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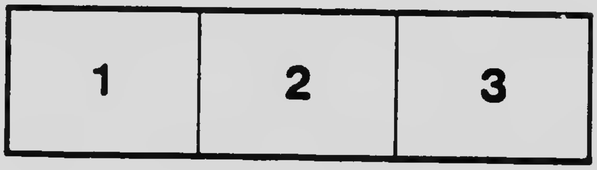

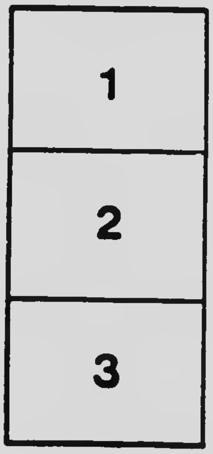

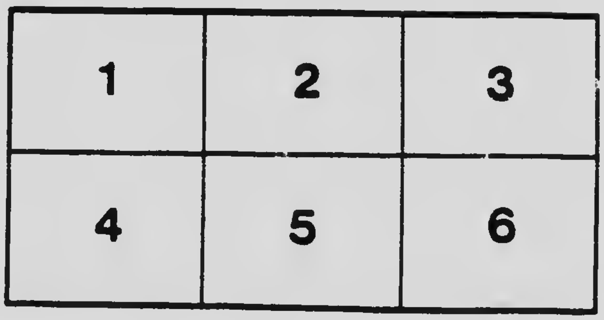

THE CURRENTS

IN THE

Gulf of St. Lawrence

From Investigations of the Tidal and Current Survey in the Seasons of 1894, 1895, 1896, 1906, 1908, 1911 and 1912.

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PREFACE.

The information herein contained, is derived from the investigations in the Gulf of St. Lawrence, by the Survey of Tides and Currents, of the Dominion of Canada. The investigations were made under the personal direction of Dr. W. Bell Dawson, C.E., the Superintendent of the Survey; and they are supplemented by information collected by him, from captains of vessels, fishermen and others, having a long experience in the Gulf.

The various seasons devoted to the Gulf of St. Lawrence are as follows: In 1894, 1895 and 1896 a general investigation was made of the Gulf area and the straits connecting it with the ocean. The season of 1906 was given to Belle Isle strait, and 1908 to Northumberland strait. In the seasons of 1911 and 1912 the Gaspé current was more closely examined, as well as the Anticosti region at the entrance to the St. Lawrence. In this work, the Superintendent had the assistance of Mr. H. M. Mackay in the earlier years, and Mr. S. C. Hayden in the later years; with the help of men engaged in the various seasons for the night observations. Captains G. W. J. Bissett, T. G. Taylor and C. T. Knowlton, successively in charge of the surveying vessel employed for the work, also gave valuable co-operation in addition to their ordinary duties.

In the investigations, the steamer employed was anchored in positions carefully selected for the purpose in view. These were in all depths, up to 250 fathoms. The steamer thus served as a fixed point from which to observe the behaviour of the current. The observations of the current were obtained with current meters registering electrically on board, and in continuous operation day and night. The speed was measured at the standard depth of 18 feet, in all cases. The wind velocity was measured by an anemometer on board; supplemented by complete meteorological observations at four hour intervals. A continuous record of the tide was obtained simultaneously for comparison with the currents, at tidal stations in the region, established by this Survey.

All directions and bearings are referred to true north. The time throughout the Gulf area is Standard time for the 60° meridian West of Greenwich.

The following arrangement of the information has been adopted:—

Part I.—Description of the currents on the surface, as a mariner may expect to find them in each locality.

Part II.—The general circulation of the water in the Gulf of St. Lawrence, and the characteristics of its waters in regard to temperature, density, etc.

Ottawa, 30 September, 1913.

GENERAL DESCRIPTION OF THE GULF AND RIVER ST. LAWRENCE.

From Montreal, at the head of ocean navigation, to Lake St. Peter the river is without tide. The tidal section of the river extends from the lower end of Lake St. Peter, where the tide is first felt, to the eastern end of Orleans island, 28 miles below Quebec. This point is the true head of the St. Lawrence Estuary, as the tide has here its greatest range. The estuary thus extends from the lower end of Orleans island to Point des Monts, where the Gulf area properly begins. The Gulf of St. Lawrence extends thence to Cabot strait, between Cape Breton island and Newfoundland. It opens into the Ocean by this strait, which has a width of 65 miles and a depth of 250 fathoms; and by Belle Isle strait, which has a width of 11 miles and a depth of 30 fathoms.

The area of the Gulf is traversed by a deep channel which runs from the mouth of the St. Lawrence past the Gaspé coast, and crossing the open Gulf to the north of the Magdalen islands, passes out through Cabot strait. Thence it continues south-eastward, dividing St. Pierre bank on the north from Banquereau and Misaine bank on the south, till it reaches the edge of the deep Atlantic basin. A branch from this channel also runs for some distance into the north-eastern arm of the Gulf, towards Belle Isle strait. (See Map.)

The depth of this channel increases from 150 fathoms at the mouth of the St. Lawrence to 250 fathoms in Cabot strait. It forms the main avenue by which the tides of the Atlantic enter the Gulf and travel across it to the mouth of the St. Lawrence; whence they continue with ever increasing height to the head of the estuary, and continue up the river with decreasing range until they finally cease in the expanse of Lake St. Peter.

FURTHER INFORMATION.

Extended explanations regarding the currents in some portions of the region here described, are given in the following Reports, published by the Tidal Survey: "The Currents in the Entrance to the St. Lawrence," 50 pages with accompanying map; and "The Currents in Belle Isle strait," 43 pages with a chart and three plates.

Information on the tides throughout the Gulf and River St. Lawrence, is included in "Tide Tables for the Eastern Coasts of Canada," published annually.

PART I.

NATURE OF THE CURRENTS IN THE GULF AREA.

General character. These currents are of two kinds; (1) Constant currents which run more or less continuously in accordance with the general circulation of the water in the Gulf area; and (2) Tidal streams, which are produced or chiefly influenced by the tide. This distinction must be taken very broadly, however; as the constant currents always show a fluctuation in speed which accords with the tide, and the tidal streams have a dominant flow by which the water makes on the whole in one direction.

In a land-locked area such as the Gulf of St. Lawrence, any disturbance in these currents from their ordinary behaviour appears usually to be due to difference of barometric pressure over wide areas rather than to the direct effect of the wind. The prevailing direction of the wind is west and south-west in summer, and north-west in winter.

Speed.—With the exception of the currents in the various straits and near the heads of the bays, the currents met with in the open Gulf seldom exceed one knot per hour. They are therefore the more easily influenced by strong winds, especially at the surface of the water. Currents which have a greater speed than this, are found off the Gaspé coast, in Belle Isle and Cabot straits, in Northumberland strait, and in the Gut of Canso, where they may attain a velocity of three or four knots per hour.

Water.—The water of the Gulf may be roughly divided by a line running from South-west Point of Anticosti, to the middle of Cabot strait. Along the south-western side of this line, the water has a lower density; as it is apparently made a little fresher by the outflow of the St. Lawrence river. To the north-east of this line, throughout the north-eastern arm of the Gulf, the water has the same density, or saltness, as in the open Atlantic.

Constant currents.—The general drift of this water of lower density is outward, towards the Atlantic. This gives rise to two constant currents, one at the mouth of the St. Lawrence along the Gaspé coast, which may be called the 'Gaspé current,' and the other on the west side of Cabot strait around Cape North, which may be called the 'Cape Breton current.' A third drift of a constant character is found on the west side of Newfoundland, making north-eastward from the Bay of Islands towards Rich Point.

There are other currents which may be termed constant, if this is taken to mean that they usually or more frequently run in the one direction. It is also possible for the most constant currents to be displaced in position, so that their route is changed.

Tidal influence.—The tide has a distinct influence upon all the currents in the Gulf area. But it is only in the principal straits and in the mouths of rivers that the direction of the flow is reversed by the tide. Its effect in the more open waters is to cause a veer in direction, which is often completely around the compass in the tidal period. Its influence in causing a fluctuation in the speed of constant currents has already been mentioned.

Order in which the currents are described.—In describing the currents in this Report, their natural order will be followed, in accordance with the general circulation in the Gulf area; as, broadly speaking, this is a rotation in a left-handed direction, against the hands of the clock.

THE GASPE CURRENT.

It has long been known that there is a constant downward current in the middle of the St. Lawrence estuary, which continues along the south shore for the whole length of the Gaspé coast. This constant outward tendency, as distingushed from the usual tidal behaviour of the Lower St. Lawrence, is first felt below Red islet, near the mouth of the Saguenay. It is met by a cross current from Point des Monts, setting towards Cape Chat. Below this, the outward current is still more pronounced, and is known as the "Gaspé current." It follows the curve of the Gaspé coast as far as Cape Gaspé, from which it sets across the Gulf of St. Lawrence toward the Magdalen islands.

The following descriptions refer chiefly to the region extending from Cape Magdalen to Cape Gaspé; as it is there that vessels make and leave the Gaspé coast on all the Trans-atlantic and Gulf routes which lead into the St. Lawrence. The descriptions are based upon investigations made with the surveying steamer in July and September, 1895, and from June to October in the two seasons of 1911 and 1912. The steamer was anchored at carefully selected stations extending from Martin river to Cape Gaspé; and the observations were continuous, day and night, their total length in the three seasons amounting to 1695 hours.

General description.—The current in the offing of the Gaspé coast runs constantly south-eastward or outward from the St. Lawrence to the Gulf. In general, it occupies a belt lying between two and fourteen miles off shore. Its greatest strength is at an offing of 4 or 5 miles, where it attains a speed of 2 knots at the springs and about $1\frac{1}{2}$ knots at the neaps. At an offing of 10 miles it is much weaker, and beyond 14 miles any current there is, is no longer continuously downward. Between this belt and the shore, a tidal stream is found which runs westward on the flood ; while on the ebb the direction is with the main current. This in-shore flood is little felt except at the springs; and it does not exceed one knot at any time.

Tidal influence and variation in strength.—Although this current is constant in the sense of being always in the one direction, it is subject to a strongly marked fluctuation in speed which is in close accordance with the tide. It is thus stronger during the ebb and weaker during the flood; and every variation in the tide, such as diurnal inequality, is accurately reflected in the current. While this fluctuation is pronounced at all times, the actual velocity may be widely different from other causes; so much so, that it is quite possible for the maximum velocity on the ebb at one date, to be no greater than the minimum on the flood at another date.

The other variations of a periodic character, occur during the course of the month. The strength of the current is distinctly greater at the springs and less at the neaps; and the change in strength from perigee to apogee is also evident. The greatest velocity observed, under a combination of these influences, was 3.92 knots, at the perigee springs, in fine weather with an ordinary west wind.

From an exhaustive reduction of all the measurements of velocity at the standard offing of $4\frac{1}{2}$ miles, the following values have been obtained: In the vicinity of the Spring tides the usual minimum on the flood is 1.10 knots and the maximum on the ebb 2.35 knots per hour. The average velocity throughout the course of the day is 1.87 knots at the Springs and 1.23 knots at the Neaps. The velocity at the moon's apogee is 82 per cent of the velocity at perigee.

Relation to the tide.—The times at which the maximum and minimum velocities occur, as determined by current meters, were carefully compared with the time of high and low water at Father Point, as recorded by the tide gauge established there, to ascertain the time-relation between the two. The following rule is based on the result as thus obtained: To find the time of minimum and maximum at an offing of $4\frac{1}{2}$ miles from the coast, in Atlantic Standard time, apply the following differences to the time given in the Tide Tables for Father Point:

For the Minimum on the Flood, subtract 1h. 50m. from H. W.
For the Maximum on the Ebb, subtract 2h. 05m. from L. W.

This will give the time of mid-flood and mid-ebb with fair accuracy, except when the moon is in high declination; when diurnal inequality may make the time nearly an hour earlier and later alternately, than the above rule gives.

Depth of the current.—A comparison of observations on the surface and at 30 fathoms, shows that the strength at that depth is never less than 60 to 65 per cent of the surface velocity; and usually it is still strong at 50 fathoms and quite appreciable as far down as 90 fathoms. When the minimum on the flood had a relatively low velocity, there were times when the under-current as far down as 30 or even 50 fathoms was as strong as at the surface. The special observations taken to determine the time of the minimum velocity, show that this is practically simultaneous in the under-current and at the surface.

The chief practical importance of these results is their bearing on wind disturbance. The great depth and volume of this current, explain in large measure its apparent indifference to the wind. Such a current, if disturbed, will also regain its normal velocity very quickly. It is also necessary to know the rate at which the velocity decreases with the depth, in order to make any estimate of the total volume of the current.

Influence of the wind.—It is noticeable to begin with, that the greatest strength of the current did not occur during heavy winds or gales, so long at least as it was possible to hold at anchor; although observations were sometimes continued in winds of 40 and 50 miles an hour and with waves eight feet in height. Nor did the weakest current occur during a period of south-east wind against its direction. On the other hand, one of the most impressive occurrences, in watching the behaviour of the current while anchored in it, was to see it setting with its full strength directly into a south-east wind, as it usually did.

The results which we here sum up, are based not only on leading examples, but also on close observation while at anchor with all the factors under consideration at the time, including special examination of the under-current to obtain an additional term of comparison. After a careful analysis of all the facts and figures obtained, the results are largely negative.

(1) The general result to begin with, is that the Gaspé current cannot be checked, much less reversed in direction, by a wind blowing directly against it. This is also true in winter, when the presence of ice gives the wind a greater influence than it would have on open water.

(2) The greatest variation in strength, as indicated by the daily mean velocities, is not caused by the wind; as the variation from springs to neaps is greater in amount than any winds met with during the summer season appear able to effect.

(3) The highest measured velocities of the current did not occur during the storms met with, up to such time at least as it was no longer possible to hold at anchor in the open. This is corroborated by both the daily mean velocities and the maximum values.

(4) The weakest current observed did not occur during a period of contrary wind from the south-east. In September 1912, the daily mean velocity fell below half a knot, at a time when the wind was light and variable; and for two days afterward, it was still below three-quarters of a knot.

(5) There is some indication that the current strengthens during the quiet time, with south-east swell running, before a S.E. wind begins. Whether this is always the case or not, one of the most striking features of the behaviour of the current is the marked increase in strength during the early part of a south-easterly blow. The current on several occasions set directly into the wind with a velocity quite above the normal, up to the time that the station was left because it was no longer possible to hold at anchor.

