THE CURRENT STRUCTURES OF RIVERS

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SUMMARY

The three prevailing currents in a river system, the gravity flow due to the water surface slope, the tidal current and the flow due to the density difference between sea and fresh water, are discussed and described with reference to Canadian rivers. From this aspect, principal methods for navigation improvements and flood control are evaluated and critically reviewed.

INTRODUCTION

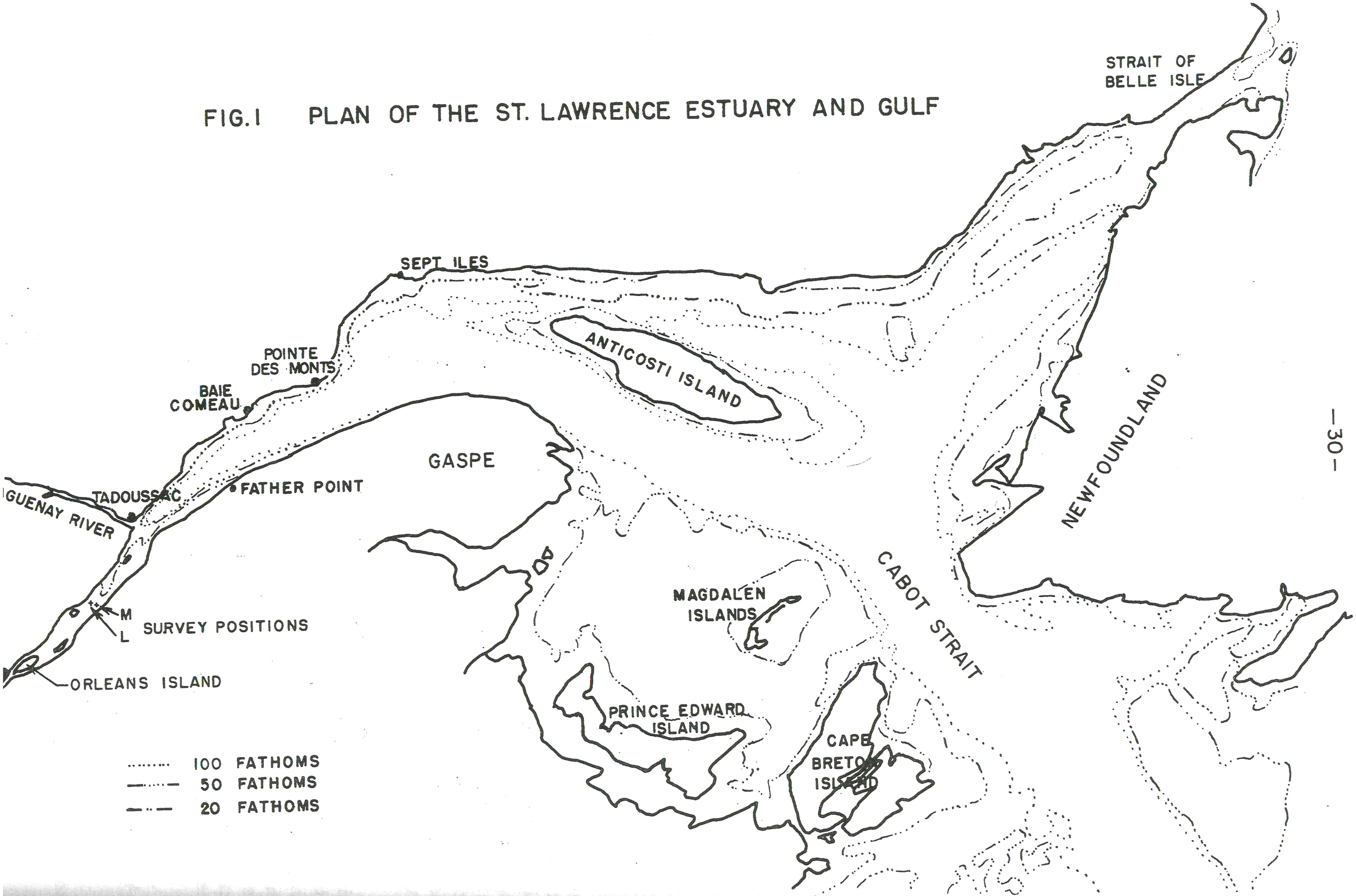
During the last three years one of the primary objectives in the Hydraulics Laboratory has been progress toward an understanding of the hydraulic structure and circulation in estuaries and tidal sections of rivers. Until recently, in Canada, relatively little work was done on these inshore waters, despite the fact that they were important in exploring the country and today are most important links in the waterways to and from this continent. Large cities like Quebec, Montreal, New Westminster and Vancouver are located on such estuaries or tidal channels. One of the largest tidal sections in the world is that of the St. Lawrence River where nearly 1000 miles of the river system are affected.

Because of the complexities involved, knowledge of the physical structure and circulation within these bodies of water is far from complete. However, with field observations conducted on the Saint John River (Ref. 1), the St. Lawrence River and on the Fraser River, with theoretical analysis, and with model investigations now under way, the understanding of the physical processes is growing. From this will come concepts by which authorities concerned with problems in coastal regions can be advised with demonstrations in nature and with models on improvement schemes based on proper principles of tidal and estuarine hydraulics.

CLASSIFICATION OF RIVER SECTIONS

A set of definitions, based upon the hydrography of rivers, is given here in an effort to classify sections of common physical structures.

FIG.I PLAN OF THE ST. LAWRENCE ESTUARY AND GULF



For this purpose, a river system extending from its head waters to its outlet into the ocean may be divided into two primary sections, depending upon the influence from the ocean. The section free of this oceanic influence is known as upland river and that affected by the ocean is defined as the coastal region of the river.

In Canadian waters, as in most other places in the world, two major oceanic phenomena impose their influence on coastal rivers. These are the tide and the exchange current from density differences between the fresh and salt water. These two properties sub-divide the coastal section into a tidal river and into an estuary, respectively. In most cases, the estuary is a part of the tidal river and extends from the mouth upstream as far as salt water can be measured. In the St. Lawrence River, for example, the tidal section, according to this definition, commences at the foot of the Lachine Rapids near Montreal and the head of the estuary is located at Orleans Island, 15 miles below Quebec City (Fig. 1, 2).

Effects from meteorological sources, such as wind or barometric pressure differences, and from the rotation of the earth will be neglected in this example, assuming that the river channels are sufficiently narrow so that the currents from these sources can be considered unimportant. This, however, does not exclude the possibility that in more open bodies of water, such as in some sections of the St. Lawrence River, in lake-like widenings and in bays and gulfs, these currents may gain momentum and achieve a dominant influence (Ref. 2). In the laboratory, an investigation is now under way to evaluate the effect of the earth's rotation on the flow in nature and in models. The results will be the subject of a later discussion.

PHYSICAL HYDROGRAPHY

Each of these classified sections has its own kinematic structure which is superimposed on the adjacent structure from section to section, finally forming a complex pattern of motion and internal circulation in the coastal region. The currents of these sections, their interaction and the forces which initiate them may be better understood by tracing them individually.

River Flow

(a) River Hydraulics

In a river system, the initial flow encountered is that due to gravity, i.e. due strictly to the slope of the water surface. The laws governing this type of flow are definitely established. The basic equation defining this type of stationary, free-surface flow is derived from the Bernoulli equation which, in concept, is a statement of the conservation of mechanical energy.

$$\frac{\partial y}{\partial x} + \frac{v}{g}\frac{\partial v}{\partial x} + \frac{1}{g}\frac{\partial v}{\partial t} + \frac{v^2}{c^2 r} = 0 \qquad (1)$$

