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The Utilization of Tidal Energy

The utilization of tidal energy has been discussed by many writers and many methods have been suggested to transform this energy possessed by the water in motion to some more useful form. In some few cases a practical method has been evolved and used. From the many suggestions four general systems may be tabulated.

(1) The float system

(2) The tidal-stream system

(3) The compressed air system

(4) The basin system

The Cooper Power Project is in effect a proposal to make use of the basin system to utilize the tidal energy of the Bay of Fundy waters. The basin system is simple in principle and is probably of the greatest importance from an engineering point of view because it permits of large scale installations. The basin system consists principally of one or more basins which are cut off from the sea by dams. By use of suitable gates and by making use of the tides a head of water is maintained between one basin and another or between one basin and the sea. Making use of the potential energy which is stored in one of the basins, turbines and auxiliary machinery transform it into electrical energy.

The Power Possibilities of Fundy Tides

Much has been written on the power possibilities of the tides in the Bay of Fundy and the more salient points only will be mentioned here. The tides in the Bay of Fundy are the largest tides in the world. The bay itself comprises an area of approximately 6000 square miles. The mouth of the bay is usually taken from Jebogue Pt. to Pt. of Main, a distance of about 85 miles. The average depth is about 275 feet, and it is to be noted that the floor of the bay slopes upward from the mouth to the head. The mean range of the tide varies from about 9 feet at Cape Sable to about 44 feet at Noel Bay. The Spring tides are about 15% greater giving for the Spring range at Noel Bay a value of about 51 feet. The average range for the bay is about 22 feet. From this data the available energy works out to about 175,000,000 horse power. It is indeed then no surprise that the power possibilities of the Bay of Fundy tides have attracted and engaged the attention of some of our foremost engineers.

The Cooper Power Project

As heretofore stated the Cooper Power Project is in effect an application of the basin system to develop some of the energy present in the waters of the Bay of Fundy. The proposal is to build a series of dams which will shut off the waters of Passamaquoddy Bay and Cobscook Bay. In effect then these two bays constitute the two basins of the system. A general idea of the proposal may be gleaned from Figure 1. From Passamaquoddy Bay 330,000 cubic feet of water per second will be run continuously through the power house into Cobscook Bay. From 1½ hours before H. W. until 25 minutes after H. W., water will flow into Passamaquoddy Bay through gates at

Letite and Kendall Head. The "draw down" of the water in Passamaquoddy between successive refills will be only five feet. From 3½ hours before L. W. until 15 minutes after L. W., water will flow out of Cobscook Bay. The scheme is however only in the making and many problems are yet to be solved before it can be placed before the public as a feasible undertaking. The possibilities of the scheme can be seen from a consideration of the energy that is potentially present in the tidal waters that enter Passamaquoddy Bay. The area of the bay is about 100 square miles and taking the mean range of the tide as 20 feet the available energy amounts to 2,500,000 horse power. It is stated that between 500,000 and 700,000 horse power can be developed profitably at a cost of about $100,000,000.

From the meagre outline of the scheme it is to be noted that the project proposes to close off Passamaquoddy Bay from the Bay of Fundy. There are a number of problems of great economic importance arising from a proposition of this kind. This paper deals with the possible effects of this scheme on the tides in the Bay of Fundy.

Tides in the Bay of Fundy

A study of the tides in this region will immediately convince one that Fundy tides are unique, not only because they are the greatest tides in the world, but because of the various factors that enter to determine the enormous range of the tides.

The tidal range in the Bay of Fundy increases from a value of 9 feet at the mouth to 44 feet at Noel Bay. Many bays along the Atlantic sea-board although possessing physical features similar to those of the Bay of Fundy have tidal ranges of only 4 or 5 feet. From this it can be seen that although the gradual decreasing depth as well as the gradual narrowing of the bay play an important part in increasing the tidal range (due to the cooping up of the waters), yet we must look for some further explanation of the large tides in the Bay of Fundy.

