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TIDE LEVELS AND DATUM PLANES ON THE PACIFIC COAST OF CANADA.

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(Read before the Annual Meeting, January, 1906.)

In extending the Survey of Tides and Currents to British Columbia on the Pacific coast, it has been necessary to decide upon planes of reference for the height of the tide in the various harbours, and to establish several new bench-marks. In doing so, any datum already established or levels previously determined have been correlated with the new work, to avoid confusion and to give the tide levels a satisfactory basis from the outset. The levels which a continuous record of the tide affords will be valuable for reference in the construction of wharves, dredging, and other harbour improvements, and in city works, as well as for marine purposes.

Owing to the planning and directing of tidal work on the St. Lawrence and the Atlantic coast, and the investigations of currents during the earlier years of this Survey, it had not been possible for the writer to visit the Pacific coast until the season 1905. Some headway has been made, however, in the publication of tide tables for the Pacific ports, and the commencement of tidal observations. The opportunity of this season enables the results with regard to datum planes and bench-marks to be given in a complete form, up to the stage now reached.

These results may be regarded as supplementary to those already published for the Atlantic coast in 1903, in a paper entitled "Tide Levels and Datum Planes in Eastern Canada." It will not, therefore, be necessary to repeat the general explanations there given, or to enlarge upon the permanent value of tide levels and the bench-marks which record them.

In any tidal observations the two essentials are the correct time and a plane of reference for height, as these are the co-ordinates of the tidal curve. The main object of this Survey, as a branch of the Marine Department, is to deal with the time of the tide, since this is the matter of chief importance to navigation, and the question of levels is quite secondary. In the strong tidal currents of British Columbia, it is information as to the time of slack water that is most wanted by the mariner. To obtain correct time for the observations is also the greatest difficulty met with on such a coast. But the value of reliable levels, which can only be obtained from tidal observations, makes it seem right to take the additional trouble necessary to secure them.

The importance of publishing such results is emphasized by what has occurred in British Columbia. Bench-marks, carefully established, are now useless because the record of their elevations is lost through fire; the loss of level notes or the destruction of primary bench-marks leaves elaborate surveys with uncertainty in their datum planes, which it is extremely difficult to re-determine satisfactorily. By publication, these records might have been preserved, and a large amount of good work, and subsequent trouble and expense in replacing it, would have been saved.

The condition of the tide levels as met with at different places, was strongly contrasted. At some places, of course, there was nothing to refer to, and it was even difficult to know at what level to set a tide scale so that the tide would keep within its range. The only course was to place an independent bench-mark, and make a beginning. At the other extreme there was a redundance of datum planes, established by various engineers and surveyors, with little regard to anything previously done, and often complicated by loss of record. In such a case, to follow the usual precedent of ignoring the past and beginning afresh, would have been unprincipled, especially when valuable tide levels were often carefully referred to an uncertain datum. In contrast with this the service rendered by Mr. H. J. Cambie, the Resident Engineer of the Canadian Pacific Railway at Vancouver, deserves mention. He has taken the trouble to furnish information regarding levels to the Public Works Department, the British Admiralty, and the city of Vancouver, which has kept the various planes of reference in relation, and has prevented uncertainty and confusion.

Character of the Pacific Tide.—The most important plane of reference which results from tidal observations is undoubtedly Mean Sea level. To understand the best method of obtaining its value, it is necessary to explain briefly the character of the Pacific tides, as at first sight they appear quite irregular. The Atlantic tide, with which we are the most familiar, follows the phases of the moon, and accordingly the alternation of spring and neap tides is its dominant feature. The tide of the Pacific, however, can best be described as a declination-tide. Its leading feature is a pronounced diurnal inequality which accords with the declination of the moon, and is subject to an annual variation with the change in the declination of the sun. Also, the unusually large solar effect, relatively to the lunar, not only accentuates this annual variation, but in some regions, especially northward, it becomes sufficient to enable the springs and neaps to be distinguished with little difficulty.

On the open coast of the Pacific, the tide curve is still fairly regular, though showing the diurnal inequality strongly. But in Fuca Strait and the region of the Strait of Georgia, which makes up half the coast line of British Columbia, and where all the more important harbours are situated, the appearance of the tide curve is anomalous. The high waters are nearly at the same level, and the range depends on the amount of fall to low water, which may be almost inappreciable or very pronounced. During the greater part of the day, there may thus be a long stand or only a slight fluctuation near the high-water level with a sharp and short drop to the lower low-water which occurs once in the day. This type only changes to a fairly symmetrical curve when the moon is on the equator near the time of the equinoxes.

The spring and neap tides of the Atlantic nomenclature are difficult to find, as they here form a minor feature which is obscured by the stronger characteristics of the tide. The "Establishment," which is so well marked in the Atlantic, is thus almost illusory unless it is strictly reduced to equinoxial and equatorial conditions in accordance with the definition used in France. In dealing with tide levels, it may still be convenient to speak of spring and neap tides, if they are understood to mean the two maxima and the two minima in range or in level which always occur in the period of the lunar month. But the two highest and the two lowest points on the tide curve for the month, may be as much as five days before or after the full or new moon, as they are so largely occasioned by the diurnal inequality.

The extreme tides of the year necessarily occur at the nearest point to the solstices at which the moon reaches its maximum declination.

A tide of this character is apt to be termed irregular by the mariner, as the tropical or declination-month, which is its governing period, is less familiar and less noticeable than the synodic month of the moon's phases. It is evident, however, that this tide is perfectly astronomical, and its analysis and prediction are just as definite as for any other type of tide.