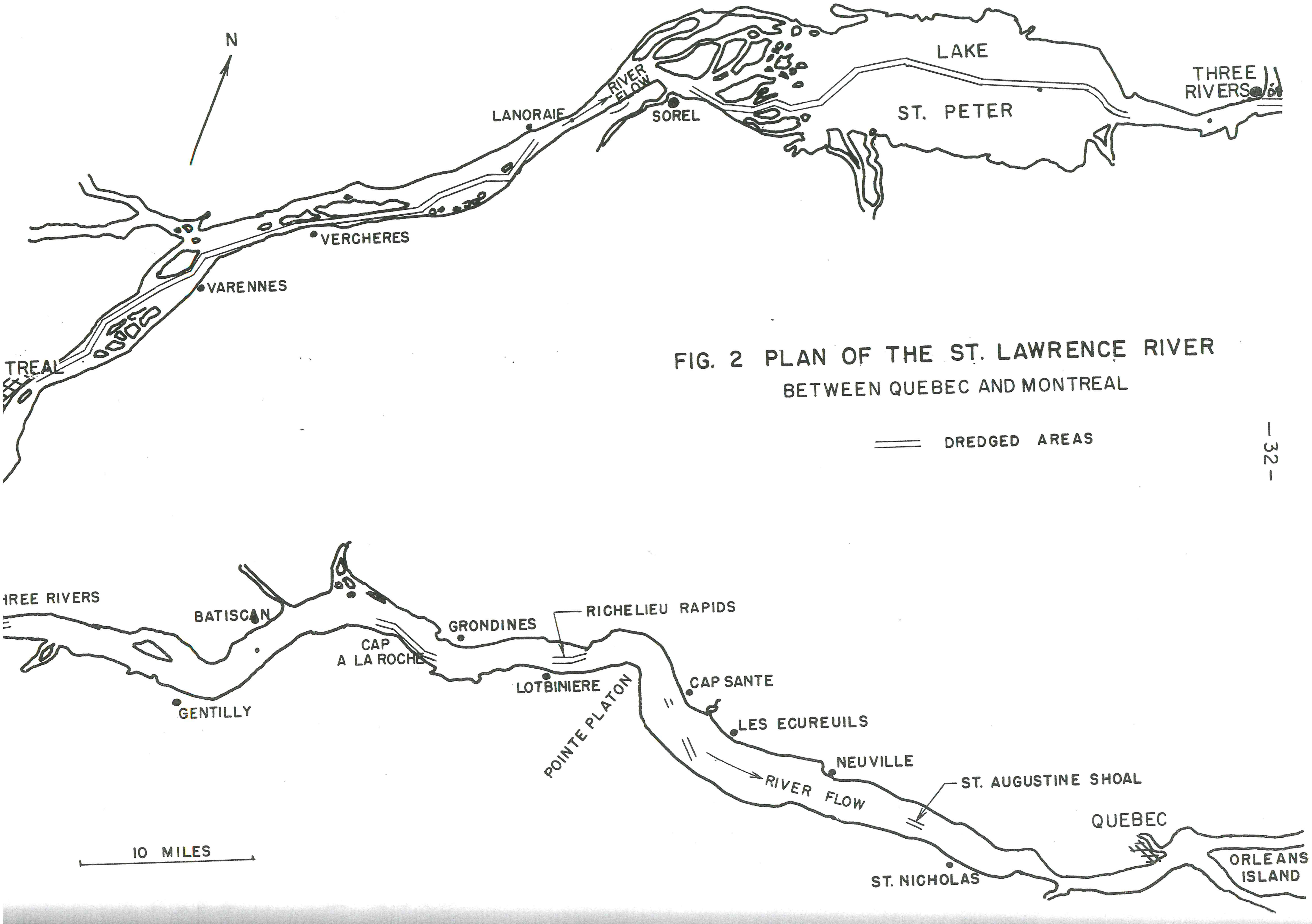


FIG. 2 PLAN OF THE ST. LAWRENCE RIVER
BETWEEN QUEBEC AND MONTREAL

In this equation the first term is the slope of the water surface; the second, $\frac{v}{g}\frac{\partial v}{\partial x}$, the rate of change of $\frac{v^2}{2g}$ and may be regarded as the component slope due to a change in the velocity head; the third term represents the effect of the acceleration or deceleration of the current, and the last is the friction term.

The flow, defined by this equation, is non-uniform with velocities changing in magnitude along the river channel. This type of flow applies to irregular channels where a detailed description is required. For the purpose of this discussion, however, it is sufficient to consider only the all-over concept of the motion which for longer reaches of the river is uniform, as demonstrated by the fact that the bed of the river and water surface are for all practical purposes parallel. Under these circumstances, the acceleration terms become zero and the equation may be written:

$$\frac{\partial y}{\partial x} + \frac{v^2}{c^2 r} = 0 \qquad (2)$$

Both terms of the equation, multiplied by the gravitational acceleration and by the mass per unit volume of water, may be converted to forces, the first representing the acting force supplied by the earth's gravitation and the second, the mass reaction, considered as the inertia force.

$$\frac{\partial y}{\partial x}\, g\, m + \frac{v^2}{c^2 r}\, g\, m = 0 \qquad (3)$$

Both forces are in a state of equilibrium, which means that in a river channel the force imposed on the water by gravity is compensated by the force required to overcome flow resistance, such as friction, form losses and internal turbulence. Further, it is evident that the strength of the acting force which initiated the flow is a function of the slope of the water surface.

(b) Problems in Nature Deriving from Gravity Flow

In nature, water is not the only substance transported in river channels. Debris, such as suspended material, sediment and ice, are common loads of Canadian rivers and it is a well-known fact that these solids are in most cases responsible for problems in navigation and flood control.

The force acting on these solids and transporting them downstream is that supplied by the energy of the moving water and by gravity on the particle itself. Because of this they are also subject to the basic law of motion, with the gravitational force initiating their transport. The amount of force involved is greatly affected by

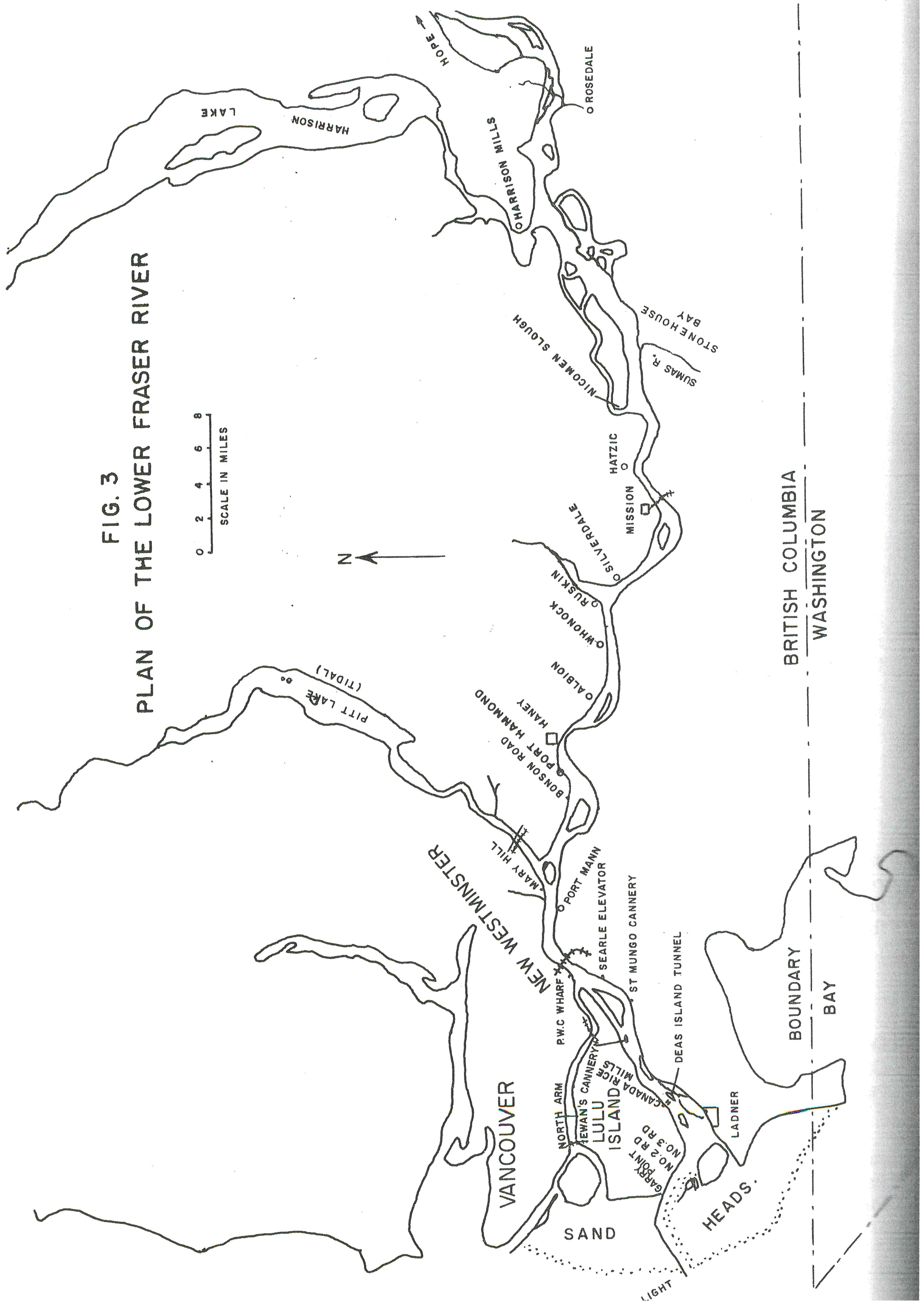


FIG. 3
PLAN OF THE LOWER FRASER RIVER

the physical properties of the material and by other hydraulic factors, such as turbulence; nevertheless, the slope of the water surface gives a very good indication of the capacity of the river to transport its solids and to keep the river stable, and also to judge the capability of the river to carry its ice load without great disturbances.