If tide tables for this region are consulted it will be noted that there is very little retardation in the time of the tide as it proceeds up the bay. This fact together with the increasing range proves conclusively that the tidal phenomenon in this region is of the "Stationary Wave" type. Several writers have likened the phenomenon to that of a body of water oscillating in a rectangular trough, the natural period of which is given by the formula,

$T = \sqrt{4L/gh}$ where,

L is the length of the trough,

h is the depth of the water and,

g is the acceleration due to gravity.

Using this formula various values between 11 and 13 hours have been obtained for the natural period of oscillation of the waters of the Bay of Fundy.

It will be noted in Figure 2, which illustrates the nature of the oscillation in a rectangular trough, that the point P is one for which the range would be zero. This point may be called a node. It is also to be noted that the surface of the water can be represented by a straight line. If the Bay of Fundy tides are of the nature of a stationary wave then an analysis should bring out some interesting facts to show this. Accordingly in Figure 3 various ranges have been plotted for various points within the bay. No attention has been paid to the tidal time differences because they are small. The values of these differences are shown for the points in question. It will be noted that the surface is represented approximately by a straight line. Again by producing the graph to the left a point is found where the range of the tide is zero and this is the nodal point. The point thus determined is in the vicinity of the waters at the edge of the continental shelf.

In dealing with an oscillating system such as a body of water contained in a rectangular trough it is to be noted that if the system is set oscillating it oscillates with its natural period determined by the length and depth of the trough. If a periodic disturbing force is applied, the period of which is the same as the natural period of the system, the amplitude of the oscillation will be increased, and will be prevented from becoming infinite by the various forces of resistance that are set up. And so it is with the phenomena of the tides in the Bay of Fundy. The disturbing force is the resultant of the tide producing forces of the sun and the moon. The period of oscillation of the bay is apparently the same as the periodic disturbing force, namely 12.42 hours. The amplitude of the oscillation is controlled by the various resisting forces.

It is to be remembered however that a progressive tide wave is also present and the enormous tides cannot be wholly attributed to a standing oscillation; it must be explained by taking all the facts into consideration, the physical features of the bay, the presence of a progressive wave, and the presence of a standing wave.

It can be shown also, that even though a progressive wave must accompany the phenomena of the tides in this region, the effects are minimized by the presence of the stationary wave. The velocity of a progressive wave is given by the formula,

$v = \sqrt{gh}$ where,

v is the velocity,

h is the depth and,

g is the acceleration due to gravity.

Taking the average depth as 280 feet we obtain v = 94.6 feet per second. Using this value, the time required for the progressive wave to travel from Grindstone Island to Grand Manan, a distance of 130 miles, is given as 2 hours. A glance at the table of tidal time differences will show that the actual time is only 22 minutes.

Nature of the Problem

The problem of detemining the effect of operation of the Cooper dams on the tidal range in the Bay of Fundy resolves itself into a study of the resulting variations of the factors determining the tidal amplitude. These factors will be discussed separately under the following headings:

1. Tidal Energy

2. Natural Period of Oscillation.

Tidal Energy

The general result obtained for the amount of energy stored in Passamaquoddy Bay (35×10^{12} ft. lbs.) during six hours points to the fact that the waters entering the Bay of Fundy sacrifice this energy to the Passamaquoddy Bay region. Anyone familiar with the general physical conditions at the entrance to Passamaquoddy Bay will realise that a further large amount of energy must be sacrificed by the waters of the Bay of Fundy to force the waters entering Passamaquoddy Bay through the many narrow channels. The amount of energy dissipated at this entrance must be enormous as the tide rips and whirlpools produced are strong and dangerous. Hence it is easily seen that if this energy was conserved by the waters of the Bay of Fundy and carried forward the range of the tides in the Fundy region would be increased. A simple calculation determines the result. If the height of the water at any point is plotted against the time a close approximation to the sine curve results and hence the motion of the water is an example of simple harmonic motion and the amplitude varies directly as the square root of the energy.