(6) The strongest current ever encountered occurred at a time when the local wind was moderate. It was apparently due to a pronounced difference of pressure, or barometric gradient, from Quebec to the Gulf area, which held for three successive days.

(7) The effect of the winds in the opposite directions up and down the coast, from a careful analysis of the observations in 1895 and 1911, is found to amount only to 0.75 knot, as closely as can be estimated. This result is based on winds having a strength of 20 to 30 miles an hour, under such conditions as have been described; and the amount found is nearly the same in each instance. If half this change in velocity is attributed to the wind in each direction, the increase or decrease in velocity due to such winds, is three-eighths of a knot. It is by no means certain that this change in velocity is occasioned by the direct action of the wind. The wind itself is caused by difference of barometric pressure in the two directions; and it is quite possible that the current is affected by this difference of pressure rather than by the direct influence of the wind. The exceptional instance met with, may corroborate this view. It is also possible that strengthening during the clearing winds, is due to their making the current narrower and stronger by pressing it against the shore, as they often veer from north-west into north.

Displacement of the current.—During exceptional weather conditions, it is possible for the main south-eastward current which consists of water of the least density, to lie in the middle of the passage between the Gaspé coast and Anticosti. When the current is in this position, the area between it and the Gaspé coast may be occupied by weak and fluctuating currents, or even by a reverse current setting inwards to the north-west. This position in the middle of the passage may therefore be regarded as a displacement of the current, or an alternative route which it may take.

One of the most experienced captains of the coasting steamers in this region has more than once met with an absence of current below Cape Magdalen at an offing of 2 or 3 miles, during south-west winds, which are here unusual. He believes that the main current then lies farther out, but cannot say definitely. In our observations, this change was only met with once in three seasons, when it was carefully investigated. It must thus be considered as being of rare occurrence.

The conditions under which this displacement occurred, are carefully described and explained in "Currents in the Entrance to the St. Lawrence," pages 33 to 35.

Winter conditions.—In judging of the effect of the wind on a current by the behaviour of the ice it carries, there are two points that require to be considered: (1) The effect when ice is present is much greater than the same wind would have upon open water; as the broken and up-turned edges of the ice give the wind a greater hold upon it than it would otherwise have. (2) Even when the ice is set off the coast, the current itself may not be displaced to the same extent. For, the open water between the stream of ice and the shore may be setting in the same direction, as usual. This has been noted by careful observers, as actually occuring.

Off Cape Rosier, there is ice from the middle of January to the middle of April; and the main body of ice always moves outward to the south-east. No wind can stop it or reverse its direction. It may be driven from the land by the wind, and after a week of off-shore winds, there may be no ice visible at all, even in mid-winter. A south-east wind against the current, and also a northerly wind which bears on shore, will bring the ice close in; cutting off the strip of open water which is here usual between it and the shore.

As seen from the high view-point of the lighthouse on Cape Gaspé, the ice runs steadily southward during the winter, and this direction is never reversed under any conditions. The movement usually extends from the shore line as far out as can be seen. The ice is mostly broken and packed; but there are fields amongst it, of as much as a mile in size.

The usual winds in winter are N.W. and N.E. With north-west winds, the ice is opened out and moves more freely on; and with north-east winds, which bear on shore, it is more closely packed and somewhat retarded. At other times there is open water for as much as a mile from the coast. This occurs with S.W. winds which are off shore. There is no change in the speed of the ice towards spring; but the fresh water ice which then begins to appear is quite different from the winter ice and can be readily recognized. The current, however, is stronger in the spring of the year than in the autumn.

These descriptions of winter conditions accord with the observations, in showing that the wind cannot check this current by blowing directly against it, even when the effect of the wind is augmented by the presence of ice in the water. They also show that the wind is more capable of displacing the current in position; although it is quite possible that when the ice is driven off shore by the wind, the current itself may continue to flow along shore as usual.

From Cape Gaspé southward.—It is possible in the offing of Cape Gaspé, for a very strong current to be met with, especially during north-west winds. Vessels making Gaspé should be aware of this; but the main steamship routes do not pass the cape so closely as to encounter it.

Information regarding the current after it leaves Cape Gaspé was obtained from fishermen at Point Peter on the south side of Gaspé bay, who have spent a life-time in this region, and are close observers. It thus appears that from Cape Gaspé the general direction of the current is southward; and its greatest strength lies inside of American bank. This makes the usual width of the current about ten miles, which is the distance between Point Peter and that bank. After S.E. winds, the current lies closer in shore and is narrower and very strong;

and there may then be a northward set over American bank. This northward set, however, is never strong and only lasts a few hours at a time, and with change of wind the set is again southward.

During N. and N.E. winds, the strength of the current is increased; and on the other hand, there are times when no current is found in the width from Point Peter to American bank. This they cannot assign to any cause; although some of them consider that northerly winds 'run the current out,' and thus occasion a slack time afterwards.

The greatest strength of the current which is met with, is not during heavy winds, however. It occurs during hot and squally weather, or when calm and showery. Weather of this character 'creates tide' as they express it.

It is interesting to note the slight emphasis laid on the direct effect of the wind by such close observers; and their recognition of the displacement of the current, as well as its great strength at times when barometric conditions afford the only explanation of the increase.

Additional information in full Report.—The foregoing summary comprises the leading features of the Gaspé current. Further explanations and more complete results will be found in "The Currents in the Entrance to the St. Lawrence;" in which also directions are given for the best routes to follow, on inward and outward courses, to gain time.

THE MIDDLE OF THE OPEN GULF.

The nature of the current in the open, is indicated by observations obtained on the Orphan bank. The speed ranged from $\frac{1}{2}$ knot to a little over one knot per hour. At another anchorage 29 miles E. by N. from Bird Rocks, the average speed during nine hours was $\frac{3}{4}$ knot. The direction of the set was very varied.

The influence of the tidal stream from Chaleur bay can be felt as far as 30 miles out from Miscou island, at the mouth of the bay.

Off the north and south ends of the Magdalen islands, at about six miles from shore, the currents are more distinctly tidal. They run alternately in north-westward and south-eastward directions, with a speed which is sometimes over one knot per hour.

From reports received from the captains of the Black Diamond Line of steamers, running from Montreal to Sydney, Cape Breton, in reply to circulars issued in the seasons of 1895 and 1896, the average currents met with on the run across the Gulf, in the summer season from June to October, were found to be as follows:—

Between Gaspé and the Magdalen islands, on 17 trips reported, there were *ten times* when the current set south-eastward, at a speed ranging from one knot to 1½ knots per hour on the average of the run; *twice* it set north-westward; and *five times* it ran south-west or north-east as a cross current, the speed in these directions being only from ½ knot to one knot on the average.

Between the Magdalen islands and Cape North, on 16 trips reported, there were *nine times* when the current set south-east or eastward, at an average speed of ½ knot to one knot; *twice* it set north-west at only ½ knot, *twice* there was a cross-current; and *three times* there was no current appreciable.

The above result is important, as it indicates the dominant direction of the set across the middle of the Gulf to be south-eastward.

CURRENTS IN CABOT STRAIT.

(I.) Cape Breton current.—On the west side of this strait for a width of some 18 miles from Cape North, there is a constant current flowing to the south-east. This is as constant in one direction, as any current in the Gulf; as it is rarely checked under any conditions that occur. It is said, however, to be checked or reversed for a few days at a time, by heavy south-easterly winds.

Direction, speed and width.—The most usual or dominant direction of this current is between S.S.E. and E.S.E. Its speed is greatest near to Cape North, where it may be as much as two knots per hour. The width of the water flowing in the south-eastward direction has been found to extend for twelve miles or more to the east of St. Paul island.

Farther out, in the middle of the strait, the current was found to be quite indefinite in direction, and usually weak.

The behaviour of the Cape Breton current in the summer season, from a number of observations made in the months of August and September, is as follows:—At an anchorage 9 miles E.S.E. from Cape North, in the middle of the width of the current passing between that Cape and St. Paul island, the speed was found to range usually from ½ knot to 1½ knots per hour. After a strong north-westerly wind, which blew continuously for forty-eight hours with an average velocity of 24 miles an hour, the current here reached a speed of 2.25 knots. This is probably as high a speed as it ever attains at this distance from shore.

At an anchorage 10 miles N.N.E. from St. Paul island, the speed was found to vary from a little over ½ knot to fully 1½ knots per hour.

Its direction at both the above points, was found to veer during the course of the day, from south-east to south-west and back to south-east. The regularity in the time of this change in direction makes it probable that it is tidal in its nature; but the observations were not continued long enough to establish any definite relation with the rise and fall of the tide, as recorded by the tide gauge on St. Paul island. The greater speed of the current seems to occur during the fall of the tide, however.

Drift of ice.—The Cape Breton current carries out much Gulf ice in the early spring; and this serves to afford an indication of its direction. Many vessels are then engaged in sealing among it, and their masters are thus able to furnish reliable information. They state that from the northern end of the Magdalen islands to Cape North the current, although it may fluctuate, makes on the whole to the south-east. Vessels caught in the ice will drift outwards past Cape North, sometimes as far as the offing of St. Pierre island.

There is reason to believe that this current is no stronger in the spring than at other seasons; although this is sometimes asserted.

This current continues to be felt along the sweep of the north-eastern coast of Cape Breton island, sometimes as far as Scatari, before it mingles with the water of the Atlantic.

(II.) Current off Cape Ray.—On the eastern side of Cabot strait, there is usually a movement of the water to the north-west, or inwards towards the Gulf. This is a continuation of a general set westward, which is felt along the south coast of Newfoundland, between St. Pierre island and Cape Ray.

Direction, speed and width.—In steady weather, a current in this inward direction is felt for a width of 10 or 15 miles from Cape Ray, or even further. In the month of August, at an anchorage 13 miles west of this cape, the speed was found to range from $\frac{1}{2}$ knot to nearly $1\frac{1}{2}$ knots per hour. The direction varied between west and north; the dominant direction being north-west. The change in direction was less regular in time than on the other side of Cabot strait; and no relation to the rise and fall of the tide could be made out.

Disturbance, and drift of ice.—There is evidence to show that this current is by no means constantly inwards. As, however, the water off the south coast of Newfoundland usually remains open and free from drift ice throughout the winter, this is in itself an indication that the general movement is westward; as the Atlantic water must then be warmer than the Gulf water. It is also stated that icebergs off St. Pierre island will make westward, even against a north-west wind.

When there is ice in the spring season in the offing of St. George's bay and off Cape Ray, the evidence goes to show that it comes from the opposite direction, with the general drift which makes across the Gulf from Gaspé towards Cabot strait, and at times when this current, or a branch of it, is driven further to the eastward than usual. It is apparently in this way that the outward drift of ice on the Cape Ray side is to be explained, as this undoubtedly occurs in the early spring of some years at least, and when certain winds prevail. The Sailing Directions remark that in changeable weather, vessels can reach as far north as Lark harbour in the Bay of Islands, in any month; as it is only strong westerly winds which bind the ice in on the coast, and it soon clears away. The ice is thus brought there under conditions which make it an indication of disturbance in the current, as otherwise the water would remain open.

WEST COAST OF NEWFOUNDLAND.

In general, from Cape St. George to Rich Point, the movement of the water is north-eastward along this coast. Even when the current on the surface is checked, the under-current continues in this direction. It is thus evident that this is the normal direction of the current, when undisturbed.

The constant current.—From the Bay of Islands to Rich Point the current is the most distinct and persistent; and it may there be termed constant. It was stated by two navigating lieutenants of cruisers of the North American squadron, who have had from two to three years' experience on this coast, that the current in the summer season is always north-eastward when it is felt at all; and that it usually amounts to one knot. It is only intercepted by the flood and ebb tides running in and out of the larger bays on the coast.

The fishermen on this coast anchor their boats as much as 10 or 12 miles off shore, in about 30 fathoms of water. They have thus an excellent opportunity of observing the behaviour of the current. They state that its prevalent direction is to the N.E., parallel with the shore; it will run constantly in that direction for three or four days together; and on the whole it has that direction for rather more than two-thirds of the time.

The current is stronger near the shore and weaker farther out. It is found accordingly that a schooner going south-west will make better headway with long tacks; but if going north-east, with short tacks inshore.

Behaviour of the current as observed.—The speed and direction of this current was observed in September at an anchorage opposite the straight shore, where it would be unaffected by local influences. The point selected was 12 miles off Cow head, which is 20 miles north-east from the mouth of Bonne bay. The current was found to set almost always to the north-east, and very seldom veered in direction through a wider range than from N.W. to E.N.E. The speed is greatest while the current has its dominant direction to the N.E., but it was not found to exceed one knot per hour.

The current while thus veering in direction, may set directly off shore and it may also set on shore for three or four hours at a time. When setting on shore, the speed was little over $\frac{1}{2}$ knot per hour, at the offing of 12 miles, above mentioned.

Drift of ice.—Flat ice of about six feet in thickness, appears off Bonne bay in January or February, and remains till the early spring. The movement of this ice serves to indicate the usual direction of the current on this coast; as it drifts north-eastward in one day as far as it drifts south-westward in three days, with the same amount of wind one way or the other. A schooner caught in the ice off Cape St. George at the end of March, drifted along the coast as far as St. Barbe in about ten days, a distance of 190 miles; which gives on the average the ordinary rate of about one knot.

Influence of the wind.—For 12 to 20 hours before the arrival of a south-westerly gale, the current sets more strongly in its usual direction. Before a north-easterly gale arrives, it slacks: although it may also become slack at other times. With long continued easterly winds it may be reversed in direction.

BELLE ISLE STRAIT.

It will be necessary to describe the behaviour of the current in this strait with great clearness and care, as there has been much misunderstanding about it in the past. This has had most serious results in misleading mariners. A trustworthy basis for the actual facts has been obtained by the thorough investigations of this Survey, carried out with a steamer at anchor, at numerous points in the extent of the strait; thus securing continuous observations day and night, with the aid of current meters, wind instruments and special appliances.

The investigations occupied nearly two months in all, at different times in the season of 1894; and in 1906 the whole season was given to this strait, from June to September, inclusive.

