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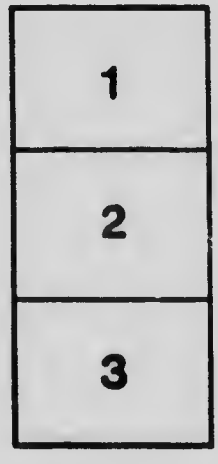

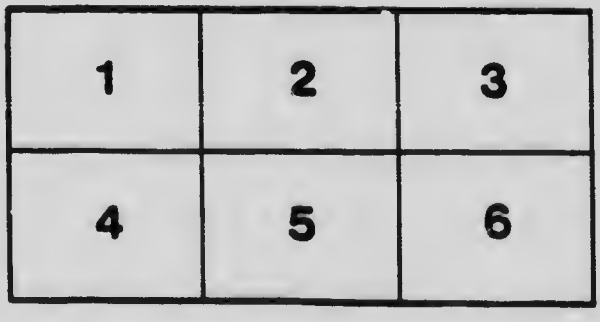

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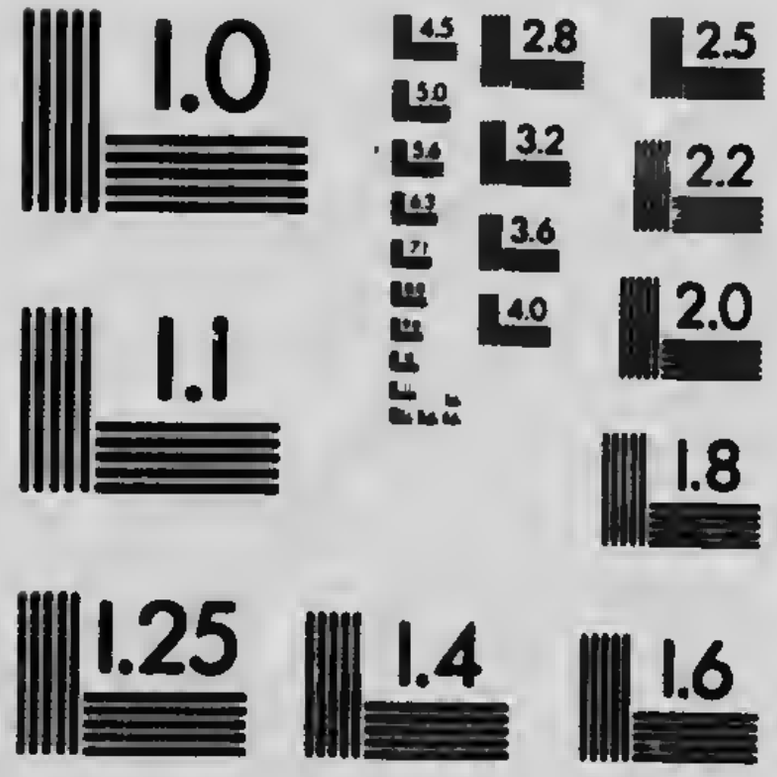

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FROM THE TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA.

THIRD SERIES—1910

VOLUME IV. SECTION III

With Compliments of
W. Bell Dawson.

Methods of Investigation of Tides and Currents: A review of the general methods adopted, in a new field of investigation, by the Tidal Survey of Canada.

BY

W. BELL DAWSON, M.A., D.Sc., M. Inst. C.E., F.R.S.C.

OTTAWA
PRINTED FOR THE ROYAL SOCIETY OF CANADA
1911

I.—*Methods of Investigation of Tides and Currents: A review of the general methods adopted in a new field of investigation, by the Tidal Survey of Canada.*

Presidential Address to Section III.

By W. BELL DAWSON, M.A., D.Sc., M. Inst. C.E., F.R.S.C.

(Read 27th September 1910.)

It may be of interest, at the present stage, to review briefly the investigations of the Survey of Tides and Currents, as these are now sufficiently advanced to afford a good general knowledge of the nature of the tides on the coasts of Canada, and to exemplify the methods best adapted to deal with tides so diversified in character and with so little known to them for guidance in their investigation. This review may also be appropriate, as the Royal Society has always shown a real interest in the matter, and has taken notice of the progress of the Survey in its annual reports to Council.

