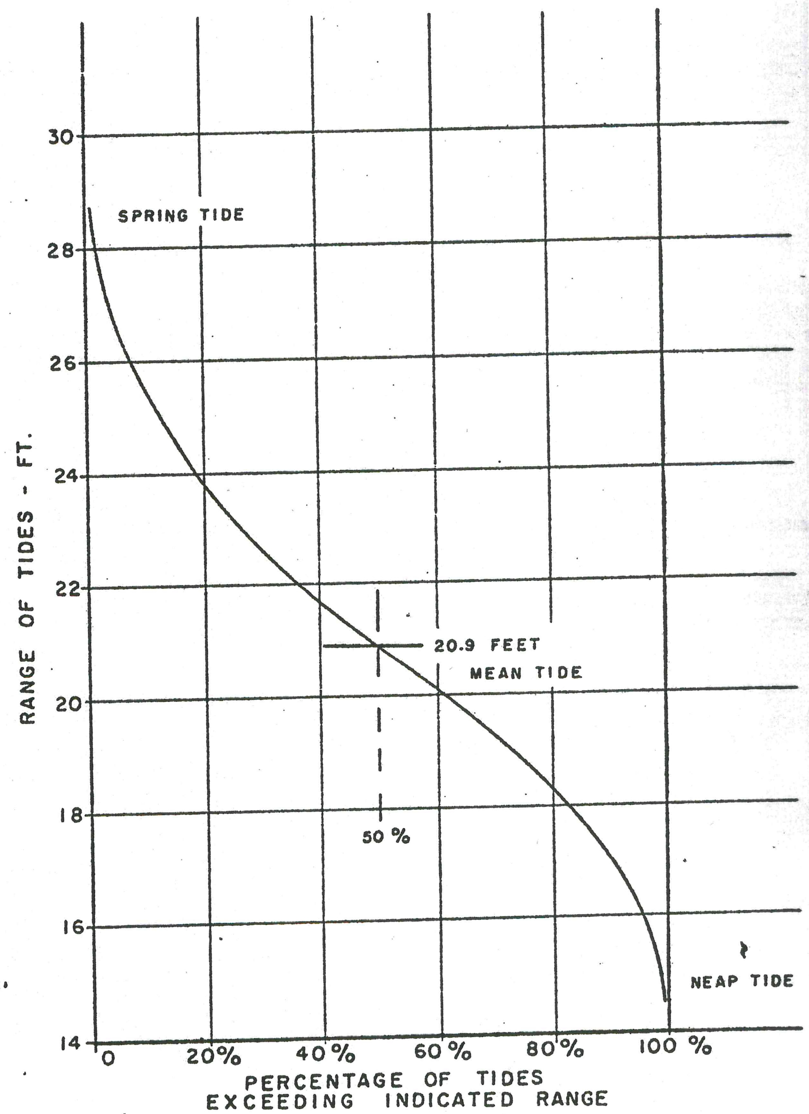
Proposals III and IV are essentially reductions of Proposals I and II in scale and effect.

