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# THE CURRENTS

AT THE ENTRANCE OF THE

# BAY OF FUNDY

AND ON THE STEAMSHIP ROUTES IN ITS APPROACHES

# OFF SOUTHERN NOVA SCOTIA

FROM INVESTIGATIONS OF THE TIDAL AND CURRENT SURVEY IN THE SEASON OF 1904.

W. BELL DAWSON, M.A., D. Sc., F.R.S.C., M. CAN. SOC. C. E., ENGINEER IN CHARGE.

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OTTAWA, Feb. 20, 1905.

During the season of 1904, from May to September, the currents were examined at the entrance of the Bay of Fundy, in the region entending from Grand Manan island to Cape Sable. The currents in this region were an entire contrast to those examined in the previous season, and required a corresponding modification in appliances and methods. They were strong, steady and deep; instead of weak and often superficial and easily disturbed by the wind as on the south-east coasts of Newfoundland.

This region is of the first importance to navigation, as it includes waters that lie on the lines of ocean steamships running to St. John, N.B., as well as steamers from United States ports which round the southern end of Nova Scotia, on their way to Europe. This is the first time that the currents on these routes have been systematically investigated with modern appliances. These outer waters are also of more importance to navigation than the tidal streams in the more restricted part of the Bay of Fundy. It has there the character of an estuary, in which the currents run parallel to the shores; and they have thus little tendency to set a vessel out of its course.

*Methods and appliances.*—The steamer *Gulnare* which was employed in this investigation, was anchored at points carefully fixed in position; and these stations were chosen in the vicinity of the steamship routes to obtain information of the most practical value to navigators. They were thus far enough from shore to avoid the local influences found among islands and shoals which are numerous on this coast within the 30-fathom line. The anchorages were made in all depths up to 100 fathoms.

A brief mention of the appliances used will suffice. The strength was determined from actual measurements of velocity with a current-meter registering electrically on board. The meters used were rated by the makers. A special method of suspension was devised to avoid error from the rolling of the steamer. When the rolling was considerable, an allowance was made by count for the excess. For the direction of the current, a float of special design was used, which was attached by a line from the stern. It was made visible at night by an electric light operated from an auxiliary battery.

The under-current was observed by means of a pendulum weight, suspended on patent sounding wire. This was the same in principle as the deep fan used for the weak currents met with in previous seasons. For these stronger currents the design was modified. The weight consisted of brass tubing 4 inches outside diameter and 24 inches long; and it was found necessary to weight this to thirty pounds. This could be lowered to any desired depth. The direction of the under-current would then be clearly indicated; and its strength became known also from the angle of the wire with the vertical, as measured by a clinometer. The actual velocity of the current corresponding to the various angles of inclination was determined by direct comparison with the meter at the same depth. The amount of experimental work which was necessary to secure satisfactory values for reducing this class of observations was considerable; but it will be unnecessary to explain the technicalities of the reduction.

*Observations of current and tide.*—In brief, the observations taken were as follows:—Surface current: The velocity was measured by the electrical current-meter at the standard depth of 18 feet; and the direction was taken every half hour day and night continuously. Under-current: The direction and strength were ascertained during the day time by the method explained; with special reference to the maximum strength during flood and ebb, and the time of slack water. The observations were taken at a standard depth of 30 fathoms, when the total depth was sufficient. Special determinations at other depths were made to determine the average speed of the whole body of the water, more especially in straits and channels. For comparison with these observations, the tide was recorded throughout the season by self-registering tide gauges at St. John and Yarmouth. In this way, the actual rise and fall of each tide was secured, as well as the time of high and low water for comparison with the turn of the current. Also, at the new lightship on Lurcher shoal, observations of the current were made throughout the greater part of the season.

*Accessory observations.*—The temperature of the surface water was taken usually every two hours, while at anchor at the various stations; and also at short intervals on runs that were made. The temperature was also obtained to a depth of 30 or 50 fathoms by deep-sea thermometers. This was done in the hope of better tracing the movements of the water. A barograph on board the steamer gave a continuous record of the height of the barometer; and an anemometer measured the velocity of the wind. The actual mileage and direction of the wind at each locality was thus known from the observations taken on board; which was valuable in ascertaining its effect upon the current. In the case of special storms, additional data were secured from the meteorological observatories at Yarmouth and St. John, N.B. The fog was unusually persistent this season; but no special investigation was made regarding the conditions of its prevalence.

In these observations, Mr. H. W. Jones and Mr. S. C. Hayden gave excellent assistance; and not infrequently, it was necessary to continue till late in the evening or after midnight to secure some maximum or turn of the current. The regular night observations were taken by the first and second officers, Messrs. Smith and Clarke. Captain T. G. Taylor, the master of the vessel, gave valuable co-operation in the work, in addition to his ordinary duties.

## THE CURRENTS; THEIR DIRECTION, STRENGTH, AND TIME OF TURNING.

*General characteristics of the tide and current.*—It had already been ascertained from tide gauges placed at a series of ports in southern Nova Scotia in 1902, that from

Cape Sable westward, the tides can be satisfactorily referred to St. John, N.B.; while eastward of Cape Sable, they can be referred to Halifax with greater advantage. It is also a noteworthy feature of the tides in the Bay of Fundy region, that the moon's distance has more influence upon them then any other factor. The difference in range between spring tides, which fall at perigee and at apogee respectively, is as great as the difference between mean springs and neaps. On the other hand the diurnal inequality, which is a dominant factor in parts of the Gulf of St. Lawrence, is not very strongly marked in this region, although still quite appreciable.

