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Westport Harbour.

By F. W. Furkert.

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The bituminous coal deposits in the valley of the Buller and on the coastal ranges north thereof became the subject of attention very early in the history of New Zealand, and in 1876 a railway was constructed from Westport, a town on the mouth of the Buller River, to serve mines then being developed. In 1877 this was extended to Ngakawau, a total of 18 miles. The harbour at that time consisted merely of the natural river mouth and the esturial section less than a mile in length. The mouth wandered to some extent as the forces of nature drove the sand, of which the coast in the immediate vicinity is composed, to and fro. The depth averaged 11 to 12 ft. at high water, and as the ordinary range of tide was about 7 ft. 6 in., it can be seen that navigation was precarious, being subject to frequent delays sometimes of long duration (O.S.T. 10 ft. 2 in.; O.N.T. 4 ft. 11 in.).

Fortunately, the mouth of the river is sheltered by Cape Foulwind from the most frequent winds and from the storms which come from all quarters west and south of west. In addition to the cape itself, there are the Steeples and a number of lower reefs which afford valuable shelter. There is no shelter between north and west, but neither the frequency nor the intensity of winds from this quarter approaches that from other directions (except the south, from which little wind is experienced). The diagram attached (No. 1) indicates the direction frequency and intensity of the winds as derived from information given by the Westport Aerodrome authorities from observation at 9 a.m., noon, and 3 p.m. It is usual for the winds to be in the north-east in the forenoon and then to swing round to the south-west for the remainder of the 24 hours, so that even this diagram does not give a true picture of the condition, while the Diagram No. 2, covering a period of 23 years (1911 to 1934), greatly exaggerates the north-east weather due to the Harbourmaster's records being derived from observations made regularly at 9 a.m., as was the custom with almost all meterological data collected by the New Zealand Government until recent years. Easterly winds are all off the land, and as the mountains are close to the shore they have little effect on surf, which continually beats in from the southwest, in which direction there is an uninterrupted sweep from the Antarctic regions. The waves approach the shore in general at an angle, such that any material on the beaches is driven northward, but as the waves swing round the cape and its outliers they approach the river mouth from the north-west. There is little doubt that Sir John Coode, who designed the present works in 1886, intended that

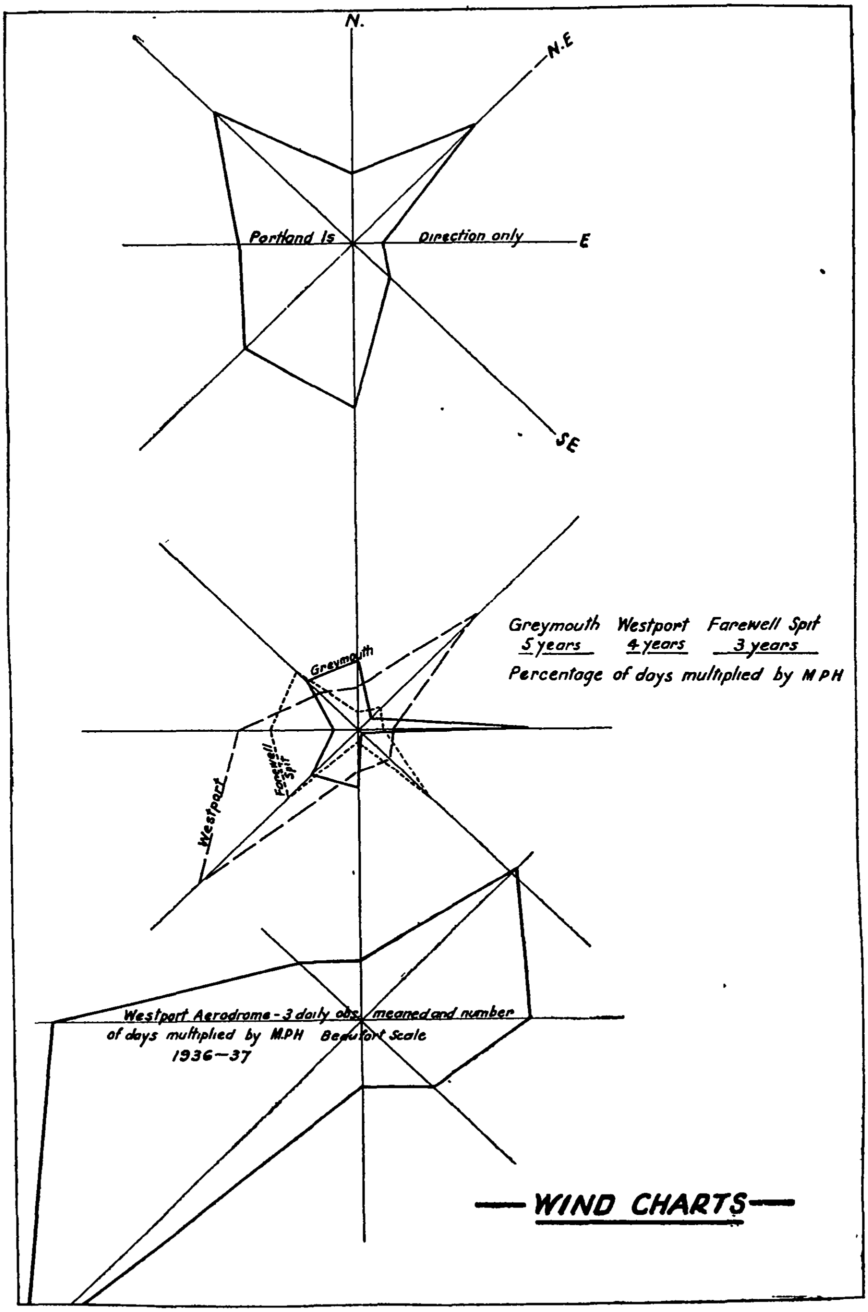

FIG. 1.—Diagrams plotted 20 units = 1 mm.

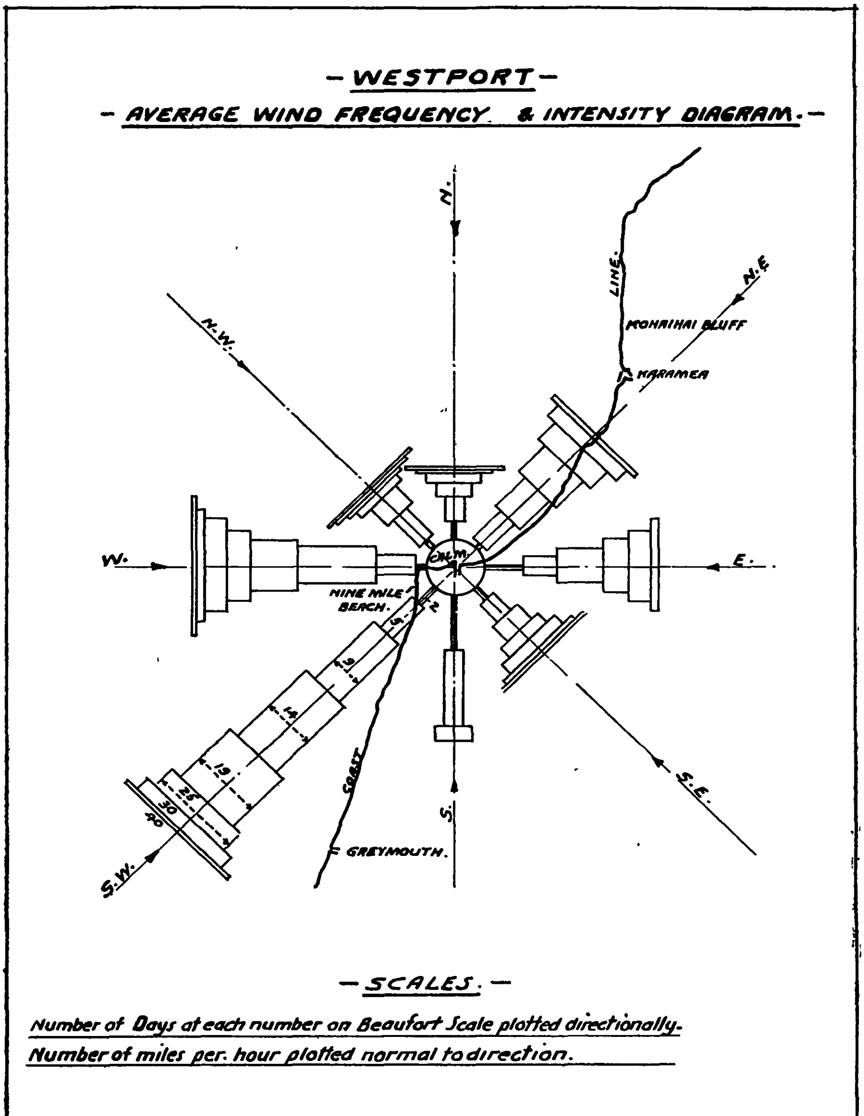

Fig. 2.—Diagram plotted 1 mm. = 2 days; 1 mm. = 2 miles per hour.

the entrance should face the heaviest, most prevalent seas, but owing to the period available for his observations being short he recommended a north-north-west alignment. During the progress of the works two successive engineers—J. A. Wilson and T. H. Rawson, A.M.M. Inst. C.E.—noted that the seas approached the entrance at an angle from the designed alignment of the harbour entrance, which fact they indicated in the papers contributed to the Institution in 1892 and 1898 (see p. 301, Vol. CXII and p. 265, Vol. CXXXVI); but neither apparently took any action to alter the direction of the entrance, which could have easily been done at that stage. Later on both C. W. Darly and R. W. Holmes, M.M. Inst. C.E., when reporting on the harbour, referred to the necessity for approaching the entrance at an angle as being unsatisfactory. Shipmasters have reported very severe set (up to 6 knots) to the eastward across the approach to the port at times, but generally the set is moderate.