/LES

FIG. 1
MH - 78



MAP OF SAINT JOHN RIVER SYSTEM AND COAST



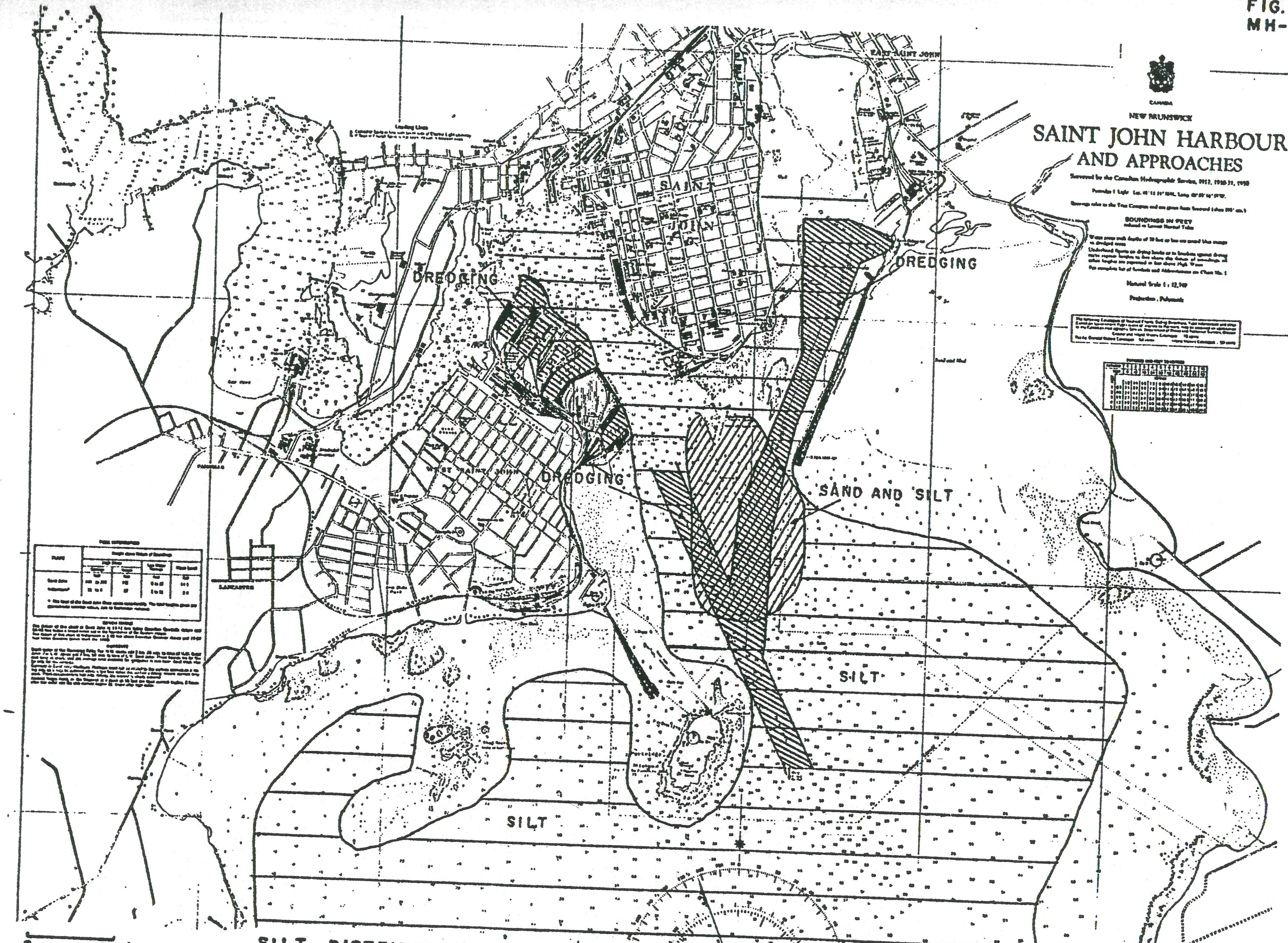
RANGE OF TIDES *in Saint John N.B.*

BASED ON 19 YEARS OBSERVATIONS

INFORMATION FROM HYDROGRAPHIC OFFICE

SAINT JOHN HARBOUR SURVEY

FIG. 3
MH-78



SILT DISTRIBUTION AND DREDGING AREAS IN HARBOUR BAY

FIG. 4
MH-78

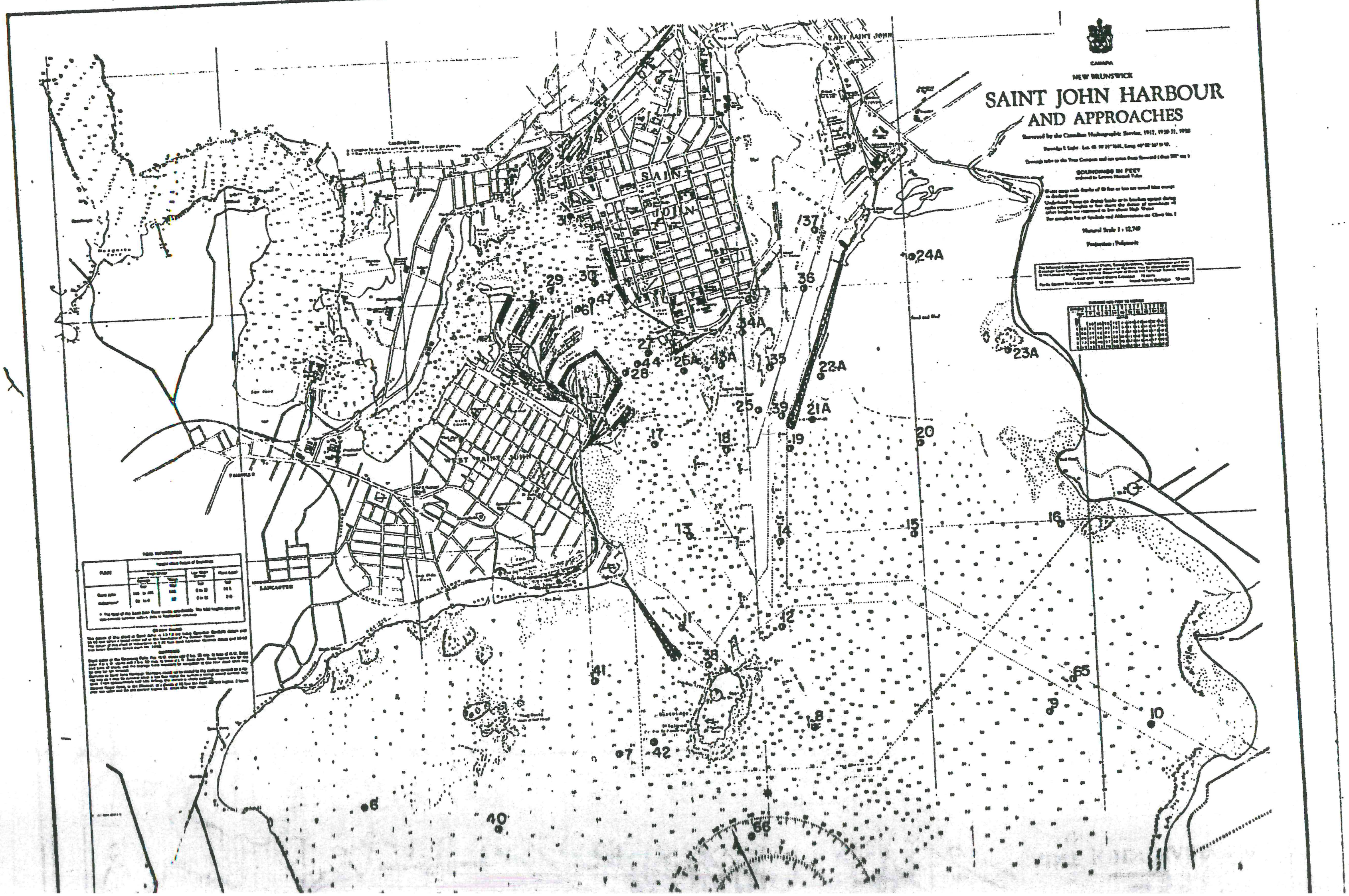