Mean Sea Level.—With a tide of this type, there is a notable difference between the half-tide level, and the true value of Mean Sea level. Its only accurate value is the mean ordinate found by the integration of the tide curve, referred to any invariable base line or datum. This mean ordinate fixes the position of the horizontal line which bisects the area of the tide curve; and this also accords with the best definition of Mean Sea level for any type of tide. We have occasion, later on, to point out the importance of adhering to this definition, as the half-tide level may differ a foot from true Mean Sea level, even in the case of a tide whose extreme range is only thirteen feet.

The advantage of a registering tide gauge is much emphasised with tides of this character. If scale readings are taken by direct observation, which the Admiralty surveyors usually prefer, they must be continuous, day and night, and afterwards plotted as a curve, or little use can be made of them except for the reduction of soundings. With a registering gauge this elaborate and expensive method can be dispensed with. The hourly ordinates of the tide curve throughout the year enable the true value of Mean Sea level to be readily found; and even with a shorter period, the continuity of the record enables the diurnal inequality to be followed, and if this is known the average level and the extremes of high and low water and other data can be correctly determined. The continuous record is equally important with respect to the time of the tide, in which there is a similar inequality of interval; but with this we are not now dealing.

The question of Mean Sea level is of unusual interest on the Pacific coast, as there is reason to believe that its elevation is changing. Some indications point to a rise in the level of the coast, at as high a rate as one or two feet per century. It is only from tidal observations properly reduced, that any trustworthy result can be arrived at; and if the change is as rapid as supposed, it will not require an interval of many years to obtain a fair approximation to its amount.

DATUM PLANES AT VICTORIA.

At Victoria and Esquimalt, the planes of reference were found to be in great confusion, no less than eight datum planes existing,

unrelated to each other as a rule, and the records regarding them often unobtainable through loss of note books, fire, or destruction of bench-marks. Most of these are defined by some reference to the tide, such as high water, Mean Sea level or low water, but the tide levels assumed do not correspond with each other, and they are thus quite indefinite unless fixed by a bench-mark.

To correlate these for tidal purposes and to re-determine the chart datum, it was necessary to go fully into the history of the whole matter, and also to run special levels for three and a half miles, to connect Esquimalt and Victoria. We have also had the opportunity this season to go over the ground personally, to examine original plans and notes at Victoria, to inspect the bench-marks, to see the records in the Public Works office in New Westminster, and to discuss matters with those who had to do with them, in the endeavour to bring all the information into correspondence. We will give the results as concisely as possible, but it will make the matter clearer to follow the chronological order. For all practical purposes, anything previous to 1880, if not prehistoric, may be regarded as ancient history.

There are several bench-marks in Victoria for which elevations are known with reference to more than one datum, but the resulting difference, instead of being constant, is found to vary within the limits of an inch or two. When a relation has had to be determined by averaging such differences, this will be explained. But there are four of the datum planes which can now be referred to an individual bench-mark, and these four are the most important from a tidal point of view. All the planes of reference at Esquimalt have also been connected with this same bench-mark, by the new levels run this season. The relations thus obtained are more trustworthy than if derived from averages, and will therefore be given the preference.

The bench-mark referred to is at the north-east corner of Wharf and Fort streets in Victoria, and is thus near the water front. The building at this corner, now occupied by the Hamilton Powder Company's offices, has a sandstone foundation below the brick work; and the top course of this foundation, which is nearly on a level with the sidewalk, forms the door sills on the Wharf street front of the building. The point used as a bench-mark is the surface of the sandstone, below the brickwork, at the corner, usually termed the plinth, or else the southern end of the first door sill, at two and a half feet from the corner. The level of these two points is identical. For brevity, we may term this the Standard bench-mark.

Hudson's Bay Co's Datum.—This is chiefly of importance because used as the basis of a contoured plan of Victoria, made by Mr.

G. Hargreaves in 1883. In making this plan, bench-marks were established throughout the city, but the level notes recording these were handed over to the city, and have been lost for many years. There are a few points on masonry buildings for which elevations with reference to this datum are marked on the plan itself, or are in Mr. Hargreaves' private notes.

The datum is defined as 100 feet below an assumed elevation for high water. This is in itself quite indefinite; but in making the plan Mr. Hargreaves checked all his levels back to the Standard bench-mark already described, its elevation being 127.11 feet above the Hudson's Bay datum. This value is marked on the original plan, now in the City Hall, and it serves to fix the datum in elevation.

City Datum for Victoria.—This datum was established by Mr. E. A. Wilmot, when laying out a sewerage system for the city in 1890 to 1892. It was originally known as the City Sewer datum; and it was adopted by the City Council, about 1893, as the city datum for Victoria, Mr. Wilmot being City Engineer from 1892 to 1899. Why the original Hudson's Bay datum was not adopted in place of this is not clear, as it only differs a few inches from it. Possibly Mr. Hargreaves' notes were lost before this date. His contoured plan has since been extended with reference to the City datum, and in the list of bench-marks at the City Hall, the entries are not infrequently for the old datum, especially in some districts, so that much caution is required in making use of the elevations given.

This datum, like the Hudson's Bay datum, is based on an assumed elevation of 100.00 feet for high water; but the levels assumed for high water were determined independently and do not correspond. How the high water level was obtained in this case, we will have occasion to explain later on. The datum itself is fixed, however, with reference to the Standard bench-mark, at the corner of Wharf and Fort streets for which the elevation on this datum is 126.76. This figure is taken from Mr. Wilmot's original level notes, and it is so entered also in the list of city bench-marks.