Definite steps to obtain information as to our tides and currents were first taken by the Marine department some 16 or 18 years ago, and the Survey for the purpose was organized as a branch of that department. Although its primary object was to secure practical data for the benefit of navigation, it is interesting to note the directions in which the results have become of indispensable value to other departments in the Government service, as well as to our coast cities, for other than maritime purposes. It may be true that these accessory results have been obtained by extra work, outside the requirements of the Marine department for the interests of trade and commerce; but they serve nevertheless to show how any such investigation which the Government may undertake becomes of far reaching benefit to the country at large.

To make the present review as brief as possible, it is only proposed to outline the work that has been done, sufficiently to explain the general procedure which has proved serviceable in obtaining the best results. The results themselves need not be enlarged upon, as they are already published; and this review may thus serve as an outline with which all the information published may be connected by references. It is hoped that this may also prove of some service to others who may undertake similar investigations in new fields in other parts of the world.

Early Representations, and Commencement made.

The importance of publishing tide tables for Canadian waters and the necessity for tidal observations was discussed as early as 1884. The question was taken up at a meeting of the British Association held in Montreal in that year; and the Montreal Board of Trade were also considering the matter independently. Ship owners and masters of vessels were practically unanimous as to the pressing need for knowledge on the subject of tides and currents; and they united with other bodies in addressing a strong memorial on the subject to the Dominion Government. During the re-survey of the St. Lawrence, in 1887 and 1888, the matter received some attention. Various representations were made and petitions addressed to the Minister of Marine and Fisheries until 1889, in which attention was drawn to the average marine loss of $2,782,000 per annum, as well as 239 lives; a certain proportion of this loss of life and property being undoubtedly due to imperfect knowledge of the currents. It was also urged that if the number of narrow escapes of vessels from disaster or wreck were known, this would add a powerful argument in favour of proceeding with the work forthwith.

A practical commencement was made in the following season of 1890, under the supervision of the Director of the Meteorological Service. By 1893, gauges had been placed at St. John, N.B., Quebec and South-west point, Anticosti; as well as a trial station on the Magdalen islands in the middle of the Gulf of St. Lawrence. The preliminary steps above referred to, and the early attempts made, are fully described in the first Report of Progress (1).

General Methods employed.

At the outset the chief desire of the shipping interests was to obtain information regarding the tidal streams and currents on the leading steamship routes. Many wrecks were attributed to unknown currents, and definite information on the subject was of primary importance. The preliminary information collected served to show that extremely little was known regarding the tides and currents of Canada, beyond the "Establishment" at a certain number of ports, and an approximation to the range of the tide; such data having been determined during the early Admiralty surveys of these coasts. There was also a crude attempt to publish tide tables for Quebec, by a difference of time from London Bridge. Some early tidal observations were found at Halifax in the archives at the Dock yard. The gathering of this fragmentary information, and the beginning of regular observations at a few places in a somewhat tentative way, was all that had been done

up to 1893, when the writer was appointed to organize a survey to carry on the work systematically.

Tides.—Under the circumstances, there was practically a clear field to work upon. The tides themselves were known to be very complex in character, as they ranged from almost nothing in the middle of the Gulf of St. Lawrence to the highest in the world in the Bay of Fundy. The general method adopted from the outset was to establish principal stations at strategic points, to which the harbours in the surrounding regions could be referred. It was the intention from the beginning that the principal stations should be adequately equipped to obtain tidal record which could be reduced by the modern method of Harmonic Analysis. For this purpose it is essential to have continuous record day and night throughout the year. There were thus many practical difficulties to be overcome; such as the heating of the tide gauges in winter by a method devised for the earliest stations, construction problems in the establishment of gauges where no artificial structures existed and the exposure was severe, and the design of an unfailing recording instrument for situations where no repair could be obtained. In such matters little help could be found in anything previously done in other countries.

The two essentials for tidal observations are correct time and some datum or plane of reference from which the height can be measured. At some of the tidal stations the time can be readily ascertained, but at others it has to be specially obtained either by telegraphic signals or by meridian instruments which determine the time directly from the sun. At almost all the tidal stations it has been necessary to originate a datum level for height, and to stablish a bench mark. A tide scale is set with reference to this bench mark, to maintain a uniform datum throughout the years of observation. As an open scale becomes useless in the winter season, on account of the accumulation of ice, it was necessary to devise special apparatus which can be enclosed and protected.