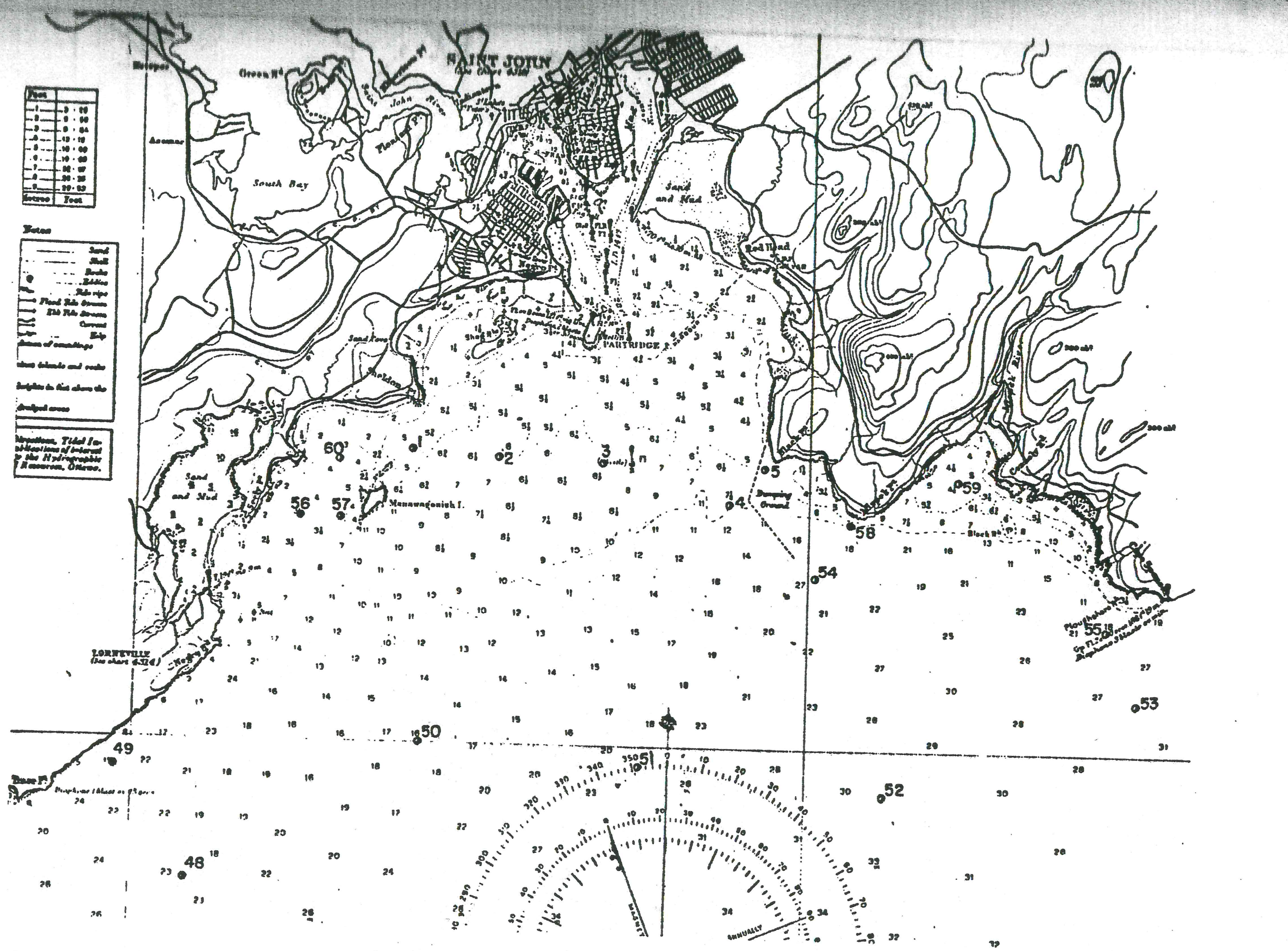
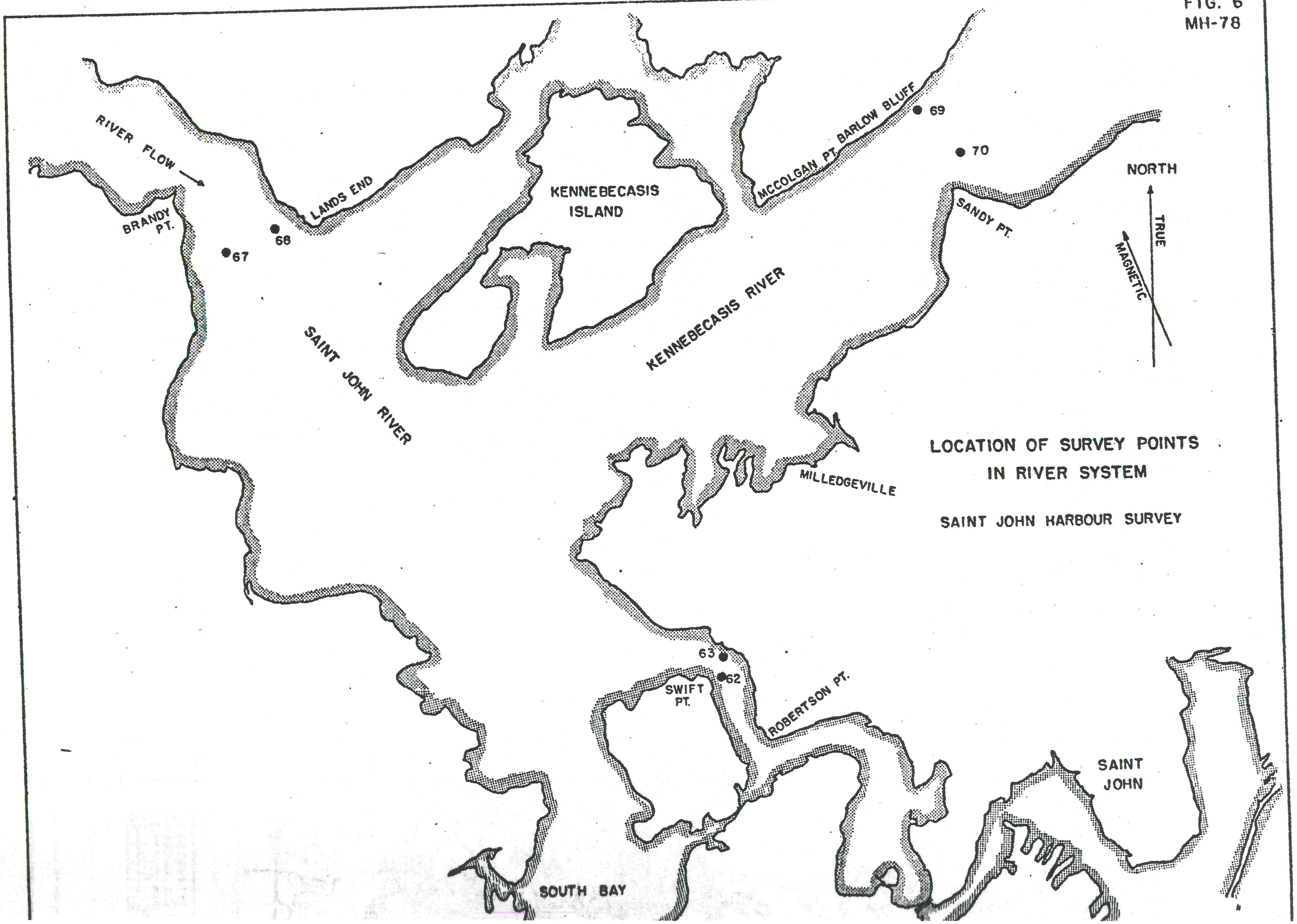

CANADA
NEW BRUNSWICK
SAINT JOHN HARBOUR
AND APPROACHES
SOUNDINGS IN FEET
EAST SAINT JOHN
SAINT JOHN
WEST SAINT JOHN
LANCASTER
37
24A
36
29
30
31
47
61
34A
27
44
26A
45A
35
22A
28
23A
25
39
21A
17
18
19
20
13
14
15
16
11
12
38
41
65
9
8
10
7
42
6
40
66