In the Fraser River (Fig. 3), for instance, the slope of the water surface above Harrison Mills, at the foot of the mountains, is more than 50 times greater than in the coastal plain (Fig. 5). Since the gravitational forces involved are of similar proportion, the force available from the river in the plain is only two percent of that which carries the sand and gravel down from the mountains. It is evident that this force is insufficient to carry the bed load without assistance from other sources. The sediment deposited at this point of the river is shown on Figure 8 (a).

In most rivers, the transition from one section to another is gradual, and at times is even difficult to locate because the transition point may move up and down in response to tide and river discharge. In the St. Lawrence River, this point is hidden by the surge tank action of Lake St. Peter damping a great deal of the vertical tide fluctuation.

Montreal and the river section below were probably unaffected by the tide before any navigation improvements were undertaken. Extensive excavations (Fig. 2) have lowered the water level all along the river channel, giving the tide an opportunity to progress farther upstream. Of still greater importance, however, is the fact that the river slope, which in this instance is required to move ice and prevent ice-pack formation during the winter months, is reduced correspondingly.

It is therefore safe to assume that there exists today a greater tendency for the formation of ice-packs than in the past, though the intensive use of icebreakers prevents more frequent blockages.

These two examples show that gravity flow plays the dominant role in the upland river, but loses its influence in the coastal section. Further, it should be recognized that interfering with the dynamic balance established by nature may be advantageous in certain ways but can also have adverse effects in others.

Tide and Tidal Current

The tide is the regular periodic rise and fall of the surface of the seas. The force which creates the fluctuation is, again, gravity, though in this case the gravity effect is created by the attraction of the moon and the sun upon the rotating earth.

Along Canadian coastlines, the magnitude and general character of the tide varies greatly. The Atlantic tide, with an average range of approximately 4 ft., is regular and sinusoidal with two daily fluctuations whose high and low waters are nearly equal. The Pacific tide is of mixed type with considerable diurnal inequality, having two daily high waters and low waters, often differing substantially. Such a tide will be reproduced in the Fraser River model in the Hydraulics Laboratory to simulate the tide of the Strait of Georgia (Fig. 8 (b)). The wave in the model will be composed of the same two major constituents which prevail in nature, the diurnal and the semi-diurnal. Mathematically, this wave form is defined as:

$$\eta_t = 4.4 \cos 15\, t - 3.8 \cos 28.8\, t$$

The periods of both constituents have been slightly changed from that in nature. This adjustment does not affect the similarity to nature and was done to have the wave form repeat itself in intervals of 25 model days.

(a) Tidal Hydraulics

Physically, the tide can be described as a long wave phenomenon wherein the vertical velocities and vertical accelerations are negligible, while the tidal currents represent the horizontal motion of the water within this wave.

The tide, when it enters coastal waters, experiences marked changes due to friction, shallow waters and constriction in the topography of the channels. The response to these flow restrictions can be illustrated in a channel of constant width and depth. In the absence of friction and assuming the channel infinitely long, the tide wave will be progressive, characterized by the fact that the two respective energy components - the potential and the kinetic - are equal in magnitude. If, firstly, the channel were suddenly closed off and, secondly, suddenly opened into a wide body of water, a standing wave will form that could be considered composed of two waves travelling in opposite directions, i.e. the incoming wave and the reflected wave. The amplitude of the wave would increase in the first instance and decrease in the second. Closures and restrictions of any kind form positive reflections and enlargements in the channel form negative reflections with respect to the amplitude of the initial wave. Mathematically, the waves can be described as follows:

Primary progressive wave: $\eta_1 = A_o \cos (\sigma t - Kx)$ (4)

Reflected progressive wave: $\eta_2 = A_o \cos (\sigma t + Kx)$ (5)

The composite or standing wave is the sum of both waves:-

$$\eta = \eta_1 + \eta_2 \qquad (6)$$

In shallow waters the tide will also be modified by the friction to which the waters are subjected. The effect of such friction on the tide wave is similar to that of a great number of small barriers, spaced along the tidal inlet, each creating a small reflec

From the foregoing description, the assumption can be made that the tide wave in coastal waters is a composite wave composed of an initial ocean wave, on which numerous reflection waves are superimposed.

A somewhat different approach is that based on the assumption of exponential damping of the initial and reflected waves. The so-called "damping factor" includes all the principal restrictions such as shallow water, friction and changes in cross-section area. If it is assumed that the amount of energy dissipated is proportional to the total energy of the wave, the introduction of the damping factor leads to an exponential decrease of the amplitude. The surface elevations of the initial and reflected waves, respectively, are then given by:

$$\eta_1 = A_o \cdot e^{-\mu x} \cos (\sigma t - Kx) \qquad (7)$$

$$\eta_2 = A_o \cdot e^{\mu x} \cos (\sigma t + Kx) \qquad (8)$$

The exponential term $e^{\mu x}$ is the "damping factor". The tidal elevation η in the channel is given by the sum:

$$\eta = \eta_1 + \eta_2 = A_o \left[e^{-\mu x} \cos (\sigma t - Kx) + e^{\mu x} \cos (\sigma t + Kx) \right] \qquad (9)$$

The time of high water at any position in the estuary occurs when

$$\frac{\partial \eta}{\partial t} = 0; \text{ therefore}$$

$$\frac{\partial \eta}{\partial t} = e^{-\mu x} \sin (\sigma t - Kx) + e^{\mu x} \sin (\sigma t + Kx) = 0. \qquad (10)$$

Until now, the tide has been treated as a simple harmonic fluctuation, the tidal currents not entering the picture. Mathematically, both are subject to the same basic laws. The tidal motion, therefore, can be described by two differential equations, that of continuity and that of dynamics.

Equation of continuity: $$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = 0 \qquad (11)$$

in which q indicates the discharge per unit width, $q = \frac{Q}{B}$.

Equation of dynamics: $$\frac{\partial y}{\partial x} + \frac{v}{g}\frac{\partial v}{\partial x} + \frac{1}{g}\frac{\partial v}{\partial t} + \frac{|v| v}{c^2 r} = 0 \qquad (12)$$