The current is strongly tidal in its general character, and any other features it presents are relatively unimportant, throughout the region extending from Cape Sable westward to the mouth of the Bay of Fundy proper. The current has therefore in general the same features as the tide as above explained. The flood sets northward towards the Bay, and the ebb southward. There is little indication of any general movement of the water in a dominant direction, nor does the current veer widely or continuously around the compass as in most of the regions previously investigated. It may be said in general to turn without much loss of time from the flood direction to the ebb direction, although there is more tendency to a wider veer in proportion to the greater distance of the point of observation from the shore, which appears to be a characteristic of the current on all open coasts. The currents are thus on the whole remarkable for their strength and regularity, and throughout the season they were seldom disturbed by wind.

*Time of slack water.*—This is the most important relation between the current and the time of the tide, as it enables the time at which the current turns to be known from the tide tables. It requires some care to determine the time of slack water correctly on a vessel at anchor far from shore. The current becomes weak before it turns; and a vessel moored by a hawser having two or three times the depth of the water, will make a wide sweep in turning. Also, if there is wind, the vessel will head round into its direction when the current slacks. With the complete system of observations employed, there is more than one way in which the time of slack water can be arrived at. There is firstly, the time of lowest velocity as shown by the current-meter; then again, the time at which the current in veering, sets at right angles to the flood and ebb directions, which are always very definite with currents of such strength. A comparison can also be made between the time of maximum velocity and the moment of half tide, taken from the registering tide gauge. It was found however that this did not give the same interval of time, as between slack water and the turn of the tide; that is to say, the time at which the current attains its maximum strength is not precisely the middle point between high and low water slack, and the maximum could not therefore be depended upon, as a check upon the time of slack water relatively to the tide tables.

For practical purposes therefore, the following method was employed:—The time of lowest velocity was found from the current-meter observations, and also the time of the cross direction of the current. These two usually agreed within 10 or 15 minutes, and the average of the two was taken as the true time of slack water. The difference between this value and the moment of high or low water, as shown by the registering tide gauge was then taken, and the average of these differences gave the desired result for the station.

This method was used at all the stations which were far enough from shore to give the current sufficient scope to set across its usual direction in turning. At the stations nearer shore, the current reversed its direction more promptly and with less veer, and thus enabled the time of slack water to be observed with more precision.

In Tables I and II appended, the results are given in a concise form. The positions of the various stations are stated, and they are placed in the tables as nearly as possible in their geographical order, from Cape Sable towards the Bay of Fundy. In Table II the average values for the time of slack water are given for all the stations, and also for the lightship at Lurcher shoal; where the result is equally reliable, as a series of 232 observations was secured during the season, although velocities with the current meter were not obtained there. At the various stations, a total of 150 observations of slack water were secured, for comparison with the tide as recorded simultaneously on the St. John tide gauge.

Station E off Shelburne, is omitted in Table II because the time of slack water there should properly be referred to the tide at Halifax. But at all other stations, from the offing of Cape Sable westward, the turn of the current is in better correspondence with the tide at St. John. The current is thus of the same character as the tide; as observations along the Nova Scotia coast have shown that immediately west of Cape Sable the tide acquires the Bay of Fundy type, and can be referred to St. John with less variation in the time-difference than if referred to Halifax.

*Variation in the strength of the current at different times.*—The large variation in the velocity of the current, which takes place regularly during the course of the month, will be seen from the following example:—At Station C, 10 miles west of Lurcher shoal, the average half-tide velocity at flood and ebb on four tides at perigee, September 9th to 10th, was 2·02 knots, with a corresponding mean range of the tide at St. John of 26·0 feet. Again, from the average of four tides, midway between perigee and apogee, July 7th to 9th, the mean velocity was 1·10 knots and the corresponding mean range of the tide was 16·8 feet. The lower of these velocities is only 54 per cent. of the higher.

With regard to diurnal inequality, which is always greater at the maximum declination of the moon, the following example may be cited from observations at Station J, which were taken continuously day and night:—During six consecutive tides, August 10th to 13th, the ebb current at night was 7 per cent. stronger than in the day on the average; and the six corresponding tides at St. John, showed an ebb range at night, which was 5 per cent. greater than the ebb range in the day time on the average. The individual tides from which these averages are taken, are shown in the table on page 8.

*Method of reduction.*—If the strength of the current at different times and in different localities is to be compared in a rational way, it is thus evident that the velocities as observed, must be reduced to some uniform standard of comparison, for it would obviously be untrustworthy to compare the springs at one place with the neaps at another, or to overlook the diurnal inequality in the relative velocity of the flood and ebb. On the other hand, if it were required to secure by direct observation the true mean strength at the springs, in each locality, this could only be obtained when the moon was at its mean distance and also on the equator, at the time of full or change. It would evidently be impraticable to limit the observations in this way.

In this region, where the currents are strong and turn so definitely without veering irregularly, there is more hope of reducing them to some standard, and thus to produce a truly comparative current chart. It was found on investigation that the maximum strength of both flood and ebb was closely proportional to the rise or fall of the corresponding tide at St. John. This indicates a method with a rational or physical basis by which the velocity of the current, at different times and places, can be correctly compared. It was found best to adopt a range of 24 feet at St. John as the standard with which to bring the strength of the current into relation. When the range of the tide is greater or less than this amount, the currents will be proportionately stronger or weaker.

*Variation in the range of the tide.*—As this variation is a direct indication of the relative strength of the current at different times, we give in the table below the comparative amounts both at St. John and at the head of the Bay of Fundy.