There are a few other city bench-marks for which elevations are still to be found with reference to the Hudson's Bay datum. The most trustworthy values for the difference between the two datum planes are given by this bench-mark and the one on the City Hall. This latter is at the side entrance to the City Hall on Pandora street, a broad arrow cut on the surface of the lower stone step near its east end, this step being slightly above the level of the sidewalk. Its elevation above the Hudson's Bay

datum is marked on the contoured plan of Victoria. The relative elevations are as follows:—

	Standard bench-mark.	City Hall bench-mark.
Above Hudson's Bay datum..	127.11	153.65
Above City datum..	126.76	153.35

The difference of 0.35 foot is considered by the engineering staff at the City Hall to be the most accurate that can be arrived at, and this value is the same as the difference given by our Standard bench-mark.

Public Works Datum.—This is a Low Water datum established by Mr. F. C. Gamble while Resident Engineer of Public Works, and used as the plane of reference for soundings in the harbour, and also for the tidal observations of 1893 to 1897. This is a most important datum, as it has become the basis of the chart of the harbour, and has afforded indirectly the starting point for the city levels. It was thought to be most definitely fixed with reference to a series of bench-marks around the harbour; but unfortunately all record of the elevation of these was lost by the destruction of the Public Works documents in the fire at New Westminster in September 1898. The most persevering efforts have been made to re-establish this datum, especially by those interested in the chart depths, the grounding of vessels, and dredging operations, but these efforts have been without definite results until a clue was obtained this season.

The Public Works datum was originally the zero of a standard tide scale set by Mr. Gamble to coincide with 2 feet 8 inches on a tide gauge on the Hudson's Bay Co's wharf, this being said to be the lowest level of low water which had been noted. The zero on this standard scale was taken to represent low water mark at spring tides, and nine feet on the scale, to represent high water at spring tides. When the continuous tidal observations were begun, the limiting values afterwards recorded were as follows: Extreme high water, 10 feet 9 inches; extreme low water, at 8.30 a.m., July 3rd, 1894, 18 inches below the zero of the scale; making the extreme range 12 feet 3 inches. The scale thus proved to be well set in its height, as the levels of ordinary high and low water fall symmetrically between these extreme limits. The facts as here stated are taken from a report of Mr. Gamble to his department, dated August, 1894. The tidal observations were continued until May, 1897, when the Public Works office was removed to New Westminster.

The only connection by which the Public Works datum can now be determined is due to Mr. E. A. Wilmot. It was made, incidentally, when he was establishing the City Sewer datum for Victoria

in January, 1891. He accepted the level of nine feet on the Public Works standard tide scale as high water at ordinary spring tides; and he took this as elevation 100.00 feet for the City Sewer datum. His levels make direct connection from the tide scale which was on the old Customs House wharf, to the bench-mark at the corner of Wharf and Fort streets; but the connection depends ultimately on a single reading on the water surface. The resulting elevation of this bench-mark above the zero of the Public Works tide scale, is 35.76; and conversely, the elevation of its zero above the City datum is 91.00. The above explanations and figures are taken from Mr. Wilmot's original level notes, as the present Engineering staff at the City Hall was unaware of the relation of their datum to tide levels, or the way in which the datum was originally established.

The value of this connection can scarcely be overestimated, as it fixes the long lost Public Works datum, and the Low Water tidal datum, with reference to every reliable city bench-mark in Victoria. The importance of this will be better appreciated when the Chart datum is next considered. This connection has also made the City datum the most desirable one to use for the comparison of the relative elevations of all the other planes of reference.

Chart Datum.—The Admiralty chart of Victoria harbour is made from two sources; the outer harbour, outside the line joining Work Point and Shoal Point, is from a survey made in 1895, by Lieut. B. M. Chambers, R.N. This is stated on the chart of March, 1896; but there is no reference on that chart to the information on which the inner harbour is based, nor is there mention of any plane of reference for the soundings.

It is now clear that the inner harbour is taken from the surveys of the Public Works Department. Such plans in that department as have survived the fire are partial and fragmentary; but a complete plan of the harbour was known to have been made in 1895, by Mr. P. Summerfield, who was employed by Mr. Gamble to do so. A copy of this plan was eventually found in a surveyor's office in Victoria. It is without title or date, but was identified by Mr. C. Worsfold, Assistant Engineer in the Public Works Department, as undoubtedly a copy of Mr. Summerfield's plan; and accordingly it is to the Public Works datum that the complete soundings given upon it are referred. It is also to be noted that this plan existed when the chart, issued in 1896, was compiled. A comparison with the Admiralty chart, made by Mr. Worsfold and myself, with care to avoid places where dredging has since been done, shows that the soundings are identical. The plane of reference for the soundings in the inner harbour, as given on the Admiralty chart, is thus proved to be the Public Works datum, for which the ele-

vation is now known through Mr. Wilmot's levels, as already explained.

Tidal Survey Datum.—This is the Low Water datum established for the recent tidal observations at Victoria. When these observations were begun in 1900, by Mr. F. N. Denison, of the Meteorological Service, the Public Works tide scale no longer existed, and all their records were already lost in the fire of 1898. On consultation with Mr. Gamble and Mr. Worsfold, a plane of reference was adopted, to correspond as nearly as might be with the former Public Works datum. The new datum plane was fixed by reference to a new bench-mark, and also connected with the Standard bench-mark on Wharf street, the elevations being given below. A complete year of the new tidal observations is included in the basis of the tide tables, the record being obtained in 1903 to 1904, by Mr. E. Baynes Reed, Superintendent of the Meteorological Office, and Mr. Denison.