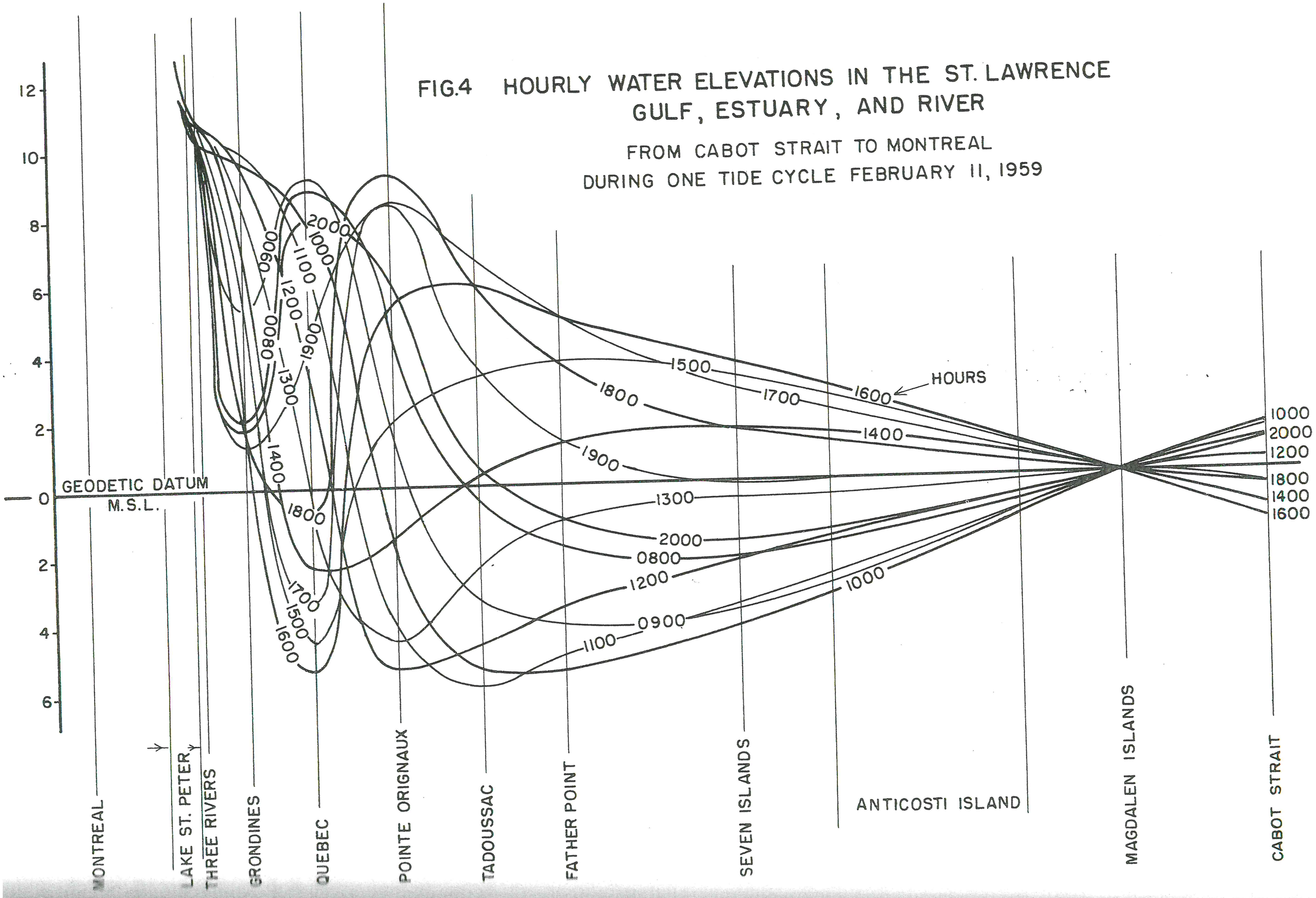


FIG.4 HOURLY WATER ELEVATIONS IN THE ST. LAWRENCE GULF, ESTUARY, AND RIVER

FROM CABOT STRAIT TO MONTREAL
DURING ONE TIDE CYCLE FEBRUARY 11, 1959

The second equation is familiar and is the same as used for the free-surface flow in open channels on Page 31.

A solution of these equations, which satisfies the boundary conditions of a channel of known tidal characteristics, gives the actual water surface elevation and flow velocities. Tidal hydraulic computations are therefore practical today and do not create great difficulties to an engineer trained in this field. The continuing problem is the prediction of properties which are required when modifications are made to the channels. For instance, the effect of simple groins on tidal motion in a regular channel is still of such complexity that a well-known continental coastal engineering institute has made it the subject of a long-term research project.

Compared with computations, models have the advantage that they take care of many of the unpredictable properties, in particular that of form losses. Under these circumstances, models are still the most reliable instruments with which to forecast changes in the hydraulic system of tidal rivers.

(b) The Tide in Canadian Rivers

The greatest and one of the most well-known tidal rivers is the St. Lawrence. Its tidal section is nearly 1000 miles long and extends from the Atlantic Ocean to the Lachine Rapids at Montreal (Fig. 1, 2).

The ocean tide enters the Gulf through Cabot Strait where it forms a standing oscillation which is further modified to an amphidromic tide by the earth's rotation. The hourly wave lines shown on Figure 4 indicate this feature and also demonstrate most impressively the reflection phenomenon which amplifies the tide range from zero in the Gulf to almost 16 ft. near Orleans Island. Above the island, shallow water, friction and severe restrictions reduce the tide range quickly. The surge-tank action of Lake St. Peter, imposing a negative reflection wave on the river section below the lake, is also an important reason for the fast decline in tide range.

In the Fraser River, the tide experiences great losses right at the mouth of the river (Fig. 5). This phenomenon is caused by the tide having to climb a steep slope into a river channel located on a kind of end moraine, elevated above the position normally expected for this type of estuary. This condition indicates that since its beginning the river has had difficulty in transporting its heavy load of sediment into the Strait of Georgia. The tide maintains its range above New Westminster, but ceases suddenly near Harrison Mills.

In both rivers, many improvement schemes have been undertaken, the methods used being:

(a) dredging, and

(b) restricting the flow by training structures such as groins, dykes and the closure of river arms.

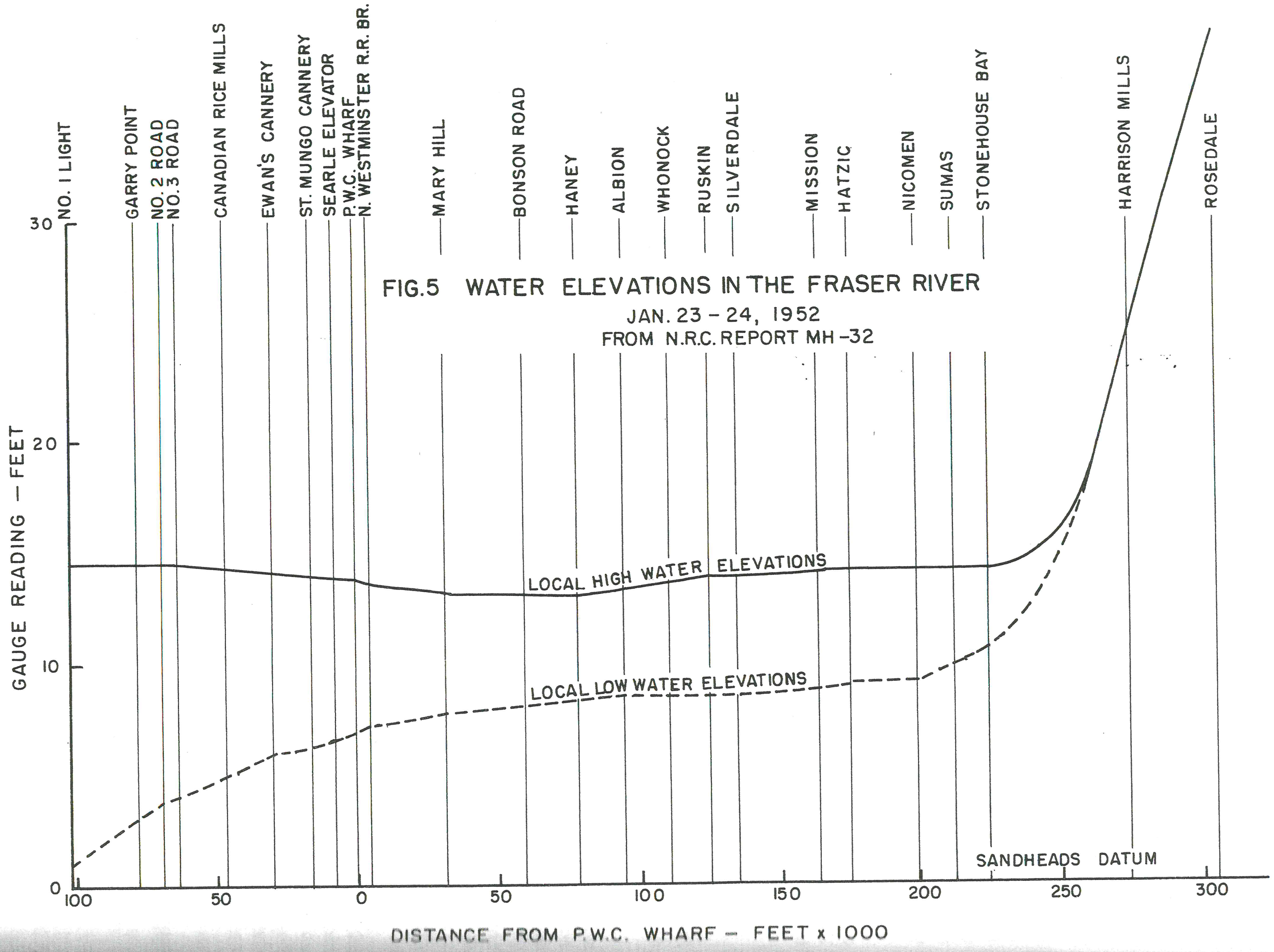


FIG.5 WATER ELEVATIONS IN THE FRASER RIVER

JAN. 23 - 24, 1952

FROM N.R.C. REPORT MH-32

Dredging in the St. Lawrence has decreased the current velocities and has in this way reduced the transporting capacity of the river to move its ice load. In the Fraser River, the annual excavation of approximately 3,000,000 cu. yd. has no lasting effect on the system because of the unlimited supplies available.