The figures for St. John are from tides registered during the season of 1904 on the tide gauge there. The springs and neaps selected are in the months of August and September, when the perigee and apogee coincided with the full and change of the moon; and the intermediate neaps were closely at the moon's mean distance. The range given is the mean for two consecutive high waters and low waters, as the diurnal inequality is thus eliminated. The figures for Cumberland Basin are from day tides only, taken in 1870 by the Engineers of the proposed Baie Verte canal. The months selected are October and November, when the above coincidence occurred in that year.

| Description of Tide. | St. John, N. B. | | Cumberland Basin. | |
|---|---|---|---|---|
| | Range in feet. | Difference. | Range in feet. | Difference. |
| At Perigee. Range at Spring Tides | 27·10 | 6·75 | 48·20 | 12·65 |
| At Apogee. Range at Spring Tides | 20·35 | | 35·55 | |
| Spring range. Mean of the above | 23·72 | 6·29 | 41·87 | 12·12 |
| Neap range, at Moon's mean distance | 17·43 | | 29·75 | |

At both the above localities, the difference in the range of the tide, at perigee and apogee, is greater than the difference in the range at ordinary spring and neap tides. This shows the dominating influence of the moon's distance in this region; and the variation in the strength of the current is found to follow the same law.

The range of 24 feet at St. John, taken as the standard of comparison, is thus the mean spring range; or the range at spring tides when the moon is at its mean distance. This is as good a value as could be adopted, with which to correlate the actual velocities of the current as observed.

*Method of reduction exemplified.*—To explain this method more clearly, it may be illustrated by the following table. This shows some of the most equal and unequal currents met with. At Station J, off Brier island, the currents were the strongest found anywhere during the season, as the observations there were taken at the spring tides which coincided with the moon's perigee. There is a diurnal inequality in the currents in evident correspondence with the inequality in the tide itself; and for this, allowance is also made by the method employed.

| Station and Date. | TIDE at St. John, N.B. | | CURRENT. | | | |
|---|---|---|---|---|---|---|
| | | | As observed. | | As reduced. | |
| | Rise. | Fall. | Flood. | Ebb. | Flood. | Ebb. |
| | Feet. | Feet. | Knots. | Knots. | Knots. | Knots. |
| C. June 16 | | 22·4 | | 1·74 | | 1·86 |
| " 17 | 24·0 | | 2·32 | | 2·32 | |
| " 17 | | 22·5 | | 1·48 | | 1·58 |
| " 18 | 23·6 | | 1·97 | | 2·00 | |
| Sept. 8 | | 23·1 | | 2·16 | | 2·25 |
| " 8 | 24·3 | | 1·43 | | 1·41 | |
| " 9 | | ........ | | ........ | | ........ |
| " 9 | 25·7 | | 2·13 | | 1·98 | |
| " 9 | | 25·4 | | 2·18 | | 2·06 |
| " 9 | 26·1 | | 1·92 | | 1·76 | |
| " 10 | | 26·9 | | 1·85 | | 1·69 |
| " 10 | 26·9 | | 1·93 | | 1·72 | |
| " 10 | | 26·5 | | 1·93 | | 1·75 |
| " 10 | 26·7 | | 2·10 | | 1·88 | |
| " 12 | 26·8 | | 1·70 | | 1·52 | |
| " 12 | | 26·5 | | 2·12 | | 1·93 |
| J. Aug. 8 | 20·0 | | 2·67 | | 3·20 | |
| " 9 | | 21·6 | | 2·90 | | 3·22 |
| " 9 | ........ | | ........ | | ........ | |
| " 9 | | 19·8 | | 2·62 | | 3·17 |
| " 9 | 21·8 | | 2·94 | | 3·23 | |
| " 10 | | 22·4 | | 2·62 | | 2·81 |
| " 10 | 24·1 | | 3·19 | | 3·18 | |
| " 11 | | 25·2 | | 3·29 | | 3·13 |
| " 11 | 24·6 | | 3·30 | | 3·22 | |
| " 11 | | 24·1 | | 3·08 | | 3·07 |
| " 11 | 25·7 | | 3·52 | | 3·28 | |
| " 12 | | 27·1 | | 3·68 | | 3·26 |
| " 12 | 26·4 | | 3·65 | | 3·32 | |
| " 12 | | 25·3 | | 3·33 | | 3·16 |
| " 12 | 26·1 | | 3·58 | | 3·30 | |
| " 13 | | 27·3 | | 3·70 | | 3·25 |
| " 13 | 26·9 | | 3·63 | | 3·24 | |
| " 13 | | 26·2 | | 3·54 | | 3·24 |

*Strength and direction of the current; resulting values for all the stations.*—Table I, appended, shows the final average results for the direction of flood and ebb and the strength at half tide at all the stations, when reduced or increased proportionately to correspond with the standard tidal range of 24 feet at St. John. This table is based on determinations of maximum velocity for 179 tides at the various stations, and on a much larger number of half-tide directions; as for these, the results obtained at night gave a more continuous series. When the observations were at the neap tides only, the velocities were so much increased in bringing them into correspondence with the range of 24 feet, that a further mean was taken between these and the velocities actually observed. The treatment was consistent throughout; the object being to make the results strictly comparative.