As the behaviour of the current is undoubtedly complex, we may best [illegible] at the outset what its general features are, and deal with misunderstandings formerly prevalent, before giving more detailed descriptions of the current and its relations to wind and ice. These misleading theories include a supposed constant flow inwards towards the Gulf of St. Lawrence; a misunderstanding of the indications afforded by the drift of icebergs; and a belief that the direction of the current is dominated by the local wind in the strait.

General character.—The current in Belle Isle strait is primarily tidal in its character. While under the control of the tide alone, it will turn regularly and run with equal strength in each direction; the flood setting westward and the ebb eastward. But in addition to this tidal fluctuation, the water has almost always a tendency to make through the strait in one direction more than in the other. While the tidal fluctuation goes on uninterruptedly, the water is thus making a continuous gain to the westward, or to the eastward, as the case may be. This over-balance in one direction we may term the element of dominant flow which is super-imposed upon the usual tidal fluctuation. It gives rise to much complication, as it is large in relation to the strength of the tidal streams, especially at the neaps when these are weak.

Old theory of constant inward flow.—This theory could hardly be more contrary to the facts, and it is therefore very misleading to shipping. For it was assumed by vessels entering Belle Isle strait, that the current must always be in their favour in making the run westward to round the eastern end of Anticosti. But they were not in reality in advance of their reckoning as they supposed, but turned too soon; which may account for some of the wrecks that used to be frequent in that region. One of the earliest services rendered by the Survey of Tides and Currents was to disprove this erroneous idea. In Reports published in December, 1894, and October, 1895, it was explained that the current in Belle Isle strait is tidal in character; also, that the general set along the west coast of Newfoundland is north-eastward, not south-westard as this theory supposes; and further, that the outgoing water through Cabot strait is on the Cape Breton side, and is quite distinct in its density, temperature and other features, from Belle Isle water; while around Cape Ray the tendency of the water is to make inwards towards the Gulf, to balance the outflow on the other side of Cabot strait.

It is surprising that the erroneous theory regarding a constant inward flow through Belle Isle strait should have gained so much currency, when the tidal character of the current in the strait was ascertained as far back as 1854.

This inform ion is contained in a report by a Newfoundland official, Mr. M. H. Warren, addressed to the Colonial Secretary of Newfoundland and dated February, 1854. Mr. Warren states that he had been more than twenty times through the strait in sailing vessels, and thrice in a steam sloop; and as Superintendent of Fisheries for the Newfoundland Government, he had spent the months of July and Augus of the previous season cruising in the strait and had anchored several times in every harbour and also rowed in a boat from harbour to harbour. He was accordingly requested to report on the navigation of the strait, and in the course of his report he says:—"The tides in the Strait of Belle Isle are generally regular, flowing east and west; on the rising tide setting to the westward, on the falling tide to the eastward alternately every six hours. When the wind prevails east or west several days, it influences the tides; sometimes with a prevalence of east or west winds, on the change of the tide there is merely slack water. In the event of a calm, there is scarcely any danger of the tide hauling a vessel on shore on the Labrador coast, the tides generally setting off the points. On the coast of Newfoundland, from Cape Bauld to Cape Norman, the tides are not regular but set into Sacred and Pistolet bays, which are very dangerous."

The idea of a constant inward flow appears to be based on the drift of icebergs, and as they are more usually seen drifting inwards, it has been inferred that this is the constant direction of the current. The converse of this is much nearer the truth, however; as it may be stated in general, that when icebergs are numerous at the outer end of Belle Isle strait and are also found within the strait, this indicates that the direction of the current has been predominantly inwards during the few days previous, while the absence of icebergs indicates a current predominantly outwards. This of course refers to floating bergs, and not to bergs which may be aground near either shore. The inward flow is thus made visible, whereas the outward flow is not so.

(I.) TIDE AND CURRENT IN THE CENTRAL PART OF THE STRAIT.—The tide in Belle Isle strait, as recorded by the gauge at Forteau bay, has a range which is seldom as much as five feet. It shows with the usual distinctness the alternation from springs to neaps; but as the range is so small, the neap tides are apt to be irregular. When the moon's declination is high, north or south of the equator, the two tides in the day are very unequal; one of the two having a range of as much as 40 per cent more than the other. The declination influence is thus almost as strongly marked as the change with the moon's phases from springs to neaps; but the effect of the moon's distance is so small as to be quite obscure. The effect of the wind on the height of the tide is well marked, as may be expected with a strait open at both ends, and where the range is so small.

Tidal ebb and flow in the strait.—The foregoing characteristics of the tide in Belle Isle strait have been described with care, because every feature which the tide shows is distinctly reflected in the current. This comes out clearly when the strength of the tidal streams is measured with a current meter and the direction noted every half hour, day and night. The strength of the current changes in the same way as the tide, from springs to neaps; when the diurnal inequality is pronounced, the current alternates in exact correspondence with the variation in the range of the tide; and any irregularity in the tide curve is equally noticeable in the current.

Greater flow in one direction.—If the current were due solely to the rise and fall of the tide, it would always be of equal strength in both directions; for even with diurnal inequality, the tidal streams would be equal in pairs. But in fact, it is the exception for the speed of the current to be quite equal in the two directions. There is thus on the whole, a gain in favour of one direction; or an overbalance of flow inwards or outwards as the case may be. This is equivalent to a continuous flow in one direction, super-imposed upon the ebb and flow of the tide. It is thus best to regard it as a separate element which, in combination with others, makes up the movement of the water as actually met with.

This view is the more reasonable, as a dominant flow of this character may go on for a week at a time, or even longer, in one direction or the other; and it must therefore be considered as something distinct from the more regular tidal fluctuations. In amount, the average rate at which the water gains or makes in the one direction may be considerably over one knot per hour. This movement comes to an end by gradually decreasing in amount and thus allowing the tidal streams to resume their equality of speed in the two directions. In this behaviour the under-current acts almost always in the same way as the surface current; so that the whole body of the water appears to be affected alike.

Cause of the dominant flow.—It must not be hastily assumed that the wind is the cause of the dominant flow. There is no evident relation between the direction of this flow and the local wind to show that one is the cause of the other. The wind would produce primarily a surface drift, whereas the dominant flow affects the whole body of the water. Examples of a true wind drift have been met with in the strait; but they are rare in the summer season, as the winds are not heavy enough or sufficiently long continued to cause the surface drift to extend to any great depth. It is also to be noted that the dominant flow may continue for a week or more at a time in the one direction, which a wind drift would not do. The probable causes are fully discussed in the Report entitled, "The Currents in Belle Isle Strait."

Practical indications of the direction of the dominant flow.—The probable direction of the flow may be inferred from the general weather conditions of the region and from the presence or absence of floating icebergs in the strait. It may be taken for granted that there are always some icebergs in the offing of the strait or eastward in the Atlantic. If a westward flow is dominant at the time, the icebergs, while drifted up and down by the tidal streams, will make their way into the strait; whereas, if an eastward flow is dominant, the strait will be free from bergs which are afloat. It is to be noted that this indication is quite independent of what may be the cause of the flow.

To take advantage of this indication, the mariner must be able to distinguish with a fair degree of certainty, the icebergs which are afloat. If they are close to either shore, they are sure to be aground; and they may have been there for a week or more. A berg towards the north side of the strait is more likely to be afloat, as the water there is deeper. In the middle part of the strait, any berg will ground if it is large enough. It is there a question of size, and the probability of its being aground is stronger if it is at a position where the water shallows to the westward, or if it is over the Cent Bank. The smaller bergs, well clear of the shore, are of course the most likely to be afloat.

The best indications of practical value, including the influence of weather conditions, may be summarized as follows:—

(1.) If the strait is clear of floating icebergs; and if the barometer is well up and rising, or high and steady; the probability is that the dominant flow is EASTWARD. It may amount at the most to $1\frac{1}{2}$ knots. The usual ebb velocity is increased by the amount of this flow, and the flood is decreased or may be reversed by it.

(2.) If there are icebergs in the strait which are afloat; and if a low pressure area is passing to the southward, indicated by broken weather; the probability is that the dominant flow is WESTWARD. It is almost certainly so after a gale from the north or north-east. It may amount at the most to $1\frac{3}{4}$ knots. The usual flood velocity is increased by the amount of this flow, and the ebb is decreased or reversed by it.

(3.) The direction of the local wind in the strait, and the temperature of the water, cannot be counted upon as reliable indications of the direction of the dominant flow.

(4.) It appears probable that on the whole there is more westward flow in the early part of the season, in May and June; that although less pronounced in the summer, there is then usually more to the eastward; and that from September onward there is more westward flow. This would correspond with the indications above given, as the weather is apt to be more stormy as the season advances.

Velocity of the current.—In giving values for the velocity, it is necessary to distinguish the various elements in the current, and the result of their combination under various conditions. These are as follows:—

(a) Current without diurnal inequality, at times when the moon is on the equator or near to it, and there is no dominant flow. Flood or ebb velocity at Spring tides, 1.50 knots; at Neap tides, 0.68 knots.

(b) Current with diurnal inequality, at times when the moon is at its maximum declination, and there is no dominant flow. At Spring tides, strong flood and ebb velocity, 2.27 knots; weak flood and ebb, 0.72 knot. At Neap tides, strong flood and ebb velocity, 1.04 knots; weak flood and ebb, 0.32 knot.

(c) Amount of dominant flow considered separately. The greatest rate of flow in each direction which occurred in the course of any one day during the two seasons, was as follows:—

Westward: Average flow 1.69 knots; the current running continuously westward without turning, but fluctuating from 2.65 knots to 0.64 knot with the flood and ebb.

Eastward: Average flow 1.30 knots; the current running continuously eastward without turning, but fluctuating from 2.76 knots to 0.50 knot with the ebb and flood.

It is thus evident that the dominant flow is often sufficient to overcome the ordinary tidal streams, and prevent the current from turning as it otherwise would. This will occur when the tidal streams themselves are weak, as they may be at the neaps, or when the diurnal inequality is large. The highest actual velocities ever observed, under such combinations of conditions as were met with, were as follows:—

Westward, during a flood period, 3.45 knots.
Eastward, during an ebb period, 2.83 knots.

Time of turn of the current in relation to time of the tide.—This relation was found to be quite definite so long as the current was under the control of the tide, without appreciable dominant flow.

The difference of time was also determined between the time of maximum strength in the current and the moment of half tide, rising or falling. These data, which are so valuable to mariners in ordinary estuaries, are unfortunately of uncertain application in this strait; unless it were possible to know, while there, that the tidal streams were normal and not modified by dominant flow, which necessarily throws them out of time.

The under-current.—The primary object in the study of the under-current is to detect wind disturbance; as the wind necessarily influences the surface of the water first, and tends to cause a drift in its own direction, while the under-current continues to turn with the tide as usual.

As a rule, the ordinary tidal streams of the strait veer completely round in turning from east to west. At high water the veer is through north and at low water through south. The under-current, at a depth of 25 fathoms, does not veer nearly so much, but turns more sharply from one direction to the other. With care, the time of turn could be ascertained within five minutes.

It may be said in general, that the under-current turned at the same time as the surface current. On the average it was within four minutes earlier or later; and there is seldom more than fifteen or twenty minutes between the two, unless the time is influenced by the dominant flow. Also, the time of maximum in the under-current corresponds with the maximum at the surface within five minutes on the average.

The results, condensed from a very large number of careful observations, are important in establishing the general rule. They thus help to make plain any exceptional influence, such as wind disturbance, which may cause a departure from the usual average.

Effect of wind and barometer.—During both seasons, a careful watch was kept, to detect any influence of the wind upon the movement of the water; and the continuous meteorological observations, taken on board, afforded complete weather data for comparison. But it may be stated in general that the effect of the local winds in producing a drift in their own direction is remarkably slight, considering the situation of this strait. In the line of the strait to the westward there is a clear stretch of 470 miles of water across the Gulf of St. Lawrence to the New Brunswick shore; and to the eastward it opens into the Atlantic with no other shelter than what the small island of Belle Isle affords.

The best indication of the effect of the wind upon the movement of the water is afforded by a difference between the surface current and the under-current, in direction or in the time at which they turn; as it can be stated definitely from the experience gained in this Survey, that the water at a depth of 20 or 25 fathoms, at which the under-current was here observed, is unaffected by any storm, at least in the summer season. A departure from the general relations between the surface and under-current as established by these observations, will thus reveal any disturbance occasioned by wind.

It was frequently observed, especially in unsettled weather, that if there is a change, it will occur at slack water. For example, when the barometer is low, and a change is to be expected, east wind will come up with the flood. Also a westerly wind will seem to be held back by the flood and will be light and variable till slack water, when it will come out strongly with the ebb. These changes with the tide, in unsettled weather, are exactly similar to those which are so familiar on the Lower St. Lawrence. It would thus appear to be quite as necessary to point out that the turn of the tide may influence the wind, as that the wind may cause the tidal stream to run longer in its own direction.

The large mileage of wind required to produce a true wind drift is further shown by the behaviour of the tidal streams with relation to the wind. While anchored in mid-strait, it was often found during a strong steady wind, either east or west, that the current in its ordinary change from flood to ebb would set directly into the wind for the usual tidal period. A strong wind has thus little appreciable effect, during a tidal period of five to seven hours, in checking the current on the surface. It appears to require a large mileage of wind to produce any noticeable effect by its direct action on the water.

Instances of the effect of gales, and the disturbance occasioned by measured mileages of wind, are given fully in "The Currents in Belle Isle Strait," pages 34 to 36.

Conclusions regarding wind disturbance in Belle Isle strait.—The effect of the wind in Belle Isle strait in raising a sea quickly, is very noticeable; but any direct effect upon the movement of the water, as far as careful observation can detect, is remarkably slight.

Most of the effects usually ascribed to the wind have been found on investigation to be due to other causes. Yet it is true that the wind itself may afford an indication of the existence and operation of such causes as those which may influence the direction of the dominant flow. But the strong preponderance of flow in one direction during quiet weather, and the small difference in time between the turn on the surface and in the under-current, show clearly that this dominant flow is not of the nature of a wind drift.

The actual influence of the wind upon the movement of the water, may be summarized as follows:—

(1) It is anything but true that the current always sets with the wind which is blowing locally in the strait; since the ordinary tidal streams as they

turn, will set directly against the wind, even when it is fairly heavy. On the other hand, in unsettled weather, the wind often comes up with the turn of the tide; or it is held back until slack water by the tidal stream setting against it.