Of greater consequence, however, are the effects of installing flow restricting measures in both rivers. Spur dykes, for instance, are restrictions acting on the tide wave as described on Page 36. The dykes reflect part of the tide wave downstream, allowing passage only to damped waves whose energy and corresponding current are proportionately reduced. This reduction in currents weakens the system with the ultimate result that ice-packs form more readily in a river such as the St. Lawrence and the river bed rises in a river with a heavy sediment load such as the Fraser River.

The question often asked, is: "Does a tidal flow, which by itself is but a periodic motion in which a particle of water will be moved some distance upstream and an equal distance downstream, help to transport solids?" The question may best be answered by two examples of tide current recordings collected at Saint John, N.B. (Fig. 6).

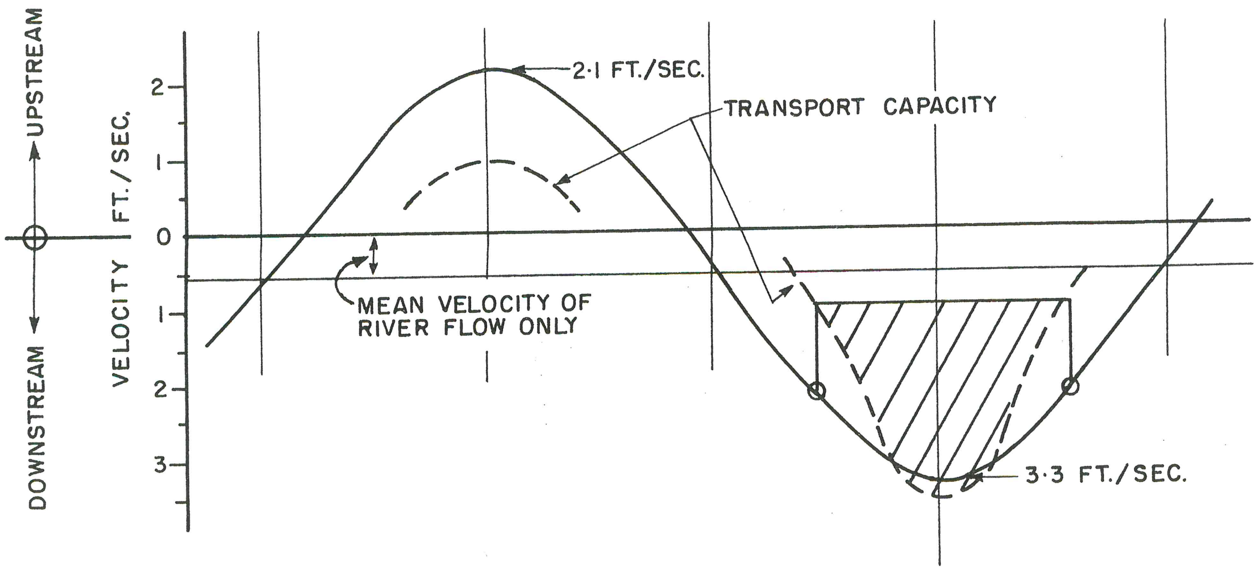
The maximum velocities in the second example are slightly greater than in the first. The river discharge in both is the same and the velocity at which the sediment starts to move is approximately 2.1 ft./sec. The transport capacity is assumed to be a third power relationship of the velocity, agreeing well with nature. The shaded area, enclosed in the dashed line, represents the quantity transported in and out during a tide cycle. In (a), no transport upstream has taken place, only downstream. In (b), sand was also carried upstream during flood tide owing to the slightly greater tide velocities; nevertheless, the residual transport downstream in (b) is twice that in (a).

From this it can be stated that the important contribution of the tide is picking up the sediment and keeping it in motion. The mass transport from the river drainage, small as it may be, is then capable of moving the material into the estuary and then into the ocean.

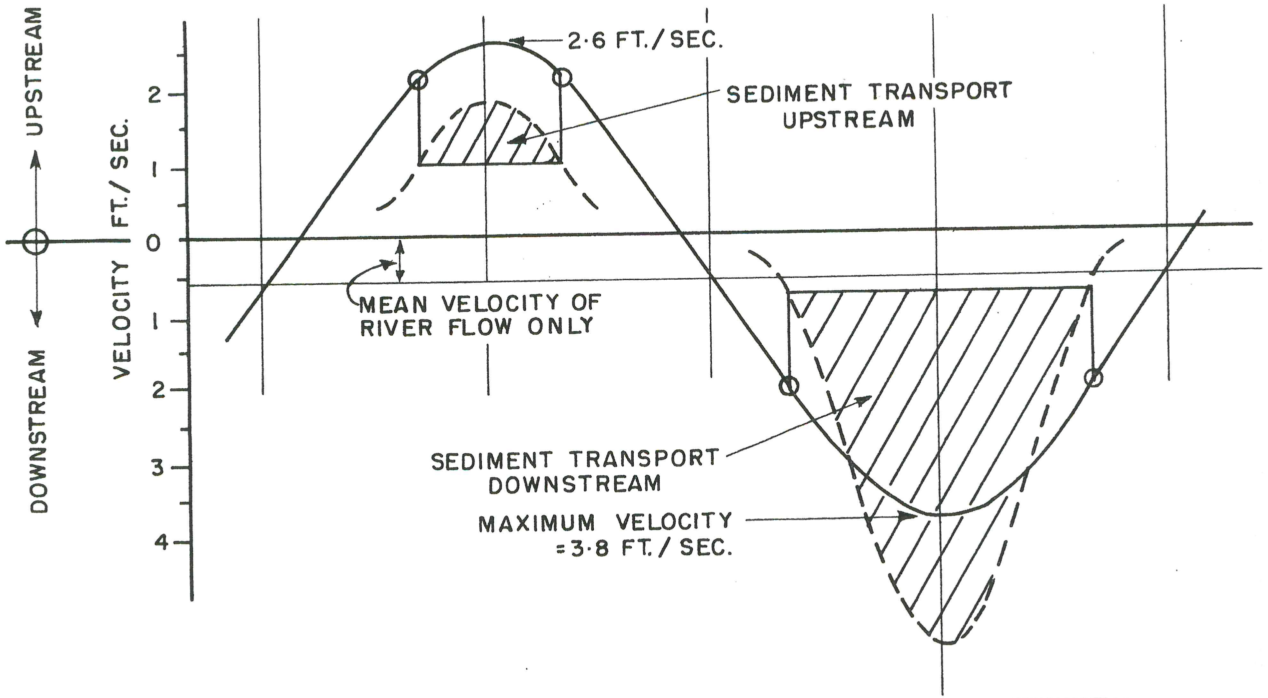
It is therefore obvious that structures which confine the propagation of the tide wave are, with few exceptions, contrary to the principle required to improve tidal rivers.

Density Current

The third principal force influencing the lower section of a river system is that of the density difference between the fresh water of the upland river and the salt water of the sea. The area affected is defined as the estuary. From the standpoint of its physical structure, it may be considered composed of two layers, an upper layer with a net flow toward the ocean and a lower layer with a net flow up the estuary toward the river.



(a) TRANSPORT CAPACITY OF A TIDAL CURRENT FLUCTUATING BETWEEN 2·1 AND 3·3 FT./SEC.



(b) TRANSPORT CAPACITY OF A TIDAL CURRENT FLUCTUATING BETWEEN 2·6 AND 3·8 FT./SEC.

NOTE – IT IS ASSUMED THAT BED MATERIAL MOVES WHEN VELOCITY IS IN EXCESS OF 2·1 FT./SEC.

FIG. 6 TRANSPORT CAPACITIES OF TIDAL CURRENTS

This pattern is more or less magnified by the oscillating current of the tide, which in fact is the primary source of the energy for the turbulent mixing between these layers. Based upon the intensity of mixing, estuaries are classified in three groups:

(1) Stratified, where the two bodies of water remain separate for a great distance.

(2) Partly mixed, where density contours are sloping, i.e. forming a wedge.

(3) Fully mixed, where no vertical density gradient exists.