Sir John Coode, in his 1880 report, speaks of the river maintaining a depth of nearly 16 ft. at high water spring tides from January, 1873, to July, 1876, but the yearly average for the four years just before the commencement of the works recommended by him, as given in the records of the port authorities, was, as stated above, 11 to 12 ft. The watershed of the river is 2340 square miles and the average rainfall is 89 inches. Two of the longest branches of the river are controlled by Lakes Rotoiti and Rotoroa, which effectively trap the detritus coming from the active denudation of the Spencer and St. Arnaud Ranges, which here form the main backbone of the South Island; a considerable portion of the rest of the watershed consists of granite rock of a very resistant nature, and there is a noticeable absence of readily erodible formations, so that the amount of detritus delivered into the river is relatively much less than that which issues from many of the rivers further south. This favourable condition impressed Sir John Coode, and he expected that "a depth of 12 ft. at low water of spring tides in the entrance being equal to 15 ft. at low water neap tides, 20 ft. 6 in. at high water of those tides, 25ft. 4 in. at high water of spring tides" would result from the execution of the works he recommended. It is perhaps unfortunate that the records have not been kept in a form which enables a direct comparison of the realised result to be made with Sir John Coode's anticipated results. The depths available daily have been recorded, as frequent bar soundings being taken as the weather would permit, and other days being deduced from the tidal gauge readings and the whole averaged over the year and so published. The graph No. 3A attached shows the effect of the works as they progressed, and it is clear that during the 54 years that have elapsed since the moles were well under way (1890) Sir John Coode's anticipations have been equalled or exceeded, except in 1934, when the average H.W. depth available, 19 ft. 7in., was at least a foot less than in any other year. This reference to Sir John Coode's anticipations is not quite correct, as in 1916 the moles were extended 360 ft. beyond the designed end and have been converted throughout from part half-tide to wholly full-tide works, but up to that time the forecast had been shown to be conservative. Until 1918 the depths increased until an average of 26 ft. 10 in. was reached, since when the depths have generally

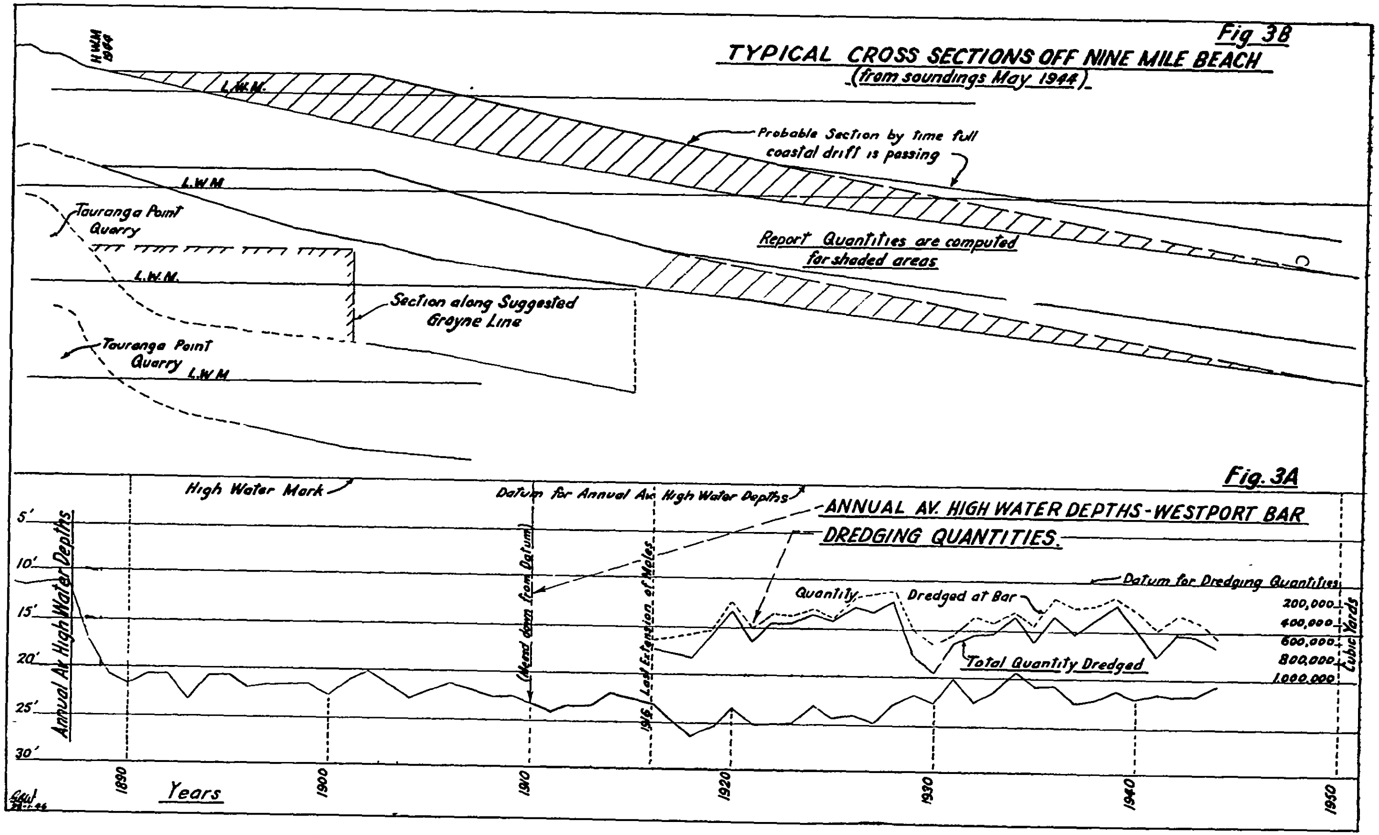

FIG. 3.—Scales: 3A—10 years = 1 inch; 2,000,000 c.yds. = 1 inch.
3B—Horizontal, 2,000 ft. = 1 inch; Vertical, 100 ft. = 1 inch.

decreased with small fluctuations so that to-day the last yearly average, 1945, is 21 ft. 4 in. (1944 was 20 ft. 8 in.)

It does not appear from Sir John Coode's report that he was at all concerned about littoral drift, and in the absence of any artificial projecting works there was nothing to draw attention to the fact that immense quantities of detritus were passing up the coast. As the works advanced seaward, the travelling material, or a good proportion of it, was arrested and the deepening from 11 ft. 8 in. to 21 ft. 7 in. took place in a very short time. Various extensions and raisings were carried out until in 1916 the entrance was 360 ft. further seaward than Sir John Coode originally designed, and the moles were all above high water mark. The beach, on the weather side particularly, grew steadily seaward. For the first few years this took the form of straightening out irregularities, but from 1895 to 1928 the stretch of three-quarters of a mile west of the weather mole, along which are sited the bases for the permanent sounding range poles, advanced on the average 900 ft. or 27 ft. per year, while from 1928 to 1944 the advance has been 400 ft, or 25 ft. per year. For comparison, Dublin, with 33 ft. per year over 93 years, and Madras, with 63 ft., 66 ft., and 48 ft. per annum for the three decades 1882 to 1912, may be mentioned. Long Island 1835 to 1927 average advance of spit was 200 ft. per year (*Geology and Engineering,* R. Legget, 1939).

It is natural that the rates of advance should lessen for at least three reasons:—

(a) As the triangular accretion increased in width measured along the mole or breakwater, it is to a much greater extent increased along the shore, so that now the accretion is definitely perceptible for three miles and may extend further west.

(b) As the shore advances into deeper water more material is required to produce a foot of new land, presuming the quantity passing up the coast to be fairly constant.

(c) As the shoreline nears the tip of the mole greater and greater proportions of the drifting material are able to pass round until now, with the L.W.M. at the " tip " and the H.W.M. only 800 ft. behind, a much greater proportion must be passing than was the case in past years. That the diminution in rate of shore advance has been so slight is surprising.

Accretion on the east or lee side might not be expected, and in the early stages of the harbour, erosion in accordance with recognised principles took place, but the whole projection of the two moles made a lee under which the waves which otherwise could have carried forward the beach material were deflected and damped out so that what material did pass the entrance found a haven behind the East Mole. This factor was assisted by the fact that easterly winds are off-shore winds and would, when in force, consequently tend to bring in sand from the sea bed. The material brought down by the Buller River also moves to the east immediately it gets past the entrance and naturally drifts under the shelter of the eastern mole. Further, the dredged material was dumped in a position which permitted it to be drifted ashore in this locality. Further up the beach, however, where the shelter of the moles was no longer effective, active erosion took place over a distance of at least three and a-half miles. This erosion has varied from time to time. Unfortunately the high-water mark in 1890, when the effect of the moles became apparent, was not recorded, but between the records of 1867, 1878 and 1884 there is little variation, and it should be reasonable to assume that the coastline of those dates was also the coastline of 1890. On this basis the erosion, where widest (and it does not vary much for the central two miles), was as follows:—

1890–1905 = 15 years, 414 ft. = 27½ ft. per year
1905–1921 = 16 years, 330 ft. = 20½ ft. per year
1921–1943 = 22 years, 165 ft. = 7½ ft. per year

This indicates, as one would expect, that as a greater proportion of drift material passes the entrance, then a less quantity can be taken up by the forces causing the drift, and thus the erosion tends to decrease so that when the western pocket is full erosion will cease on the eastern coast.

The works have behaved like a groyne and, in combination with the material brought down by the river, have built up the sea bed for miles to a surprising extent.

The problem of all ports on the West Coast of New Zealand is complicated to a great extent by the presence of the heavy littoral drift. Volumes have been written about the magnitude of the drift across the entrance to harbours, both bar harbours and artificial deep-sea harbours, notably in connection with Madras, Vizagapatam, Timaru, Durban, East London, Newcastle, Clarence River, the Western Bar Harbours in U.S.A., etc. Madras has been under careful and continuous observation for about a century, and the littoral drift there has been computed within close limits. Although these investigations have attracted world-wide interests, the amount of material to be dealt with does not approach that passing up the West Coast of the South Island. From the Cascade River northwards there is a succession of steep swift rivers, many delivering a load of detritus direct into the sea with no flat stretch near the mouth nor any tidal compartment and draining mountain areas in which the forces of denudation are exceptionally active. The rocks over a large portion of the country are of a type which readily breaks down into sand, and although gravel is to be seen on many beaches, in some places almost to the exclusion of anything else, yet the greater part, in fact almost all, of the littoral drift consists of sand. The careful computations which in recent years have been made of drift material deposited in reservoirs and other measurable localities have enabled a relationship between drainage area, rainfall, rock structure and amount of denuded material to be arrived at. All observations support the contention that enormous quantities of material are poured into the sea by almost every river from Jackson's Bay to Cape Farewell and careful investigations which the author made into the growth of Farewell Spit corroborated the figures of West Coast denudation.

In 1928 the author made a computation which showed that between 1911 and 1927, for which extensive and careful soundings were available, more than half a million cubic yards per annum had accumulated around the Buller River mouth. This was over an area of two and a-half square miles. In 1934 John Wood, M. Inst. C.E., went into the same question and found that over an area of three square miles since the inauguration of the works an average of 660,000 cubic yards per annum had accumulated. Again in 1943 Mr. Wood found that in the nine years since his last report an average of 720,000 cubic yards per annum had lodged, making a total of 38,500,000 cubic yards. The shoaling extends seaward at least out to seven fathoms, so that over the area examined we find an average loss of depth nearly 10 ft. 6 in. The author endeavoured to carry the matter further and to compute the total deposit between the points three miles west where the measurable accretion begins and the mouth of the Orowaite one and a-half miles east where erosion becomes evident. This indicates that not less than 65,000,000 cubic yards has been deposited. This is on the assumption that the deposit of drift material has not extended seaward beyond the area sounded and that at each end of the beaches it has decreased to nothing. Both these assumptions are conservative, and it seems reasonable to conclude that during the past 54 years one and a-quarter million cubic yards per annum has lodged about the harbour works and as a consequence of their construction. It is difficult to obtain the quantity represented in the loss of land about Deadman Creek, but assuming that the natural average slope of the sea bottom out to seven fathoms is bodily moved inland by the width of the erosion, we get in round figures 22,000,000 cubic yards of erosion. The erosion has probably nearly reached its limit, the reduction in its rate being due to the increasing proportion of drift material passing the works. The appearance of the coast north of Westport beyond the active erosion just described has given rise to no reports of great erosion, though about 20 years ago there was evidence of erosion for a few miles between Little Wanganui and Karamea, about 40 miles to the north. Recent erosion in this locality is explainable by the general lowering of the coastal lands at the time of the Murchison earthquake in 1929. Had all or even a substantial proportion of the littoral drift been trapped at Westport and Greymouth, then the beaches to the north would all have been stripped and, more significant still, the sandspit at Cape Farewell would have shown erosion. This sandspit (Figs. 4A and 4B) extends in an easterly direction for a length of 16 miles from the northern end of the South Island. It appears to consist entirely of sand, and cross sections of it and the ocean bed on each side show it as very similar to an embankment across a valley. Surveys made in 1851, 1867 and 1938 are available. These show no extension of the high-water mark to the east, but that the average width of the spit has increased by 238 ft. throughout its length, that the tip at low water has extended 2,000 ft., and that the outer 1,000 ft. as depicted on the early survey has widened considerably. Since the survey of 1938 there has been formed, south-east of the end of the spit, a considerable island now used as a nesting place by seabirds and on which a certain amount of scrub is growing. Close survey has not been possible, but stop-watch and air-speed data give a length of 35 chains and a similar distance off shore. Indications from air inspection convince the author that it will soon be joined up to the spit. If the same average conditions existed during the past 80 years as had existed in the past milleniums, as no doubt they did, there seems no reason to suppose that the batters of the spit would alter in such a way that the widening would be only at or about tide level; but belief that there would be a bodily lengthening and widening of the filling at its normal batters seems logical. On this assumption the total bulk increase indicates an annual increment of 4·5 million cubic yards per annum. If this is accepted, and allowances made for the detritus brought down by the Buller River and the streams between the Buller and Farewell Spit and also for the measured deposit at Westport, it appears that four and three-quarter million cubic yards must pass Cape Foulwind annually and must be dealt with at the bar in addition to what is brought down the river.