With regard to the limits of accuracy, it is sufficient to have the time correct within one minute, as this is as close as individual readings can be taken on the tide diagrams. The limit of accuracy for height is in general 0.01 foot.

The equipment of the tidal stations to secure a continuous record, summer and winter, for harmonic analysis, and to obtain time and height for the observations under conditions of isolation and winter ice, are described in a Paper communicated to the Institution of Civil Engineers of London (2).

Currents.—In the investigation of the currents the advantage of current meters registering electrically was very evident; but at that

date they had only been used in fresh water, and there was much difficulty in making them work satisfactorily at sea. By their use, however, constant observations could be secured day and night, which was essential in dealing with tidal streams which show so much inequality in strength. The velocity of the current was measured at the standard depth of 18 feet (three fathoms). This was adopted to place the meter below the keel of the surveying steamer when lying between wind and weather, and as this depth may be considered to be the average draught of an ocean steamer, it thus represents the actual effect of the current upon a vessel. The appliances used for all the purposes in view are described in the Reports of Progress (3). Special attention was also given to the study of the under-current, as normal conditions often continue below the surface during times of wind disturbance (4). The other observations taken, included the temperature and density of the water, and meteorological data for comparison with the behaviour of the current. The wind record was obtained from an anemometer on board, and the barometric variations were registered by a barograph.

In carrying on the work of the Survey, the surveying vessel was anchored at carefully selected stations, and the vessel itself served as a fixed point from which to determine the direction and velocity of the current. In this way as much information can be obtained in 24 hours of continuous work, as in a week by running measured courses. Interruption from fog is also avoided, as it does not interfere with the continuity of the observations.

Investigation of the Currents.

Gulf of St. Lawrence.—In the first three seasons, 1894, 1895 and 1896, a general investigation of the Gulf of St. Lawrence was made. The relation of the Gulf area to the ocean was ascertained by observations in Cabot strait, between Cape Breton and Newfoundland, and also in Belle Isle strait. Similar observations were carried on at the mouth of the St. Lawrence, north and south of Anticosti, to determine the relation of the St. Lawrence estuary to the Gulf. The temperature and density of the water were taken throughout the Gulf, which proved a valuable means of tracing the general circulation of the water. The results of these investigations have been fully reported in the Reports of Progress, and they are also summarized in a special pamphlet (5).

It will therefore suffice to note regarding the results, that no currents exceeding one knot were found in the open waters of the Gulf, apart from local straits and passages. This in itself served largely to dispel the supposed dangers to navigation in these waters. Erroneous

theories were also disposed of, such as a constant inward flow through Belle Isle strait, which has undoubtedly led to the occurrence of wrecks.

Pacific Coast.—In dealing with the passes and narrows in British Columbia a different procedure is necessary. The strength of the current is from 8 to 10 knots per hour, and it is impracticable to anchor a vessel for their investigation. Navigation through these passes is only possible at slack water, and vessels have to time their trips accordingly. Several of the most important industries of the province are dependent upon towing, as in the transportation of lumber and coal; and a knowledge of the time of slack water is therefore essential, as the most powerful tugs cannot handle a coal barge, a raft, or a scow-load of freight cars when the current is running.

In these circumstances, the method adopted is to observe the turn of the current from the shore. This has been done for several of the passes where there is any habitation or lighthouse from which observations can be made. Other passes, through which an immense traffic goes, have uninhabited shores. A consequent difficulty is to obtain correct time. It is necessary to place a meridian instrument by which the time can be obtained direct from the sun, or to furnish the observer with a chronometer.

The object in view is to ascertain the time of slack water relatively to the time of the tide as observed simultaneously at some principal station. A basis is thus obtained for the calculation of a slack water table in advance, similar to a tide table. In reducing the observations for this purpose, it was found that the time at which the current turns is not constant with relation to the time of high and low water; but in the difference between the two, there is a variation of a complex character, because of the half tides and other special features in the tidal fluctuation. The annual variation is so large that it is essential to continue the observations throughout the course of the year, to obtain a satisfactory basis for calculation.