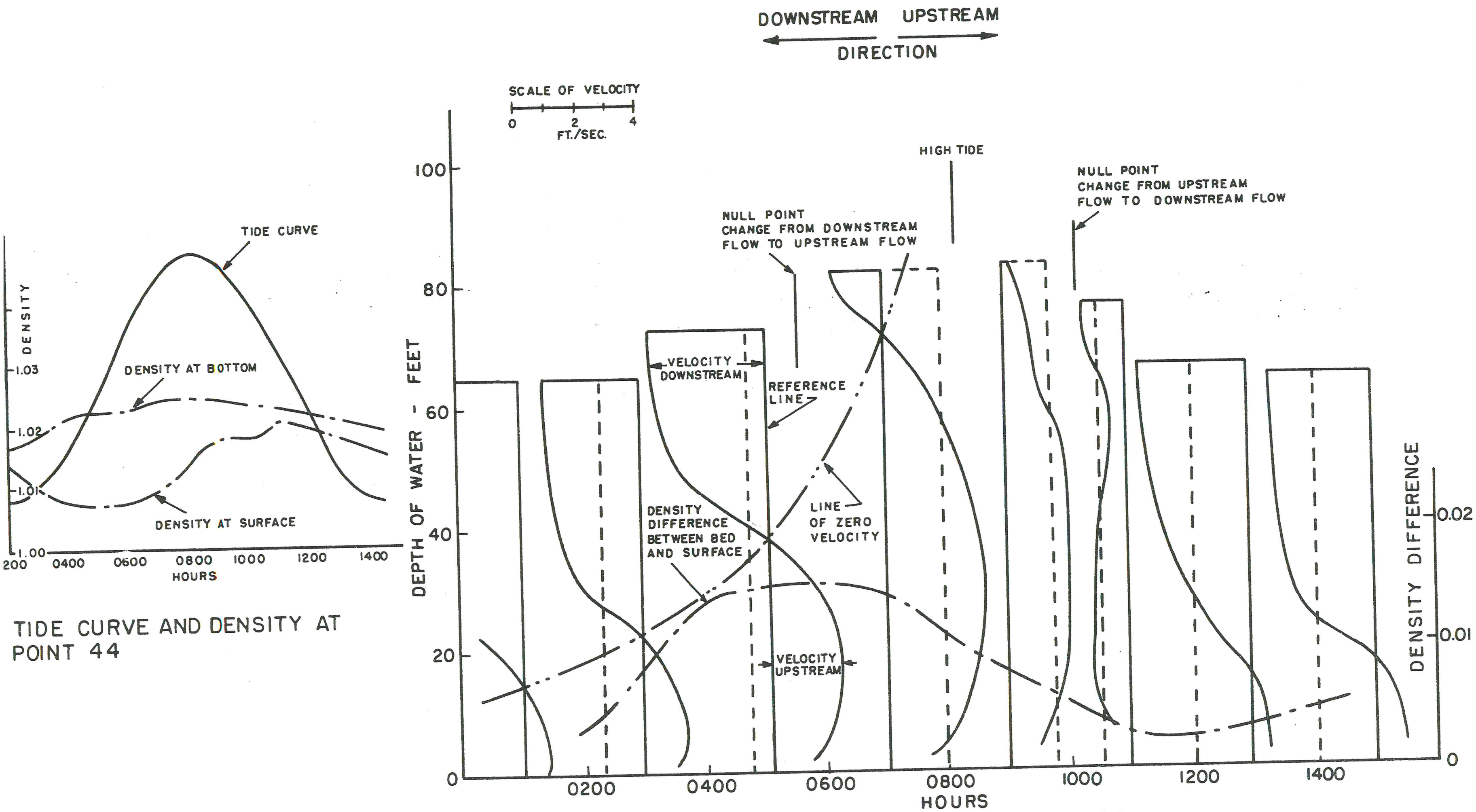
(a) Density Currents in Estuaries

In Canada, where most of the coastal waters are under the influence of an appreciable tide, estuaries generally are in the partly and fully mixed categories. In the partly mixed group, mixing occurs between the salt water flowing inward along the bottom and the fresh water of the upper layer flowing seaward. The volumes of flow involved in this net circulation pattern are often many times the volume of the fresh water outflow or the tidal prism. Thus, at the entrance to the Bay of St. John in the Bay of Fundy, about five times more salt water flows through the lower layer into the bay than is required to fill the tidal volume.

In Saint John Harbour (Fig. 10), where there is, on one hand, a tide averaging 21 ft. and, on the other, a very undiluted fresh water outflow through the "Reversing Falls", density currents are created which are unique. In Figures 7a, 7b, and 7c are plotted the tide curve, the density of the water at the bed and surface, the density difference and the velocities at a survey position in the centre of the harbour channel. During low tide the density difference between surface and bed is about 0.005. The ebb water flows out strongly over the top three-quarters of the depth, while in the remaining bottom quarter of the depth denser sea water moves in at 0.8 ft./sec.

On the rising tide the density of the surface water decreases and that of the bottom water increases. Over a time period of three hours a maximum density difference around 0.015 (compared with the full difference of 0.025 between fresh and salt water in this region) exists, with its peak at the slack water point, where the over-all movement of the water reaches a standstill before changing from downstream to upstream flow. At this particular moment 90,000 c.f.s. (velocities of 4 ft./sec.) flow through this channel outward at the surface and the same quantity inward at the bottom. From this time onward the salt water rises steeply to the surface and at high tide the density difference is substantially reduced, thereby reducing the superimposed density current.

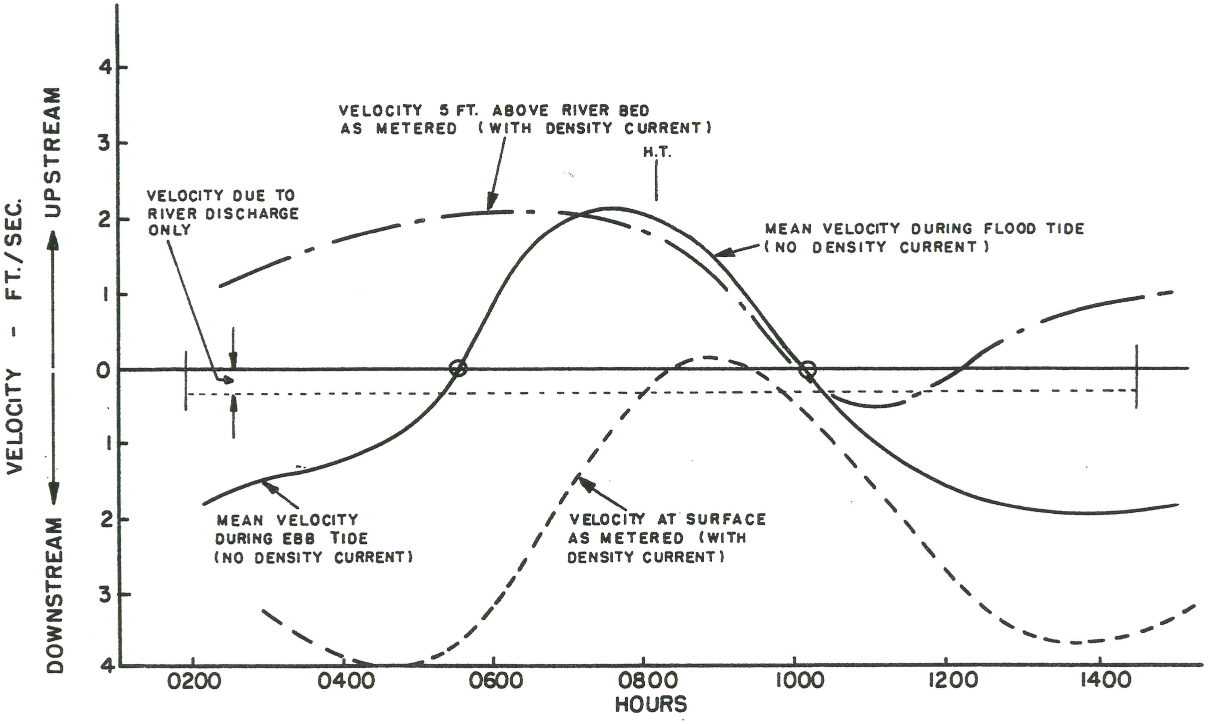
From the velocity measurements, the strengths of the three principal currents were evaluated for this river channel (Fig. 7c). The river discharge alone would cause currents not exceeding 0.33 ft./sec. With tide these increase to 2 ft./sec. but, with density effects imposed, the flow picture changes entirely. While the velocity



TIDE CURVE AND DENSITY AT POINT 44

(b) DENSITY DIFFERENCES AND VELOCITIES AT POINT 44

FIG.7 SURVEY DATA OF POSITION No. 44, SAINT JOHN HARBOUR, N.B.
AUG. 22, 1958



(c) RIVER, TIDAL, AND DENSITY CURRENT AT POSITION 44

FIG. 7 (cont'd) SURVEY DATA OF POSITION No. 44, SAINT JOHN HARBOUR, N.B.
AUG. 22, 1958

which would occur with tides but without density effect is zero at slack tide, surface velocities of 4 ft./sec. are directed downstream and bottom velocities of 2 ft./sec. upstream. At the surface the flow is continuously directed outward and at the bed nearly always inward.