In the past 34 years dredging has been carried on at a varying but substantial rate, so that in that period 19,700,000 cubic yards have been dredged and dumped to leeward of the entrance. Approximately one-third has been bucket dredged in the river from the upstream end of the wharves to near the mouth and the other two-thirds have been taken from the bar by suction dredgers. Some dredging was done prior to 1910, but the records are not systematic, though it is probable that about 3,300,000 cubic yards were removed between 1890 and 1910, of which bar dredging accounted for 1,000,000 cubic yards. Bar dredging was commenced on a small scale in 1904. I do not consider that the dredged material influences figures given above, as all dumping was done within the area covered by the systematic periodic soundings on which the amount of littoral deposit was computed.

It may be questioned as to where nearly five million cubic yards per year could come from, south of Cape Foulwind. The Southern Alps, the dividing range between Westland and Canterbury, is not central but much closer to the West Coast, averaging roughly 25 miles as against 75 miles on the east side. There are many rivers on the 250 miles of coast from Cape Foulwind to Cascade River, where topography alters so much as to negative the idea that any appreciable quantity of littoral drift comes from south of the latter. The Southern Alps rise to 12,349 ft., with many peaks exceeding 10,000 ft., and are covered with perpetual snow supporting many glaciers, some very large with steep gradients and great eroding power. The rainfall varies from 100 in. at the coast to 250 in. at the divide per annum. All the rivers which rise in the main range are steep and transport large quantities of detritus to the sea. No measurement of the quantity has been made or, indeed, is possible in the absence of any dams or lakes along their main courses, but comparison with watersheds elsewhere where exact measurements have been made lead to the expectation that 16 million cubic yards are yearly delivered into the sea on the stretch of coastline under consideration. The mean of a large number of determinations by the U.S. Dept. of Agriculture (Silting of Reservoirs, Eakin and Brown, 1939) shows that two and a-half cubic yards per acre of

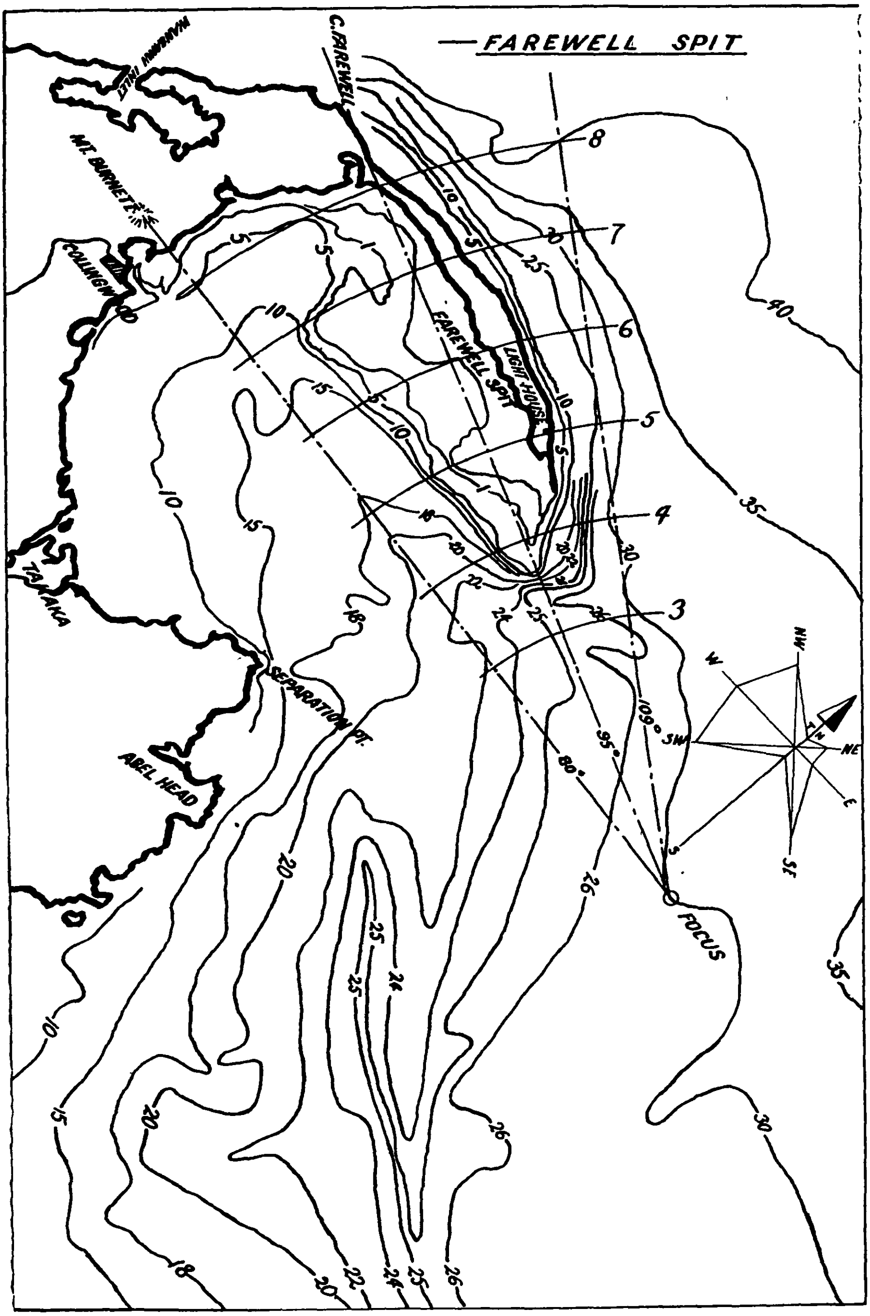

Fig. 4A.—Farewell Spit, with Seabed Contours. Scale: 8 miles = 1 inch.

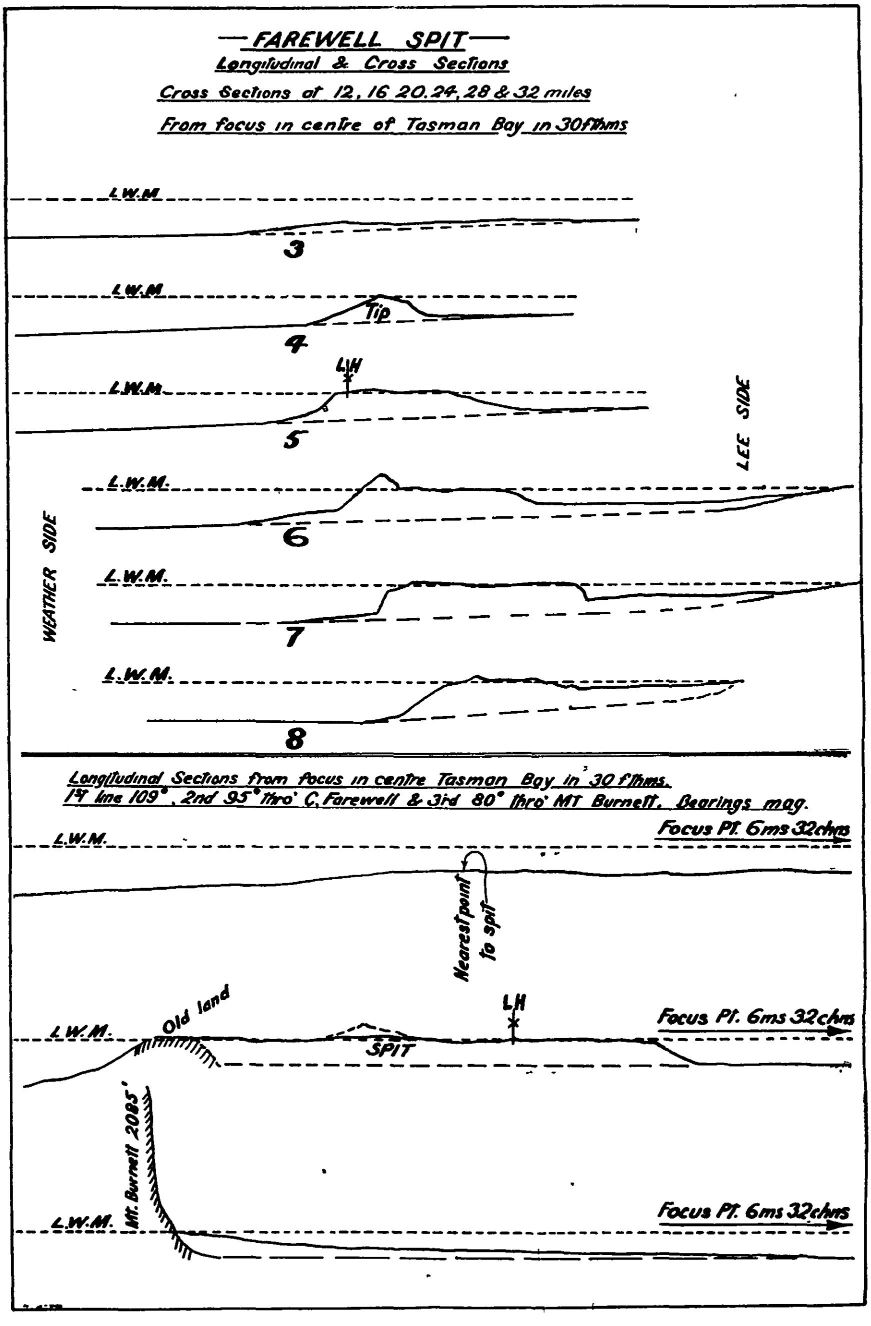

FIG. 4B.—Scales: Horizontal, 8 miles = 1 inch (approx.); Vertical, 200 fathoms = 1 inch (approx.).

drainage area per annum are carried down by rivers which rise in less precipitous country than that under consideration, which has no glaciers, and over which the rainfall is probably less than a quarter of that in Westland. The mean of 39 examples with watersheds varying from 9,057 down to 4 square miles averaged by the Soil Conservation Services of U.S.A. (Control of Reservoir Silting) gave 3·15 cubic yards per acre per annum. Two determinations made in dams fed from mountainous country in New Zealand support the estimates given above. The upper 2,860 square miles of the Rhone Basin on one determination gave nearly two and a-half cubic yards per acre per year, and most of the Westland rivers are eroding much faster than the Rhone.