When these variations are determined, the time of slack water can be computed in advance from the calculated tide tables. In this way, slack water tables are now published annually for First Narrows at the entrance to Vancouver harbour, Active Pass and Porlier Pass; and good determinations have been obtained also for Seymour Narrows.

Atlantic Coast.—When a vessel and funds were again available for current investigation, the seasons of 1903 and 1906 were given to the steamship routes around the south coast of Newfoundland and to a more systematic investigation of Belle Isle strait. The question of indraught into the large bays on the south coast of Newfoundland was fully examined, because many wrecks were attributed to this

influence. The results for this region and for Belle Isle strait are fully given in pamphlets issued by this Survey (6). In the seasons of 1904 and 1907 the outer part of the Bay of Fundy was examined, chiefly on the lines of the International and Atlantic steamship routes, from St. John N.B. to Cape Sable. As a result, the direction and strength of the current at each hour of the tide, has been published in the form of tables (7). This is the first region of extended area in North America for which detailed information is available, of a similar character to that published for the English channel and the North sea.

The currents in Northumberland strait were investigated in the season of 1908. These proved to be exceedingly complex, owing to tidal interference from its two ends; which occasions a large diurnal inequality in the maximum velocity and in the time of slack water. The strength of the current amounts to three knots in some of the narrower parts. Its general characteristics are explained in a report of progress (8).

The character of our tides and currents, as described in the reports of this Survey, have been extensively republished, especially in Germany; and the reports have also been noticed in British and French magazines, and periodicals in the United States. Some general articles by the writer have also appeared in "Nature" (9).

Wind Disturbance.

When the writer first began these investigations, the general impression derived from books was that the current would always be found to set in the same direction as the wind. But the longer the investigations were carried on, and the greater the care to assign each movement of the water to its true cause, the less residuum there remained to ascribe to the wind, as otherwise unaccounted for.

This impression seems to have gained currency chiefly because of a faulty method of observation, by which the drift of small floating objects was taken to represent the set of the current. The drift of the mere surface or skin of the water cannot be accepted; as the direction of the current should mean its movement at a depth of at least half the draught of an ordinary vessel. The impression may also be due in part to the difficulty of distinguishing leeway from current drift, especially in the old sailing-ship days. It is also noteworthy that in obtaining information from fishermen, only the least observant men speak in a vague way of the current running with the wind. The more intelligent men attribute less to the direct action of the wind, and distinguish the various effects more carefully.

The effects of the wind in disturbing the current, as observed throughout the eight seasons above noted, have been collected and

summarized in a paper contributed to the Royal Society of Canada (10). The effects are classed under the headings of Weak Currents, Constant Currents, and Strong Tidal Streams. The importance of a comparison of the under-current with the surface direction, as an indication of disturbance, is also explained.

Little has yet been done by this Survey in the study of the influence of wind and barometer in modifying the height of the tide. There is more published information on this subject, however, than on the effect of the wind in increasing or retarding the horizontal movement of the water and disturbing the normal conditions which would otherwise prevail. Some attention has been given to the secondary undulations shown by the tide curves, which are apparently related to meteorological conditions; and two papers in which examples are given, and some general characteristics in their mode of occurrence, have been contributed to the Royal Society (11).

It may be well to draw attention, however, to the excellent opportunity for the study of this whole subject which the St. Lawrence estuary affords. It is one of the largest estuaries in the world, with a tide of only four or five feet at its mouth, increasing to nearly 20 feet at its head. A large amount of material is now available for the purpose, as this Survey has now accumulated record from registering tide gauges continuously during 14 years; and with this, there are meteorological observations from ten stations in the area extending from Quebec to Newfoundland, and daily weather charts, which have been fyled from the outset for comparison with the tidal observations themselves.

Tidal Investigations.

The general method adopted for the investigation of the tides, both on the Atlantic and Pacific coasts, has been the same in its general features. Principal tide stations were established at stategic points to serve as reference stations for the harbours in their vicinity. Owing to the clear field which this Survey had before it at the beginning, the choice of principal stations was unhampered; but as practically nothing was known regarding the character of the tides, it was necessary to feel the way carefully to avoid the undue multiplication of principal stations and to extend as far as possible the region referred to each of them.