FIG. 8
MH-78



LOCATION OF SURVEY POINTS
OUTER BAY

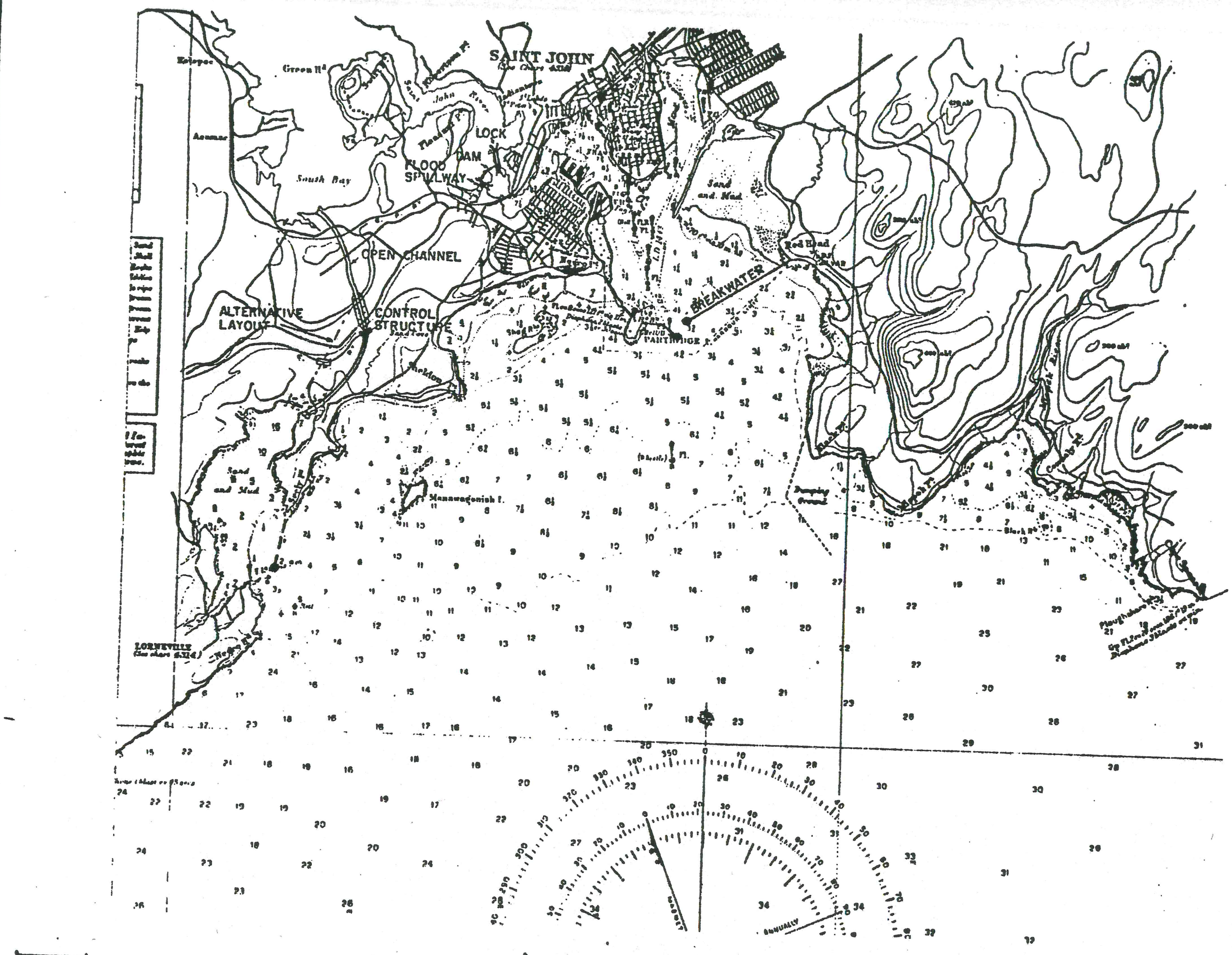
FIG. 6
MH-78



LOCATION OF SURVEY POINTS IN RIVER SYSTEM

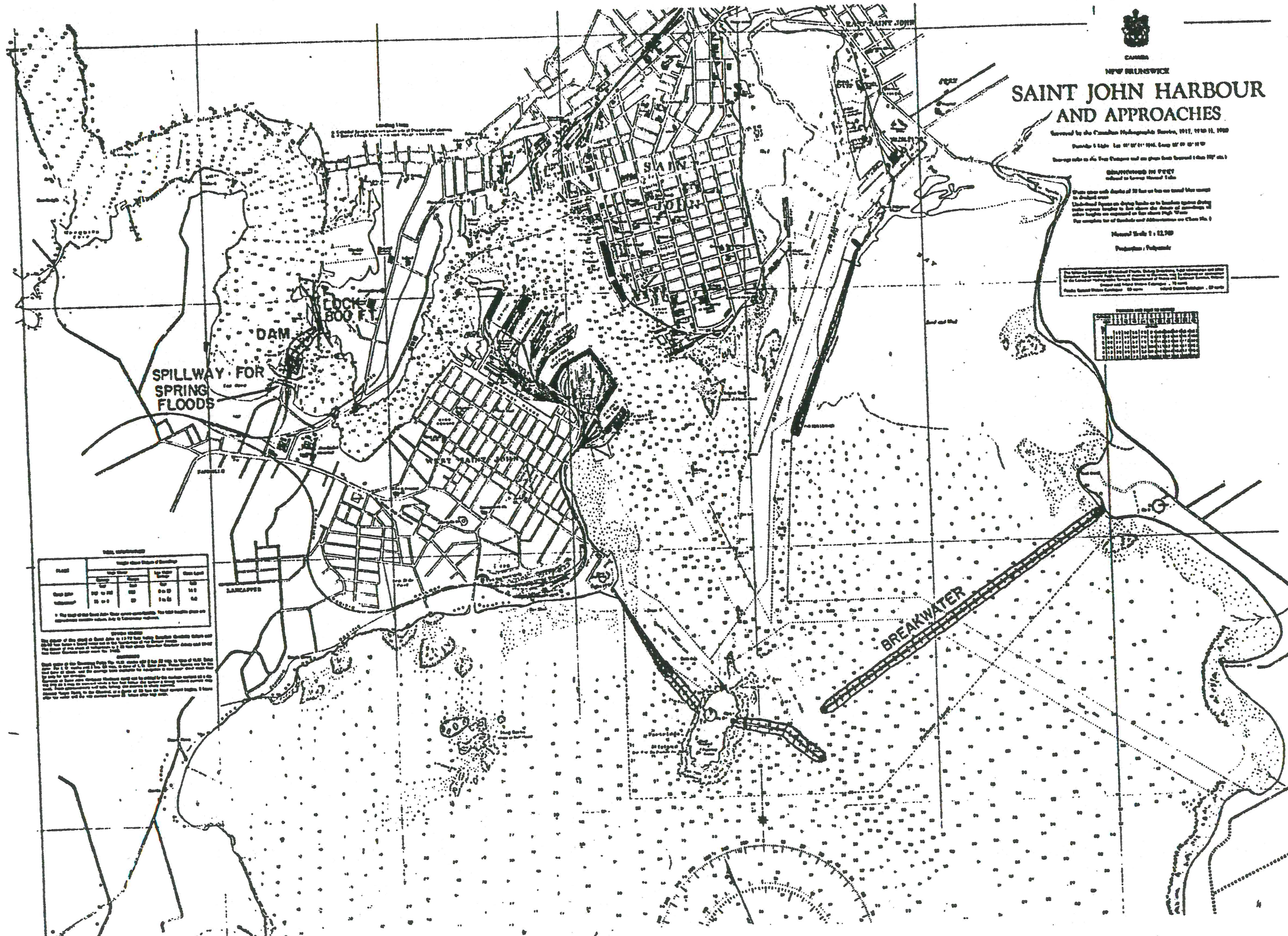
SAINT JOHN HARBOUR SURVEY

FIG. 7
MH-78

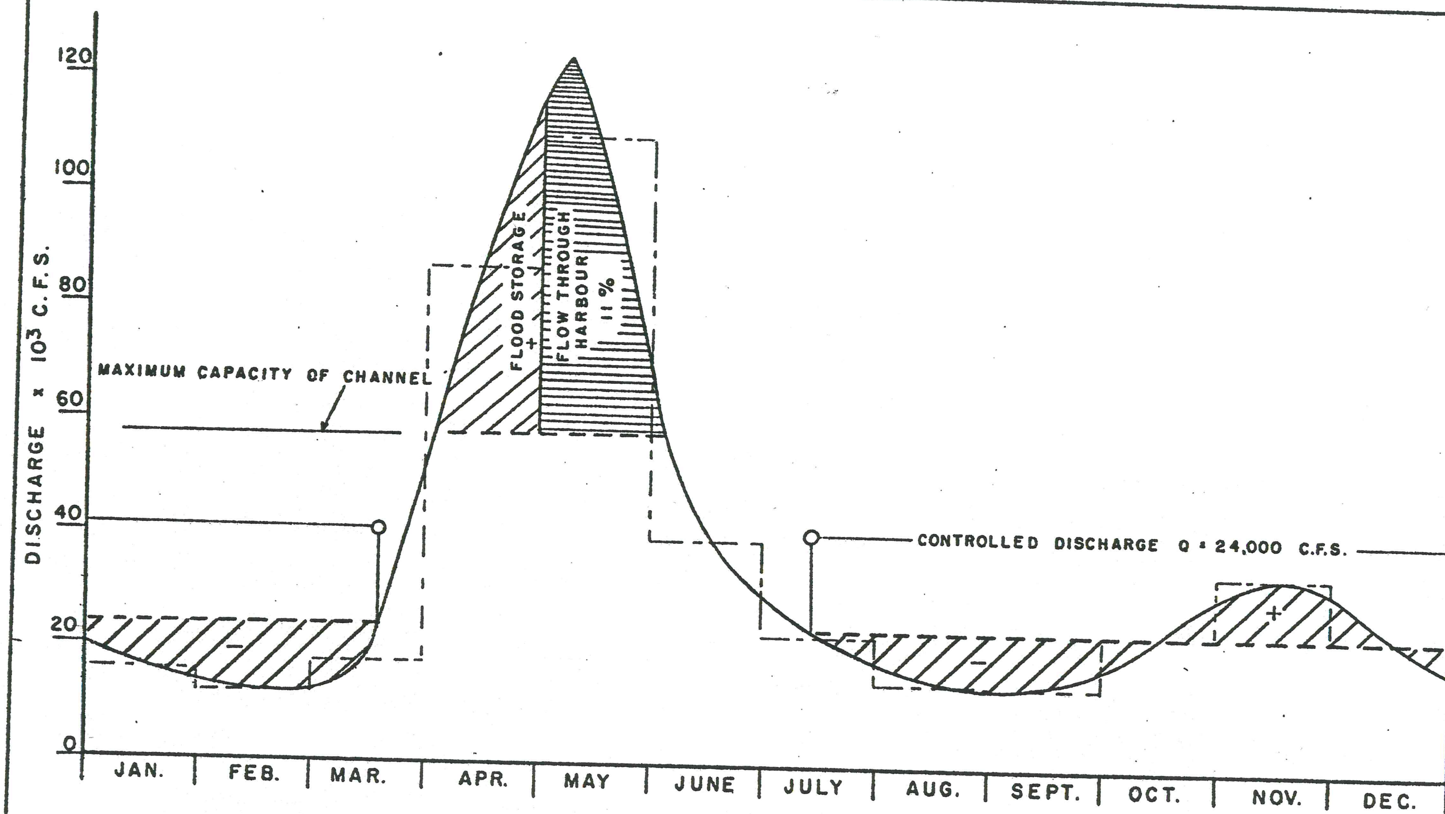