Calculated energy carried into the Bay of Fundy in six hours ———————————— 25×10^{14} ft. lbs.

Calculated energy transferred to Passamaquoddy Bay in six hours ———————————— 35×10^{12} ft. lbs.

% increase in the energy of the waters of the Bay of Fundy if Passamaquoddy Bay were shut off —— 1.4 %

Resulting change in amplitude ———————— 1.2 %

If we give an approximate value to the energy that is now lost in the entrances to Passamaquoddy Bay the percentage increase would be higher. Suppose that this energy lost amounts to about 35×10^{12} ft. lbs. The resulting percentage increase in energy in the Bay of Fundy following the closing off of Passamaquoddy Bay would be 2.8%. The resulting percentage increase in the amplitude of the Fundy tides would then be 1.7%. The effect at several points are noted as follows:

Welchpool:
At spring tides an increase in range of .4 ft.

St. John:
At spring tides an increase in range of .45 ft.

Grindstone Is.:
At spring tides an increase in range of .7 ft.

Burntcoat Hd.:
At spring tides an increase in range of .85 ft.

Natural Period of Oscillation

It has been pointed out that the amplitude of the tides in the Bay of Fundy depends upon the natural period of oscillation of the bay. From this it follows that anything which would enter to change this natural period of oscillation would result in a change in the tidal amplitude. It is then of importance to determine whether the waters of Passamaquoddy Bay enter to determine the oscillatory period of the waters of the Bay of Fundy.

Length and depth are primary factors in determining the natural period of a bay. Other factors enter however, to determine the actual period with which the waters contained will oscillate. A simple experiment with models has demonstrated this fact. Troughs were constructed, as shown in Figure 4, to approximate to the actual model of the Bay of Fundy and Passamaquoddy Bay. The troughs were filled with water to a suitable depth and an oscillation was set up. The general results may be noted as follows:

1. Using troughs whose periods of oscillation were equal,
   (a) closing off Passamaquoddy Bay resulted in an increased amplitude in the Bay of Fundy,
   (b) closing off Passamaquoddy Bay did not effect the period of oscillation in the Bay of Fundy.

2. Using troughs whose natural periods of oscillation were different,
   (a) closing off Passamaquoddy Bay resulted in a decrease in period in the Bay of Fundy.

The results in 1 (b) and 2 (a) can also be deduced theoretically by a consideration of the compounding of two vibrations.

It is then of importance for the problem in hand to answer the following questions:

1. Do the waters of Passamaquoddy Bay oscillate with a definite and regular period?

2. If there is an oscillation present,
   (a) what is the period?
   (b) what is the relation between the oscillation in Passamaquoddy Bay and that in the Bay of Fundy?

Considering Passamaquoddy Bay as a unit by itself it is quite probable that left to itself various forms of seiches may be set up. As part of the Bay of Fundy system an oscillation may be communicated to it from the Bay of Fundy waters if conditions at the mouth are suitable. Japanese investigators have made extensive investigations of the conditions necessary for the communicating of oscillations from a large body of water to bays and estuaries. As a result they have reached the following general conclusions:

1. In a bay of considerable area or a shallow bay communicating by a narrow opening, the secondary undulation is in ordinary cases inconspicuous.

2. In a deep bay or estuary, the breadth of which is not large in comparison with its length, the secondary undulations are most pronounced.

From these considerations it is to be expected that any oscillation transmitted to the waters of Passamaquoddy Bay will be inconspicuous.

Simultaneous tidal readings were taken at various points in the Bay and the results show that there is very little oscillatory movement of the waters. The tidal water is carried in and out as though a large tank were being filled and emptied. The kinetic energy of the incoming water sometimes results in a piling of the waters at one end of the bay. Similarly the outgoing waters may have a similar effect at the mouth of the bay. This piling of the waters is more often inconspicuous due to adverse wind action.