For a satisfactory reference station the position chosen had to be free from local influences. It thus happens that an important harbour may be entirely unsuitable as a port of reference, because of its situation at the mouth of a river or within an inlet. On the other hand, some isolated island or lighthouse, of no importance whatever on its

own account, may prove eminently satisfactory as a reference station for a number of harbours in its region.

The comparisons with the principal stations are obtained by means of a small type of registering gauge, kept in operation for three or four months at secondary stations in the region. The object of these comparisons is two-fold; to obtain a tidal difference with the principal station, and to ascertain the limits of the region which can be referred to it. If the difference in the time of high and low water proved to be constant, it was accepted as satisfactory. Otherwise, further comparisons were required with other principal stations, or the variation in the difference itself had to be reduced to some law for calculation purposes. A great deal of such trial work can be done, without the expense of additional field work.

The Gulf and River St. Lawrence.—For the main entrance between Cape Breton and Newfoundland, by which the tides of the Atlantic enter the Gulf of St. Lawrence, a tidal station was established at St. Paul island. It was found possible to refer to this station all the harbours on the Gulf coast, in Nova Scotia, Prince Edward island and New Brunswick. The gauge at this station was braced between the rocky cliffs, and it has been very difficult to maintain. It was twice carried away, but it was re-established; as comparisons showed that the nearest harbours on the Cape Breton and Newfoundland coasts were not suitable as reference stations to command this main entrance to the Gulf.

On the Lower St. Lawrence three stations were established; at South-west Point, Anticosti, to command the entrance to the estuary; at Father Point, in the middle of the estuary itself; and at Quebec. An endeavour was made to deduce tide tables for Father Point from Quebec by means of variable differences (12). The variation proved so complex, however, that Father Point was raised to the rank of a principal station. It was also found that all the open estuary of the St. Lawrence, as well as Chaleur bay, could be referred to it with much better advantage than to Quebec. On the other hand, the difference between the Anticosti station and Father Point was so constant that it could be dispensed with as a port of reference. The remaining region, from the Traverse to the head of tide water at Lake St. Peter, is referred to Quebec.

A Paper contributed to the Royal Society explains the character and progress of the tide from the open Atlantic to Quebec. It is illustrated by a set of simultaneous tide curves from the series of stations above referred to (13).

Bay of Fundy.—St. John, N.B. was found satisfactory as a reference station for the whole bay and also for its approaches as far as Cape

Sable. A second station, established at Yarmouth to command the outer part of the bay, was therefore dispensed with; as the difference between the two, in the time of the tide, was found to be quite constant throughout the year as well as during the course of the month. This difference is used to compute the Yarmouth tide tables. The limit between the Bay of Fundy and the Atlantic coast of Nova Scotia, which is referred to Halifax, is sharply defined; as immediately inside of Cape Sable the tide shows distinctly a Bay of Fundy type. The turn of the tidal streams throughout this region is also referred very satisfactorily to St. John.

The Bore.—The opportunity was taken in 1898 to make an examination of the bore on the Petitcodiac river at Moncton. The rate of rise of the water after the bore passed was reduced to the form of a profile of the water surface, which served to throw light on the nature of this tidal feature. A description and diagrams given in one of the reports of progress is republished in "Nature" (14).

Summary.—With the discontinuance of the stations above referred to, after a sufficient time to serve their purpose, and the establishment of an additional station at Charlottetown because of the complexity of the tide in Northumberland strait, there come to be six principal stations in Eastern Canada, for which tide tables are calculated directly by harmonic analysis. The regions commanded by these stations have now been sufficiently well defined to make it certain that all the harbours of Eastern Canada can be referred to them by tidal differences; and the stations serve also for reference in the investigation of the currents. The extent of the various regions is described briefly in the tide tables, in which the tidal differences throughout each region are given.