The weighted average of eleven determinations in Italy (allowing for the greater influence of large areas on the total effect) shows denudation from areas varying between 16 square miles and 1,000 square miles of two cubic yards per acre per annum. One record covers 116 years and gives just under two and a-half cubic yards per acre per annum with an annual rainfall of 51 in. The average rainfall of the group is 50 in. and the instances cover both Alpine and Appennine rivers. Two rivers have eroded over 10 cubic yards per acre per annum. It is recorded that the quantity varies greatly from year to year in sympathy with variation of rainfall, but the greatest figure, 10·6 cubic yards, comes from an area with a rainfall of only 37 in. per annum.

Viewing all the bases given above, the quantity from Westland could hardly be below 10 millions (two and three-quarter cubic yards per acre), and if the great difference in the rainfalls was allowed for by simple proportion we would get 25 millions. But the transporting power of water varies between the 4th and 6th power of the velocity, and the velocity must vary fairly well in consonance with the amount of water running off, so that there is no difficulty in accounting for the figure of 16,000,000 delivered into the sea, one-third of which has been assumed for the purpose of this discussion to travel up the coast as littoral drift.

As another method of arriving at the quantity of detritus, very extensive work has been done on the amount of sediment carried by rivers in various countries in proportion to their volume. One part in a thousand would be a low figure to adopt in the light of this information, but with a rainfall of even 10 ft. annually on an area of 3,800,000 acres south of Westport this would account for 61,000,000 cubic yards. A great deal of this would be impalpable silt and mud which would go straight out to sea to be deposited in deep water, but to assume that 25 per cent. would be sand or coarser seems reasonable. Many determinations show only 10 per cent. of detritus as being sand or coarser, but as against that a result obtained at Coeur d'Alene Lake in Idaho, U.S.A., showed more than half coarser than ·01 in.; the watershed here has points of similarity to that of Westland. The Sweetwater Reservoir in California records show that the average sediment content has been, over 39 years, almost 10 parts for 1,000. The sand on the Buller bar is very fine, 3 per cent. passing a 200-mesh-to-the-inch sieve, 38 per cent. passing 100 mesh, 62 per cent. passing 80 mesh, and 75 per cent. 60 mesh. The work of Dr. P. Marshall on the wear of beach gravels, published in the *Transactions of the New Zealand Institute* (Vol, 59, p. 332, 1928), shows that large gravel is quickly reduced in size, but that the rate of reduction decreases very steeply as the pebble sizes are reduced, so that a stone with a diameter one-tenth of X is reduced in Y time only one-ten thousandth part as fast as one X diameter, or even less. In other words, while coarser gravel and even boulders are quickly reduced largely to mud and carried off into deep water, sand is hardly worn at all as it passes up the beach. At, and north of. the mouths of most West Coast rivers large gravel strews the beaches, but within a few miles this disappears and the beach is sand until the next river is reached. Grey Beach is an exception, as Teremakau gravel reaches to north of the Grey. This is unnatural and due to denudation of mining tailings. Petrological examination of the sands discloses that on the Buller Bar and the beaches northward as far as and including Farewell Spit minerals are found which are characteristic of rocks being freely eroded by southern rivers, but which are not apparent in the Buller watershed. As one indication of the difference between the material brought down by the Buller and that which forms the littoral drift, the suction dredger can fill her hopper in the estuary in 18 minutes, but on the bar it takes one and a-quarter to one and a-half hours to collect even 75 per cent. of the hopper capacity owing to the extreme mobility of the bar sand which is carried over the side in ever-increasing ratio as the hopper fills.

Touching the possibility of this large amount of material being carried northward by the combination of waves and currents, observations in " The Wash " some miles offshore in depths varying from 3 ft. to 16 ft. showed that for 28 samples during 14 stages of the tide a mean value of 2·5 parts per 10,000 was transported for a mean velocity of 1·5 ft. per second. With a width over which movement is plainly manifest equalling not less than 2,000 ft. at Westport, and an assumed average depth of only 10 ft., the amount moved annually would be about eight and three-quarter million cubic yards.

Mr. Zahrtmann of Copenhagen reports that the sand drift on the coast of Jutland extends over a ribbon 8,000 ft. wide and into a depth of 60 ft. and also that the movement is nearly equal all over this belt (*I.C.E. Proceedings,* Vol. cxciv, 226).

Observations on the Dahlia Canal in water 1 ft. deep with sand held on a 200-mesh sieve gave 12·2 parts per 10,000 with $v = 1{\cdot}42$ f.p.s. and 17 parts with $v=1{\cdot}77$ f.p.s. On this basis the quantity in the bottom foot due to the coastal current alone would be about four million cubic yards.

However, the turbulence in the coastal current of the West Coast of New Zealand due to incessant and considerable wave action is such that the disturbance to the bottom material must be much greater than in the examples given above and the material, once disturbed, would be carried along in depth much greater than the 1 ft. or 10 ft. taken in the computations above.

Determinations of the settling speed of sand from the Westport Bar made by Dr. P. Marshall show that sand passing 1/50 sieve falls in sea water only 1 in. per second, while 1/100 sand falls less than $\frac{3}{4}$ in. per second. Any irregularity of bottom causing turbulence sufficient to create upcurrents in excess of these extremely low velocities would put sand into suspension and allow of it being carried forward by the current, whether that current be an ocean current or merely the longitudinal component of the oblique waves. Actually the disturbance in rough weather brings sand to the surface in quite deep water and at such time the current is also accelerated in the prevalent westerly or southerly weather. In the belt covered by breakers, 2,000 ft. in quite frequent weather, the water is heavily charged with sand, so that it would not be unreasonable to assume 10 parts for 10,000 and an average depth of 15 ft., which would give a transporting power for 50 millions if continuous, while if this class of weather only lasts 15 per cent. of the year this would account for 5 million cubic yards.

Fortunately for the Westport Harbour, the Buller River carries less than the average West Coast quantity of detritus. This is due to a number of factors, for example, the detritus from the more erodible rocks of the main divide is trapped entirely in Lakes Rotoroa and Rotoiti, granite rock largely represented in the Buller Basin is pre-eminently inerodible, and limestone rock wears down by solution and does not form sand. This helps the keeping of the river channel from the wharves to the sea to the desired depth, but it has little or no effect on the entrance depth, which is dependent on the continual contest between the littoral drift on one hand and the scouring effect on the other hand of the waters issuing from the river, concentrated as they have been so effectively by the works of man. "The waters issuing," are meant to refer to both the tidal water and the upland water. The latter cannot in any useful degree be regulated by man and is very variable and, one might say, erratic, but the tidal water due to the filling and emptying of the tidal compartment twice a day is regular and unfailing and quite independent of the weather. Even at present without any work having been done to extend the tidal basin the volume of water flowing to sea on the ebb tide is, except in flood time, well over twice that which would be available from the upland water alone, and it is volume with its consequential velocity that keeps a channel through the cross stream of littoral drift. If the velocity falls below a critical value, no movement of sand is caused, while an adequate velocity will result in the movement during hours of more than the dredgers would move in weeks. Tidal influence is even more effective than the above might indicate, the figure of twice was based on average flow, but it is well known that at about half ebb the velocity, which is the major working influence, is much greater than the average. There is a feeling amongst uninformed people that all the talk about the value of tidal compartments is engineers' theorising, but apart from logical demonstration of why and wherefore, there is no gainsaying the facts that wherever tidal areas have been reclaimed or been allowed to deteriorate, depth in the navigable channel has decreased, while, conversely, wherever the tidal compartment has been enlarged or more directly trained improvement has resulted. This cannot be all coincidence all over the world. (See Furkert, *Proceedings N.Z. Inst. Engrs.*, 1947.)

A supply of material on to the beaches such as in indicated above, plus the large deposition measured, plus the moderate erosion recorded to the north, plus the accretion at Farewell Spit, all seem to indicate that a drift across the harbour mouth at Westport of the order of four to five million cubic yards per annum must be faced as soon as all the storage space formed by the projecting moles is full.

A number of possible methods of meeting this difficulty suggest themselves:—

1. *The dredging could be increased.* So long as the amount of littoral drift passing up the coast was not beyond the capacity of the ebb stream to cut through, the channel was good, but at times the set of the waves, wind and currents carried more across than could be naturally coped with, and then there was deterioration, the excess material being carried on when more favourable conditions returned. In the interim the top of the bar was scraped off by the dredger, and this may have helped to improve matters sooner than natural causes would have done. To illustrate how quickly and extensively conditions can alter, Figs. 5 and 6 show the contour of the bar on two dates six months apart. On the small area covered the rise of the ocean floor represents half a million cubic yards. It may be claimed that the work of the dredgers has had an important bearing on the depths of the bar. There have been times when the taking off of the top of a sandbank has been followed by improvement in the depth of the navigable channel, but, taking the long view, it is hard to see that the average depths on the bar have had any connection with the amount of material dredged. If the gross amount of dredging since 1916 be divided into five-year periods, the following conditions are found:—

Period.	Average cubic yards per annum of dredging.	Average depths on bar.
1916-20	711,200	24 ft. 11 in.
1921-25	485,696	24 ft. 5 in.
1926-30	525,219	23 ft. 3 in.
1931-35	554,928	20 ft. 11 in.
1936-40	396,068	21 ft. 9 in.
1940-44	586,620	21 ft. 5 in.

The higher figures in the earlier groups of years were probably due in a greater degree to the extension of moles completed in 1916 than to the dredging, for the figures show that an increase in dredging from 485,696 to 525,219 cubic yards was accompanied by a decrease in depth of over a foot (24 ft. 5in. to 23 ft. 3in.) and similarly an increase from 396,068 to 586,620 cubic yards (a 50 per cent. increase) was again accompanied by a loss in depth from 21 ft. 9 in. to 21 ft. 5 in., while on the other hand a falling off in dredging from 554,928 to 396,068 cubic yards, instead of being detrimental to the port, actually paralleled an improvement of 10 in. (20 ft. 11 in. to 21 ft. 9 in.)