The explanation for the absence of a pronounced oscillation in Passamaquoddy Bay rests in the fact that conditions at the mouth of the bay are unsuited for the transmission of the oscillation from the Bay of Fundy. Coupled with this explanation must be the supposition that the natural period of Passamaquoddy Bay, as determined by the length and depth, is unsuited for resonance with the movement to and fro of the tidal waters.

Conclusions

We are then led to the conclusion that the required amplitude effect on Fundy tides brought about by the operation of the proposed dams can be obtained by a consideration of the additional energy that will be carried forward into the Bay of Fundy. This additional energy represents that which is now carried forward into Passamaquoddy Bay and that which is used up in forcing the waters through the various channels at the mouth of Passamaquoddy Bay. In deriving our results we have sought for the maximum change which would be obtained when all inlet gates are closed over a complete tidal period. Hence no account was taken of the actual amount of water that would be taken through the gates. No account has been taken of the operation of the outlet gates nor the damming of Cobscook Bay. Hence our results are only a fair approximation for the maximum effect.

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The Tides.-----------------Darwin

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Handbuck der Ozeanographie------Krummel.


New Brunswick
Maine
Passamaquoddy Bay
St. John
Quaco Hd.
Lepreau
Bay of Fundy
Noel Bay
Port George
Cobscook Bay
Lubec
Seal Cove
Nova Scotia
Jeboque Pt.
Cape Sable

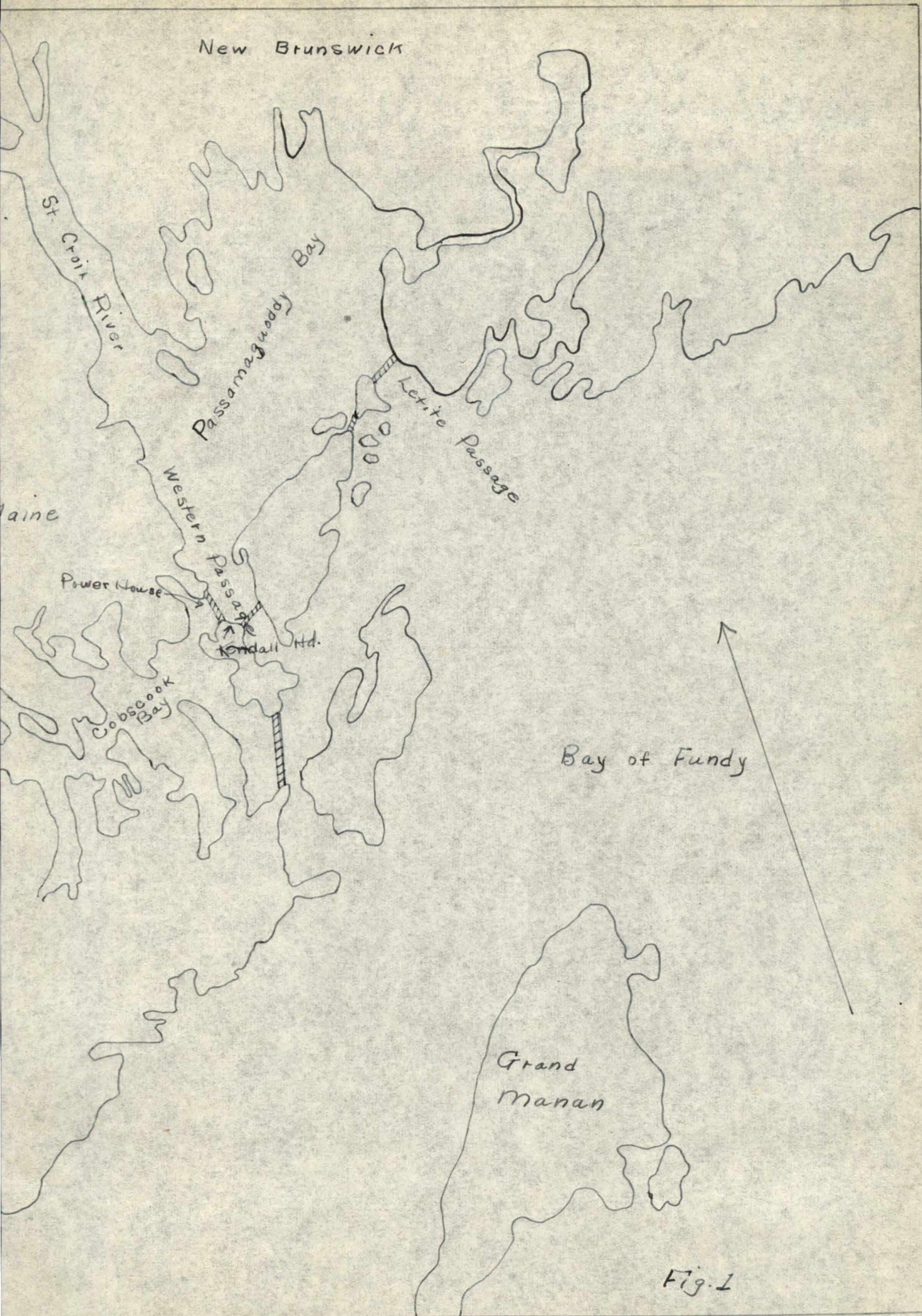
New Brunswick
St. Croix River
Passamaquoddy Bay
Letite Passage
Western Passage
aine
Power House
Kendall Hd.
Cobscook Bay
Bay of Fundy
Grand Manan