(2) There was no evidence, after any of the gales, that the wind was able to reverse the direction of the tidal streams, or that it was able to check to any noticeable extent, the dominant flow which prevailed at the time.

(3) From direct comparisons of the velocities of the surface and under-current, made in 1894, it appears that when a period of several days is considered as a whole, the current which sets against the wind prevailing at the time, is somewhat retarded on the surface. This is inferred from the velocity it otherwise would have had, as indicated by the under-current.

(4) The only other effects of the wind upon the movement of the water which can be detected, are these:—There may be a slight change in the time of veering at the turn of the current when it is weak; and the period of flood or ebb which is in the direction of the wind may become slightly longer on the surface than in the under-current.

These results are based upon observations taken as soon as the weather moderated. If the effects are greater while a gale lasts, the current must recover its usual behaviour almost at once, when the wind falls.

Temperature of the water and wind disturbance.—In the early part of the season when the surface temperature is only 35° Fahrenheit, there is little difference between this and the under-water; but after June the surface layer warms up to 45° or even 55°, while the deeper water remains almost as cold as before. A sudden change in the surface temperature may thus afford a valuable indication of wind disturbance; as the wind, especially when off shore, may drive off the surface water and allow the colder under-water to come up to replace it.

The amount of change which the wind can thus occasion is indicated by the following instances in 1906:—On August 16th, the average surface temperature from Red bay on the north shore to the middle of the strait, was 52.7°. After a N.E. gale on the 17th, the temperature on the following morning over the same extent was 45.2°. For the next two weeks, the temperature of the surface water recovered very little, not rising much above 46°. This was partly due to another N.E. gale on September 4th. On September 7th and 8th a heavy northerly gale occurred, which again lowered the surface temperature 2° for two miles from the north shore. (Full details regarding these gales, with the mileage of wind which produced these changes, is given in "The Currents in Belle Isle Strait," page 37.)

Water temperature and icebergs.—Temperatures were taken from a boat around a large iceberg, 780 feet long, at a time when the surface water in the vicinity was 39°. It was thus found that the water temperature was lowered less than 2° at distances ranging from 130 to 1320 feet from it.

Another iceberg about 140 feet long was aground in the middle of the strait in 38 fathoms. The surface temperature in the strait at the time was $35\frac{1}{2}$°, and the temperatures taken from a boat close around the berg were found to be the same, except on the west side, where the water tailing from it with the flood was 35°. There was thus only $\frac{1}{2}$° difference of temperature to be found near it.

It is evident that such small differences as these, taken with ordinary thermometers, and found closer to icebergs than a steamer would willingly venture, cannot be relied upon as an indication of value. At times when the surface temperature is higher, more difference might be expected; but this usually occurs while the dominant flow is eastward, which prevents the bergs from coming in.

It might be thought probable that when many icebergs come into the strait, the colder water of the Labrador current off its mouth would come in with them, and thus give a general indication of their presence. Broadly speaking, this may be true; but there is the corresponding disadvantage of less indication locally, near individual bergs, because of the water being colder.

It is also when the surface temperature is high that a gale may occasion the greatest change met with. When a gale can lower the average surface temperature by $7\frac{1}{2}$° Fahr. over an extent of five miles from shore, the much smaller changes such as those cited above, can hardly be relied upon as an indication of the proximity of icebergs under the conditions obtaining in this strait.

(II.) Current off the Eastern end.—The general Labrador current setting southward past the mouth of the strait, is influenced by the tidal inflow and outflow of the strait itself. It is found accordingly on the whole, that the greater inflow towards the strait takes place on the northern side of the mouth, north of Belle Isle, and the greater outward flow on the southern side.

The small amount of indraught towards the strait, relatively to the general drift of the Labrador current, is also shown by the icebergs; for only a very small percentage of the bergs off the outer end of the strait ever enter it. Captain Vaughan, who resided four years on Belle Isle, states in a pamphlet on the subject that for ten icebergs which enter the strait, there are fifty that pass the mouth and go southward. In doing so they follow the general drift of the Labrador current which passes Belle Isle; and the larger bergs also ground at the entrance to the strait.

This general southward drift past the mouth of the strait is corroborated by Mr. P. J. Colton, lightkeeper of the south light on Belle Isle. He has lived there all his life, and had then been in charge for five years. He describes the icebergs, which follow the outer Labrador coast, as passing the mouth of the strait and keeping right on towards the outer capes of Newfoundland at Fogo. It is only bergs that are close to the Labrador side that enter the strait, and these are not one in ten of the whole number. After they thus enter the strait, if they come out again at all, it is always along the Newfoundland side, as viewed from Belle Isle.

(III.) CURRENTS AT THE WESTERN END.—The area between Rich Point and the western end of Belle Isle strait, is intermediate between the constant current on the west coast of Newfoundland, and the tidal current of the strait. The tidal element predominates however, and the current does not usually make in one direction more than the other on the whole. As a result, the currents are variable and uncertain in their direction, and cross-currents are frequent. When flat ice is present, it may make a considerable drift when the wind is with the current; but when against it, the ice stands and shoves.

The area in which such currents may occur, extends westward from the narrowest part of the strait at Amour Point to a line through Rich Point running magnetic north to the west end of the Esquimaux islands. Towards the western side of this area, the currents are usually less than one knot, and seldom exceed $1\frac{1}{2}$ knots; but towards the entrance of the strait their strength increases, while in direction they are more nearly in the line of the strait itself.

In the offing of the Esquimaux islands, fishermen when anchored six miles from shore find that the current usually runs along the shore in one direction or the other; but there are times when it sets off or on shore for a whole tide.

There is also a cross-current which is sometimes found to run from Greenly island south-eastward; and forms a strong set on shore towards Flower cove.

THE NORTH SHORE OF THE GULF.

THE MEKATTINA SHORE; FROM THE ESQUIMAUX ISLANDS TO CAPE WHITTLE. —On this shore the general movement of the body of the water, when the direction of the under-current is also taken into account, was found to tend westward.

When the weather is calm, and also during easterly winds, the current on the surface will usually follow this general movement of the water to the westward. The actual current, under the influence of the prevailing winds from the westerly quarter, is very irregular however, and may set in almost any direction.

The direction in which the body of the water makes on the whole, is also indicated by the drift of icebergs. These have been seen as far west as the Mekattina islands; and sometimes, though rarely, they reach Cape Whittle. Icebergs on this shore therefore, are carried westward more than twice as far as on the Newfoundland side, where they are rarely found beyond Rich Point.

Speed and direction.—In the summer season, the speed of the current usually ranges from a half to one knot per hour; and it may be in any direction. As between off-shore and on-shore directions, a set off shore is the more frequent.

The captains of trans-Atlantic steamships, in reply to circulars issued in the seasons of 1895 and 1896, report that the average current met with on the run from Heath Point to Greenly island was as follows:—On thirty-two trips made between July and October there were *sixteen times* when there was no current appreciable; *nine times* the current set eastward, and *seven times* it set westward; the speed in each case ranging from $\frac{1}{4}$ knot to $\frac{3}{4}$ knot per hour on the average during the above run.

In the early spring, at Great Mekattina island near the middle of this shore, it is stated by an old resident that the current runs in either direction, but is strongest to the westward. The ice when going westward, passes at a walking pace, or about three knots per hour. It is unlikely that the current in the open is ever as much as this. The fishermen not infrequently speak of a much higher speed; but it is always found on inquiry that this is over-estimated, or that they refer to local rips or tidal streams in confined channels.

From Cape Whittle to the East end of Anticosti.—As the current in Mingan strait was found to be tidal, and to run with nearly the same strength in each direction, there is no through current to be expected in the channel north of Anticosti.

At an anchorage 18 miles off Cape Whittle a continuous record of the direction of the current was obtained during five days in the month of July, and again during four days in August. The current was found to veer completely around the compass in a period of about sixteen hours on the average. The speed of the current did not exceed one knot per hour in any direction.

Where the currents are so slow, the influence of the wind is the more considerable. From observations at an anchorage mid-way between Cape Whittle and Heath Point, made continuously day and night for five days in the month of July, the current was found to set in all directions with a low speed; the dominant direction being with the winds which were most continuous at the time. Thus when a period of several days is taken as a whole, it is found that the greatest amount of set has taken place in the same general direction as the greatest total mileage of wind; but at any particular time, the direction of the current is seldom the same as the wind which is blowing locally.

It thus appears that the general tendency of the water to move westward, when combined with the influence of the prevailing wind in the contrary direction, has for its result an actual set which is nearly equal in every direction.

As winds from the westerly quarter are the most prevalent at any time, it is probable that the surface current usually has an outward tendency. This accords with the experience of Captain Macauley of the Dominion Line; who states that in crossing from Heath Point to Cape Whittle, vessels are set more to the southward by north-west winds, than to the northward with south-east winds.

At Natashkwan Point, the current at two miles from shore, was noted every two hours during daylight for seventy-two days in the months of July, August and September. Its direction was usually W.N.W. or E.S.E., along the general bearing of this coast; although it sometimes veered two points or more from these directions. On the whole, from a total of 627 observations, the set was south-eastward for two-thirds of the time.

Tidal influence.—There is reason to believe from a close study of the manner in which the current veers, and the directions in which it holds the longest, that these may be due to tidal influence. In the case of these currents, which are well out in the offing, the tidal relations that have been made out, are found chiefly to govern the movement of the under-current; and they have relatively little influence on the surface current, except in very calm weather.

MINGAN STRAIT.—An examination of the currents in this strait was made in the month of July at its narrowest part; between North Point of Anticosti, and Niapisca island, one of the Mingan group. The current proved to be tidal. It runs north-westward through the strait with the rising tide, and south-eastward with the falling tide. It often veers considerably from these directions, however. The speed in the open strait, during neap tides, does not amount to as much as $1\frac{1}{2}$ knots per hour in either direction.

The difference in the amount of set each way, as shown by the surface current during calm weather, is in favour of the inward direction; being on the whole 24 per cent more to the north-west than to the south-east.

WEST END OF ANTICOSTI.—It is stated by the light-keeper at West Point that the current on the south of Anticosti, in that vicinity, sets along shore either south-east or north-west. In the summer the usual direction is north-westward. At times when the current on the south shore is south-eastward, it appears to divide at West Point while the tide is falling in Mingan strait; but while the tide is rising, the currents meet on the north shore within eight miles of West Point.

In the spring, the ice on the south shore drifts with the wind and current to the south-east, except when the wind is easterly, which is not frequent. The ice is not over six feet thick, except when packed or in shoves.

EAST END OF ANTICOSTI.—Continuous observations day and night were obtained at the Lightship off Heath Point during the two seasons of 1910 and 1911, from June or July until October. This Lightship is moored at 8 miles E. by S. from the lighthouse on the point, in 22 fathoms.

The current as a rule veers continually in a right-handed direction making a complete revolution in the tidal period. The speed, as found from measurements in this vicinity, seldom exceeds one knot per hour in any direction. This behaviour is maintained while the tidal influence is pronounced; and even at the neaps the veer continues regular in quiet weather, although the strength is weaker and may fall at times to nothing. The wind has also a marked effect on the surface direction, as might be expected with such weak currents as these.

The rate of veer is not uniform; but it is more rapid through the N.W. and S.E. quarters, and it holds longer north-eastward and south-westward. This more definite and stronger set continues for two hours before and after high water and low water, and its direction is across the end of the island. The more rapid veer occurs at about half tide, rising or falling; and the speed is then least, falling often to nothing for an hour or two. This rapid veer and slack time corresponds with the directions towards and from the end of the island.

Under-current.—Good observations of the under-current were obtained in this vicinity in 1896, at two anchorages at 13 and 25 miles of E.S.E. of Heath Point.

It thus appears that the under-current has a definite set in two directions in accordance with the tide; and these dominant directions, just as in the surface current, are nearly across the end of Anticosti island.* The under-current, however, maintains the normal behaviour, even when the surface current veers as irregularly as it sometimes does at the neaps; whereas in the surface current this behaviour, though distinct at the springs, is not always evident at other times in the month.

A special reduction of these observations was made to determine in which direction the greater amount of flow occurs. The result shows that the general movement of the water in this region is south-westward, which will be explained further in its place.

Wind effects off Heath Point.—In the undisturbed behaviour of the secur-rents, there are not only the tidal influences and their variation, but also a dominant tendency towards the southwest quarter; which is apt to be more persistent during the neaps when the tidal influence is at its least. This tendency should not be overlooked in estimating the influence attributable to the wind itself. It is also to be noted that the observations at the Lightship were obtained from a surface float, unaccompanied by the direction of the under-current, and the apparent effect of the wind may thus be exaggerated; as quite possibly the disturbance may be so superficial as not to extend to the draught of an ordinary vessel. On the other hand, the observations were long-continued; and they include heavier weather than a surveying vessel could work in, as the Lightship is adequately moored for holding.

There were occasionally periods of as much as 14 to 54 hours when the surface current ran continuously south-westward, and it once held for even longer in the south-west quarter. This may be partly due to the dominant set in that direction, as it occurred sometimes during light and variable winds at the neap tides. It is quite evident however, that strong winds and gales from the N. and N.W. give assistance to this tendency. On the other hand, the current as it veers around, is less strong in north-westward directions at any time; so that the set in that quarter is easily checked by contrary winds. N.E. winds were so rare in both seasons, that their effect was not ascertained.

During strong south-westerly winds, the results are just the contrary. The effect of these winds is slight, because they are unable to overcome the strong south-westward tendency of the set. It thus frequently happens that the current when S.S.W. or W.S.W. will set directly into the wind; and it is only occasionally when the tides are weak, that the wind is able to check this, or to reverse its direction. In one instance, at spring tides, during a steady S.S.W. wind, which was strong for two days and moderate for two and a half days more, the behaviour of the current was quite normal, and in veering it set directly into the wind for the usual length of time.

South-east wind has an appreciable effect in checking the set against it; as the set has this direction when it is weakest. It may thus hold the set longer in the eastward, or make it veer more quickly into south. The most noticeable effect of S.E. wind however, is to check the south-westward set which is so frequent, and to occasion a larger amount of set into the N.E. quarter. Several flood tides were thus reversed and made to set into the N.E. This wind has little effect upon the ebb which is normally north-eastward.