If, instead of groups of five years, the outstanding differences covering two-year periods are taken they show:—

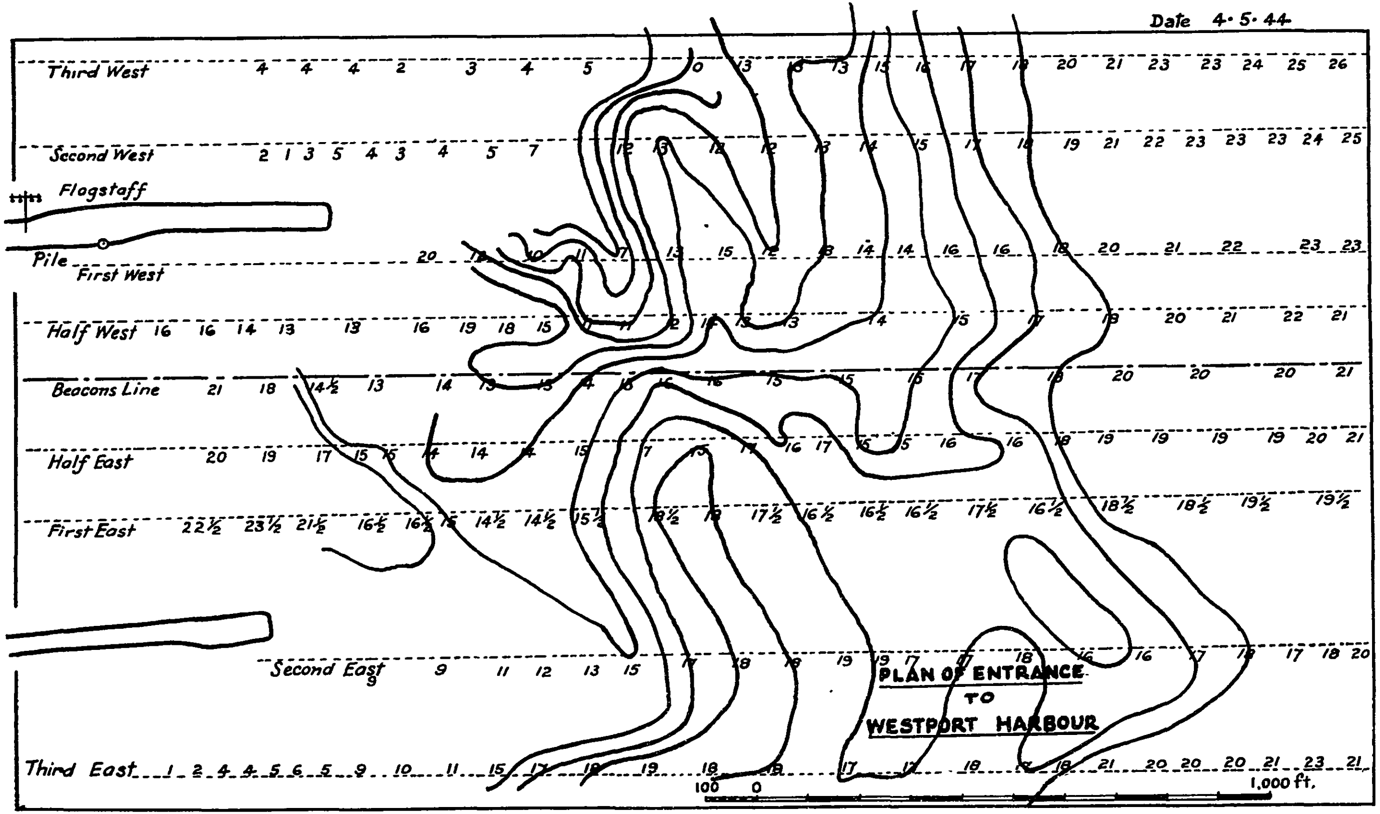

FIG. 5.—Buller Bar Contours, May 4, 1944.

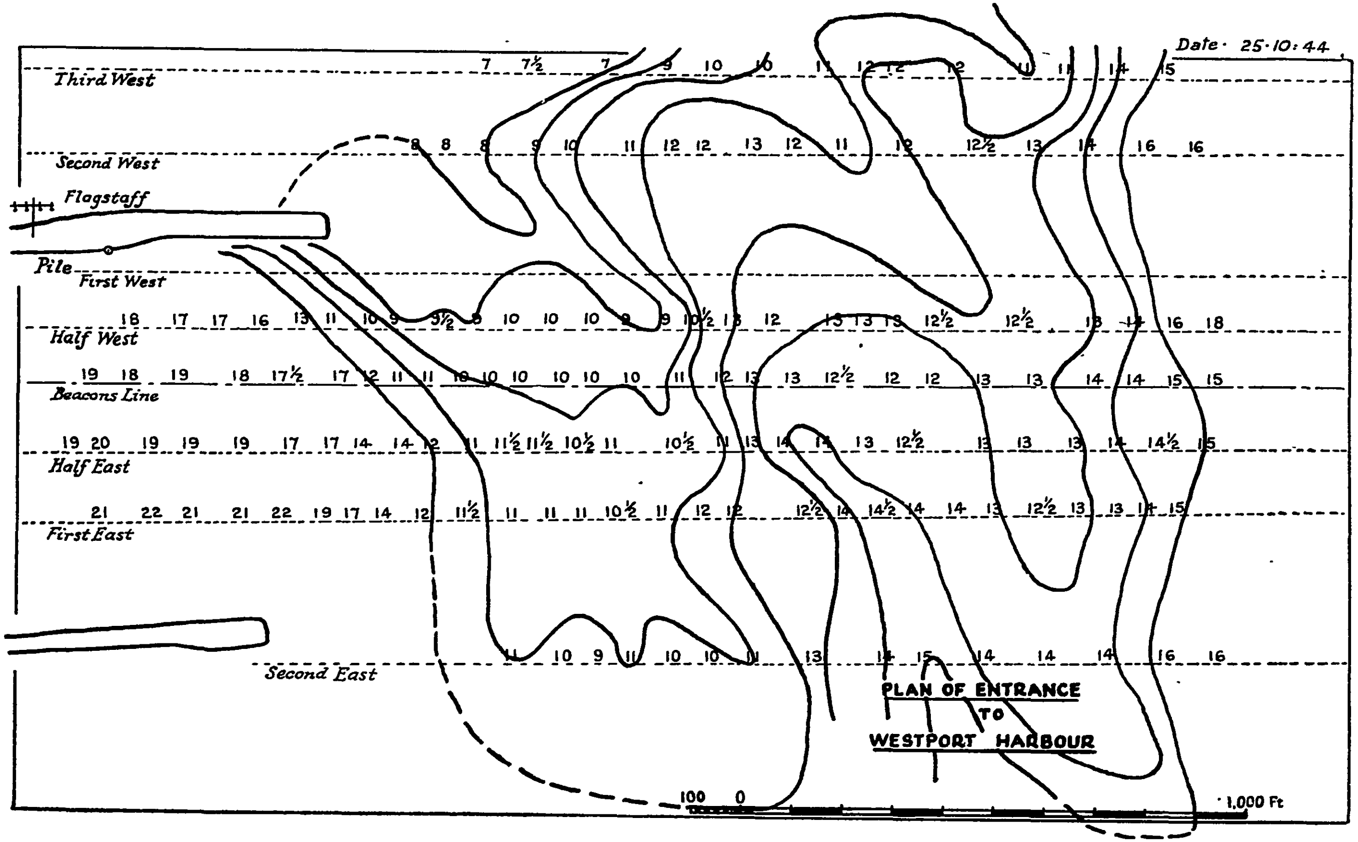

FIG. 6.—Buller Bar Contours, October 25, 1944.

Period.	Average dredging.	Average depth.
1927 and 1928	275,145	23 ft. 10 in.
1930 and 1931	896,645	22 ft. 2½ in.
1938 and 1939	307,170	21 ft. 8½ in.
1941 and 1942	660,660	21 ft. 7½ in.

These results indicate that increases of more than double in the quantities dredged have been paralleled by decreases in depth, in one case considerable, 1 ft. 7½ in. Least dredging was done in 1928 (212,950 cubic yards), but the depth was 22 ft. 11 in. Most dredging was done in 1931 (990,710 cubic yards), but the depth was only 22 ft. 8 in. It could not, of course, be suggested that heavy dredging was detrimental or that cessation of dredging would improve conditions, but all this goes to show that powerful influences were at work which entirely obscured the effect of the dredging, and these influences are still at work.

There is another development which gives cause for considerable uneasiness and that is the extensive shoaling taking place immediately to the westward of the weather mole and seaward of the entrance. This may continue until the depths alongside the navigable channel are so reduced that the dredger cannot steam over the shoal, and thus her difficulties of manoeuvring as she works on the bar will be greatly increased.

It must also be self evident that the more shoal water there is close to the channel, the easier it is for the transporting agencies of nature to sweep the material forming the shoal water into the channel, thus undoing the work of the dredger and the ebb tide either partially or entirely as soon at it is executed.

The present bar dredger of the trailing suction type with two 23 in. suction pipes and a 1,000-ton hopper only averages a little over 400,000 cubic yards per year, which is clearly inadequate. But difficulty in employing a larger vessel arises from two causes. First, the low-water depth over which she must manoeuvre (disregarding the actual channel), being under 12 ft., negatives the use of a very large craft. Secondly, the bar lies normally so close to the ends of the moles that there is appreciable risk in navigating even a small vessel of this type so close to the rocks. Even with the present vessel and her stand-by, which is still smaller (650 tons), many days are lost from the above causes in combination with swell and bad weather. Night work has never been considered practicable and the use of two dredgers simultaneously, though tried, was considered too dangerous. Since the foregoing was written two bar dredgers have been employed for over a year, but the quantity moved off the bar was less than with one previously.

2. *The estuarial lagoons could be enlarged by dredging,* thus improving tidal scour. The present tidal compartment, which has silted up from 505 acres in 1892 to 380 acres to-day, at neap tides (6 ft.) equals 160 million cubic feet and at springs (10 ft. 3 in.) equals 269 million cubic feet. There is an area of 200 acres which could be deepened by a shallow-draft suction dredger, the average depth of excavation being 9 ft. Three feet of this is for flotation of the dredge below L.W.S.T. and to provide for future silting. This would increase the total compartment by 54,000,000 cubic feet,

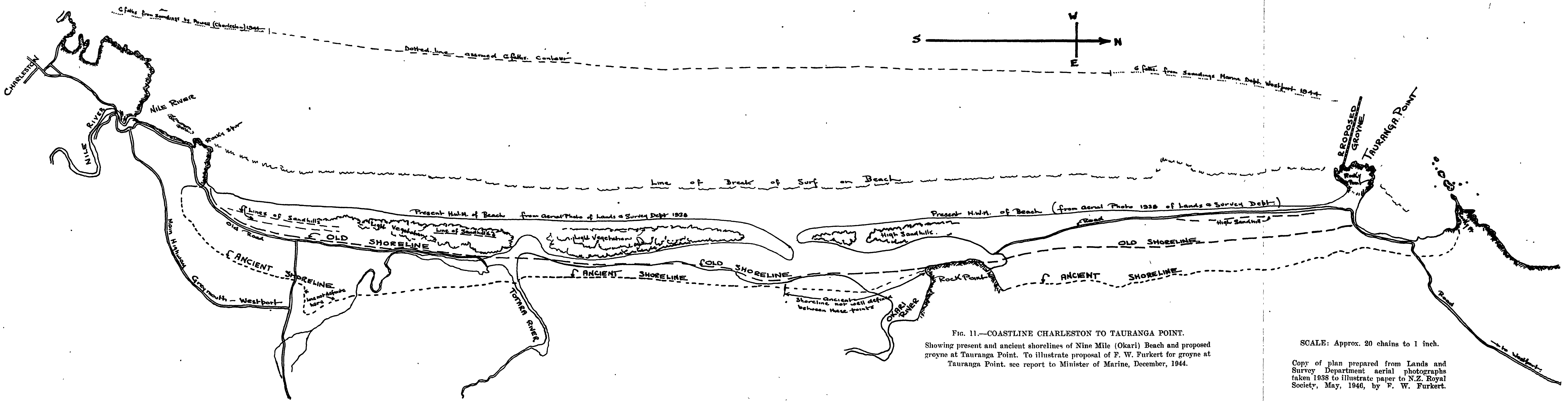

Fig. 11.—COASTLINE CHARLESTON TO TAURANGA POINT.