Fig. 1

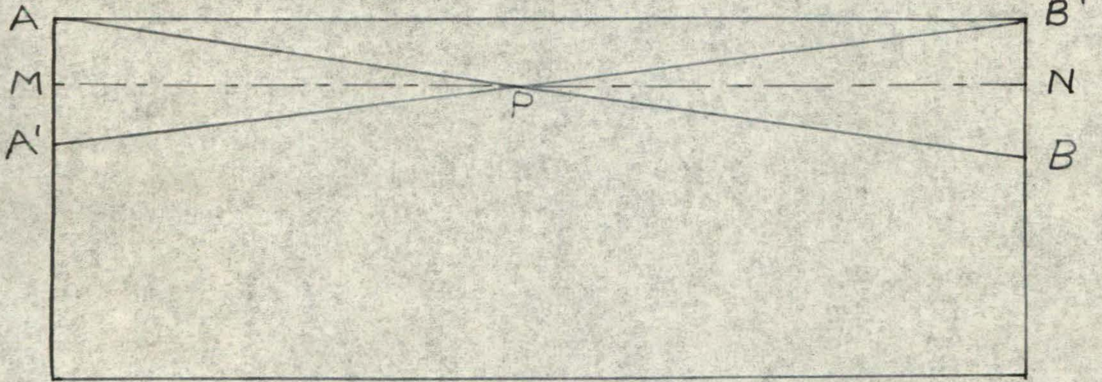

Fig. 2.