At two of these stations there are irregularities in the current, and the period of observation was not long enough to secure as good averages as might be desired. At Station N, within the mouth of the Bay of Fundy, the irregularity appears to be due to the sudden opening of the Bay immediately inside of Grand Manan island. At Station B, off Seal island, the flood was much stronger than the ebb at the date when the observations were taken. This will be referred to again, in discussing the relative strength of the flood and ebb.

| Station. | Period of observations. 1904. | Number of maximum velocity measurements. | Velocity corresponding to 24 feet range. | | Ratio of the EBB velocity to the FLOOD. |
|---|---|---|---|---|---|
| | | | Flood. | Ebb. | |
| H. | July 25 to 29...... ..... | 9 flood; 8 ebb.......... | 2·34 | 2·37 | 101 per cent. |
| C. | June 16 to 18.. .. . . ..<br>Sept. 7 to 12....... ... | 8 flood; 7 ebb.......... | 1·82 | 1·87 | 103 per cent. |
| J. | Aug. 8 to 13....... .. . | 8 flood; 9 ebb.......... | 3·25 | 3·19 | 98 per cent. |
| A. | June 23 to 30..........<br>Aug. 15 to 18. ........ | 13 flood; 10 ebb......... | 1·67 | 1·62 | 97 per cent. |

*Relative strength of flood and ebb.*—In the above table, the ratio of the ebb velocity to the flood is given for four stations lying in the order shown, between Cape Sable and the mouth of the Bay. These are the best adapted for the comparison, as they are the most open stations, least liable to local influences.

In obtaining the ratios, the velocities are first reduced to correspond with the standard tidal range of 24 feet at St. John. The advantage of this treatment will be evident from the reasons already explained. To arrive at any better relation of flood to ebb, a long series of observations would be required; or else observations at two different times at which the diurnal inequality is reversed.

According to this comparison the current in the flood and ebb directions does not differ more than 3 per cent. in its strength. This is probably as near as a comparison of the kind can be relied upon. This result has two different bearings which it will be necessary to consider separately.

(1) The practical equality of the strength of the current in the two directions, is in accord with the nature of the tidal movement in the Bay as already ascertained. At the head of the Bay, the rise of the tide above mean sea level is equal to its fall below that level. This results from measurements by the Engineers of the proposed Baie Verte canal, made on the two sides of the isthmus of Chignecto; in Cumberland basin and Northumberland strait. The reduction of these measurements and a diagram illustrating them, are given in the Report of Progress of the Tidal Survey, December 1898, pp. 29 to 32, and Plate. III.

It thus appears that the filling and emptying of the Bay with the tide, is equally above and below the plane of mean sea level. There is no large volume of fresh water discharge at the head of the Bay, to disturb this equality, as there is in some estuaries. It is thus evidently to be expected, that the strength of the flood and ebb should be equal in the two directions, if the tidal influence is the only one to be considered. This conclusion is confirmed also by the behaviour of the under-current at Station A, as explained under that heading. The inequality of the flood and ebb which is found at some stations, should probably be considered therefore as a local feature; because the current is obliged to take different courses on the flood and ebb, on account of some obstruction in its way.

(2) In the case of currents so distinctly tidal in their character, a difference between the strength of the flood and the ebb is the only indication to show that the water makes in one direction rather than in the other. In a comparison for this purpose, it is necessary to take the under-current into account also, as it is a question of the movement of the whole body of the water. It appears from the observations at all the more outlying stations that, with the exception of Station B, the relative strength of the surface current in the two directions varies less than fifteen per cent. from equality. Also, at Station C, off Lurcher shoal, where the longest series of observations were obtained, the average strength in the two directions, when the surface and under-current are taken together, is just equality.

At Station B, off Seal island, where unusually high velocities were found, both the surface and under-current were much stronger during flood tide. There was little diurnal inequality at the time to account for this, nor sufficient wind disturbance to occasion it. It may thus be an indication of some balance of flow in the westward direction, unless it is due to a local strengthening of the flood, which is not impossible; as this station is within four miles of a well marked projection from the edge of the 30-fathom bank. It was also noticed at Stations A and K, south of Grand Manan island, that the direction of the ebb veered more to the westward than the flood, by one or two points. To follow up these indications, a station was occupied on the coast of Maine; namely, Station D, six miles off Moose Peak light, in 42 fathoms. It was there found that the ebb, setting westward, is 38 per cent. stronger than the flood, when the under-current is included. Also, the directions of both flood and ebb bear two points on the shoreward side of a line parallel with the coast; and at slack water the current in turning, veers to the landward side in both cases. The water has thus a tendency to bear against this coast, which would correspond with a westward movement across the mouth of the Bay of Fundy.

On the other hand, at Station E, off Shelburne, from observations at the spring tides, it appears that the ebb is 6 per cent. stronger than the flood; the ebb direction being north-eastward along the Atlantic coast of Nova Scotia. At Station F, twelve miles off Cape Sable, the ebb setting E. S. E. was slightly stronger than the flood when the under-current is included. When these indications are balanced against each other, there is little evidence of a general movement of the water in any one direction, as this cannot be inferred with certainty from the present observations.

## The Under-current.

At all the stations the maximum strength of the under-current, at each flood and ebb, was carefully measured. These observations afford direct simultaneous comparisons with the surface current from which the proportional strength of the under-current can be found. The movement of the under-current is always of much assistance in determining the relative strength of the flood and ebb, and it thus helps to indicate any tendency of the water to make in a dominant direction.

The observations were taken with the appliances described, at a standard depth of 30 fathoms; and if the depth of the water did not admit of this, which was quite exceptional, a depth of 15 fathoms was adopted. In such observations it is always easier to obtain the relative or comparative strength than the absolute velocity; but the experimental comparisons with measured velocities, enabled very satisfactory results to be arrived at.