This example is exceptional in its magnitude, but is typical for a partly mixed river and demonstrates most impressively the modification that density currents can impose on the current structure of a tidal river.

This fact is of the utmost importance to engineers dealing with rivers which open into coastal waters having littoral drift and in estuaries whose rivers have heavy loads of sediment or silt of colloidal origin. Using the example of the Saint John River again, sand is drawn, in this instance, into the harbour by the density current from the sand passing by along the west coast of the Bay of Fundy. Silt of colloidal origin is supplied from the Saint John River, which flocculates and falls when mixed with salt water. It was found that the strength of the current in the bed layer was so intense that silt deposited by hopper barges five miles off the harbour was returned into the river system within one tide cycle.

In the St. Lawrence, conditions are in general similar but with a change from less mixed in the Gulf and Anticosti Island area to partly mixed in the middle section and nearly fully mixed towards the head of the estuary. From a survey of the river, 75 miles below Quebec City, it was established that a strong density current is superimposed on the tidal current. This two-layer flow system in this section of the river is affected by the rotation of the earth in such a way that the surface layer flowing outward and the bed layer flowing inward are (in their residual motions) directed toward the south shore and north shore respectively. A calculation of the strength of the deviating forces acting on a 20-ft. deep surface layer reveals that those to the south shore are three to four times greater than those to the north shore. Density current is here the initial cause for the phenomenon of ice accumulating along the south shore during the winter months. The excess of deviation forces on the surface layer piles up the ice and holds it against the south shore until melted during spring. The wind, which is predominantly from the northwest, contributes to this deviation, but cannot alter it.

The estuary is so large that engineering methods will not be able to modify its kinematic structure for quite some time. However, one would think that a stronger density difference would deflect the ice still more to the south, leaving a more ice-free navigable channel along the north shore, which is one of the requirements for winter navigation. Since the outflow of Lake Ontario is controlled, a greater discharge released during the critical winter period may give this desirable effect.

The density structure of the Fraser River cannot be discussed, because, to our knowledge, no such survey exists.

In the United States, a number of estuarine problems have been studied recently, such as the Mississippi Delta, the Delaware Estuary, the Chesapeake Bay and the lower Hudson River. Experimental work and basic investigations are under

FIG. 8(a)

View of the Fraser River near Chilliwack. Vast gravel and sandbanks cover the river bed. Tide fluctuation commences in this area.

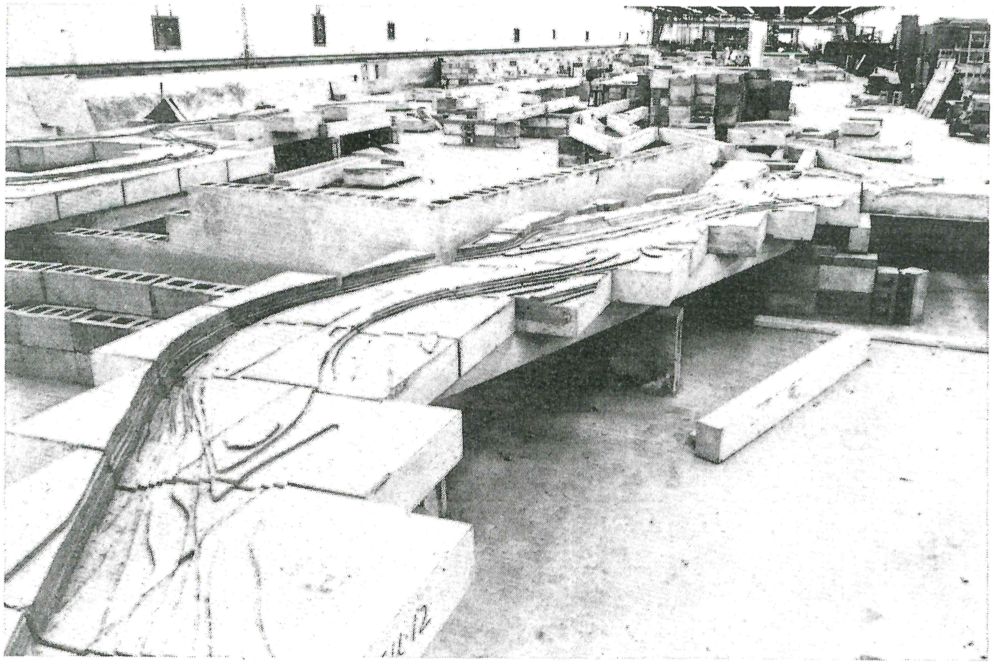


FIG. 8(b)

Fraser River Model under construction in the Hydraulics Laboratory. View of the model from the Strait of Georgia inland. In the foreground are placed the river blocks between Sandheads and Steveston.

FIG. 8

FRASER RIVER INVESTIGATION

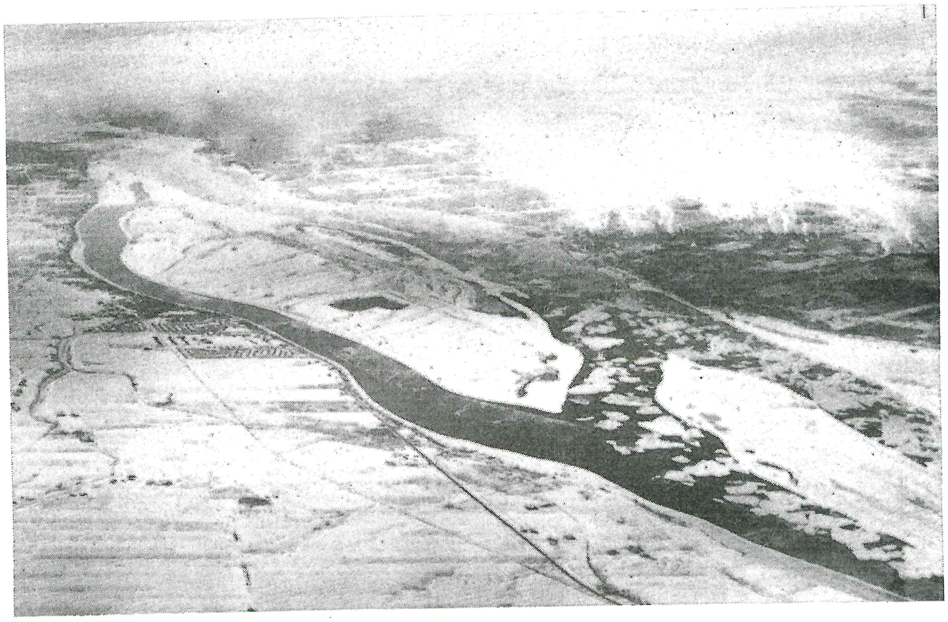


FIG. 9(a)

View of the St. Lawrence River at Montreal on Dec. 24, 1959. Sheet ice has formed but still free floating. Two days later, the river was completely closed.

FIG. 9(b)

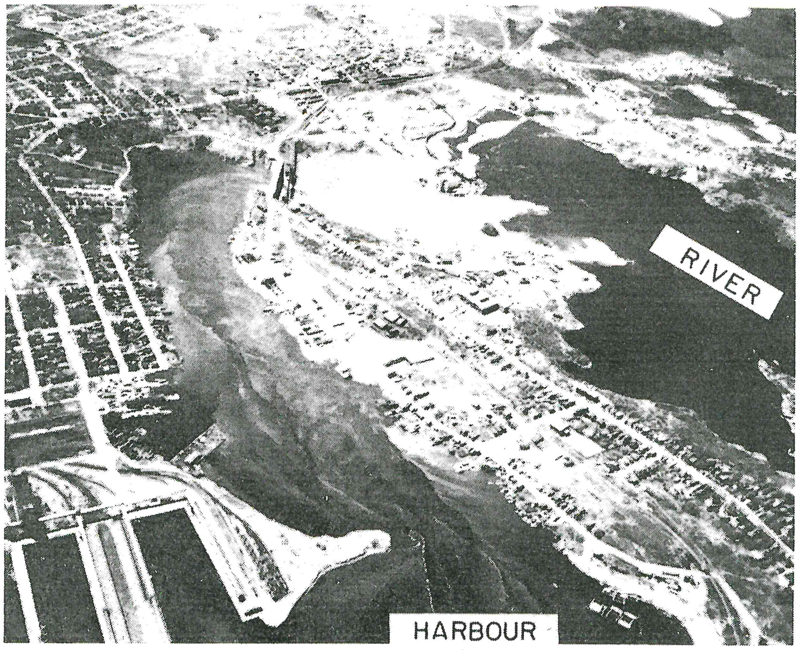
View of the St. Lawrence from Three Rivers downstream on Dec. 24, 1959. Landfast has formed, but channel remains open because of tide action.