MN - undisturbed Surface

AB and A'B' - Surface resulting from oscillation

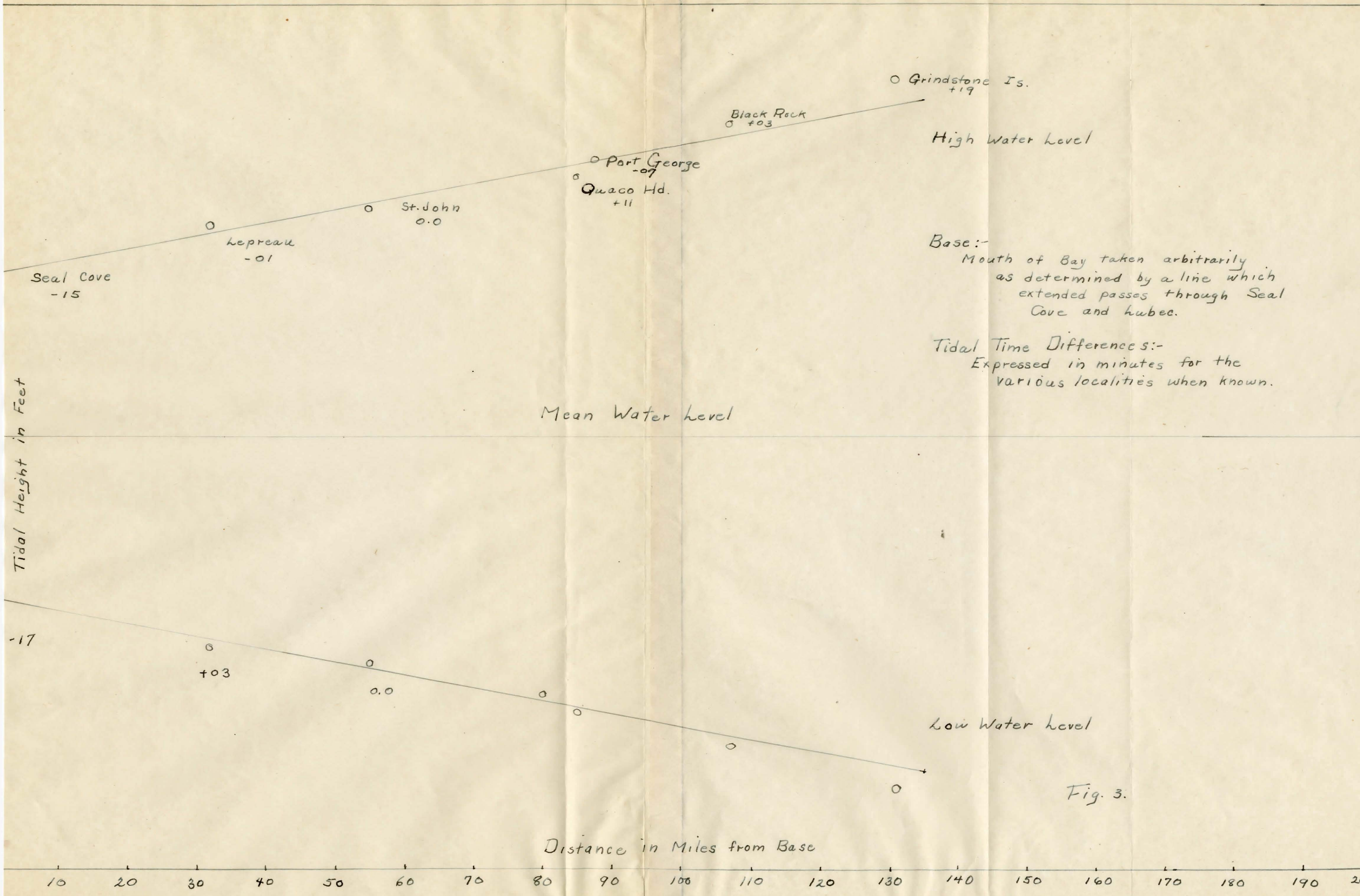
Grindstone Is.
+19
Black Rock
+03
High Water Level
Port George
-07
Quaco Hd.
+11
St. John
0.0
Lepreau
-01
Seal Cove
-15
Base:-
Mouth of Bay taken arbitrarily as determined by a line which extended passes through Seal Cove and Lubec.
Tidal Time Differences:-
Expressed in minutes for the various localities when known.
Mean Water Level
Tidal Height in Feet
-17
+03
0.0
Low Water Level
Distance in Miles from Base
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

Fig. 3.