*Relation to the surface current.*—The relation between the strength of the under-current and the surface current is the question of most importance. The most trustworthy results were those obtained at the more outlying stations, which were free from any local influences. The final percentages at these stations, found from the average of eighty-one comparative observations at half-tide, are given in the following list. It thus appears that almost everywhere, the velocity of the under-current varies only within the limits of 7 per cent. more or less than the surface velocity. As this is not more than the usual irregularity in such currents, it may therefore be said that the whole body of the water moves with the same speed to a depth of at least 30 fathoms. This proves the depth as well as the strength of the currents in this region, which is important with relation to wind disturbance, and will be referred to again under that heading.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Station | F. | Off Cape Sable. | Under-current at | | 30 fathoms. | 95 per cent. of surface current. | | |
| " | H. | Off Blonde Rock. | " | " | 15 " | 98 | " | " |
| " | B. | Off Seal island. | " | " | 30 " | 104 | " | " |
| " | C. | Off Lurcher shoal. | " | " | 30 " | 93 | " | " |
| " | A. | At mouth of Bay. | " | " | 30 " | 105 | " | " |
| " | M. | Grand Manan ch'l. | " | " | 30 " | 107 | " | " |

*Time of the turn of the under-current.*—It was found from the longest series of observations obtained at stations which were occupied on several different occasions, that the turn of the under-current was practically simultaneous with the turn on the surface. On the average it was within five or ten minutes of the same time; and it rarely exceeded half an hour. This result was obtained at five stations which were the best adapted for securing such a comparison.

*Relation of flood to ebb in the under-current.*—A special series of observations was taken at Station A, at the mouth of the Bay of Fundy, on five successive days, from June 23rd to 28th. The under-current was observed at the depths of 15, 30 and 50 fathoms. The average values were submitted to a reduction proportionately to the rise and fall of the tide by the method already explained; because at the time the rise was nearly 7 per cent. greater than the fall. The ratio of the flood to the ebb velocity which finally resulted, was found to be just equality. This affords further corroboration from the under-current of equal strength in the two directions, which thus corresponds with the equal rise and fall of the tide itself above and below mean sea level, as already explained.

## Wind Disturbance.

The depth of the current has an important bearing on the question of wind disturbance. As the current maintains the same strength as on the surface to a depth of 30 fathoms, it will regain its strength and direction very quickly if disturbed by heavy winds. It has been found even in regions where the currents are much weaker, that wind disturbance is seldom felt to a depth of more than 10 fathoms. It requires a long-continued wind from one direction to affect this depth; and in ordinary storms, in which the wind veers or changes its direction after a few hours, it is unlikely that the disturbance extends to more than 5 fathoms from the surface.

The winds during the season afforded little opportunity of investigating the question of disturbance. The only severe storm of the season occurred on Thursday, September 15th, when the maximum wind velocity was 72 miles an hour. The total mileage of wind from S. W. and S. was 663 miles during 16 hours. As soon as the storm moderated, an anchorage was made at Station N, just within the mouth of the Bay. On Friday, the ebb setting out of the Bay, was 16 per cent. stronger than the flood, on the surface. This indicated a reflow of the water after the wind fell, to make up for the inward drift caused by the heavy south-west wind; as the under-current at thirty fathoms remained equal in the two directions.

The current also appears to be affected in advance of a storm. It is stated by fishermen that the currents set more strongly towards a coming wind, before it arrives. Of this we found some evidence during the season. This is also definitely stated to be the case on the west and south-eastern coasts of Newfoundland. The evidence of this, is given in the report on the Currents of Newfoundland in 1903 by this Survey, page 20.

It appears unlikely that the wind is ever able to reverse these strong tidal currents; and it is especially to be noted that any disturbance which occurs, will in all probability be quickly overcome, because of the depth of the current, which maintains its strength to a depth of 30 fathoms. The normal conditions will thus be quickly restored.

It is stated by fishermen with reference to the vicinity of Yarmouth, that the winds do not have any appreciable effect on the strength of the ebb; but the flood is strengthened by a south or south-east wind, and checked by a north-west wind, which is contrary to its direction.

## Difference in the Current with change of Position.

*Local features in the currents.*—There are localities where special features are noticeable in the currents, which may deserve mention. This is due to islands which lie directly on the route which the current would otherwise take; or to the great rise of the tide, 18 to 28 feet, which is sufficient to make the configuration of the shore materially different at high and low water, in the vicinity of shoals and islands.

The principal obstruction in the way of the current, is Grand Manan island and its surrounding shoals, which lie in the entrance to the Bay proper. This island appears to obstruct the ebb more than the flood. The flood and ebb are fairly equal in the channel to the westward, and also on the straight Nova Scotia shore opposite to it. But off its southern end (Station K) the ebb is exceptionally strong, and nearly double the flood strength. Again, on its eastern side (Station L) the flood is obstructed and quite weak. Thus at points in its vicinity which are only a few miles apart, there is a marked change in the current, and a full hour of difference in the time of slack water; as will be seen by comparing Stations K and L in Tables I and II. These apparent irregularities are no doubt due to the configuration of this island, and its position.

At Station M, in the channel west of Grand Manan, at low water slack the set is across the channel to the north-westward. Similarly at high water slack, the current in turning veers through the south-eastern quarter. This shows that both the rise and fall of the tide begin first on the Grand Manan side; thus causing a cross current in the channel, though necessarily a weak one. Also, the under-current sets in the ebb direction first, while the surface current in still veering. This tends to make up for the greater strength of the flood, and helps to equalize the flow in the two directions through this channel.

There is no doubt that similar local irregularities would be found in the currents among the islands and shoals bordering the south-western end of Nova Scotia. The above examples may serve to show how such effects may be explained when all the circumstances of topography tide and under-current are taken into account. Such local effects were avoided in these investigations; as the object was to obtain information on the leading steamship routes which keep outside the 30-fathom line.