SAINT JOHN HARBOUR IMPROVEMENT
PROPOSAL I

FIG. 8
MH-78



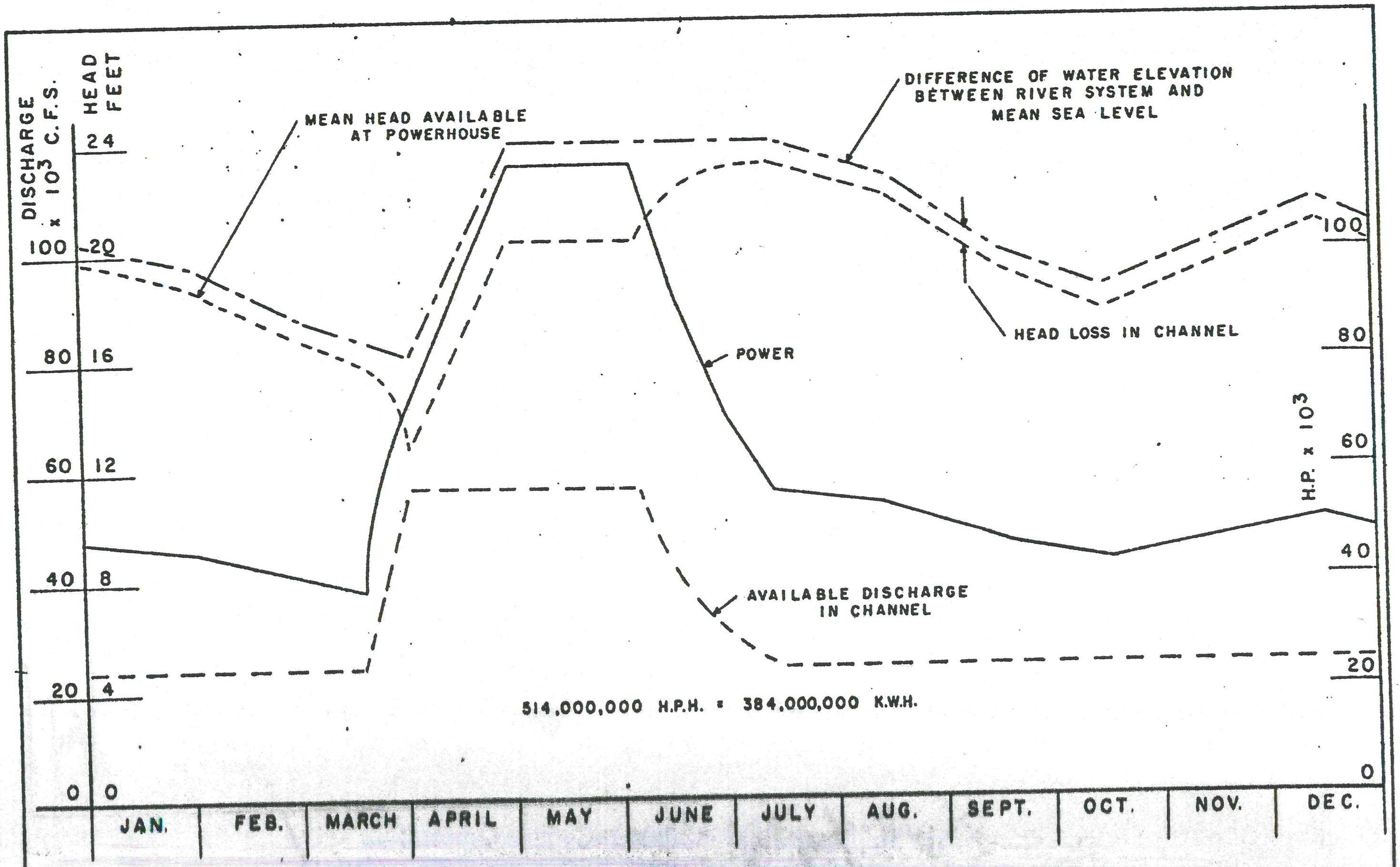
HARBOUR BAY
PROPOSAL I

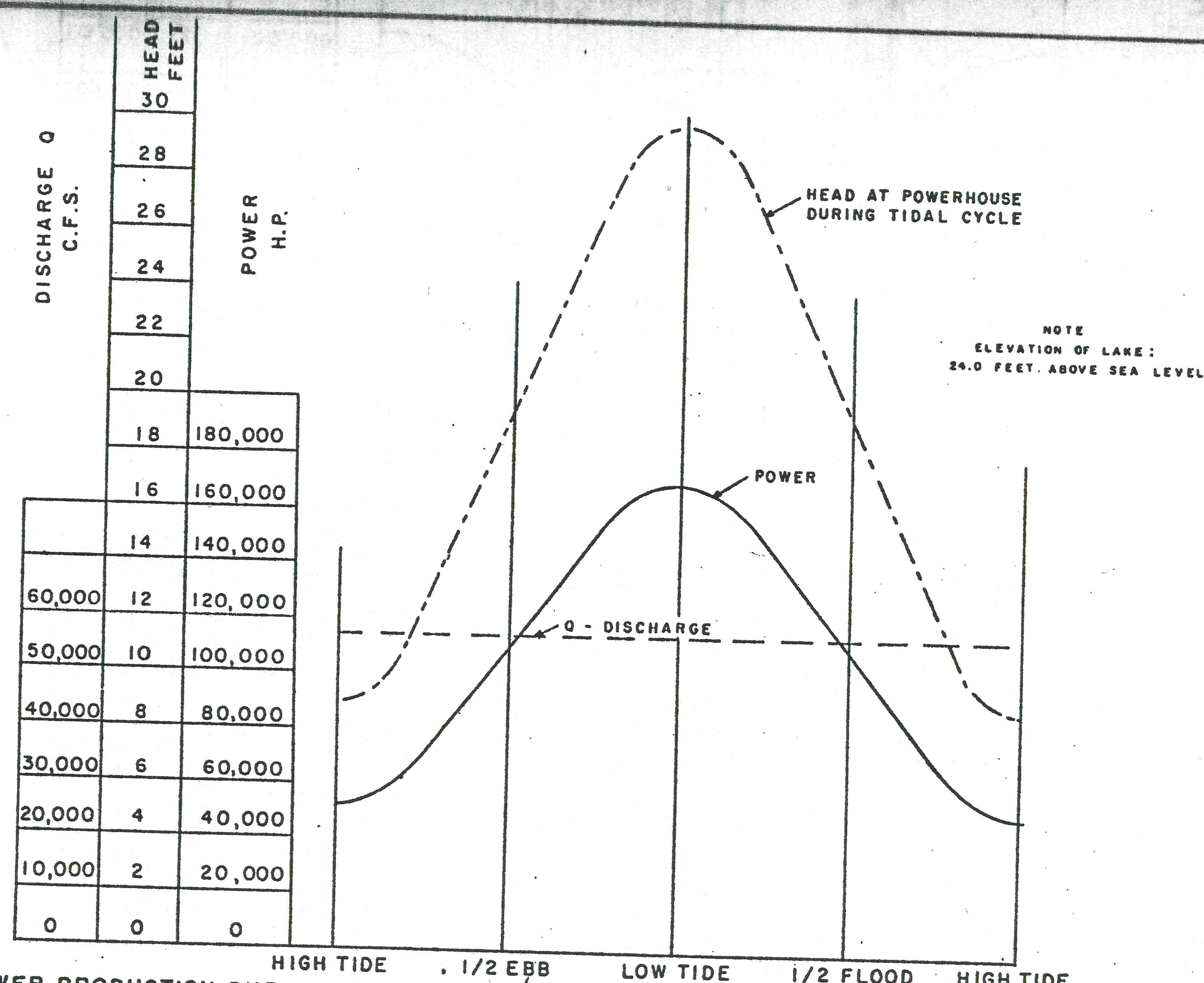


WATER UTILIZATION PLAN OF SAINT JOHN RIVER

BASED ON MONTHLY MEANS OF PERIOD SEPT. 1918 TO SEPT. 1956