Pacific Coast.—On this coast, tidal information was in a very unsatisfactory position. The harbours of British Columbia were referred to ports of reference in the United States, situated in Puget sound or on the open coast. These were necessarily unsuitable owing to the difference in the character or type of the tide. A tidal station was established by the Public Works department as early as 1895 in the middle of the Strait of Georgia. It was situated at Sand Heads, off the mouth of the Fraser river. The record obtained, although much broken, was brought into shape for harmonic analysis. This station proved eminently suitable as a port of reference for the harbours throughout the Strait of Georgia; and by 1901 tide tables for it were published by this Survey. This proved a great boon, as the tide of that Strait presents special features which make it impossible to deduct its time from ports of reference in other regions. A summary of the early results, up to 1902, is given in one of the reports of progress.

These results were based partly on tidal information obtained during the Admiralty surveys and partly on observations arranged for by correspondence, before the Pacific coast was visited (15).

In 1905, several stations were established along the coast; and on reducing the results, it was found possible to divide the whole coast into three regions; namely, the West coast of Vancouver island, the region of the Strait of Georgia, and the Northern coast from Vancouver island northward. Principal stations are maintained in each of these regions; in Clayoquot sound, at Sand Heads, and at Port Simpson. The cities on the coast are quite unsuitable as ports of reference; but tide gauges are maintained at Victoria, Vancouver and Prince Rupert, and tide tables are specially calculated for these harbours, on account of their intrinsic importance.

As a rule, the tide on the Pacific coast is strongly influenced by the declination of the moon, and it is also subject to an annual variation with the change in the declination of the sun. On the open coast the spring and neap tides are quite distinguishable, notwithstanding the other inequalities. In the Strait of Georgia the diurnal inequality becomes so large as to dominate every other feature of the tide. Next in importance is an annual variation, as the influence of the sun is very great relatively to the lunar effect. The turn of the current in the Passes is similarly affected, as the relation between the time of slack water and the tide shows a marked annual variation. To obtain good comparisons, it is thus desirable to have a full year of simultaneous observations. If this is not possible, at least six months are necessary; or else the comparisons with the reference station must be made about the time of the Equinox.

Variable Tidal Differences.—The use of variable tidal differences is very valuable in extending as far as possible the region that can be referred to each of the principal stations, and thus avoiding the need for an additional reference station. As a rule, the variation is so largely in some one period, that all others can be neglected; but even if there are two periods involved, their laws of variation can be determined for calculation purposes.

On the Pacific coast generally, the annual variation in the tidal difference, as already explained, is the only one necessary to take into account. For, in most cases, the diurnal inequality is so much the same, both at the principal and secondary station, that it does not cause variation in the difference.

In the Strait of Georgia, where high water and the half tides are so nearly at the same level, it is only the difference for lower low water that is affected by variation. For example, on the Fraser river, from Sand Heads at its mouth to New Westminster, the difference in time

for lower low water is an inverse function of the height to which low water falls. This would not justify a principal station at New Westminster; as the variation can be ascertained for calculation purposes, and the tidal differences for high water and the half tides are constant. A similar distinction is required in the case of lower low water, in calculating slack water in First Narrows from the reference station at Sand Heads.

On the Lower St. Lawrence, between Father Point and Quebec, the variation is also very large in the difference of time for low water. It was not possible to bring the variation into any direct relation to the height of the tide. It was found to be chiefly in the period of the synodic month with the moon's phases, but requiring a large outstanding correction in relation with the moon's distance. The tides for Father Point were calculated by this double series of variables in the early years, before the harmonic constants were determined there.

In comparing the Miramichi region with St. Paul island, on the opposite sides of the Gulf of St. Lawrence, there is apparently a reversal in the diurnal inequality. This is of such a character that if the tide is followed in its actual progress, the difference in time is not constant, but varies so widely as to be practically valueless. Nevertheless, the tides at Miramichi can be deduced from St. Paul island by a constant difference, provided that it is taken as earlier, or for the preceding tide, as this reverses the alternation to which the diurnal inequality gives rise.

After entering the Gulf of St. Lawrence through Cabot strait, the tide changes its character during its progress towards Northumberland strait; and on reaching that strait, the diurnal inequality has developed to such a degree that the tide is practically under the control of the moon's declination. There are times when the difference in range between the two tides of the day is as great as the difference between springs and neaps. It is possible, however, to refer this strait to St. Paul island by means of two series of variable differences, for high and low water respectively; both series varying in accordance with the declination of the moon and alternating with its upper and lower transits. The tide tables for Pictou, in the middle of the strait, are calculated from St. Paul island by means of these differences, and the variation in the moon's declination during the 19-year cycle is also allowed for. The tides for Charlottetown are then computed from Pictou by means of differences by which allowance is next made for a variation in the period of the synodic month. On account of this double variation, Charlottetown has now been equipped as a principal station.