Much trouble has been taken to ascertain the relation of this datum to the chart soundings. With this object, special soundings were taken in the harbour by Captain Walbran, of the Marine Department, for comparison with the tidal record. Simultaneous observations of the water level at Victoria and at Esquimalt were also made, in the hope of obtaining a connection there. But the results need not be detailed, as these methods are necessarily uncertain, and the relation has now been ascertained from instrumental levels.

This datum is in use for the dredging operations now in progress, and for the check soundings taken by Captain J. M. Newcombe, who is in charge. The depths as dredged are thus brought into correspondence with the zero level of the tide-tables. This datum is also cited by Mr. Thos. C. Corby, on the plan of Victoria harbour, which he compiled and published in 1904. The following bench-marks serve to fix this datum:—

Tidal Survey Bench-mark.—At the rear of the old Custom House building on Wharf street at the foot of Broughton street. The top of a brass bolt drilled vertically into the granite rock, at 16 feet from the north-west corner of the building, with the letters "B. M." cut beside it on the sloping surface of the rock. Elevation above the Tidal Survey datum, or zero of the present tide scale, 15.40 feet.

Standard Bench-mark.—On the building at the north-east corner of Wharf and Fort streets, now occupied by the Hamilton Powder Co's offices. The top of the sandstone foundation below the brickwork, at the street corner, nearly on a level with the sidewalk. Elevation above the Tidal Survey datum, 36.36 feet. The surface of the same course of sandstone forms the door sills along the

Wharf street front of the building. The southern end of the door-sill next the corner, is used as a city bench-mark. Its level is identical with the point above described.

This datum is thus 9.60 feet below the level for high water, which was taken as nine feet on the standard tide scale placed by the Public Works Department, and which was made 100.00 feet in establishing the City datum. The Tidal Survey datum is thus at elevation 90.40 feet above the City datum.

Royal Engineers' Datum at Victoria.—This datum is defined as Mean Sea level. Its relation to the City datum has been obtained from seven of the bench-marks established in Victoria by the Royal Engineers, for which elevations were determined by Mr. Wilmot in his sewerage levels. The seven differences are as follows:—3.88, 3.88, 3.77, 3.70, 3.74, 3.76, and 3.75 feet. The resulting mean value is 3.78 feet below elevation 100.00, which places the Royal Engineers' datum at 96.22 feet above the City datum. The reason for the considerable variation in the difference is not evident. Mr. Wilmot's levels are always carefully checked, no total closing error of more than 0.03 being found in his notes; and the residual error would be half of this. It is equally difficult to admit the error to be actual, in bench-marks established by the Royal Engineers. In any case, the resulting mean value must be very close to the truth.

The question of the true elevation of Mean Sea level, we will discuss later, in the light of other determinations.

DATUM PLANES AT ESQUIMALT.

Some valuable planes of reference exist at Esquimalt, more especially the Low Water datum for the tidal observations which the Public Works Department is taking there. As the harbours of Victoria and Esquimalt both open on the Strait of Fuca at a distance of only three miles from each other, the tide levels at both places must coincide closely. The only reason apparent for any want of correspondence in the data, is their determination in different years. To correlate the Esquimalt data with Victoria the Tidal Survey in the spring of 1905, arranged with Mr. G. Hargreaves to connect the bench-marks at Victoria by instrumental levels with the Esquimalt dry dock. These were run both ways, and checked.

At the Dry Dock, there are two scales of feet cut on the masonry, one inside and the other outside the dock gate. These consist of Roman numerals, six inches high, the lower edges of the numerals being the even feet. The lowest figure is V, where the arc of the invert meets the side of the dock. The zero of both

scales is at the level of the invert forming the dock sill. To verify this, check measurements have been taken which indicate that there cannot be more than quarter of an inch of discrepancy between the scale and the invert. Strictly speaking, the level herein termed the dock sill is the elevation of the zero of the inside scale, taken from the figures as actually cut.

The elevation of the dock sill, referred to in the Victoria City datum, is 71.45 feet as found by the instrumental levels of this season which connect Esquimalt with Victoria, and which have for their point of reference the Standard bench-mark on Wharf street, at elevation 126.76. These levels were run both ways over the distance of three and a half miles, with a closing error of 0.04 foot; the mean of the two results being accepted.

Dry Dock Datum.—Used in the construction of the Dry Dock, from 1883 to 1886. The datum is defined by an assumed elevation of 50.00 feet for ordinary high water at Esquimalt. It is also stated in the Engineer's levels that this elevation for high water is the same as 26 feet 6 inches above the sill of the dock; but this may be only approximate, as the dry dock was not completed when the datum was established.

This datum would be of little interest in itself, and might not now deserve to be re-established, were it not that Mean Sea level, which forms the starting point of the Royal Engineers' levels, is determined with reference to it. The bench-mark by which it was originally fixed was a ring bolt on the Admiralty pier; but this has been built over, and is now lost. This ring bolt was also the initial bench-mark in the Royal Engineers' survey. Fortunately a record of its elevation with reference to both datum planes exists in the level notes. The relation between the two is thus accurately known, the resulting difference being 47.665; and accordingly this is the elevation of the Royal Engineers' datum above the Dock datum.

The data above cited were given by Lieut. G. C. E. Elliott, R.E., in reply to enquiries from Mr. Baynes Reed, in January, 1902, before the Royal Engineers left the country. Lieut. Elliott recognizes the difficulty, however, of re-determining the original Dock datum.

Royal Engineers' Datum.—Used in the surveys made by Lieut. Lang in 1885 to 1889. The datum is defined as Mean Sea level, which was determined with reference to the Dock datum, as above explained, and fixed with reference to the lost bench-marks.