Showing present and ancient shorelines of Nine Mile (Okari) Beach and proposed groyne at Tauranga Point. To illustrate proposal of F. W. Furkert for groyne at Tauranga Point. see report to Minister of Marine, December, 1944.

SCALE: Approx. 20 chains to 1 inch.

Copy of plan prepared from Lands and Survey Department aerial photographs taken 1938 to illustrate paper to N.Z. Royal Society, May, 1946, by F. W. Furkert.

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though 81,000,000 cubic feet of excavation would be required. The attached results of current meter observations quoted by Mr. John Wood, M. Inst. C.E., show the value of the present tidal flow.

FLOOD TIDES.

	Neap tide.	Average tide.	High spring tide.
Tidal Range	5 ft. 8 in.	7 ft. 8 in.	10 ft. 10 in.
River water entering tidal basin during flood tide in cubic feet	130,000,000 = 6,000 cusecs (low)	134,000,000 = 6,200 cusecs (average)	233,000,000 = 10,800 cusecs (high river)
Outflow of upper layer of fresh water during flood tide in cubic feet	107,000,000	98,000.000	133,000,000
Balance of river water that would be stored during tide in cubic feet	23,000,000	35,000,000	100,000,000
Inflow of sea water during flood tide in cubic feet ..	163,000,000	150,000,000	237,000,000
Totals of fresh water that is stored and inflow of sea water during flood tide ...	186,000,000	185,000,000 = 14,300 cusecs	337,000,000 = 26,500 cusecs
Volume of tidal compartment as calculated from lagoon areas and normal tide levels in lagoon, as a check on line immediately above	150,000,000	196,000,000	269,000,000

During a spring tide on the flood there is about 269,000,000 cubic feet in the tidal compartment, which more than doubles the amount of water discharged on the ebb. Similarly at neap tides and with a low river, the tidal compartment increases the outflow on the ebb from 130,000,000 cubic feet on the six-hour flow of the river to 280,000,000; and yet there is great difficulty in convincing the public that increasing the tidal compartment will cause improvement.

Sir John Coode recommended increase in the tidal compartment by dredging in 1884, and successive engineers have reiterated the advice right up till the present day, and yet no action has been taken by those responsible.

Now the local conditions are not such that at any reasonable expense a tidal basin could be obtained which would solve all the bar problems, but benefit would surely result from this work either regarded singly or in combination with any other works.

3. *The moles could be extended.* Further storage space for drift would be made by extending the moles, but the condition of the sea floor around and opposite the entrance is such that any extension much less than 1,000 ft. would hardly be worth considering. This extension would do no more than enable the present depth to be maintained, as at 1,400 ft. out, in good times, and even at 1,800 ft., after adverse weather conditions, the sea bed is as high as the bottom of the river inside the moles with all the intervening distance about half-river depth. The west mole is now approximately 4,500 ft. long, and for the 28 years since its completion it has only sufficed partially to hold the drift, so that less than a quarter of that length could have only a moderate life, its full effect being lost before its cost

could be recovered by ordinary financial measures. Within two years of the last extension of 360 ft. the increased depth observable after the extension began to diminish and within 10 years all effect was considered to have passed away; by some observers, six years is regarded as the period. There is another difficulty about extending the moles to any considerable distance, not connected with their high cost or limited life, and that is the risk that the lessened shelter afforded by Cape Foulwind and its outlying islands and reefs which would be available in the more seaward position of the entrance and the bar may result in the dredger having to work in a location subject to a swell which would restrict its actual dredging time to a greater extent than is now the case. If a decision to extend the moles were made it would be advisable that a fresh start be made from the beach clear of the present "tips" so as—

(a) To provide another wave basin.
(b) To avoid some of the strong scour existing around the present end which experience has shown to deepen the water ahead of the work and thus to greatly increase its cost.
(c) To avoid the considerable extent of tipped rock beyond the end of the moles into which it would be most difficult, if not impossible, to drive staging piles.
(d) To take advantage of the opportunity to turn the entrance more into the line of the heaviest seas as Sir John Coode intended.

Another matter which merits very serious consideration is that of reducing the width of the channel, as a moderate reduction in width would improve the scouring effect of the ebb tide and of floods. Sir John Coode proposed 600 ft., and though he allowed for a certain amount of latitude plus or minus, as experience might indicate as work proceeded, he undoubtedly admitted the possibility that this width might be narrowed. Unfortunately, it was widened, though Durban, with a width of 600 ft., has dealt with a trade of 6,000,000 tons per annum carried in the largest vessels which trade south of the Equator, and had the Westport entrance faced the heaviest seas a width of 600 ft. would certainly have been satisfactory.

At East London the distance between moles is 700 ft., but the navigable channel is only 500 ft. The Sulina mouth of the Danube is dredged to a bottom width of 300 ft. with depth of 23 ft. Vizagapatam channel is 300 ft., widening where it meets the open sea to 500 ft.

Now that mariners for half a century have enjoyed the 700 ft. Westport entrance they will be averse to accepting anything less. When the details of any new extension, if adopted, are being settled, the very widest enquiry should be made as to the experience elsewhere with channels of 650 or 600 ft. in width.

4. *An island breakwater could be built* under the shelter of which the dredger could operate in most weather, making in addition to the actual channel a considerable hole into which the drift material might drift and be held for removal from time to time. This system has been employed at Vizagapatam, where a million yards per year are dredged, but it has elements of uncertainty about it.

If the island is placed too near the shore it may produce so much shelter that the drift will settle and build up a connection between the island and the shore; if too far off, the drift may not be carried into the sheltered area behind the island and seas may swing round too freely. The use of a floating pipe-line would be impracticable at Westport, so that self-propelled hopper barges would be required to remove the dredgings. As at Vizagapatam 30 in. pipes with a pump having a 6 ft. 6 in. impellor driven by a 900 h.p. engine plus 300 h.p. on the cutter have been used, it will be realised that Westport would require decidedly larger equipment with the much heavier drift obtaining there. This seems a scheme which should be tried out with a large model before it is seriously considered.

5. *A groyne might be run out from a headland a few miles south of Cape Foulwind* which would trap the littoral drift for a period long enough to justify the cost of the groyne. In other words, if the interest and sinking fund can, without placing a crippling burden on the port, pay off the cost of the groyne before the storage space thereby provided for drift has been filled up, then it would be a good investment. This problem was discussed very fully by Sir Frances Spring in his paper on coastal drift at Madras in 1913 (*Min. Pros. I.C.E.*), but in the case of Madras there was a difference of opinion as to the probable storage. At Tauranga Point there is a sudden projection in the form of a granite knob some acres in extent on which the Westport Harbour Board had a quarry during the execution of the main works. This knob was not connected to New Zealand until comparatively recent times, and when it was an island the coastline had established an alignment almost due north and south for some miles. When, owing to the shelter caused by the islet, the sand drift settling behind it eventually connected it to the shore there was a natural groyne about half a mile long which trapped the littoral drift and gradually built out the coast until the present shoreline was established parallel to what it was before the connection between the island and the mainland took place. Tauranga Point now projects about a quarter of a mile from the coast, and if by the construction of a mole the natural groyne could in effect be extended another half-mile, then the whole of the littoral drift would be held up until the projection was reduced to what it is to-day and perhaps for a longer period. That the present shore alignment is not a changing one, but is such as the balance of all the natural forces tends to establish, is shown, not only by the geologically recent old shoreline practically parallel to the present one south of Tauranga Point (which runs due south for three miles and then 4° west of south for five miles), but by a still older coastline parallel to the present and to the above-mentioned one and roughly a quarter of a mile behind (see Fig. 11), and also by another stretch of coastline north of Westport where a rocky bluff stands out square to the beach nearly a quarter of a mile and south of which the alignment runs due south for three miles and then 3° west of south for five miles. These similarities seem to be too close to be mere coincidences. (No beach for 250 miles south or 150 miles north is oriented west of north, even for a short distance.) If in nature there were any beaches on this stretch of

coast where the sandy shore between headlands tended to assume an alignment west of north, the author would not be so confident about the storage capacity of the area south of Tauranga Point. The very ancient embayments which extended where now the two coastlines in question exist would have established equilibrium on an alignment more or less parallel to these ancient rocky shores, if such had been possible in the face of forces affecting littoral drift, and the fact that this equilibrium was established definitely four times, thrice south of the Buller and at least once north of the Buller, and where the weather conditions are as nearly identical as they ever are, gives grounds for the belief that any projection of sufficient length on the coast in this locality would tend to develop a beach alignment on the southern side of the projection on a north-south bearing. Similarly, the cross-section of the beach as it advances seaward is likely to remain similar to that now existing. Some opinions have been given that the beach advanced by such obstructions as are now under discussion tends to be steeper the further it is advanced, but with similar weather, currents, tides, alignment and drift material there seems no reason, taking a long view, to suppose that nature would adopt a different cross-section. The observations off the port of Westport indicate that the cross-section, while steep inshore in the early days, tends now to become very closely parallel to what it was 50 years ago. The results of model tests by Major (now Colonel) Ralph Alger Bagnold are here quoted.

"*Lateral Stability of the Beach Contours:* In all the experiments where shingle was used, the model beaches which were thrown up by the unimpeded action of the waves set themselves at right angles to the line of the wave advance. When more material was added on one side of the tank, this soon became distributed evenly over the width of the mobile portion of the beach. From this it appears that if waves strike a stretch of shingle beach obliquely the beach-line will, provided that coastwise losses of material away from the farther boundary of the stretch are prevented, become re-oriented so that its contours run at right angles to the line of advance of the waves.

"*Continued Supply of Material and Constancy of Profile:* A further experiment was made by adding a small but continuous supply of fresh material to the shelf after a mature beach had been thrown up. This was intended to imitate the accumulation of material by coastwise drift. The effect was that the whole beach advanced seawards, but its profile remained entirely unchanged. The topmost surface, previously a narrow ridge, became a flat horizontal table as the beach top moved forward."