These will suffice as examples of variable tidal differences, as

utilized in this Survey to avoid the multiplication of the principal tidal stations. This method is fully explained, with tabulated examples, in a Paper on the subject contributed to the Royal Astronomical Society of Canada (16).

Tide Levels and Bench Marks.

As there is no general system of levels as yet throughout Canada, it has usually been necessary to establish a local Bench Mark and to originate a datum plane for the tidal observations. Wherever a plane of reference had already been established, it was made use of; but it is only in two harbours in Eastern Canada that Bench Marks exist to which the Admiralty low water datum is referred; namely, Quebec and Halifax. At St. John, N.B. all such marks were destroyed in the great fire of 1877, and although much trouble was taken to re-establish the datum of the harbour chart, the result was only approximate (17). At the head of the Bay of Fundy, a good datum was established by the engineers of the Baie Verte canal; and simultaneous observations in Northumberland strait connect this with the open sea level. To this datum the exceptional tides at the head of the bay are referred. An interesting result for mean sea level at the head of the Bay of Fundy has been deduced from these observations (18).

Bench Marks have almost always been established both at the principal and secondary stations, even when tidal observations have only been continued for a few months. These are valuable at present for local reference, and will be more so in future, when they are connected together by some general system of levels. The Bench Marks thus established along the St. Lawrence and throughout the Maritime Provinces, are described in a Paper communicated to the Canadian Society of Civil Engineers (19). The extreme levels of high and low water in the various harbours are there given; as well as the tide levels at the head of the Bay of Fundy, which are valuable for the security of the extensive hay lands in that region, known as dyked marshes.

The value of mean sea level at Quebec had long been desired by engineers; and accurate local data have now become available there, from tidal observations during eight complete years. The relation with Atlantic mean sea level at New York was accordingly worked out from connections recently made by geodetic surveys and canal levels, and from revised determinations made in the United States. The result is given in a Note communicated to the Canadian Society of Civil Engineers, the data on which the result is based being carefully explained (20).

In British Columbia the levels were in an unsatisfactory condition, especially at Victoria. In that harbour it was found that a new datum

had been adopted for each new purpose as it arose. The datum for city works had been altered more than once. The Royal Engineers and the Public Works department had independent levels of their own. Another datum was used for the harbour chart, and so on. When the tidal observations were begun, much trouble was taken by the writer to correlate these various levels and to adopt a satisfactory plane of reference for the future. For this purpose, instrumental levels were carried to Esquimalt, as some datum planes were better defined there than at Victoria. The relation between all existing planes of reference was eventually determined and brought into relation with the tidal observations.

The results for Victoria, Vancouver and other cities and towns of British Columbia, are given in a Paper, prepared by the writer, which was published by the Marine department, entitled "Tide Levels and Datum Planes on the Pacific Coast" (21). This paper contains a complete list of the Bench Marks which define datum planes in the cities, and also those which define the low water datum of the charts at all points along the coast where Admiralty surveys have been made.

Importance of Bench Marks.—The importance of establishing Bench Marks in connection with tidal observations is very evident, as it is only from these observations that data for many purposes can be obtained. The extreme levels of high and low water are important for wharf construction and docks, and also for sewerage and other city works. They are also essential for dredging operations in the deepening of harbours and channels. The value of mean sea level is very accurately determined by the continuous observations required for harmonic analysis; and where there is a Bench Mark for reference, the level is permanently fixed. This determination in our principal harbours affords a basis for geodetic levelling; and it is also utilized by the Public Works department, the Interior department and the Geological Survey, as well as for our principal canals. Such determinations of mean sea level afford the only means by which an alteration in the level of the continents relatively to the ocean can be detected. In several regions such gradual changes are taking place, and they have a practical bearing on the depth of harbours and channels. In such ways as these, the levels as determined by the Tidal Survey have an extended value; and they will become increasingly useful for reference in the future as the country develops and a wider accuracy is required.

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