To correlate this datum with the other elevations, instrumental levels were run by the writer this season to the dry dock, from the nearest bench-mark on the Esquimalt road. These levels were run both ways with a closing error of 0.02 foot, which was averaged out. The bench-mark is on the retaining wall built on the

south side of the Esquimalt road, opposite Signal Hill, a broad arrow cut on the side of the wall facing the road, at 46 feet from its eastern end. The elevation of this bench-mark, as stated by Lieut. Elliott, is 37.24 feet above the Royal Engineers' datum.

We are thus able to give two values for the Royal Engineers' datum with reference to the dock sill:—

By new levels; bench-mark above dock sill..	61.51
Elevation of bench-mark on R. E. datum..	37.24
R. E. datum above Dock sill..	24.17
Assumed level of high water above dock sill, taken as elevation 50.00 on Dock datum..	26.50
R. E. datum below assumed high water, or 50.000 less 47.665..	2.33
R. E. datum above dock sill..	24.17

The value derived from the bench-mark is preferable, and by its adoption, the elevation 50.00 on the Dock datum, is found to be actually 26.60 feet above the dock sill, instead of 26 feet 6 inches as supposed; but this discrepancy is not unlikely in the circumstances already explained.

As a final result, we find the elevation of the Royal Engineers' datum at Esquimalt, to be 95.72 feet above the Victoria City datum. The difference between this value and the elevation of their datum in Victoria itself, we will refer to later on.

Public Works Datum.—This is a Low Water datum, used as the zero level for the tidal observations taken at Esquimalt since 1897, and still continued there. It was determined by Mr. G. A. Keefer, the present Resident Engineer of Public Works, by taking the mean level of the lowest low water recorded in each month, throughout the year. It is fixed with reference to the sill of the dry dock, at 19 feet 6 inches above it, on the inside masonry scale. The elevation of this datum is accordingly 90.95 feet above the Victoria City datum.

The usual method by which the Admiralty determine their datum where there is a pronounced inequality in the tide, is to take the mean low water level at each spring tide, or every fortnight throughout the year. The method adopted by Mr. Keefer should therefore give a plane of reference which is lower than the Admiralty standard, by the semi-monthly inequality in the height of low water. The difference given by these two methods is 0.44 of a foot, as found from two years of continuous tidal record in 1895 to 1897, at Victoria.

Summary of Tide Levels at Victoria and Esquimalt.	Above Victoria City Datum. *Feet.*
Bench-mark, corner of Wharf and Fort streets; as already described..	126.76
Tidal Survey Bench-mark; a brass bolt in the rock in rear of the old Custom House building, foot of Broughton street..	105.80
Extreme High Water, during three years observation, in 1895 to 1897, and 1903 to 1904. Occurred, 1896, Jan. 26..	102.20
High Water at Spring tides; average level of the two highest high waters in each month, during two complete years in 1895 to 1897..	100.19
Ordinary High Water; taken as nine feet on Public Works scale, and adopted as elevation 100.00 in establishing City datum..	100.00
Mean Sea Level; from hourly ordinates during two complete years, from April, 1895 to April 1897. Above zero of tide scale or Public Works datum in the two years 5.728 and 5.776 feet. Mean elevation resulting..	96.75
Mean Sea Level; from hourly ordinates during one complete year, from March, 1903, to March, 1904. Above Tidal Survey datum 6.143 feet. Elevation..	96.54
Harmonic Tide Plane; as determined in 1895 to 1897. At a distance below Mean Sea level given by the sum of harmonic constants $M_2+S_2+K_1+O$	91.89
Low Water at Spring tides; average level of the two lowest low waters in each month, during two complete years in 1895 to 1897..	91.15
Average level of the lowest low water in each month during the two years in 1895 to 1897..	90.71
Public Works datum; the zero of their tide scale at Victoria, in 1893 to 1897	91.00
Datum of the Public Works tidal observations at Esquimalt; 19 feet 6 inches above masonry sill of dry dock...	90.95
Tidal Survey datum; the zero for the heights in the Tide Tables..	90.40
Extreme Low Water, during three years observations, in 1895 to 1897, and 1903 to 1904. Occurred, 1895, June 24..	89.45
Sill of masonry Dry Dock at Esquimalt..	71.45

Mean Sea Level Determinations.—Some explanation of these is required, especially as there is an apparent want of correspondence between the Royal Engineers' datum and Mean Sea level. The various determinations are now correlated by the instrumental

levelling referred to; and this also enables the results of the harmonic analyses of the records from registering tide gauges, to be compared on the same basis. In this analysis Mean Sea level is the average value found from the summation of the 8760 hourly tidal ordinates throughout the year; and on this principle, the most accurate results possible is obtained. The determinations reduced to the City datum in Victoria, are as follows:—

At Victoria; tidal observations by Public Works Department; two complete years from April, 1895, to April, 1897. Mean Sea level above Public Works datum, from hourly ordinates in each year; 5.728 and 5.776 feet. Average elevation resulting.. .. .. 96.75

At Victoria; Tidal Survey observations; one complete year from March, 1903, to March, 1904. Mean Sea level above Tidal Survey datum, from hourly ordinates, 6.143 feet. Elevation resulting.. .. .. 96.54

At Victoria; Royal Engineers' datum at 3.78 feet below 100.00 on the City datum.. .. .. 96.22

At Esquimalt; Royal Engineers' datum, in surveys of 1885 to 1889; 37.24 feet below bench-mark on Esquimalt Road.. .. .. 95.72

At first sight it might be considered a better method of procedure to assume Mean Sea level to have the same absolute elevation in every case, and to take the coincident value as a basis of comparison for the various datum planes. But this assumption when carried out, is found to imply a two-fold error in the levels of two different Engineers; namely, a minus error of 0.50 foot in Mr. Hargreaves, and at the same time a plus error of 0.53 foot in Mr. Wilmot's. These errors do not attach to any assumed values for high water, or such like, but to actual instrumental work; and they are therefore quite inadmissible.