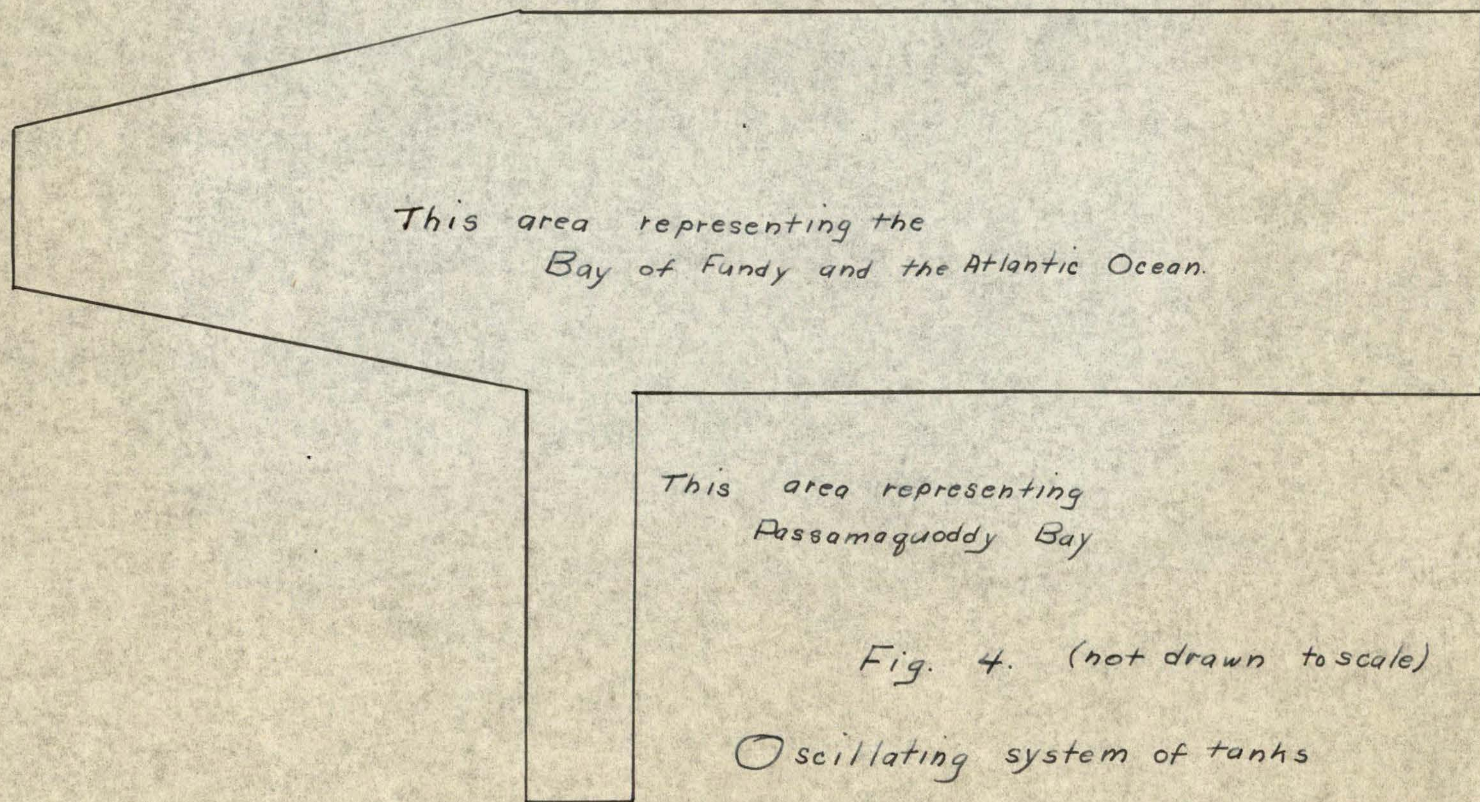

Fig. 4. (not drawn to scale)

Oscillating system of tanks