The reason of this influence is not apparent, unless it may be that the effect is modified by difference of barometric pressure. In some instances also, strong S.E. wind of as much as 22 hours duration, had no influence at all on the usual directions of the current as it veered.

The results of the extended observations off Heath Point are fully discussed in "The Currents in the Entrance to the St. Lawrence," pages 7 to 11.

THE SOUTH COAST OF ANTICOSTI.—On the steamship route along the south coast of Anticosti and as far as the middle of the passage between Anticosti and the Gaspé coast, the current shows a very variable behaviour. As a rule, the set veers continuously around the compass in the right-hand direction; but there are times when the veer may be to the left through more than one quadrant, or when the set may hold in one direction for several hours. The speed, however, is never great; as the maximum velocity observed at an offing of five miles or more from shore, was less than $1\frac{1}{2}$ knots; and the strength in any on-shore direction as the current veers, was much less than this, seldom exceeding half a knot.

At two anchorages off Bagot Point, at $5\frac{1}{2}$ and 6 miles from shore, the current veers continually in direction. The veer is usually right-handed, but backing in the opposite direction sometimes occurs. The rate of veer is not uniform, but is more rapid in passing the on-shore and off-shore directions. The current thus sets for a longer time and more strongly in directions which are along shore; and this tendency is more marked in the under-current, which turns by reversing its direction instead of veering as widely as the surface current does. These directions are in correspondence with the tide, being in a general way to the westward during the flood and eastward during the ebb. The greatest velocities in any direction, as observed at these two stations, were 1.35 and 1.14 knots.

Although the relation to the tide cannot be very definite with such weak currents and a tidal range of only five feet at the most, yet after making trial of a number of different methods, a satisfactory correspondence was found with the time of maximum velocity.

As the tides fall off towards the neaps, the direction becomes more indefinite, and last of all the time of the maximum velocity becomes uncertain. There can be no doubt, however, that the behaviour of the current is primarily due to tidal influence.

At an anchorage farther westward, at $8\frac{1}{2}$ miles from shore off the mouth of Pavillon river, the general behaviour is much the same as the above. Being farther from shore than the stations off Bagot Point, the veer around the compass is more regular in its period, as it always is in such circumstances.

On-shore directions.—To judge of the effect of the current when setting on shore, a special study of the movement of the water from the surface downwards was made to ascertain the depth to which the surface direction extends. It may be definitely stated that there is no on-shore set on this coast that an ocean-going vessel need be concerned about. Such a set is not only weak, but is usually less in thickness than their draught. The conditions as found, serve also to explain the repeated reports of fishermen that the current often sets obliquely on shore. The men who have a long acquaintance with these coasts state that for some distance both ways from South Point, they have found the current to set obliquely on shore from a southerly direction; more especially during S.W. and S. winds, and with a rising tide. This may very well be true of their fishing boats when becalmed, although the depth of the movement might not be sufficient to affect appreciably a steamer of ordinary draught.

THE MIDDLE OF THE PASSAGE BETWEEN ANTICOSTI AND THE GASPÉ COAST.—Anchorages were made several times at two points in the middle of the passage between the Gaspé coast and Anticosti, where the depth is about 180 fathoms. One of these is on the direct line of the steamship route, and the other on a line indicated as a constant current on the chart of the Entrance to the St. Lawrence. The currents are too weak to be of much importance to navigation, so far from shore; but their behaviour is important with relation to the movements of the water on the two sides of the passage.

In general, the current was found to veer continuously in a right-handed direction, making a complete revolution in the tidal period. The velocity rises regularly to a maximum which occurs near the time of high water, when the direction is almost always between W.S.W. and W.N.W. This behaviour continued until the neap tides, when it became less distinct; there being then as much backing to the left as veering to the right.

It thus appears that in the middle of the passage the current is tidal in character, with the same general features as on the south shore of Anticosti. This is further confirmed by the period in which the direction veers completely around the compass. This period during the more definite tides, omitting the neaps, is on the average 12 h. 24 m. or 12 h. 33 m. as found by two different methods; which is just the tidal period.

Under-current.—In general, the set of the under-current at 15 and 30 fathoms, was north-westward during the flood and south-eastward during the ebb; in correspondence with the general direction of the passage itself. It held these directions more steadily and with less veer than the surface current; and in these directions also the depth was great, the current being still strong at 50 and 90 fathoms, especially when north-westward.

While the surface current, in veering, set transversely to the direction of the passage, the under-current was slack. In these cross directions the current is thus usually thin. There were times when it was still appreciable to a depth of 15 or 20 fathoms; but as a rule it was not more than 3 to 6 fathoms in thickness. These directions, at stations nearer the coast, would be off and on shore; but so far out as this, they have less importance, and it is not therefore necessary to describe them in greater detail.

It throws an interesting light on the nature of the on-shore set, to find that even here in the middle of the passage, the current in the transverse direction is relatively thin and superficial; as this helps to explain its character nearer shore.

NORTHUMBERLAND STRAIT.—Tidal Streams.

In this strait, the flood sets south-eastward through the Western narrows off West Point of Prince Edward island and through the Central narrows at Cape Traverse, and it sets westward through the Eastern narrows off Wood islands; the ebb having the reverse directions. The tidal streams thus meet in the expanse between the Hillsborough and Baie Verte.

Observations obtained.—The currents in this strait were investigated in 1908, during four months, from June to October, by means of a surveying steamer anchored in the middle of each of these narrows, and at other selected points in the extent of the strait.

As the observations were obtained day and night continuously by means of current meters, the variations in strength and the time of maximum velocity were definitely ascertained for comparison with the time of the tide as observed simultaneously at the principal tidal stations.

Observations of the turn of the current in the narrows between Capes Tormentine and Traverse were also secured in the two seasons of 1902 and 1903, from fishermen who haul their traps at slack water; and who can thus note the turn very definitely from the attached floats. The turn of the current was thus observed 134 times in the two seasons.

Effect of the moon's declination.—When the moon is in high declination, north or south of the equator, the two tides of the day are quite unequal. This change in the moon's declination from north to south, is exactly similar to the sun's variation in altitude from summer to winter; but the moon completes the change in the course of the tropical month. As this is shorter than the synodic month of the moon's phases, the one over-runs the other. Hence, when the inequality in the tide is greatest, it occurs in some months at the springs and again in others at the neaps, which gives the tide an appearance of great irregularity if the cause is overlooked.

In Northumberland strait, this diurnal inequality is the leading feature which dominates the tide. With the moon in high declination, the tide as observed at Charlottetown shows an inequality in range between the two tides of the day, which is half as much again as the true difference between the springs and the neaps.

Characteristics of the current.—The behaviour of the current is in close accord with these features of the tide. When the moon is i high declination, the turn of the current is alternately earlier and later than the average, in relation to the time of high and low water; and the strength of one flood and one ebb in the day is much greater than the strength of the other two. These inequalities occur in some months at the springs and again in other months at the neaps, for the reasons explained; and they are reversed, as between the day and night tides, when the moon's declination is reversed from north to south. Such variations are apt to be attributed to the wind, whereas they recur with astronomical regularity.

Reduction of the observations.—An endeavour was made to reduce the observations obtained in the various narrows, by several carefully devised methods; but the variations proved to be so wide, that no rules of practical value could be derived from them. Further light was thrown upon the problem, however, by subsequent investigations. The tidal observations of 1910 on the North shore of the Gulf of St. Lawrence, enabled the general behaviour of the tide throughout the Gulf area to be better understood. It was thus ascertained that on the North shore, high water corresponds with the tide in the main entrance at Cabot strait, while low water corresponds with the tide in the St. Lawrence estuary.

Again, it became evident from the investigation of currents elsewhere, that the best relation with the time of high or low water is the moment of maximum velocity on the flood or ebb. This can be determined accurately from continuous observations with the current meter; and it is much more definite than the time at which a current turns, as it is then necessarily weak and variable. In this respect, such currents are the converse of those in the passes of British Columbia, where navigation is only possible at slack water.

By following up these clues, successful results for Northumberland strait were arrived at. With the time of maximum velocity as a basis, relationships were determined by means of exhaustive comparisons with the time of the tide at the principal stations, as observed simultaneously. As the outstanding variations proved to be due almost wholly to diurnal inequality, this became the criterion in the comparisons. The reference stations giving the best results were thus ascertained; and these proved to be the stations on the opposite sides of the Gulf area as already indicated, the local tidal stations in the strait itself at Charlottetown and Pictou being much less satisfactory. The final outcome was as follows:—

In the Eastern narrows where the tide enters directly by way of Cabot strait, the relation of both flood and ebb to the tide at St. Paul island is rather more satisfactory than with any other reference station. At the inner end of the strait, in the Western and Central narrows, where the tide enters indirectly from the Gulf area, the flood is related to low water at Father Point and the ebb to high water at St. Paul island.

This alternating accord with the tide on the opposite sides of the Gulf area, is in harmony with the behaviour of the tide on the North shore, as already explained; and the greater constancy of the time-relations, when taken with this alternation, is noteworthy in view of the reversal of the diurnal inequality which is now known to occur between Cabot strait and Miramichi, on a transverse line across the Gulf of St. Lawrence.

Time-relations.—The observations obtained by the surveying steamer were reduced in accordance with the relationships above indicated; and it was also found possible to utilize the series of slack water observations in the Central narrows, by employing the differences of time between the turn of the current and the maximum velocity, as determined from the observations on the steamer. The rules thus obtained are given below in tabular form. The mariner may thus know at any moment whether the flood or ebb is running, and the time when each attains its maximum strength, which are the matters of chief practical importance.

Locality.	For time of Maximum strength on the Flood.	For time of Maximum strength on the Ebb.
In Eastern narrows off Wood islands.	Add 6 h. 00 m. to L. W. at St. Paul island.	Add 5 h. 57 m. to H. W. at St. Paul island.
In Central narrows at Cape Traverse.	Add 10 h. 35 m. to L. W. at Father Point.	Add 4 h. 04 m. to H. W. at St. Paul island.
In Western narrows off West Point.	Add 11 h. 32 m. to L. W. at Father Point.	Add 4 h. 38 m. to H. W. at St. Paul island.

The above values, when added to the time of the tide as given in the Tide Tables for the localities indicated, will give the result in Atlantic Standard time.

For the Central narrows at Cape Traverse, greater accuracy can be obtained by allowing for variation with the moon's declination. To do so, the tides in the Tide Tables must be thus distinguished: The high or low waters which follow the moon's Upper transit when in North declination, and those which follow the moon's Lower transit when in South declination, are termed "Similar." The remaining high or low waters, which follow the moon's Lower transit when North or the Upper transit when South, are termed "Opposite." The time of the maximum strength on the flood or ebb are then found by the following rules:—

For the time of maximum on the Flood—

To "Similar" Low Waters at Father Point, add 10h. 40m.
To "Opposite" " " " " " add 10h. 15m.

For the time of maximum on the Ebb—

To "Similar" High Waters at St. Paul island, add 3h. 50m.
To "Opposite" " " " " " add 4h. 35m.

To simplify the application of these rules, all the tides when the moon is near the equator have been included with the "Similars" in obtaining the first of the two values. It is only necessary therefore to make use of the second value for the "Opposites," when the moon is in high declination.

Strength of the current.—The maximum velocities at mid-flood and mid-ebb at the spring and neap tides, respectively, are given in the following table. The values are the averages for two days before and after the springs, and for two days before and after the neaps, in each month of the observations. The diurnal inequality is thus eliminated.

Locality.	On the Flood.		On the Ebb.		Greatest velocity observed.
	Springs.	Neaps.	Springs.	Neaps.	
In Eastern narrows	1.79 knots	0.98 knots	1.81 knots	0.98 knots	2.35 knots
In Central narrows	1.65 "	1.17 "	1.31 "	0.83 "	2.21 "
In Western narrows	1.64 "	1.20 "	1.44 "	1.00 "	2.03 "

The high value of the greatest velocities observed, relatively to the average velocities, is largely due to diurnal inequality; as the velocity on the other corresponding tide, 12 hours earlier or later on the same day, was quite half a knot less.

Dominant flow eastward.—A comparison of the above values corroborates the belief that the water in Northumberland strait makes on the whole to the eastward. In the Western and Central narrows where the flood is eastward, it is stronger than the ebb; and in the Eastern narrows where the ebb is eastward, it appears to be rather the stronger of the two, so far as these maximum velocities can indicate. The ice in winter, while it runs east and west with the flood and ebb, is also said to make eastward on the whole.

CURRENT IN THE GUT OF CANSO.

In the Gut of Canso, the apparent irregularities in the current are due to the difference in the character of the tide itself, at the north and south ends of the Gut. The tide in the region of Northumberland strait shows a marked diurnal inequality, which accords with the declination of the moon; and while this change recurs in the period of the tropical or declination-month at the northern end of the Gut, the tide at the Atlantic end maintains the usual variation in height from springs to neaps in the period of the moon's phases. As the leading variations in range are thus quite out of accord, and the current through the Gut depends on the difference in the level of the tide at the two ends, it necessarily shows great complexity under such conditions.

Before this explanation was found by the investigation of the characteristics of the tide, it was supposed that the currents were chiefly governed by the wind. The winds may have a disturbing effect, especially as the range of the tide is not great; but the main variations are undoubtedly astronomical, with the moon's declination as probably the leading factor.

PART II.

THE GENERAL CIRCULATION IN THE GULF AREA, AND THE CHARACTERISTICS OF ITS WATERS.

The foregoing part has been restricted to a description of the currents on the surface, which a seaman may expect to find in each locality in the Gulf of St. Lawrence.

The following part is now added to explain more comprehensively the conditions in the Gulf area, and the causes which influence the currents in moving as they are found to do; and to point out the general relation of the waters in the Gulf area to the St. Lawrence river and the Ocean; on which the work of this Survey has thrown considerable light.

In the language used, technicalities will be avoided; and no description will be given of the methods and appliances employed in tracing out the currents, although some of these had not before been used at sea, or were specially adapted to meet the conditions in the Gulf.