Some small part of the difference may be due to actual variation in the annual value of Mean Sea level, for which we give data further on. But the true explanation of so large a difference is to be found in the type of the tide, or the form of the tide curve, at Victoria and Esquimalt, to which we have already alluded. Towards high water, the tide curve is very flat, and the long stand of the half-tides is at a high level; while the low water falls sharply and is of short duration. With such a tide, if Mean Sea level is taken as the half height or mid-range, it is plain that this may be very different from the mean level derived from its height at every hour throughout the year. This latter method undoubtedly gives the true mean level of the sea as this integration of the tide curve furnishes the height of the horizontal line

which bisects its area. This shows also the superior character of the tidal record obtained from a self-registering tide gauge.

The amount by which the values for Mean Sea level differ, when obtained by the two methods indicated, we can illustrate from the tidal observations at Victoria. The result is entirely independent of instrumental levelling and also of any absolute elevation as it can be referred to an individual tide scale. The comparative results are as follows:—

From Public Works observations at Victoria; in 1895 to 1897.

	Scale Reading.	Reduced Elevation.
High Water Spring Tides. Average level of the two highest tides in each month during two years; April, 1895, to April, 1897	9.19	100.19
Low Water Spring Tides. Average level of the two lowest tides in each month; during same period	0.15	91.15
Half height, or mid-range	4.67	95.67
Mean Sea Level from hourly ordinates during the same two years, 1895 to 1897; above zero of scale	5.75	96.75

It thus appears that the level obtained for the half height of the tide may be a foot lower than when derived from hourly ordinates. The relatively low elevation of the Royal Engineers' datum, if determined in this way, would thus be fully accounted for, as the elevation which we find by this method is lower than their datum at either Victoria or Esquimalt. The difference of half a foot in the elevation of their datum at the two places, we have no means of explaining unless possibly these determinations were independently made.

As to the amount of actual or physical variation in the height of Mean Sea level in the Pacific, the values already given show a difference at Victoria of 0.21 of a foot between the years 1896 and 1903. Determinations have also been made during a series of years by the United States Coast Survey in California and Puget Sound, as well as during five years in the Strait of Georgia by this Survey. The greatest variation in level between any two years in the period of the observations is from 0.30 to 0.34 of a foot, in these localities. The variation may thus be considerable when

special years are selected; but even then, it is much less than the large difference we have here to account for.

Where the tide is of so unusual a type, it is the more important that the best method for the determination of Mean Sea level should be clearly understood; because it is only with reference to this level that any variation in the land elevation can be detected. The evidence on this question points to a rise of the land, and some approximation to the rate of rise per century it would evidently be valuable to ascertain. A basis for this is now established by the reliable values obtained for Mean Sea level, with reference to bench-marks.

DATUM PLANES AT VANCOUVER.

The datum planes at Vancouver are all in harmony with each other, and when they do not coincide, the difference between them is known. This fortunate result is due to Mr. H. J. Cambie, the first Resident Engineer of the Canadian Pacific Railway since its completion. The various datum planes are all referred to the same bench-mark on the C.P.R. station building.

C. P. R. Bench-mark.—On the north front of the Vancouver station building, near its east end, on the granite sill of the most easterly door opening on the train platform. A broad arrow cut on the surface of the sill at its east end and marked "B.M." on the plinth above. Elevation above the C. P. R. datum, 108.35 feet.

C. P. R. Datum.—Defined as 100.00 feet below ordinary high water and fixed with reference to the above bench-mark.

Vancouver City Datum.—On this datum, elevation 100.00 is supposed to be extreme high water; but the level adopted is higher than the highest tide ever recorded. The datum is fixed with reference to the bench-mark already described, its elevation above the City datum being 170.10 feet. The City datum is thus 1.25 feet above the C. P. R. datum.

Chart Datum.—The Low Water datum for the reduction of the soundings was established by Mr. W. J. Stewart, of the Marine Department, when making the survey of Vancouver harbour in 1891. It was originally fixed with reference to a broad arrow cut on one of the iron piles supporting the C.P.R. wharf. The datum was afterwards referred to the bench-mark on the station building, it being stated in a note on the present chart of the harbour that the soundings are reduced to a level of 23 feet 7 inches below that bench-mark.

TIDE LEVELS AT VANCOUVER.

	Above C.P.R. datum. *Feet.*
Bench-mark on Canadian Pacific Railway Station building, as already described	108.35
Surfaces of railway wharves. Approximate mean level	106.00
Extreme High Water of December, 1887, which reached the grate bars of the Hastings saw mill	100.70
High Water level, adopted as elevation 100.00 in establishing the C. P. R. datum	100.00
Highest High Water recorded by the tidal gauge during the six months in June to December, 1901, and during the year from March, 1902, to March, 1903. Occurred, 1901, December 26	99.75
Chart datum, to which the soundings in Vancouver harbour are reduced. At 23 feet 7 inches below the C. P. R. bench-mark	84.77
Lowest Low Water recorded by the tidal gauge during the eighteen months already indicated. Occurred, 1901, December 27	83.75
Zero of the tide scale, in the observations of 1901 to 1903	82.30

BENCH-MARKS AT OTHER TIDAL STATIONS.