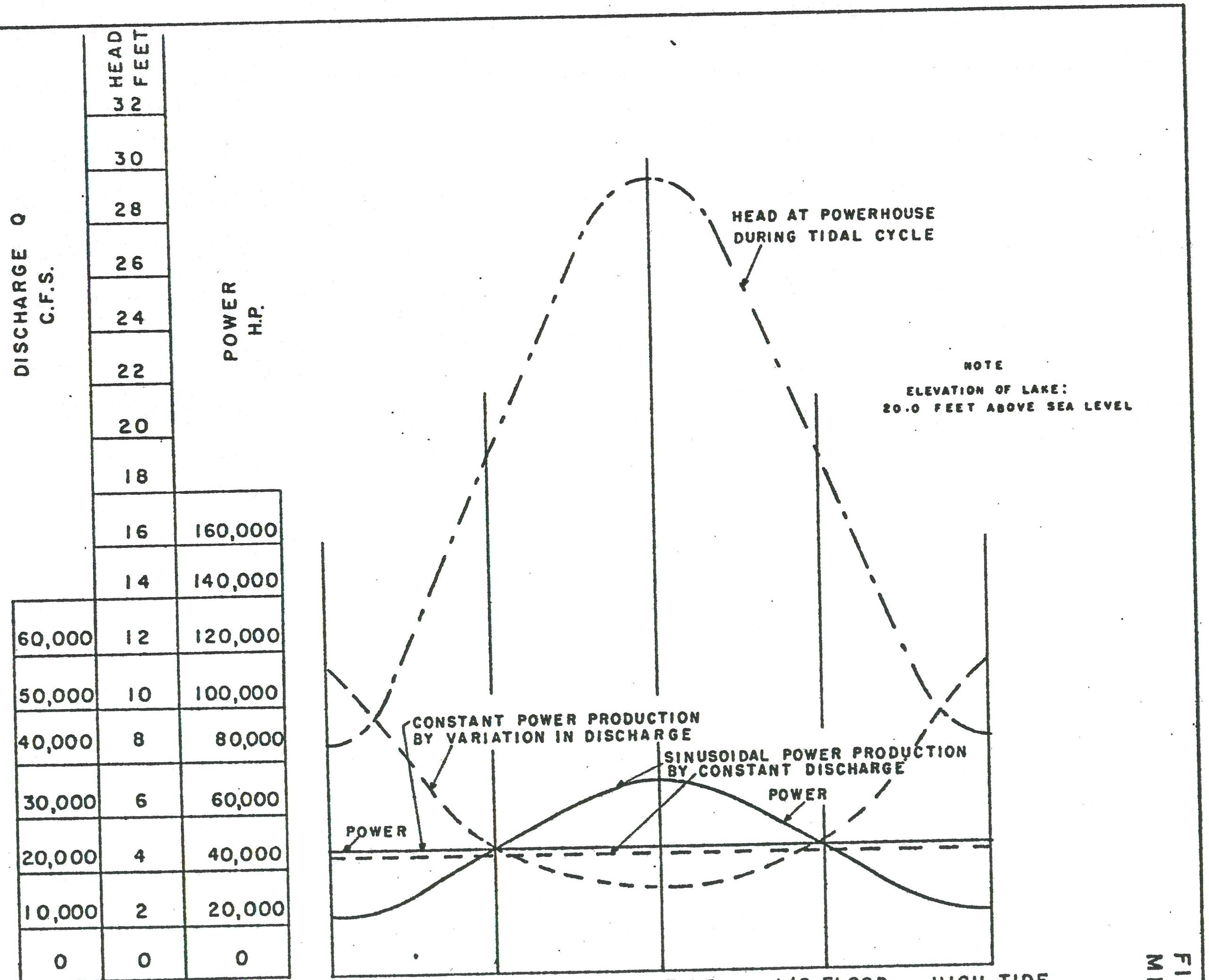
FIG. 9
MH-78


DISCHARGE x 10^3 C.F.S.
HEAD FEET
MEAN HEAD AVAILABLE AT POWERHOUSE
DIFFERENCE OF WATER ELEVATION BETWEEN RIVER SYSTEM AND MEAN SEA LEVEL
HEAD LOSS IN CHANNEL
POWER
AVAILABLE DISCHARGE IN CHANNEL
H.P. x 10^3
514,000,000 H.P.H. = 384,000,000 K.W.H.
JAN.
FEB.
MARCH
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
0
20
40
60
80
100
4
8
12
16
24



POWER PRODUCTION DURING TIDE CYCLE IN FLOOD SEASON APRIL AND MAY, PROPOSAL I
AND MAXIMUM PEAK LOAD PRODUCTION DURING YEAR
(AVERAGE TIDE)