Surface current in relation to the under-current.—It may be thought at first sight that the direction of the under-current has no bearing upon the movement of the water as it affects navigation. In such a region as the Gulf of St. Lawrence, however, the currents in the summer months are all very moderate in their speed, usually ranging from half a knot to one knot per hour; and their direction on the surface is often influenced by the wind. It was found in these circumstances that the movement of the under-current at 20 or 30 fathoms, often showed more definite characteristics; as for example, a tendency to make constantly in some one direction, or to vary with the tide. The wind is thus a disturbing element; and the under-current being more in accordance with the normal conditions of the locality, will come up to the surface as soon as the disturbing influences which have been acting on the surface of the water, cease to operate.

It may be unfortunate from the point of view of the navigator, that it is the surface of the water to a depth of about five fathoms which is so readily disturbed; but on the other hand, it is quite incorrect to take the mere surface drift, indicated by floating objects, as the direction of the current. For this movement may be only a few inches in thickness and far less than the draught of even a small vessel. It is essential, however, to make a careful investigation of the under-current in order to understand the surface current itself. The study of the under-current is also necessary, if any hope is entertained of arriving at the general circulation in the Gulf, or the true relation of its currents to the causes which influence them.

The general causes which act upon both the surface and the under-current, but often affect them differently are:—1. Tidal influence. 2. The influence of the wind and barometer. 3. A cause of a wider character which shows itself as a tendency in the current to make on the whole in some one direction.

When a period of some length is considered as a whole, and the under-current is also taken into account, it becomes possible to trace the general circulation of the water; which depends upon a greater movement in some dominant direction rather than in other directions, when long averages are taken.

The primary tendency in the surface current is thus to follow the direction which the general circulation has in the locality in question; but this tendency is disturbed and often overcome by the influence of the tide and the wind. The tidal influence shows itself chiefly as a veer in the direction of the current, which is either through a limited range, or completely around the compass; and in constant currents, a tidal fluctuation is always present. When the wind remains in one quarter and has any considerable strength, the drift which it gives to the surface water may extend to a depth of five fathoms, and its influence thus makes itself felt throughout the thickness of the surface layer which affects shipping.

As a rule, these influences are all acting at the same time; and it is their combined effect which gives rise to the actual behaviour of the surface current.

For examples of the relation of the under-current to the surface current, see Report of Tidal Survey, January, 1897, Table II; and accompanying explanations in that report.

Temperature and density.—The two characteristics chiefly relied upon in tracing the general movement of currents, are the temperature and density of the water.

In the Gulf of St. Lawrence, the surface temperature in the summer season usually ranges from about 50° to 65°, and in proceeding downwards this temperature gradually falls, until at a depth of 40 or 50 fathoms it is only 31° to 34°, or practically at the freezing point. Where the greater depths are met with, the water below this again is found to be appreciably warmer. There are considerable areas, however, in which the depth is less than 50 fathoms, and where the conditions are accordingly restricted.

The best observations to ascertain the amount of change in the temperature of the surface water with the season, were obtained at a series of points, five miles apart, extending across the width of the Gulf on the following lines:—(1.) From 30 miles off Heath Point, to Cape St. George, on July 6. (2.) From a point off Cape Whittle, to the offing of Cape St. George, on August 3. (3.) Same line as No. 1, run a second time on September 28. The results were as follows:—

(1.) July 6. From 49½° to 51½°. Average 50°.93.
(2.) August 3. From 50° to 54°. Average 52°.68.
(3.) September 28. From 52° to 54½°. Average 53°.62.

It appears, therefore, that in general, the temperature of the surface water merely rises with the progress of the season; and it is also natural that the water should become warmer to a greater depth as the season advances. Even this has its limitations, however; as at a depth of 50 fathoms no greater rise in temperature has yet been found than from 32° to 34°, between the month of June and the end of September.

At all three angles of the Gulf, the coldest water forms a layer between the depths of 30 and 50 fathoms. In the vicinity of Belle Isle strait, the same low temperatures are also found at these depths; although there the temperature towards the surface is relatively lower as a rule, than in other regions. It is probable that this cold layer extends very generally over the Gulf area; and it cannot, therefore, be taken as an indication of direction of movement of the water.

Below this cold layer, in the deep channel of the Gulf, the temperature from 100 to 200 fathoms is found to range very constantly from 37° to 41°. This result was obtained in Cabot strait, and also between the Gaspé coast and Anticosti, 220 miles further in from the Atlantic, along the deep channel. This deep water, from such indications as have been obtained, appears also to be entirely quiescent, and to have therefore little direct relation to the currents in the Gulf, in so far at least as they affect navigation.

With regard to the density, it may be stated broadly, that throughout the north-eastern portion of the Gulf the average surface density ranges from 1·0235 to nearly 1·0245; while in the south-western portion, the density is below 1·0235, ranging usually down to 1·0220, and falling in the Gaspé current to 1·0210. The dividing line between these two portions of the Gulf runs approximately from South-west Point, Anticosti, to a point in the middle of Cabot strait. The densities in the border region near this dividing line, naturally vary to some extent. The density of the north-eastern portion is practically the same as in the open Atlantic; as it was there found to range from 1·0237 to 1·0242, as shown by seven determinations made at the end of June, off the south and south-east coasts of Nova Scotia.

This result is important, in showing that the lower densities found in the south-western portion of the Gulf of St. Lawrence are confined to that side; and this further confirms the conclusion that the general set or drift across the

Gulf, as shown by the water of lower density, is in the direction of a line from Gaspé to Cape Breton. On the other hand, the endeavour to obtain some differences locally, which would correspond to the various directions of the current, was without result; although a large number of temperatures as well as densities were taken at the various anchorages for this purpose.

The deep water as found from samples taken at depths of 100 and 150 fathoms, both in the vicinity of Gaspé and in Cabot strait, ranges in density from 1·0254 to 1·0261. The density of this deep water is very interesting in affording an explanation for the otherwise anomalous fact that the colder water at 50 fathoms is found to float upon it. This also corresponds with the density at similar depths, off the coast of Nova Scotia.

The following tables give summaries of the temperatures and densities as found in the deep channel. In obtaining these temperatures, registering thermometers are not suitable, as they will only register the temperature of the coldest layer irrespective of its depth. For this reason the temperatures below 50 fathoms were taken with a deep-sea reversing thermometer, which gives the actual temperature at the depth to which it is lowered. This thermometer has to be used with some care, as in rough weather the release which is mechanical, is apt to take place prematurely. In these observations two thermometers were used which were kept in perfect working order. The thermometers were checked against each other by duplicate readings at the same depth, and were also compared directly with a standard thermometer. Any readings which there was reason to suspect of inaccuracy are omitted from the results given. The temperatures are Fahrenheit. The densities are all reduced to the standard temperature of 60° Fahr.

TEMPERATURES AND DENSITIES IN THE DEEP CHANNEL, GULF OF ST. LAWRENCE.

(From observations extending over a distance of 200 miles from Cape Breton to the Gaspé region.)

Locality and Date.	Surface.	50 Fathoms.	100 Fathoms.	150 Fathoms.	200 Fathoms.
	°	°	°	°	°
Between St. Paul island and Cape Ray; at three points 12 miles apart. 16th Aug., 1894	58 60 59	31½ 33 ..	37½ 38½ 40	40½ 40½ 40½	39½ .. ..
At 13 miles W. by S. from Cape Ray. 22nd Aug., 1894	58	..	39	..	40
At 14 miles W. by S. from Cape Ray. 28th Aug., 1894	..	32½	40	[illegible]	39½
At the centre of Cabot strait. 30th Aug., '94	63	34	40	40	39½
On a line along the middle of Cabot strait, at three points 7 miles apart. 27th Sept., 1894	53 52 52	32½ 32½ 32½	37 .. 39	38 40½ 40½	40 39½ 39½
Between Fame Point and Ellis bay, Anticosti; at three points 6 miles apart. 29th June, 1895	53 46 48	32 31½ 32	36½ 36½ 37	38½ 38 39½	..
At 29 miles E. by N. from Cape Gaspé. 23rd Sept., 1895	52	32½	37½	39½	..
At 40 miles E. from Cape Gaspé. 23rd Sept., 1895	53	33½	38½	40	..
At 12 miles E. from St. Paul island. 24th Sept., 1895	55	35½	39	40½	..
At 30 miles E. from Cape Egmont. 25th Sept., 1895	54	37	39½	40½	..
Mean Temperatures	54·4	33·0	38·4	39·8	39·6

Locality and Date.		Surface.	50 Fathoms.	100 Fathom	150 Fathoms.
At 24 miles N. by E. from Fame Point.	12th Sept., 1895	1·0222	. .	1·0258	1·0262
At 11 " N. by E. " "	13th " 1895	1·0220	1·0248	1·0260	1·0261
At 29 " E. by N. from Cape Gaspé.	23rd " 1895	1·0234	1·0248	1·0255	1·0259
At 40 " E. " "	23rd " 1895	1·0238	1·0251	1·0257	1·0258
At 12 " E. from St. Paul island.	24th " 1895	1·0221	1·0250	1·0257	1·0263
At 30 " E. from Cape Egmont.	25th " 1895	1·0229	1·0251	1·0256	1·0260
Mean Densities		. .	1·0250	1·0257	1·0261

(See also the densities, to a depth of 60 fathoms, given in Report of Tidal Survey, April, 1896, Tables A, B, C, D, E and F, and Plate VIII; and the general chart of surface densities in the south-western half of the Gulf, Plate III. Also, temperatures and densities to 100 fathoms, in the north-eastern arm of the Gulf, in Report of January, 1897; page 26. Temperatures throughout Belle Isle strait to corresponding depths are given as tables in "The Currents in Belle Isle strait," pages 42 and 43.)

Influence of the wind.—In the case of weak currents met with in the open area of the Gulf, the effect of the wind in giving the current a set in its own direction is evident when a long period is dealt with. The long-continued observations at the Lightship off Heath Point illustrate this; and good examples were also derived from observations in the season of 1896, in the vicinity of Heath Point and Cape Whittle, at anchorages distant 18 to 32 miles from the nearest shore. The observations were taken every half-hour continuously day and night for periods of 130 hours, 107 hours, and 90 hours, respectively; the wind being measured by an anemometer on board. The results when reduced to tabular form, make evident the relation between the direction of the wind and the set of the surface current. The depth to which the wind disturbance was felt, was also ascertained. (See Report of Tidal Survey, January, 1897, pages 22 and 23.)

The effect of the wind upon a strong tidal current, as in Belle Isle strait, and the conditions under which the most persistent flow in each direction may occur, have already been explained in the First Part of the present Report.

When the movement of the water is in the same direction as the wind, it must not be too hastily assumed that the wind alone is the cause. For it appears probable that the current and wind frequently flow in the same direction because of difference in barometric pressure over wide areas. As an example from a region of strong tidal streams, on the Lower St. Lawrence when a change of weather is pending, it is a matter of common observation that the wind seems often to be held back by the current against it; and east wind, bringing rain, will come up with the turn of the flood.

Another effect which is of wide-spread occurrence, exemplifies a relation between the wind and the strength of the current that cannot be due to the direct action of the wind.

The current is found to run more strongly before a heavy wind comes on, and this change is so noticeable, that fishermen when anchored in their boats, take it as an indication of the approach of heavy weather. This is found to occur on the south and west coasts of Newfoundland, as well as off the east coast in the Labrador current; and also in the Gulf of St. Lawrence on the North shore and in Miramichi bay and Northumberland strait.

According to wide-spread testimony, the change in the behaviour of the current is noticeable for about twelve hours before a storm comes on. In most localities, the current sets more strongly towards the direction from which the wind is about to come, although there are other localities where the reverse of this behaviour may occur. The change also differs according to the tidal or constant character of the usual current.

These effects seem to be due to the action of the wind in first holding back the water and then releasing it; and the influence of the low pressure of the storm as it passes along, also increases the result.

When these local results are so evident, the effect should be all the more marked when the pressure is exceptionally high or low over a large area like the Gulf of St. Lawrence; as the corresponding flow has to take place through comparatively narrow entrances or straits. In such straits, while the direct effect of the wind would produce primarily a surface drift, a difference of pressure would cause a more even flow throughout the whole depth.

A comprehensive summary entitled "Effect of the Wind on Currents and Tidal Streams," based on the investigations of this Survey, is published in the Transactions, Royal Society of Canada, Third Series, Vol. III, 1909. The various points here touched upon are there discussed fully, and numerous examples are given to illustrate them.

Drift of ice in relation to the current.—The currents are often well indicated by the drift of ice; but in order to infer correctly the set of the current from its drift, it is necessary to distinguish between the different kinds of ice met with, and their relation to the movement of the surface of the water, and to the under-current, respectively. In the early spring, numbers of small vessels are engaged in seal fishing; and information of importance can thus be obtained, if the relation of the ice to the current is understood.

The ice met with is of three kinds:—(1) Berg ice, or true icebergs, such as those met with in Belle Isle strait. They are also found off the south coast of Newfoundland, nearly as far west as Cabot strait. (2) Flat or pan ice, forming fields or in broken pieces, usually not more than six feet in thickness, but sometimes as thick as 10 feet. This often jams or shoves along the shore or between islands, and may form masses 20 feet or more in thickness, but it can never be mistaken for berg ice. (3) River ice, from the St. Lawrence river and its estuary. This is also flat ice, and in the Gaspé region it can be readily distinguished by its appearance from the Gulf ice.

The berg ice, from its great depth in the water, will evidently move with the under-current; and it will not be appreciably affected by the wind. These bergs do not necessarily indicate the direction of the current as affecting shipping, except when the surface current has also the same direction. They show in reality the average direction the current has, between the surface and the depth of their draught. In Belle Isle strait, their draught is limited to about 30 fathoms by the depth of the strait. They are thus of much value as an indication of the general movement or circulation of the water.

The relation of the flat ice to the wind and current requires some little consideration. It is, of course, just as true of this ice as of the berg ice, that the greater part is under water; but, as it is almost always in broken pieces, more or less piled and with upturned edges, the wind has a much greater hold upon it in proportion to its total weight, than on berg ice. Even when this is allowed for, its depth in the water still gives the current a greater hold upon it than the wind has. For example, if such ice is drifting with a current in a given direction, and the wind is blowing across that direction at right angles, the ice will seldom be set more than two points, or three at the most, off the true direction of the current. When the ice becomes soggy or water-soaked and loses its edges, as it does later in the spring, it will set still more correctly with the current.