Tidal stations equipped with registering gauges have been established recently, as a basis for the whole coast of British Columbia. At those of the greatest strategic importance, bench-marks have been put in, and the instrumental levelling done personally by the writer. The tidal record secured will soon enable the more important tide levels to be deduced from the observations. The tide scales used are of enamelled iron, which is very durable and readily cleaned.

Port Simpson, B.C.—The bench-mark to which the tide levels are referred, is a brass bolt with a round head, drilled into the rock, in the rocky foreshore which extends northward from the Hotel Northern. This rocky part of the foreshore is dry at half tide. The bolt is to the west of the wharf, at 174 feet from the angle between the side of the wharf and the hotel platform.

The elevation of 100.00 feet was assumed for the reference point first used, which was cut on the rock in another position. In the summer of 1905, the final bench-mark was put in, and the levels completed.

The tide levels are from the registering gauge which has been in operation since November, 1902.

	Feet.
Cap of wharf, beside the tide gauge..	109.10
Extreme High Water, during seven months, from December, 1902, to June, 1903, inclusive. Occurred, 1902, December 16th..	104.90
High Water at Spring tides. Average level of the highest High Water at each Spring tide during the above period..	103.26
Bench-mark. Top of brass bolt as described..	98.91
Low Water at Spring tides. Average level of the lowest Low Water at each Spring tide during the above period..	83.28
Extreme Low Water during the above period. Occurred, 1902, December 15th..	81.50
Zero of the Tide Scale, from the beginning..	80.89

The period of tidal observations above indicated, includes the seasons at which the tides usually have their extreme range in the course of the year. The extreme levels are in all probability the limiting values for the year.

Wadhams, Rivers Inlet, B.C.—The bench-mark is a broad arrow cut on the rock at the south side of the bay in which Wadham's cannery is situated. It is 55 feet from the point at which the rock begins, which rises to the southward into cliffs. Its level is reached by unusually high tides.

A registering gauge was placed here, and observations begun in July, 1905.

	Feet.
Surface of Wharf, beside the tide gauge..	103.21
Extreme High Water. Elevation which the highest tides are said to reach..	101.60
Bench-mark on rock, as described..	100.00
Extreme Low Water. It is probable that the tide never falls below elevation	83.80
Zero of Tide Scale..	81.59

Hardy Bay, Vancouver Island.—This bay is situated in Queen Charlotte Sound. The bench-mark is a copper bolt, 1¼ inches diameter, drilled into the rock on the north side of the Government wharf. It is 58 feet from the first pile bent of the wharf at the shore end, and 8 feet from the side of the wharf. It is about 2 feet below extreme high water.

The elevation assumed for the top of this bolt is 100.00 feet, and the zero of the tide scale is at elevation 78.37.

A registering tide gauge was placed here, and observations begun in July, 1905.

Banfield, Barkley Sound.—This is the Pacific cable station, at four miles from Cape Beale, on the west coast of Vancouver Island. Tidal observations were secured here, from February, 1903, to June, 1904, with the exception of one month.

The tide scale used was attached to the wharf that is immediately below the cable offices, and in August, 1905, the elevation of the zero of the scale was fixed with reference to a bench-mark, consisting of a brass bolt drilled into the rock opposite the south-east corner of the wharf, about the level of high water.

	Feet.
Bench-mark. Top of brass bolt, as described..	100.00
Low Water datum to which the tidal observations are reduced; at one foot on the tide scale..	89.40
Zero of tide scale, during the period of the observations; allowing one inch for settlement of wharf since then..	88.40
Zero of tide scale as found in August, 1905..	88.33

Clayoquot, Vancouver Island.—The registering tide gauge, placed here in August, 1905, is at a small wharf, extended to deep water for the purpose, situated near the telegraph office at the so-called Town site on Low Peninsula opposite Stubbs Island, in the mouth of the Sound.

The bench-mark is a brass bolt drilled into diorite rock, at 23½ feet from the shore end of the wharf, on its east side. It is about the level of high water.

The elevation assumed for the top of this bolt is 100.00 feet, and the zero of the tide scale is at elevation 85.01. The surface of the planking of the wharf is approximately at elevation 107.00.

PUBLIC WORKS DATUM, ON THE FRASER RIVER.

The Department of Public Works has had three registering gauges on the tidal portion of the Fraser River since 1895. These are situated at New Westminster, at Garry Point at the mouth of the river, and at Sand Heads on the edge of the extensive shoal which has formed off the mouth of the river, in the Strait of Georgia.

The zero level for the tidal observations at Sand Heads was established by Mr. F. C. Gamble, as the average of the lower low waters. The record since obtained shows that extreme low water falls some ten inches, or a foot, below it.

The same Low Water datum is used for the other tide stations at Garry Point and New Westminster. Its level has recently been carried to the new Post Office building by the present Residing Engineer of Public Works, Mr. G. A. Keefer, who has cut a bench-mark on this building to record it permanently. The elevations with reference to the datum are as follows:—

	Feet.	
Bench-mark on the Post Office building, New Westminster..	52.34	
Mean Sea Level.—Deduced from the hourly ordinates of the tide during five years of observations, as follows:—		
During one year, May 1, 1895, to May 31, 1896.. ..	8.458	
" " " Oct. 1, 1896, to Oct. 29, 1897.. ..	8.416	
" " " Nov. 1, 1898, to Nov. 15, 1899...	8.474	
" " " Nov. 15, 1899, to Nov. 24, 1900...	8.561	
" " " Jan. 16, 1901, to Jan. 27, 1902...	8.425	
Low Water datum. The average of the lower Low Waters used as the zero level of the tide gauges..		0.00
Mean value for the five years..	8.467	8.47

ADMIRALTY BENCH-MARKS.