*Change in the character of the current with change in position.*—When an anchorage was made a second time at the same station, the current was found to act as before. The direction of the current and the time of slack water is thus remarkably constant at any given point, the only variation being a fluctuation in strength as usual with the course of the month. But it is important for the navigator to note that a change in position of only a few miles, may make a marked alteration in the strength of the current and in the time at which slack water is met with. This is a noteworthy feature in the behaviour of the currents in this region. The following examples may be given in illustration.

If a vessel enters the Bay of Fundy along its centre line, from Station A to N, midway between the 50-fathom lines on each side, it would find an ebb current of only $1\frac{1}{2}$ to $2\frac{1}{2}$ knots against it; but if it passes nearer either shore, some eight miles to the right or left, it would have against it a current of 3 or 4 knots or more at the springs.

Also, as regards time, at five miles off Brier island, (Station J) the ebb continues to run for $1\frac{1}{2}$ hours after it slacks at an offing of 15 miles. A vessel would thus find this difference in the time of slack water with ten miles more offing from Brier island. Or again, if entering at half tide, the strength of either flood or ebb would be found just double as great at the offing of five miles as at fifteen miles off.

A vessel, coming inward past Cape Sable about the end of the flood, may find slack water extending westward from the cape for 16 miles as far as Station H ; but at Station B, only 11 miles further on, a strong flood would be met, which would run for 1½ hours longer.

In passing Lurcher shoal, at the end of the flood the current slacks simultaneously on the shoal itself and for some distance on each side ; but after the ebb, it slacks on the shoal half an hour before it is slack midway between the shoal and the mainland (at Station P), and a full hour before slack water occurs at an offing of ten miles westward (at Station C).

The characteristics thus described are clearly shown in the tabulated results, given in Tables I and II, and also in the form of a Current chart, from which the relative strength and direction of the current and the time of slack water at the various stations will be readily understood. A little consideration will also show many ways in which slack water may be taken advantage of, and the stronger currents made use of or avoided as occasion may require. The positions of the stations are given accurately in Table I, to enable any navigator to plot them on his own chart, if desired for reference.

## Temperature of the Water.

The temperature of the water was taken while at anchor and on the runs made, with two objects in view : to trace any general movement of the water ; and from any difference in the temperature of the flood and ebb, to infer any general displacement of the water. Deep temperatures were also taken at the stations, as far down as 30 fathoms ; and owing to the strength of the current these could only be taken at slack water, which thus gave a valuable comparison of the temperatures at the end of the flood and ebb, when the greatest difference was to expected if the water came in from one direction and went out in another. The indications given by these observations were not sufficiently distinct to be of value for the main objects in view ; but the results deserve to be noted. On the other hand they show distinctly the change in temperature with the progress of the season. The values are in degrees Fahrenheit throughout.

*Relative temperatures of flood and ebb.*—The temperature of the surface water was taken every two hours while at anchor ; and the average temperature of the flood and ebb was thus found for the period of two to six days or more, during which the station was occupied. With the exception of Stations F and G off Cape Sable, these averages seldom differ more than a fraction of a degree at any of the stations in the region.

The advantage of determinations below the surface for this purpose, deserves to be noted ; for if there is a difference in the tempetature in the two directions, it is more distinct at 10 or 15 fathoms than on the surface ; while at 30 and 50 fathoms the temperature is again more uniform, as it usually is at such depths. The most definite indication was at Station A, at the mouth of the Bay of Fundy, where the depth is over 100 fathoms. The following average results at the depths indicated, are from eleven determinations at a series of depths in June, and eight in August, at slack water on the dates given :—

| | | | | |
|---|---|---|---|---|
| Station A. | June 23 to 29..... | Depth 10 F. | After the flood 48°.7 | After the ebb 45°.2 |
| | " ..... | Depth 15 F. | " 48°.4 | " " 44°.6 |
| | Aug. 16 to 19..... | Depth 10 F. | After the flood 53°.4 | After the ebb 49°.6 |
| | " ..... | Depth 15 F. | " 52°.1 | " " 48°.0 |

At both dates there is thus a mean difference of 3°·8. The ebb water from the Bay is colder than the incoming water by this amount; and the other temperatures of the series show that this is the case from the surface as far down as 50 fathoms. It is not easy to explain why this should be, without more extended investigation.

*Effect of islands and shoals in modifying the temperature of the water.*—This effect is very distinct; and it appears to result from the stirring up of the water. It causes a long trail or wake of colder water to extend from islands or shoals along the line of the current; as for example, north and south from Lurcher shoal. Where the water moves to and fro in an unbroken sheet, as it does outside the 50-fathom line where clear of obstruction, the surface temperature is more uniform; and the rise in temperature with the progress of the season is more easily ascertained.

The lower temperatures on the 30-fathom bank off Cape Sable may thus be explained. In the middle of July the surface temperature as found from runs in the vicinity of Yarmouth, and also on the south-east coast of Nova Scotia (Station E) was 50° to 51°; while at Stations F and G off Cape Sable, it was only 45° to 47°. This would correspond with water at a depth of 15 fathoms, brought to the surface by the shoal.

Where the islands and shoals are numerous, the general effect of these strong currents is to chill the water in the vicinity of the coast, by mixing the surface water with the colder water from below. It is possible that this may have a bearing on the formation of fog in these regions, by the lowering of the surface temperature.