When the surface current itself is moving in the direction of long-continued or prevalent winds, as it does in some parts of the Gulf, the flat ice naturally follows the same direction. Also in regions where the current is tidal, and the ice in calm weather would drift as far in the one direction with the flood tide as in the other direction with the ebb, the direction in which it makes on the whole will depend upon the wind. It is probably for these reasons that it is so often said that the ice drifts with the wind; although this may merely express the fact, without distinguishing between the relative influence of the wind and the current upon it.

There is also a direct effect which the ice has upon the strength of the current in regions where the direction of the surface drift is under the influence of the wind. The broken and upturned edges of the ice give the wind a much greater hold upon the water than it otherwise would have. Hence during long continued winds the speed of the current is appreciably greater than if the ice were not present. This is undoubtedly the explanation of the common belief which is expressed by saying that 'the ice makes its own current.' It may be well to recall that the weight of the ice itself is the same as the water which it displaces; and therefore, the wind has no greater mass to set in motion in producing a surface current than if the ice were to melt and re-fill the hollow which it makes in the water; while the presence of the ice gives the wind a better hold than it would have upon the surface of open water, free from ice.

There is one condition of the ice which may prevent it from showing correctly the drift of the water. When it is set against an island or headland and packed together for a long distance out, with open water beyond, it may circle round as on a pivot. The outer edge of the pack may thus make a long sweep very different in its path from the true set of the current; and its movements also become irregular.

GENERAL CIRCULATION IN THE GULF.

A knowledge of this general direction is important to mariners, as it includes all the more constant currents, and it also shows the direction which the surface current tends to take when undisturbed. Although there are few instances of currents in the Gulf area which run steadily enough to be termed constant, we have yet found it possible from continuous observation or long experience to arrive at a dominant direction for each locality; or the direction in which the current runs more frequently, and in which therefore, the water makes on the whole.

In reviewing the movements of the water, with a view to tracing the general circulation in the Gulf, it is the principle of the balance of flow which is the most evident. Wherever a current of a constant character occurs, there is a corresponding return current to make up for it. Thus in Cabot strait, the outflowing water in the Cape Breton current is balanced by the inflow at Cape Ray; the north-eastward current on the west coast of Newfoundland is balanced by the contrary direction of the movement on the North shore opposite; and we have fairly good indications of a return flow to compensate for the Gaspé current.

It is this balance of flow which points to the nature and direction of the circulation of water in the Gulf. If we begin to trace it from Cabot strait, where the balance between the Gulf and the Ocean takes place, the inflow at Cape Ray appears to diffuse itself more or less widely over the central part of the Gulf, but it regains its strength farther north on the west coast of Newfoundland, and makes a deep bend into the north-eastern angle of the Gulf, and returns westward along the north shore. On reaching Cape Whittle, it still makes westward; and, whether as an actual set, or by displacing water which comes more directly from Cape Ray, it appears to work around the eastern end of Anticosti, and so to compensate for the outflow of the Gaspé current from the estuary of the St. Lawrence. This current after rounding the Gaspé coast, makes south-eastward as a general set or drift across the Gulf to the western side of Cabot strait; and its waters there leave the Gulf in the outflow of the Cape Breton current.

It also appears that on the whole, the balance or compensation in the Gulf currents takes place at the surface and in ordinary under-currents, which do not usually extend to a greater depth than some 40 or 50 fathoms. There is little therefore, to show the necessity for any appreciable movement in the deep water from 60 or 80 fathoms downward, which lies in the deep channels of the Gulf. Where direct observations have been obtained, the deeper water appears to lie quiescent, without any movement that can be detected.

Relations of Belle Isle strait and Cabot strait.—On account of the tidal character of the current in Belle Isle strait, it is clear that no great volume of water can enter the Gulf of St. Lawrence from that quarter. The tidal character of the flow in this strait is described in the special Report already referred to, where the relation of the current to the tide, the temperature of the water, and the drift of icebergs, is fully explained; with diagrams showing the flow of the current in the two directions as observed.

During the summer season, the current flows in the strait with a speed which is nearly equal in each direction, with only a difference in favour of inward flow to the west, which on the whole does not probably amount to more than a moderate percentage. It is perhaps possible that in the early spring the preponderance of inward flow may be proportionally greater than at other seasons. There is some evidence to show that the incoming water ma then penetrate the Gulf as far as Bonne bay on the west coast of Newfoundland. But no reasons have been found for supposing that this water passes completely round the west coast of Newfoundland and finds its way out into the Atlantic through Cabot strait, in accordance with the theory which had been more or less accepted in the past. All the indications are against this theory as they show that any general current across the extent of the Gulf must lie in an entirely different direction. It may be allowable therefore to sum up briefly the reasons for this conclusion.

The water in Belle Isle strait is exceedingly clear. It is also very cold, and when flowing in the inward direction, its temperature as late as September is below 45° for the average of its depth from surface to bottom. Its density is as high as that of any water found within the Gulf, being on the average 1·0244 at the surface.

The water in Cabot strait is quite different from this in its character. The greater part of the width of that strait is occupied by water which has the milky-green colour of ordinary sea water. The out-flowing current in Cabot strait is on the side next to Cape Breton, or the farther side from Belle Isle. This out-flowing water has also a distinctly brown tinge; its surface temperature ranges from 55° to 65°; and its density is low, as the average to a depth of 10 fathoms from the surface is 1·0230; and as far down as a depth of 20 fathoms it is still both warmer and fresher than the Belle Isle water. If, therefore, the Belle Isle water has any influence on this current, it must be indirect; for even if the water itself does not reach Cabot strait, it might still be possible that a greater in-flow through Belle Isle strait would cause a greater outflow through Cabot strait. Even this measure of influence cannot, however, be definitely asserted.

There is not only this difference in the character of the water in these two straits, but also a want of connection between them. On the west coast of Newfoundland the current sets north-eastward, or in the contrary direction to that which the theory supposes; and around Cape Ray the water makes inwards on the whole.

It might still be supposed, however, that any water entering through Belle Isle strait would be most likely to pass out at Cabot strait as a cold under-current along the bottom. The total depth of Cabot strait is 250 fathoms; the coldest water forms a layer between the depths of 30 and 50 fathoms, and below this the water is again warmer but with a higher density, which ranges from 1·0255 to 1·0262. As this cold layer occurs in other parts of the Gulf area also, it cannot be taken as an indication of any special direction; and the characteristics of the deep water from 100 fathoms downwards show how different it is from the Belle

Isle water. The indications, so far as obtained, also show that the deep water from 100 fathoms downwards is entirely quiescent.

There is, therefore, no confirmation to be found for the theory that a constant current enters the Gulf by Belle Isle strait and leaves again by Cabot strait; but on the contrary, all the evidence met with, is directly against it.

The St. Lawrence River in relation to the outflow from the Gulf.—It can hardly be doubted that the low density of the water in the Gaspé current is to be attributed to the outflow of the St. Lawrence; and we are thus able to trace the influence of this water as far as Cape Breton, where it finally mingles with the water of the Ocean. In discussing the relation of the St. Lawrence to these currents, however, it is to be noted that the water of low density forms only a small part of the total volume which is in motion. There are thus two problems presented: (1) The amount of the decrease in density below standard sea water, and whether the dilution occasioned by the fresh water of the St. Lawrence is sufficient to account for it; this dilution in the case of the Cape Breton current being further assisted by the rivers discharging on the south-western side of the Gulf; and (2) The total volume of these currents in relation to the volume of the St. Lawrence, and how far a return flow must be sought to balance the outflow which these currents occasion.

The discharge of the river St. Lawrence, including its principal tributaries, amounts to 240,000 cubic feet per second. This volume of fresh water will mingle with sea water for which we may assume a density of 1.0240; as this may be taken to represent either the mean density of Atlantic coast water to a moderate depth, or the density of the salter water in the Gulf itself. The surface water in either the Gaspé or Cape Breton currents is seldom lower than 1.0218 or 1.0217 near the shore; but the reduced density to a moderate depth may be taken as 1.0230 on the average. (See cross-sections and density charts of these currents in Report of Tidal Survey, April, 1896, Plates III to VIII.)

The discharge of the St. Lawrence is sufficient to furnish a stream of water reduced from the density 1.0240 to 1.0230 which would be ten miles wide and 56 feet deep, moving with a speed of one knot per hour. This is a fair approximation to the extent and volume of the water of lowest density in the Gaspé current; and such a comparison may therefore serve to illustrate the way in which the conditions may be accounted for, if the data themselves were more closely known.

As regards the total volume, however, the St. Lawrence river is quite insignificant as compared with the outflow of the Gaspé current. Its usual width is 12 miles, whether it flows near the coast or lies farther out owing to displacement in position. The average surface speed was determined from all the values of the mean velocity throughout the course of the day, obtained from the observations during three seasons. This average, at an offing of 4½ miles, where the strength is greatest, is 1.65 knots per hour. The velocity falls off from this value to nothing at the outer edge. The movement, in the main strength of the current, was found to extend to a great depth. A comparison of all the observations at 30 fathoms shows that the strength at that depth is never less than 60 to 65 per cent of the surface velocity; and usually it is still strong at 50 fathoms and quite appreciable as far down as 90 fathoms.

On the best estimate that can be made from these data, the volume of the Gaspé current is 95 times the volume of the St. Lawrence river. The volume of the Cape Breton current also, is probably much the same. It is thus quite erroneous to speak of these currents as St. Lawrence water; as the most that the river can do is to reduce their density towards the surface by an appreciable amount.

It is thus quite evident that this large outflowing volume must be replaced by a return movement at the entrance to the St. Lawrence, somewhere in the

Anticosti region, and also by a return flow from the Ocean into the Gulf area; as the discharge of the St. Lawrence furnishes little more than one per cent of the amount required.

Current across the Gulf area.—The general connection of the Gaspé and Cape Breton currents was made evident when it was ascertained that the water of lower density kept to the south-western side of the Gulf. The observations of the current in the open, and the reports from steamships above cited, also accord with a general movement of the water towards the south-east; as this is the more usual direction, and the currents which are found at times to run across this prevailing direction, are to be attributed to the influence of the tides and the wind.

As to the route taken by the water in traversing the Gulf from the Gaspé region to Cape Berton, it seems fair to conclude from the evidence furnished by the density observations, that the greater proportion finds its way eastward between the Magdalen islands and Prince Edward island; while a certain amount may also pass north of the Magdalen islands, on the line from Bird Rocks to St. Paul island. That some water passes round both ends of the Magdalen islands on its way to Cape North is also confirmed by the steamship reports in that region; as the currents from the north-west and south-west towards Cape North, correspond with these two routes respectively. It is probable also that some of the water may come from Northumberland strait, as the water there is also low in its density.

(For a discussion of the probable reasons why the water of lower density keeps to the south-western side of the Gulf, see Reports of Tidal Survey, April, 1896, pages 14 and 15; and January, 1897, page 36.)

Balance of flow in Cabot strait.—The volume of fresh water from the St. Lawrence as already explained, may be sufficient to dilute the sea water to the low density found in the Gaspé current or in the corresponding current flowing outward through Cabot strait; but the total volume of water which actually leaves the Gulf is vastly greater than the volume of fresh water which it receives from the St. Lawrence river. The volume so leaving the Gulf must therefore be replaced by water which enters it from the Ocean.

The current which usually makes inwards on the east side of Cabot strait, may be sufficient to compensate for the outflowing water of the Cape Breton current; although it is also possible that the outflow from the Gulf may be partly made up for, by the difference of flow in the inward direction through Belle Isle strait; which in some years may be considerable in the early spring. The relation of the current in this strait to the Gulf as a whole, has already been explained; as well as the probable amount of inflow at Cape Ray, in continuation of the general westward tendency of the water along the south coast of Newfoundland. The quiescence of the deep water in Cabot strait has also been pointed out in this connection.

It may be well to note, however, that although the outflowing water of the Cape Breton current is much warmer in the summer season than the incoming Atlantic water, it is not so at all seasons of the year. While it is probable that the total result is on the side of loss of temperature to the Gulf area, it would require extended observations throughout the year to ascertain the amount of loss, and the probable effect in consequence upon climate in the surrounding regions.

(See temperatures of Cape Breton current from the surface to forty fathoms, given in tabular form, in Report of Tidal Survey, December, 1894; pages 25 and 26.)

North-eastern arm of the Gulf.—It is not clear what becomes of the current which passes in at Cape Ray. As a rule there is no appreciable current off St. George's bay, and very little from Cape St. George to the Bay of Islands. We cannot thus trace this inflowing water as an actual current, but it is probable that it makes to the north-eastward, and diffuses itself over the Gulf in that region, because we find that the density of the water throughout the north-eastern portion of the Gulf is the same as in the open Atlantic, and this density could not be so maintained without some inflow of this character.

Further north on the west coast of Newfoundland, from the Bay of Islands to Rich Point, the current is distinct, setting north-eastward. The under-current has this direction even more persistently than the surface current; and at a depth of 30 fathoms the speed is still half as much as on the surface. There is no other locality in the north-eastern arm of the Gulf where the movement of the water is so definite and constant in one direction.

The prevailing winds over the Gulf area, which are south-westerly in summer and north-westerly in winter, may have an appreciable influence in maintaining the current on this coast, and in carrying it further into the north-eastern angle of the Gulf before it returns.

It is more than probable that the water which makes westward along the North shore is a return current corresponding with the north-eastward set on the Newfoundland side. There is no other direction from which this water can come, as any inflow that there may be through Belle Isle strait is quite insufficient to keep up the supply. A large volume must make to the westward, if this is in reality the usual direction of the under-current from about 15 fathoms downwards, where the total depth is seldom less than 40 fathoms.

The water must make across from the Newfoundland side to the North shore in the area lying between Rich Point and the west end of Belle Isle strait. On the western confines of this area there is a constant current setting in from the south-west, and another setting out to the westward, while on its eastern side there is the strong ebb and flow of the strait itself. There may also be times when long-continued winds give the surface current a drift which is either eastward or westward according to their own direction. As the depth ranges from 30 to 70 fathoms, it is sufficient to allow the water to make across to the northern side as an under-current, as it is quite possible that it does. The irregular character of the currents in this area is thus accounted for.