The Admiralty surveying steamer *Egeria* has been engaged in hydrographic surveys for some years in British Columbia waters and its various commanders have established bench-marks or other reference points to fix the Low Water datum to which the chart soundings are reduced.

Some of these are points of natural rock at about half-tide level, which may answer to define a Low Water datum for soundings that are only taken to the nearest foot, but a rock within the range of the tide, overgrown with sea-weed and barnacles in these prolific waters, is scarcely suitable as a bench-mark for definite tide levels. It is unfortunate when such a rock is the only reference mark for levels, in a water area around which new towns are springing up, and where harbour improvements and drainage works may soon be required.

We give a description of these reference marks in the more important localities, or where a continuous tidal record of sufficient length has been secured to furnish a basis for satisfactory tide levels. The record must evidently be continuous, day and night, to be of use when diurnal inequality is the leading feature of the tide. Some of the descriptions which are given, are from personal inspection.

Comox.—The chart survey was made by Commander M. H. Smyth, R.N., in 1898; and the bench-mark at Comox serves to

define the datum for the whole extent of Baynes Sound. It is of the more importance as tidal observations were secured at Union Wharf in this sound, for fifteen months in all, during the years 1898 to 1900. By comparison with these, this datum has been carried northward to Mitlenatch Island and to Quathiaski Cove near Seymour Narrows. The observations were taken with a registering tide gauge, and the record has been handed over to this Survey through the courtesy of the Admiralty. The tide levels thus secured will serve for the mining town of Union when the results are worked out.

The note on the general chart of Baynes Sound is as follows:—"The soundings are reduced to 23.9 feet below the level of the slab at Goose Spit Magnetic Observation Spot." This spot is marked by a triangle on the charts of Baynes Sound and Comox. We can give a description of it from personal inspection, which will enable it to be found and identified.

The Magnetic Observation spot is on the north-west shore of Goose Spit, in the second bay west of the Admiralty building and wharf. It is between the last two rifle butts towards the south-west end of the Spit, and ten feet back from the edge of a low bank running along the beach. It consists of a cement slab, about 16 inches square, in the sandy ground, level with the surface. It is marked "Mag. Obsy. Egeria. 1898," in letters of lead let into the cement. Its level is about ten feet above high water mark.

There is another observation spot for latitude and longitude, which is farther to the south-west and farther back from the shore. It is a similar slab of cement; but it is a few inches above the ground, and differently marked, and cannot be mistaken for this one.

Nanaimo.—The chart survey was made by Commander Smythe in 1899. The note on the chart regarding datum, is as follows:—"The datum to which the soundings are reduced is 18.6 feet below the summit of the masonry beacon on Beacon Rock, which corresponds to 10 feet below a mark (10) cut in the perpendicular rock surface close to the small landing stage on the north side of the peninsula fronting the town, and adjoining the Ballast Wharf."

The beacon referred to is a truncated cone of concrete and iron, and its surface is rough and somewhat rounded. The mark on the rock would give a more definite elevation, but after careful search it could not be found, owing to the vagueness of the description. The mark is within the range of the tide, and the rocks are grown over with barnacles.

Telegraph Harbour.—This harbour is on Kuper Island, on the same body of water as the new towns of Ladysmith and Chemainus; the three places being within seven miles and within sight of each

other from the water. The Chart datum is referred to a natural rock, and to a bench-mark, serving as reference for levels of these towns. The rock is thus described by Captain J. F. Parry, R.N., the present commander of H. M. S. *Egeria*:—"The datum for the reduction of soundings is Low Water Ordinary Springs, which corresponds to 7 feet 2 inches below the top of the most westerly of a group of rocks lying just outside the low water line, immediately abreast of the Indian Industrial School."

This harbour serves as a port of reference for a number of other places amongst the Gulf Islands in the Strait of Georgia. Continuous tidal observations have been secured here by Captain Parry, in 1904, from April 11th to November 28th, a duplicate being kindly supplied to this Survey.

Bench-marks to define the Low Water datum of the charts have also been established by the officers of the *Egeria*, at Blunden Harbour in Queen Charlotte Sound, Percy Anchorage in Dodd Narrows, and Miners Bay in Active Pass. There is little or no population at these places as yet, and not more than three months of tidal record has been secured at any of them; and it is only at Blunden Harbour that the record is continuous, day and night. On the Pacific coast, serviceable tide levels cannot well be secured in less than six months. A shorter period does not afford a reliable average, owing to the large variation in range with the sun's declination during the year, the extreme values occurring at the solstices.

The Low Water datum is referred to tide rocks at the following places on the eastern side of Vancouver Island:— Southgate Anchorage in Queen Charlotte Sound, Nanoose Harbour, Hammond Bay, and Departure Bay, which is only three miles from Nanaimo. The tidal observations at these places were not continued more than six weeks, and were in the day time only.

There are several other places at which broad arrows have been cut or tide rocks made use of by the Admiralty. They appear usually to have served for reference during the reduction of soundings, without being accompanied by a tidal record of any great length.

ERRATUM.—In "Tide Levels and Datum Planes in Eastern Canada," Vol. XVII, page 98. Under Tidal Levels at St. John, N.B., second line; for "Gnomon or zero-point of sight gauge..... 97.94" *read* "79.94."