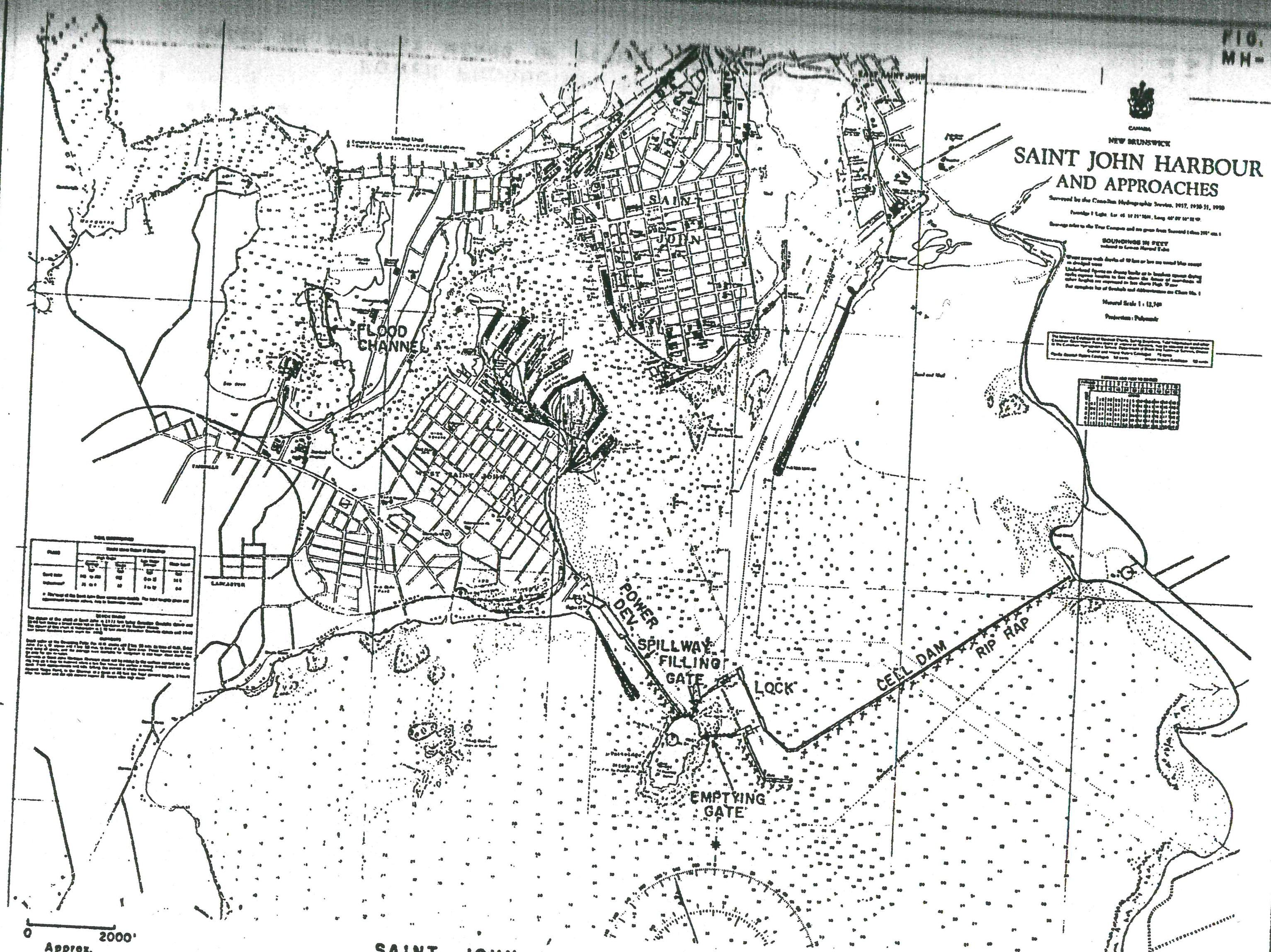
FIG. 11
MH-78



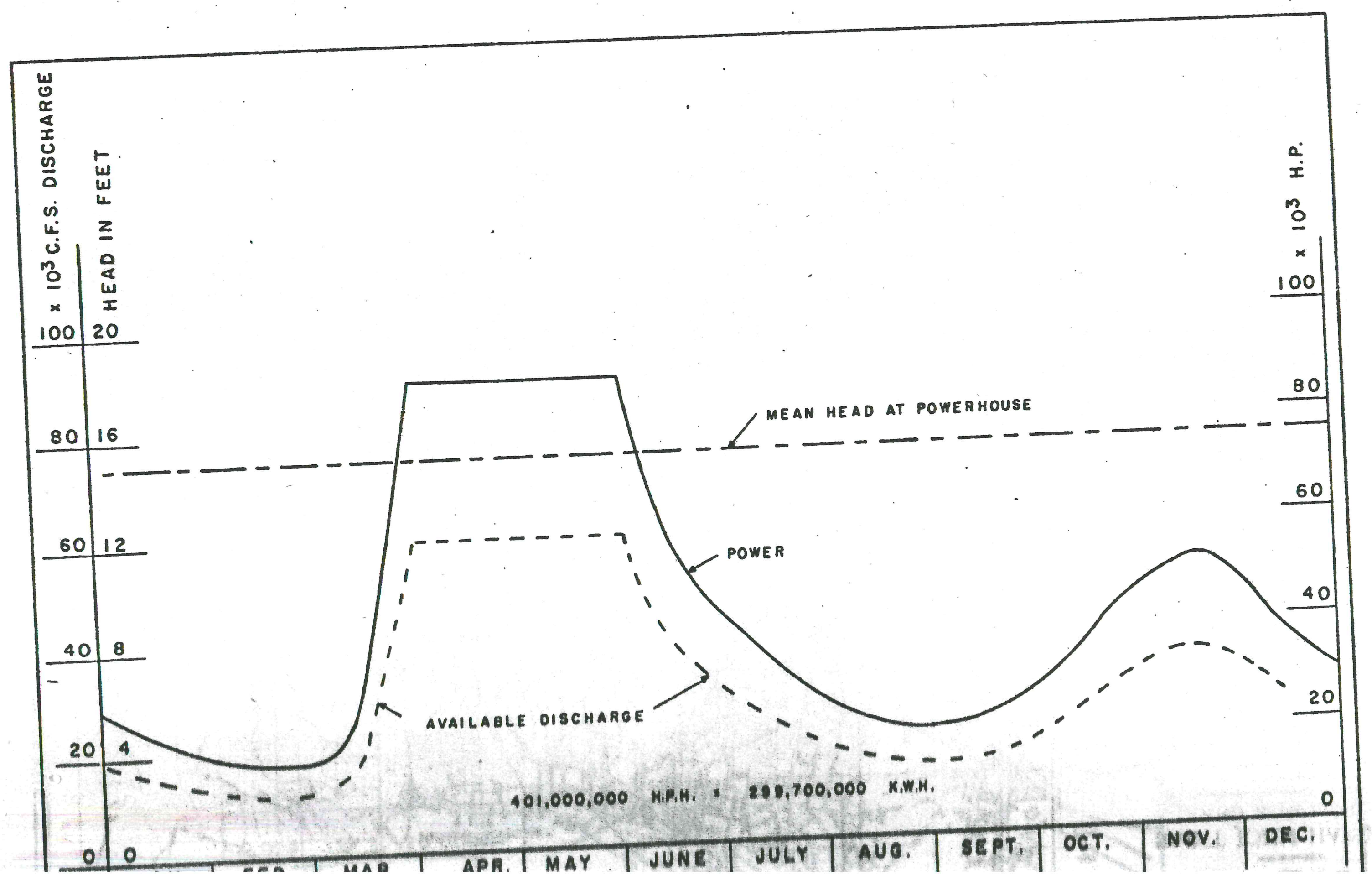
POWER PRODUCTION DURING TIDE CYCLE IN SUMMER, FALL AND WINTER SEASONS, PROPOSAL I

FIG. 12
MH-7

FIG. 13
MH-78



SAINT JOHN HARBOUR IMPROVEMENT
PROPOSAL II


x 10³ C.F.S. DISCHARGE
HEAD IN FEET
x 10³ H.P.
100 20
80 16
60 12
40 8
20 4
0 0
100
80
60
40
20
0
MEAN HEAD AT POWERHOUSE
POWER
AVAILABLE DISCHARGE
401,000,000 H.P.H. = 299,700,000 K.W.H.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.