On the west coast of Newfoundland, the surface current and the under-current have the same direction; but in the return current on the North shore the direction is maintained chiefly by the under-current, while the current on the surface is not infrequently to the eastward. The reason of this must be that the prevailing winds are westerly, and they are with the direction of the one current, and against the other; and thus often reverse its surface drift.

Although the current on the Newfoundland side is thus the more distinct, the North shore current is the better known, as it lies more directly on the route of the Atlantic steamships, and that coast is also more frequented by fishermen.

(A full account of the currents in this arm of the Gulf is given in the Report of Tidal Survey, January, 1897.)

Return flow in the Anticosti region, to compensate for the Gaspé current.—It has been pointed out that the volume of the Gaspé current is vastly greater than the discharge of the St. Lawrence river, and that there must be a return flow somewhere in this region, to make up for it. We may now pass in review the various areas in which this return flow may be looked for, in the light of the extended information now obtained by this Survey.

In Mingan strait the current is tidal in character, and runs to the north-west and south-east alternately, though often veering considerably from these directions. Observations were taken continuously day and night, and two periods of 24 and 49 hours were selected for reduction, as it was necessary to have complete tidal periods to make the comparison a fair one. An exhaustive reduction was so made as to give the total mileage of water passing in each direction through the channel. The final result showed 24 per cent of excess in favour of the inward direction to the north-west; although the actual difference in favour of that direction was only 0.13 of a knot per hour. The under-current proved to be nearly as strong as the surface current; but its variation was so great that it could not safely be said in which direction it would in general be strongest relatively to the surface current.

Although these observations only comprised six tidal periods, it is at least clear that there is no constant inward current north of Anticosti, at all comparable with the Gaspé current.

Off the east end of Anticosti, from long-continued observations in various seasons, it is now well established that the water makes on the whole towards the south-west quarter around the east end of the island.

Observations at the east end of Anticosti were taken for over a month in July and August of 1896, by means of a pair of flag buoys attached to each other, and moored at 1½ miles off East Cape in 30 fathoms. These were observed from the shore, which here runs north and south. The current is nearly parallel to the shore; but in direction it is irregular, as it might set in the same direction all day or turn twice a day. The prevailing set was found to be southward however. Out of 231 observations of the direction, taken every two hours during daylight on clear days, the direction was northward 78 times, and southward 153 times. This may be taken as a fair comparison; for, during the course of a little more than a full month, the observations are distributed pretty evenly over all states of the tide. These observations showed that the set is southward for two-thirds of the time.

Two anchorages off the east end of Anticosti were occupied in 1896, one at 24 miles E.S.E. of Heath Point for seven days in July, and the other at 13 miles E.S.E. of that point on seven days in September. The surface current veered around the compass, but often quite irregularly; as the more continuous observations in July included the period of the neap tides. The behaviour of the under-current was much more regular; and it is also more important in better indicating the general movement of the water.

From numerous observations of the under-current at 20 and 30 fathoms in both July and September it appears that it has a definite set in two directions in accordance with the tide, while the surface current continues to veer around. The two dominant directions of this set are, to the S.W. while the tide is high and to the N.N.E. while the tide is low, with a slack time which occurs at half tide, either rising or falling. These directions are nearly across the end of Anticosti island. To determine the true relative amounts of the set in these two opposite directions, a computation was made by a special method. When finally reduced to a percentage for convenience in comparison, it was found that the amount by which the under-current makes south-westward is 16 per cent greater than north-eastward.

The water thus makes southward and westward on the whole, around the east end of Anticosti; which is very significant in showing the direction from which the water comes, that forms the return flow to make up for the Gaspé current. This is further confirmed by the continuous observations on the Lightship off Heath Point, during the seasons of 1910 and 1911. Although they gave the direction on the surface only, they were so continuous as to afford a good average indication; and they show that the set south-westward is more frequent and stronger than in other directions.

From the observations of the season of 1911 at the anchorages off the south coast of Anticosti and those in the middle of the passage between Anticosti and the Gaspé coast, all the evidence indicates a preponderance of inward flow to the northwest. The stronger and more persistent set on the surface is in that direction, and the under-current gives the same indication. It also appears from the investigations of 1895 that the deep water, below 100 fathoms, is practically quiescent.

We may therefore conclude that the water after passing around the east end of Anticosti, continues to make inwards on the whole, over the greater part of the width of the passage on the Antlcosti side. This movement appears to take place from the surface to a moderate depth, and does not extend to the deep water below perhaps a third of the total depth of 200 fathoms. We may assume this inward flow to be sufficient in amount to compensate for the outflow of the Gaspé current, with possibly a small contribution also from Mingan strait.

This westward movement of the water to the south of Anticosti, is also in harmony with the general circulation of the Gulf of St. Lawrence. In accordance with this circulation, the water makes westward on the whole along the North shore of the Gulf; and the dominant inward direction around the east end of Anticosti and along its southern coast, must be considered as a continuation of this general movement.

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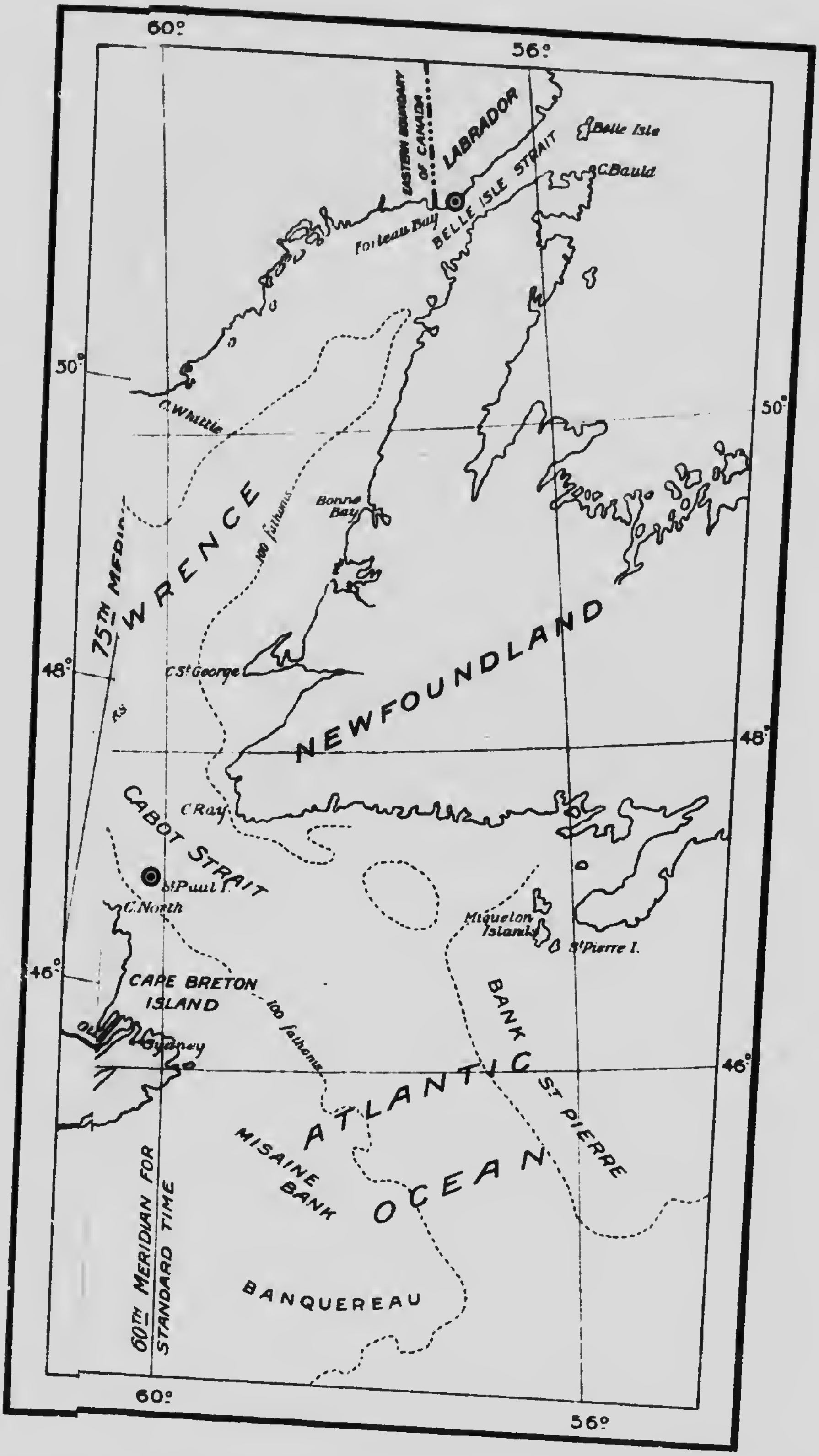

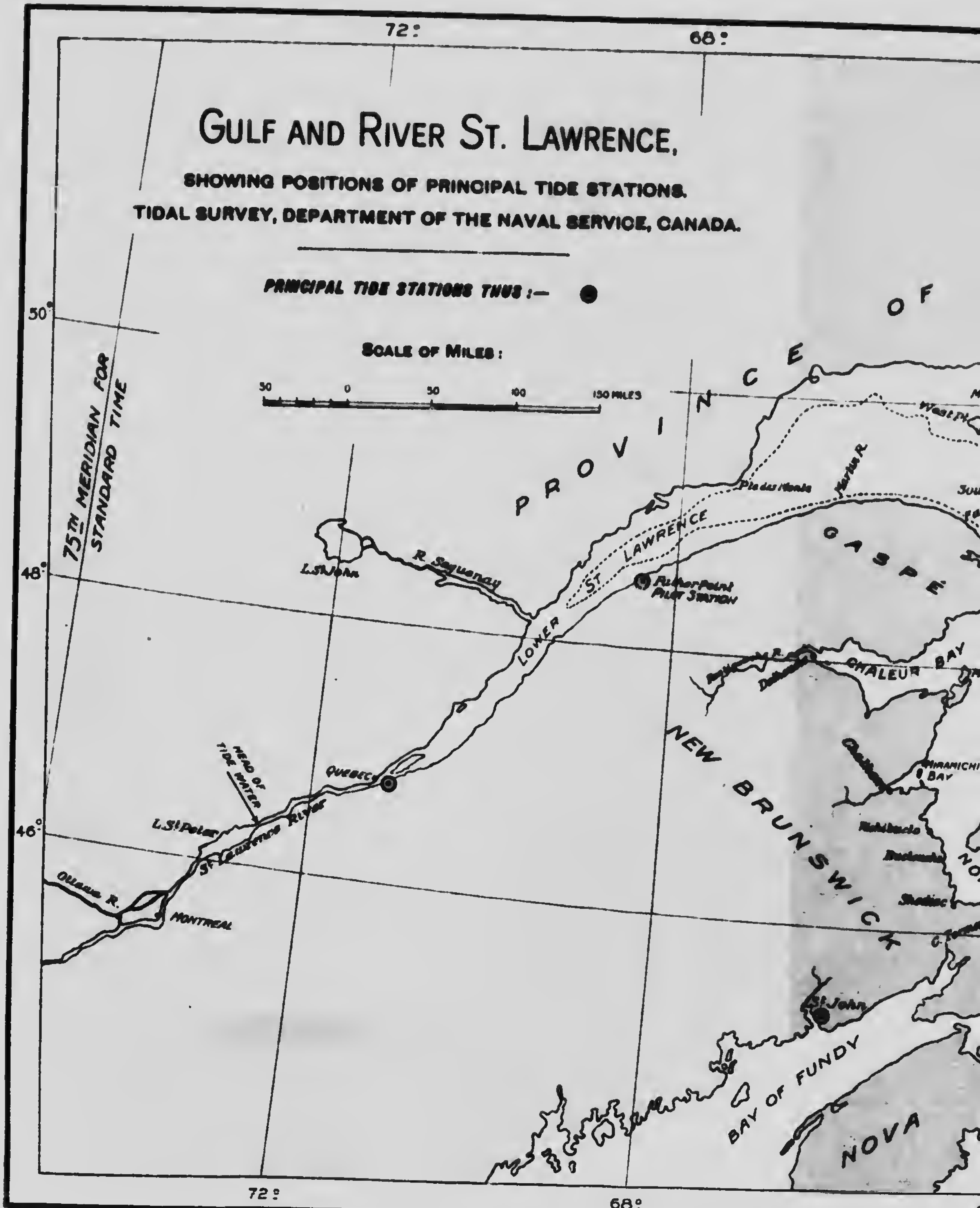

GULF AND RIVER ST. LAWRENCE,
SHOWING POSITIONS OF PRINCIPAL TIDE STATIONS.
TIDAL SURVEY, DEPARTMENT OF THE NAVAL SERVICE, CANADA.
PRINCIPAL TIDE STATIONS THUS :—
SCALE OF MILES :
50 0 50 100 150 MILES
72°
68°
50°
48°
46°
75TH MERIDIAN FOR STANDARD TIME
PROVINCE OF
GASPE
L. St. John
R. Saguenay
LOWER ST. LAWRENCE
Father Point Pilot Station
Quebec
HEAD OF TIDE WATER
L. St. Peter
St. Lawrence River
Ottawa R.
MONTREAL
CHALEUR BAY
NEW BRUNSWICK
MIRAMICHI BAY
Shediac
St. John
BAY OF FUNDY
NOVA

64°
60°
56°
QUEBEC
LABRADOR
Belle Isle
C.Bauld
BELLE ISLE STRAIT
Forteau Bay
50°
MINGAN STRAIT
West Pt
ANTICOSTI IP
100 fathoms
South West Pt
East C.
Heath Pt
C.Whittle
LAWRENCE
ST
GULF OF
C.Gaspé
100 fathoms
Bonne Bay
NEWFOUNDLAND
C.St George
48°
BAY
Bird Rocks
CABOT STRAIT
C.Ray
MAGDALEN ISLANDS
MIRAMICHI BAY
St Paul I.
C.North
PRINCE EDWARD ISLAND
Rustico
Souris
Charlottetown
NORTHUMBERLAND STRAIT
Pictou
CAPE BRETON ISLAND
Sydney
100 fathoms
Miquelon Islands
St Pierre I.
BANK ST PIERRE
46°
ATLANTIC OCEAN
MISAINE BANK
GUT OF CANSO
SCOTIA
Halifax
60TH MERIDIAN FOR STANDARD TIME
BANQUEREAU
64° LONG. W. OF GREENWICH
60°
56°