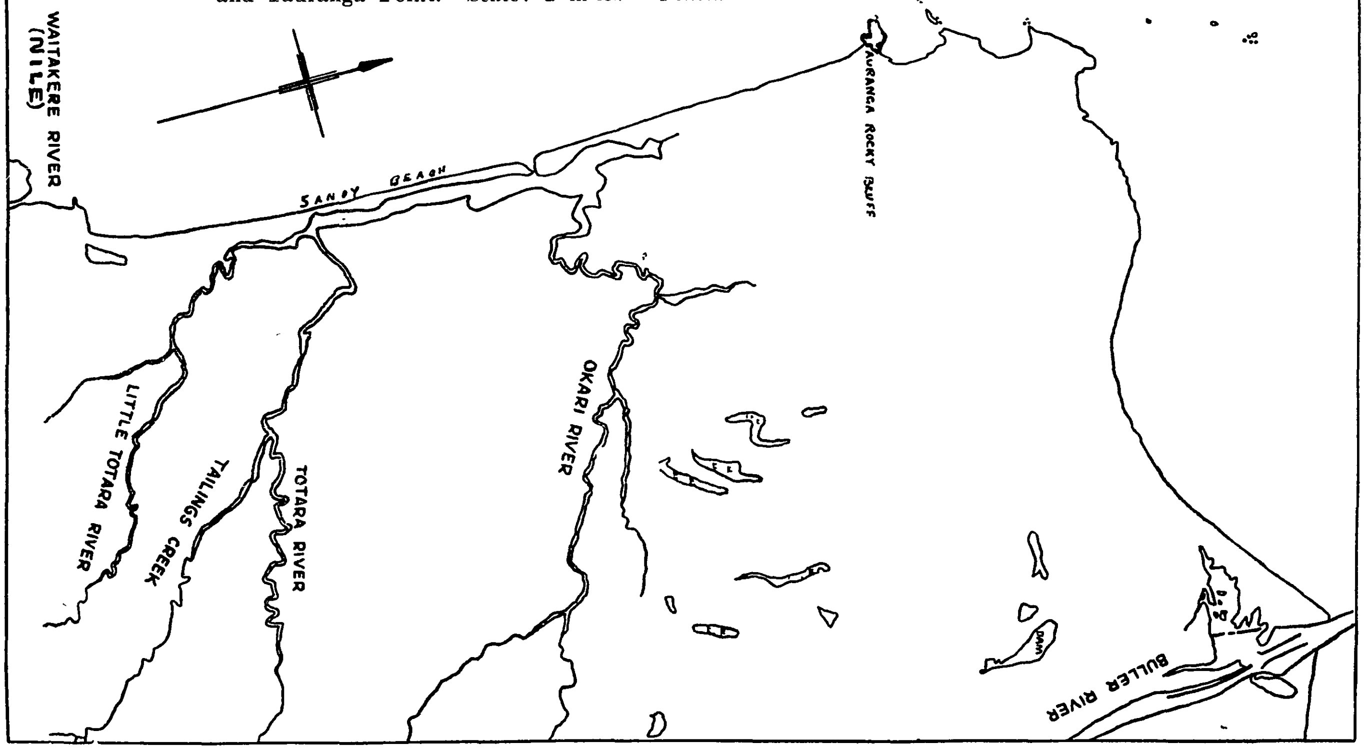
If it is assumed that the coast will advance parallel to the present line and that the under-water profile out to seven fathoms will remain substantially as at present, then the storage will be approximately 300,000,000 cubic yards, or adequate for 60 or 70 years, and it may even last 100 years if consideration is given to the fact that some of the drift material is always being ground fine enough to float away into deep water beyond the influences which cause coastal drift, and this tendency would be encouraged by the halt in northward progress and the grinding caused by the run of the waves along the mole and the headland from the sea towards the shore. It may be contended that a mole half a mile long, which with the present promontory will make a groyne projecting 4,000 ft. beyond the average run of the Nine Mile Beach, will not stop all or even a very substantial proportion of the coastal drift which earlier in the paper has been mentioned as moving over a very wide belt, perhaps 8,000 ft. wide. Notwithstanding the statement by Mr. Zahrtman that on the coast of Jutland the sand moves on a belt 8,000 ft. wide extending into 60 ft. of water and that it moves equally throughout this belt, the author is of the opinion that there is much more transport of material where the water is violently agitated by the breakers than there is in deeper water beyond wave break. The Vizagapatam experience supports this view.

The fact that variations of depth are disclosed by successive soundings in deep water shows that material does travel in these depths, but the movement there is slow, and until the steady advance of the coastline and consequent rise of the sea bottom brings the present deep bottom up to such a level that it is affected by wave action no great disturbance and forward movement of the sand can be expected. The depth into which the suggested groyne would project is between 30 and 35 ft., and if the slope of the ocean three-quarters of a mile off shore along the beach south of the groyne remained substantially as it now is, the shoreline would have to advance 2,700 ft. before the depth in line with the end of the groyne was reduced to such a figure as would permit of the passage of a major portion of the coastal drift around its end. (See Figs. 3B, 7, 8 and 9.)

Such portion of the total drift as passes up the coast in water deeper than 30 ft. would continue to do so, but this should have little if any effect on the Westport bar, the 30 ft. contour being about half a mile seaward of the end of the breakwater, while the forces of nature should cause material in that and greater depths to roll seaward rather than up the slope of the bottom towards the beach. Even if after passing the groyne this deep-water material did work in to the shore, its volume would be small compared with the mass which now travels in the breakers (cf. Hokitika, where an accumulation between two groynes, six chains apart, of 10,000 cubic yards was observed in one tide in 1917).

The amount of storage on the Nine Mile Beach is such that even if there were an error of 100 per cent. in the quantity of the littoral drift, or if the required projection of the groyne were twice as great as has been assumed—in other words, if half a mile of groyne only stopped half as much as has been set out above—there would still be 30 years in which to pay off the whole of the capital cost; which would be in accordance with sound finance. As the site of the work would be unprotected by any physical features from all storms, the groyne would need to be very substantial, but, on the other hand, it not being connected with any navigation channel, the fact that in a record-breaking storm it was washed down or breached would not be disastrous, as would a similar occurrence on the moles enclosing the harbour entrance. Experience is available as to what is necessary in the works at both Westport and Greymouth, so that there is no

FIG. 7.—Present-day sandy Nine Mile Beach oriented by Coastal Drift and Tauranga Point. Scale: 2 miles = 1 inch.



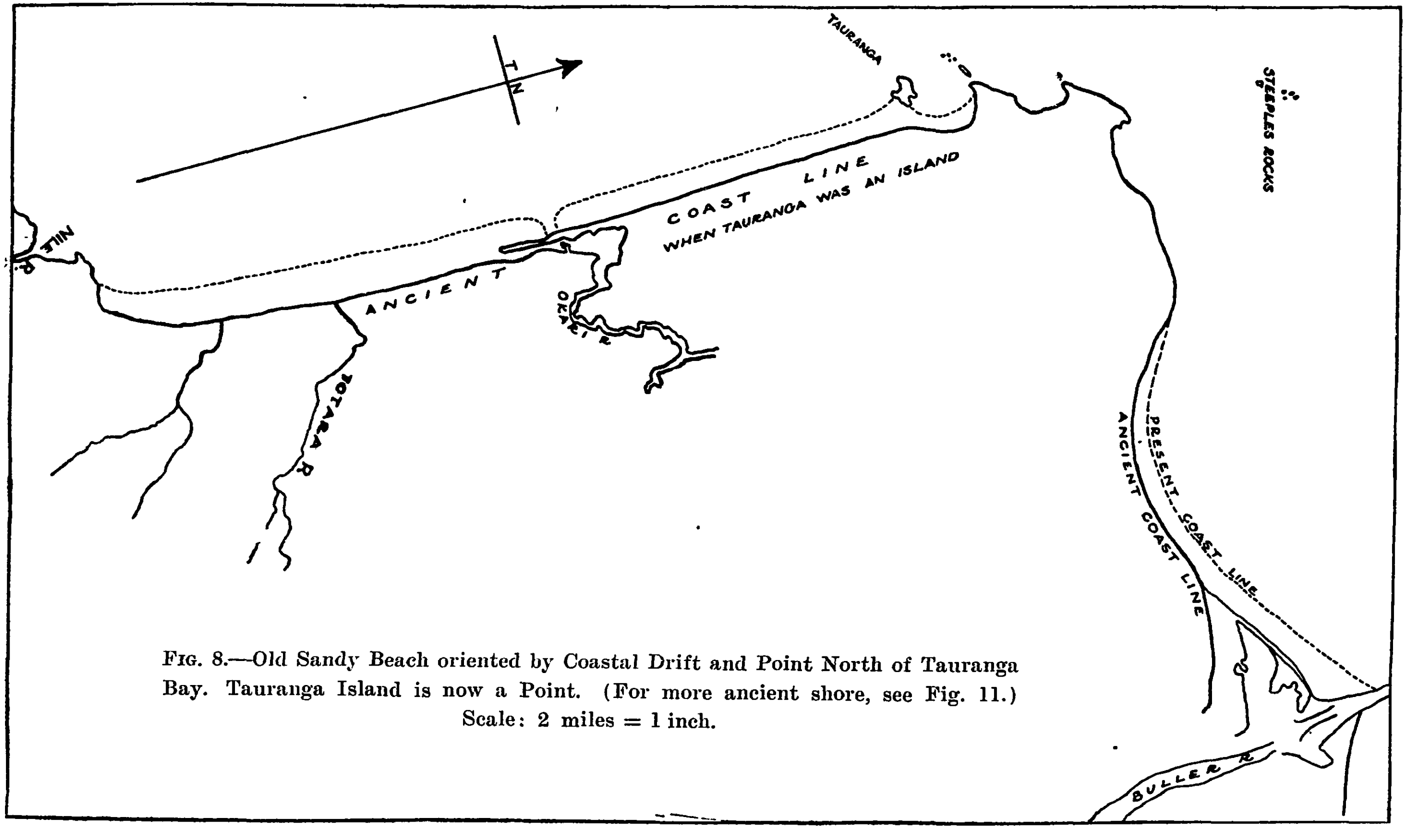


FIG. 8.—Old Sandy Beach oriented by Coastal Drift and Point North of Tauranga Bay. Tauranga Island is now a Point. (For more ancient shore, see Fig. 11.) Scale: 2 miles = 1 inch.