FIG. 9

AERIAL PHOTOGRAPHS OF ICE CONDITION
IN THE ST. LAWRENCE RIVER

FIG. 10(a)

View from the Bay of Fundy, 7 miles outside the harbour of Saint John, N. B., into the Bay of Saint John. In the left background Saint John Harbour and River. The water in foreground is sea water, the darker is a relatively thin layer of river water overlaid on the sea water of the Bay of Saint John.



TIDE STAGE:
HIGH WATER

FIG. 10(b)

View of river section in Saint John Harbour from City Harbour to Indiantown. In the centre, above the bridge are the Reversing Falls. The clouds below the Falls are fluid mud along the bed being agitated on its way to the Falls. In the Falls, the silt is thoroughly mixed but reforms immediately as a bed layer under the fresh river water upstream, because of the higher density of the silt and sea water mixture.

FIG. 10

AERIAL PHOTOGRAPHS OF FRESH AND SEA WATER MOVEMENTS
IN THE BAY AND HARBOUR OF ST. JOHN, N.B.

way in various institutes and research centres to bring more order into this subject and to supply data and coefficients which will enable the engineer to deal with the problem more analytically. A method is described in Reference 3 for uniform estuaries with co-oscillating tide; diffusion and tidal parameters were developed which give a possibility of making quantitative predictions regarding salinity intrusions without prior knowledge of any existing salinity condition.

An investigation of the salinity intrusion in the St. Lawrence along this line appears promising.

CONCLUSION

Usually engineers and scientists are called upon to predict changes in the structure of a river which will occur as a result of modifications to the geometry or hydraulic characteristics. The methods utilized, such as dredging, training works and diverting and closing off channels, are well known and in world-wide use. Their generalized application, however, has often damaged certain sections of rivers, because procedures which solve problems in one part of the river may have an adverse effect on others. As has been shown, measures developed for the upland river in accordance with river hydraulics, such as restrictive flow measures, are contrary to the principles for improving tidal rivers. In estuaries, this may prove to have still greater consequences owing to the superimposed two-layer density flow. It has been found that only fundamental changes in the structure of a system, such as bypassing the fresh water and discharging it into the ocean where it cannot create any disturbance, as in the case of the Saint John Harbour, could be considered a lasting solution.

It is customary to speak of "nature's delicate balance" which man cannot touch without bringing about adverse effects. However, this is only true when the measures applied contradict the basic principles of the dynamics of motion.

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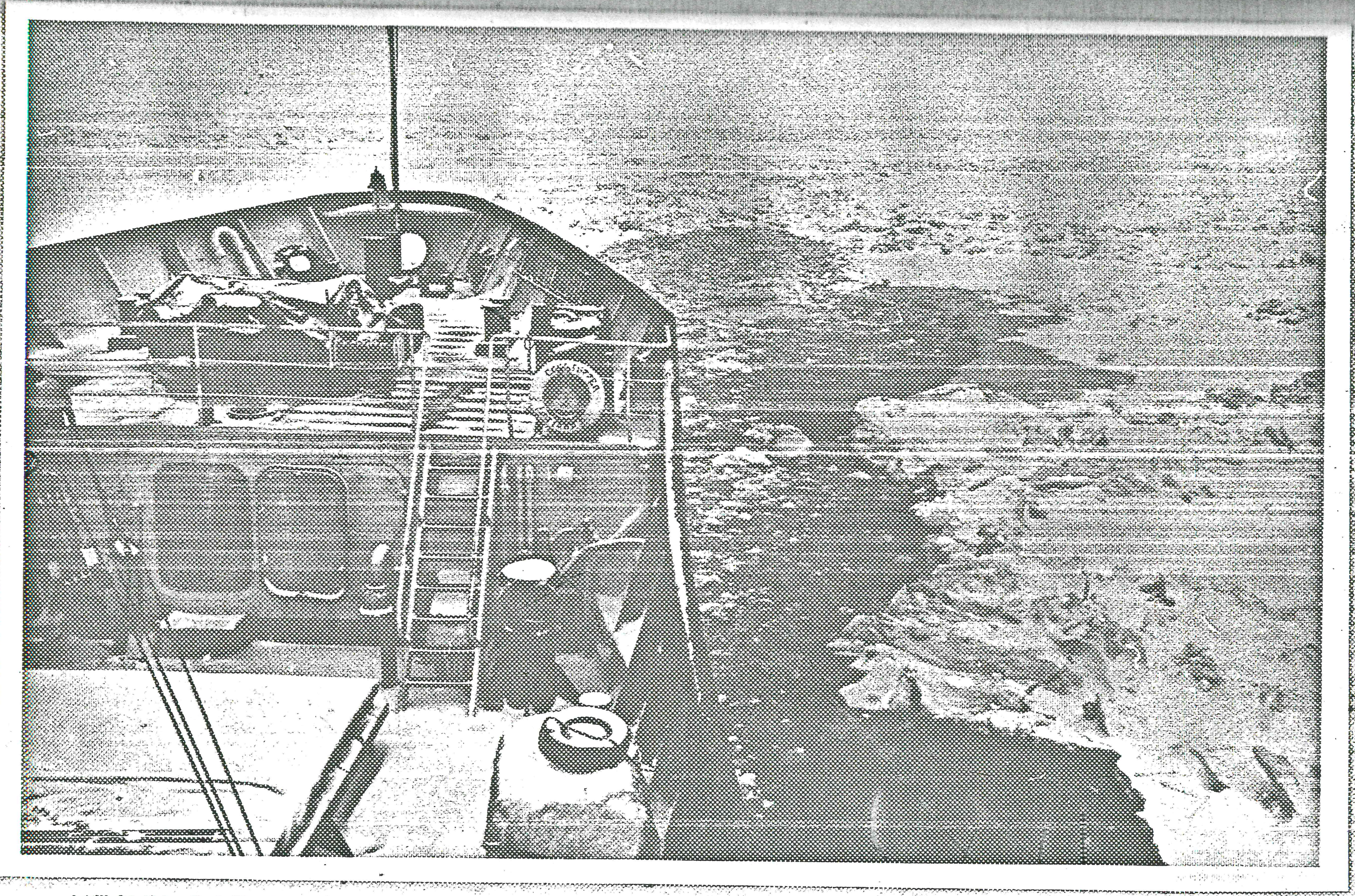
LIST OF SYMBOLS

Symbol	Definition
y	Vertical direction, ft.
x	Longitudinal direction, ft.
$\frac{\partial y}{\partial x}$	Slope of the water surface
v	Mean velocity in the direction of channel, ft./sec.
$\frac{\partial v}{\partial x}$	Rate of change of velocity over distance, sec.^{-1}
t	Time, sec.
$\frac{\partial v}{\partial t}$	Change of velocity (at given point), ft./sec.^2
g	Acceleration of gravity, ft./sec.^2
c	Chezy coefficient, $\text{ft.}^{\frac{1}{2}} \times \text{sec.}^{-1}$
r	Hydraulic radius, ft.
η	Tidal wave elevation above or below mean sea level, ft.
η_1	Tidal wave elevation of initial wave, ft.
η_2	Tidal wave elevation of reflected wave, ft.
A_o	Amplitude of initial and reflected waves at closed end of tidal channel, ft.
$\sigma = \frac{2\pi}{T}$	(T = period of ocean tide)
$t_o = 0$	(corresponds to high water at end of channel)
$k = \frac{2\pi}{\lambda}$	(λ = wave length)
μ	Damping coefficient
e =	2.718



HEAVY RAFTED ICE OFF SOUTH SHORE OPPOSITE POINTE DES MONTS
C.C.G.S."TUPPER" HAS BEEN STOPPED BY THE ICE, HAS BACKED OFF AND IS
PREPAIRING FOR A FURTHER ASSAULT
FEBRUARY 21, 1963