*Rise in temperature with the progress of the season.*—From runs made at different times in the same vicinity, and stations occupied twice at different dates, the best comparative results are as follows. They are the averages of 8 to 55 individual observations.

| | | | | |
|---|---|---|---|---|
| Yarmouth to Station B. June 7, | Temperature 41½°...... | July 12-30, | Temperature | 51° |
| Station A. June 3-5.......... | " 43°....... | Aug. 15-18 | " | 55° |
| " C. " 16-18............ | " 47°...... | Sept. 6-12 | " | 53½° |
| Brier island to Station C. July 6, | " 50°....... | " 3 | " | 51½° |
| Grand Manan island south-east to Station N............ | | " 1 and 16 | " | 53° |

NOTE SUMMARIZING THE CHARACTERISTICS OF THE CURRENTS.

The following notes are given in the endeavour to summarize the leading characteristics of the current is this region. They refer to the currents at an offing of 3½ to 15 miles from shore, on the routes usually taken by steamships, and they are not intended to include the currents among the islands and shoals nearer shore.

(1) The currents are predominantly tidal in their character, running strongly during flood and ebb in the two directions, which are usually opposite. Any veering, or

set in a cross direction, occurs only when the current is weak. At the points farther from shore, the current veers more in turning and does not reverse its direction so promptly. (2) From Cape Sable westward to the mouth of the Bay of Fundy, the time of slack water has a definite relation to the tide at St. John, N.B. It can therefore be found from the St. John tide tables by means of the differences herein given. (3) The direction of the current and the strength in knots at half tide, flood and ebb, are shown on the Current chart. The strength given corresponds to the mean spring range of 24 feet at St. John. In this region the moon's distance, as it varies from perigee to apogee, alters the strength of the currents quite as markedly as the change from springs to neaps with the moon's phases. (4) While the behaviour of the current is very regular and constant at any definitely fixed point, it is specially to be noted that a change in position of even a few miles may make a marked difference in its character. This difference is chiefly in the strength and in the time of slack water, and not so much in the direction. (5) Almost everywhere, the current is as strong down to a depth of 30 fathoms as it is on the surface; and at most places it turns in direction on the surface and below at practically the same time. (6) This has an important bearing on wind disturbance, as it shows that the current will soon regain its normal direction and strength after a storm moderates. Some illustrations of the effect of the storms met with during the season have been given. (7) There is no general movement of the water in any one direction in this region which is at all well marked; nor did the temperatures give any definite indication of this.

The characteristic of the current which deserves special attention, is the change found at points only a few miles apart. In passing islands the strength may be very different indeed, according to the offing given; and in channels and passages there may be a difference, between the centre and the sides, of an hour in the time of slack water. Also, towards the end of the flood or ebb, a vessel may pass through slack water, and a few miles further on, it may find the current still running strongly in the old direction, owing to a time-difference in the turn of the current at the two positions. These features will be seen on giving a little study to Tables I and II given opposite, and comparing them with the Current chart.

Respectfully submitted,

W. BELL DAWSON,
*Engineer in charge of Tidal and Current Survey.*

## TABLE I.—AT HALF TIDE.

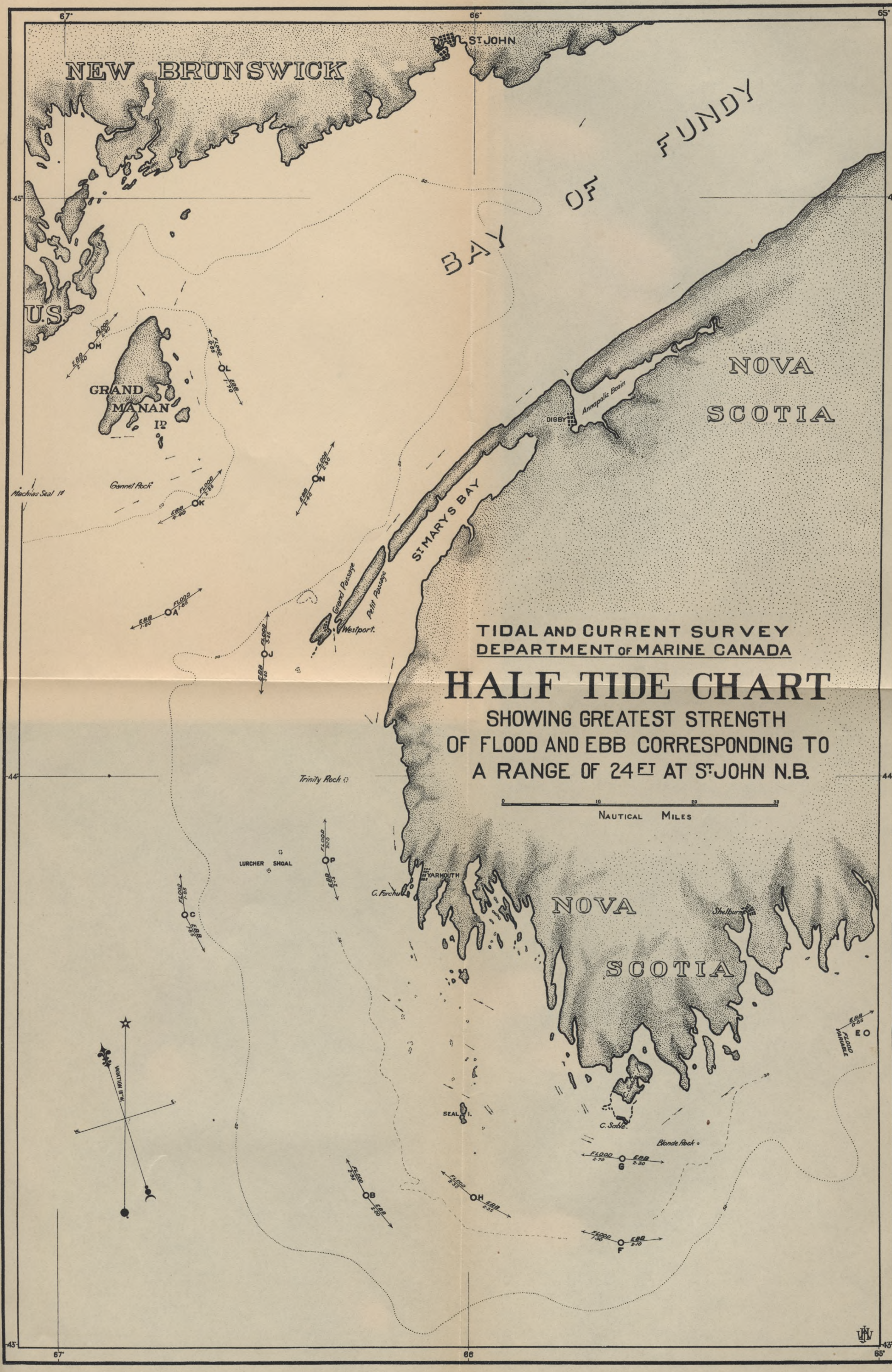
DIRECTION of the Current at half tide; and VELOCITY in knots, corresponding with the mean spring range of 24 feet at St. John, N.B. From observations in the season of 1904; June to September.

| Station and Position. | Flood. | | Ebb. | |
|---|---|---|---|---|
| | Velocity. | Direction. | Velocity. | Direction. |
| E. From C. Roseway; S 51° E, 11 M ........ | 0·80 | Southerly. | 0·85 | E. *b* N. |
| G. " Cape Sable; S 22° W, 3½ M.............. | 2·70 | W.N.W. | 2·30 | E. S. E. |
| F. " " S 22° W, 12½ M............. | 1·90 | N.W. *b* W. | 2·10 | E. *b* S. |
| H. " Seal island light; S 8° W, 8 M............ | 2·34 | N.W. *b* N. | 2·37 | S.E. |
| B. " " " S 70° W, 13 M........ | 2·95 | N. *b* W. | 2·00 | S.S.E. |
| P. " Lurcher shoal; S 82° E, 6 M............. | 2·20 | N. *b* E. | 2·15 | S. |
| C. " " S 80° W, 10 M .......... | 1·82 | N. *b* E. | 1·87 | S. *b* E. |
| J. " Brier island light; S 84° W, 5¼ M......... | 3·25 | N.N.E. | 3·19 | S.S.W. |
| N. " Petit Passage; N 28° W, 9¾ M........... | 2·30 | N.E. | 2·40 | S.W. |
| A. " Brier island light; N 63° W, 15 M. ...... | 1·67 | E.N.E. | 1·62 | W. ½ S. |
| K. " Gannet rock; S 48° E, 5 M.............. | 2·85 | N.E. *b* E. | 4·40 | W. *b* S. |
| L. " Big Duck island; N 87° E, 3¾ M.......... | 0·65 | Northerly. | 1·70 | S. *b* E. |
| M. " W. Quoddy light; S 17° W, 4½ M......... | 2·90 | N.E. *b* E. | 2·40 | S.W. *b* W. |
| D. " Moose Peak light; S 48° E, 6 M. ........ | 1·00 | N.E. *b* N. | 1·55 | W. *b* S. |

## TABLE II.—SLACK WATER.

TIME of Slack Water before or after High and Low Water at St. John, N.B.

| Position. | Depth. | Slack Water at High Tide. | Slack Water at Low Tide. |
|---|---|---|---|
| | | h. m. | h. m. |
| Station G........................ | 20 F..... | 2 : 30 before High Water... | 3 : 15 before Low Water. |
| " F.......................... | 34 F..... | 1 : 08 " ......... | 1 : 17 " |
| " H.......................... | 26 F..... | 1 : 13 " ......... | 1 : 02 " |
| " B.......................... | 44 F. .... | 25 after High Water.. | 13 " |
| Lurcher shoal...................... | ......... | 23 " .......... | 34 " |
| Station P........................ | 33 F. ... | 20 " ............ | 10 after Low Water. |
| " C.......................... | 53 F..... | 22 " ............ | 35 " |
| " J.......................... | 50 F..... | 44 " ............ | 41 " |
| " N.......................... | 98 F..... | 1 : 00 " .......... | 43 " |
| " A.......................... | 105 F.... | 04 " ............ | 49 before Low Water. |
| " K.......................... | 45 F.... | 05 before High Water .. | 35 after Low Water. |
| " L.......................... | 70 F..... | 55 " ......... | 1 : 40 " |
| " M.......................... | 48 F..... | 30 after High Water.... | 10 " |
| " D.......................... | 42 F..... | 05 " ............ | 1 : 05 " |


TIDAL AND CURRENT SURVEY
DEPARTMENT OF MARINE CANADA
HALF TIDE CHART
SHOWING GREATEST STRENGTH
OF FLOOD AND EBB CORRESPONDING TO
A RANGE OF 24 FT AT ST JOHN N.B.
NAUTICAL MILES
NEW BRUNSWICK
ST JOHN
BAY OF FUNDY
U.S.
GRAND MANAN ID
NOVA SCOTIA
Annapolis Basin
DIGBY
ST MARYS BAY
Grand Passage
Petit Passage
Westport.
Gannet Rock
Machias Seal Id
Trinity Rock
LURCHER SHOAL
YARMOUTH
C. Forchu
NOVA SCOTIA
Shelburne
SEAL I.
C. Sable
Blonde Rock
VARIATION 18° W.
67°
66°
65°
45°
44°
43°