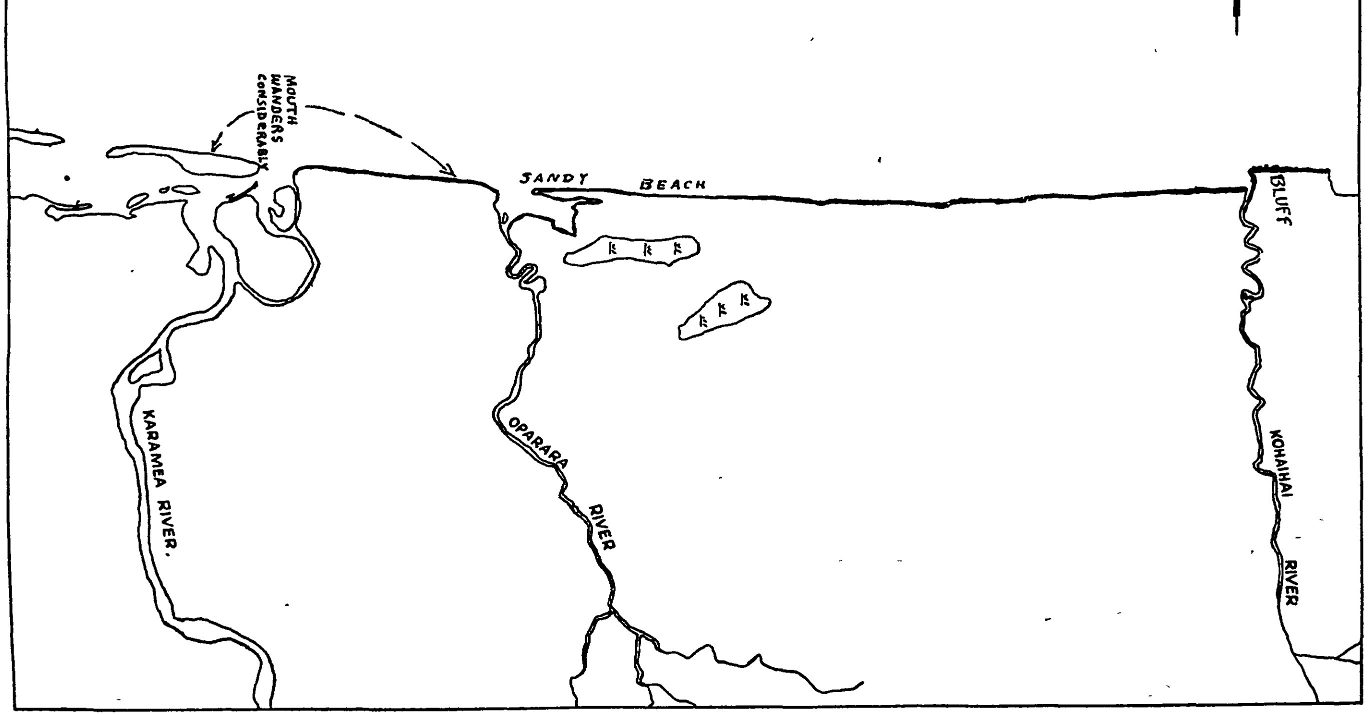


Fig. 9.—Sandy Beach oriented by influence of Coastal Drift and Kohaihai Bluff.

Scale: 2 miles = 1 inch.

need for trepidation. Damage by storm would only affect the portion assailable by the waves and this could be later restored, and the base would still be effective as a drift retainer in the meantime.

Benefit from such a work would be obtained long before it was completed. This was proved at the commencement of the Westport Harbour works in 1887 and again when the 360 ft. extension was carried out in 1915–16 (see Fig. 3A).

The foregoing sets out the past history and the difficulties in connection with the port of Westport and indicates various ways in which improvements may be effected.

Taking these possibilities seriatum and indicating their costs and advantages, it should be possbile to arrive at a conclusion as to which, if any, should be adopted.

DREDGING.

Undoubtedly, if a sufficiently large and powerful dredger could be built to operate over the shallow water on and adjoining the sailing course (see Figs. 5 and 6) and to be sufficiently manoeuvrable to work at and turn in the entrance, the drift material which forms the bar could be removed, but there immediately arises the question of how much material must be shifted. The channel required in order that there should be no bar problem and so that the river depth should be the governing factor, is roughly 10–12 ft. deep by, say, 800 ft. wide by 1,600 ft. long, or about half a million cubic yards. However, even if such a cut could be made by the waving of a wand, it would immediately commence to fill probably at the rate of 12,000 cubic yards per day. Indeed, for some time it would fill much faster, as in addition to the annual quantity normally passing up the coast there would be the more rapid supply from the shallow sides, particularly the western side, which would be swept in. When this phase had been overcome, the annual rate would be the task. At present the port possesses two trailing-suction bar dredgers, one of 1,000 tons capacity and one of 650 tons, as well as a bucket dredger for use in the river. The average quantity shifted by the whole plant has been around half a million yards per year, or about one-tenth of the 12,000 yards per day moving. This gives some scale on which to judge the problem. It has been argued that as the amount deposited per year has been about one and a-quarter million cubic yards, that is all that needs be moved, but if a navigable channel is continuously to be maintained across the stream of drift, then all that passes up the coast within 1,500 to 2,000 ft. of the shore, except such as is floating high above the bottom, must be dredged. In the past the efforts of the dredger have not done more than scrape off the high spots, no definite channel being formed, so that most of the travelling material merely rolled over the bar or floated in the disturbed water. But if one and a-quarter million cubic yards is all that must be moved regularly per year, then for the reason given above the plant must at any rate in the earlier stages be capable of considerably more, say, one and a-half million, or more than three times what has been done in the past.

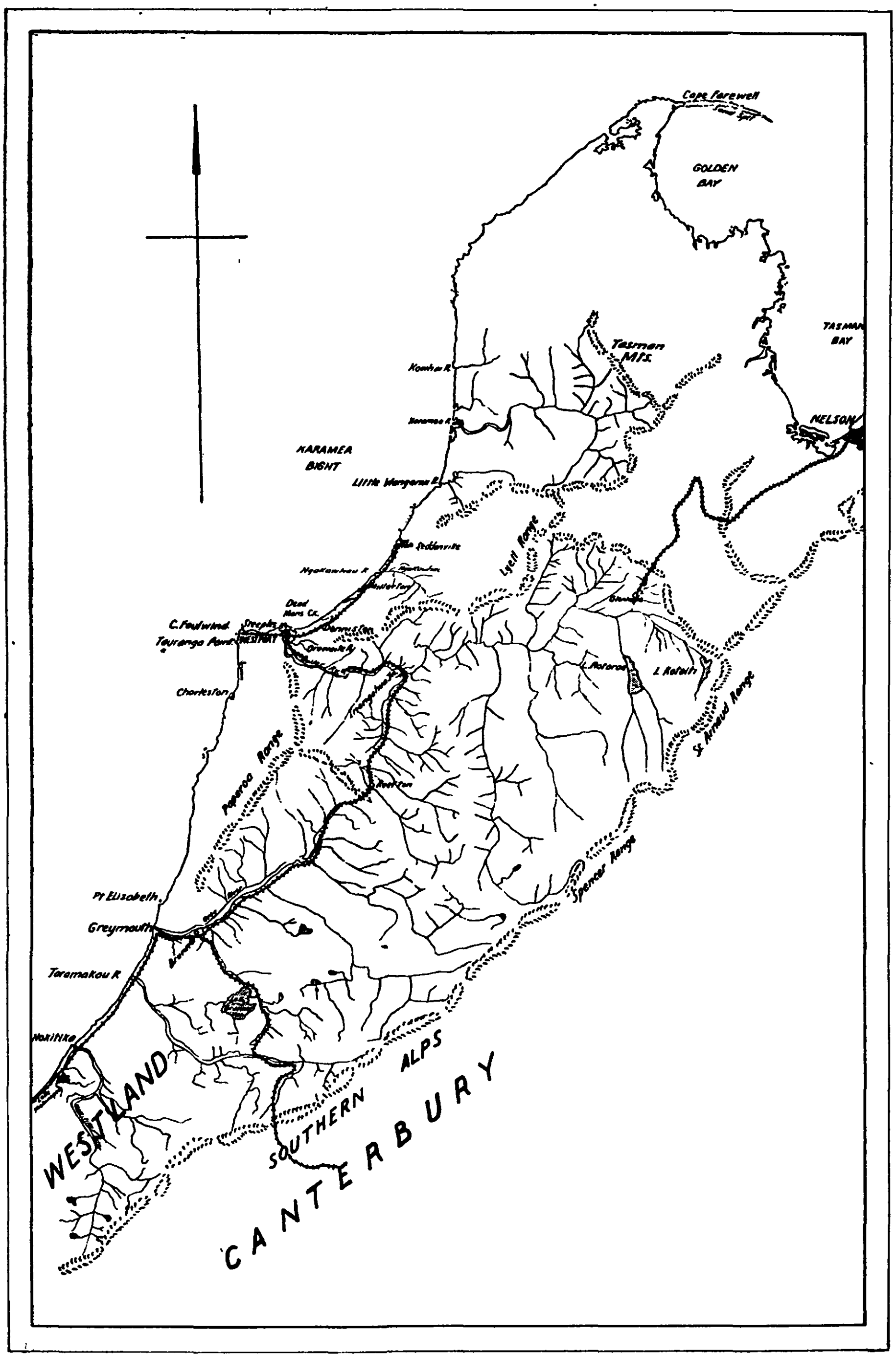


FIG. 10.—Scale: 32 miles = 1 inch.

Experience with the present two small vessels has shown that in the opinion of the local staff it is impracticable to use two vessels simultaneously on the bar. The cost per annum of operating the "Eileen Ward"—1,000 ton capacity—is £15,000, and two vessels twice as large which would be required on the assumption six lines above would probably cost £40,000 per annum if they could both be operated. It might be mentioned here that the actual dredging time of the "Eileen Ward" is only about one-tenth of the possible daylight hours of working days. If two large vessels could not be operated simultaneously, as seems likely in view of the inability to work two small vessels together, then the suggestion of two large dredgers must be ruled out. One vessel might dredge on the bar and the other to windward, but the coast is such that dredging would be impracticable within the area in which most of the drift takes place. It does not seem likely that one vessel of four times the capacity of the present could work on the bar sufficiently regularly to be satisfactory. The sea conditions are often such that no vessel can enter or leave the port and such conditions sometimes last for days or even longer. At such times, if there is not a flood in the river, the bar may shoal up so that even after the sea moderates the bar is too shallow for the "Eileen Ward" and would be still more impracticable for a large vessel. To compensate for these delays the hourly capacity would need to be still greater.

However, if all physical obstacles could be overcome, there would still be a capital expenditure of £300,000 to £350,000 plus an operating cost of £40,000. Approached in another way, it now costs £15,000 to dredge 400,000 cubic yards per year, so that it seems not unreasonable to expect that the dredging of four times that quantity will cost £45,000 per year even when the higher efficiency of larger plant is allowed for. But as a final point, it is not likely that the dredging of 1,600,000 cubic yards per annum will be adequate.

ENLARGING OF TIDAL COMPARTMENT.

Unfortunately, the physical features are such that the dredging required in order to increase tidal scour to a stage at which it would force the littoral drift material to pass the entrance in water 20 ft. deep or deeper would be so great that it cannot be considered. All that can be said for the practical expansion is that £170,000 will enlarge the compartment sufficiently to increase the flow out on ebb tide by 15 per cent., which will increase the depths over the bar by between 1 ft. and 2 ft. This improved tidal flow would operate on every tide irrespective of weather, and every cubic yard scoured off the bar by this agency would be so much less to dredge. Taking the annual costs, interest and sinking fund at 5½ per cent. = £9,350, then it would be necessary for the scoured material to equal 250,000 cubic yards per annum for the cost to be less per unit than that of the present dredging. Assuming the additional volume as an average of 2,500 cusecs for half the day, this would only require that the suspended matter lifted off the bar should equal one and seven-tenth parts per 10,000. This would seem entirely within the bounds of probability.

It cannot be contended that the limited amount of tidal basin enlargement is a complete answer to the problem, but either alone or in conjunction with other works it would seem well worth doing.

Extension of Moles.

This would be a certain method of improvement, but the period over which the improvement would last would be short and consequently the annual cost, including the provision for paying off the capital expended on the extension, would be very heavy and probably beyond the capacity of the trade to bear. It may well be, however, that whatever else is done some extension of the moles may be found advisable, but as a complete solution extension alone will probably be found inadequate. The cost of 1,000 ft. of extension is estimated at £350,000, with annual charges equalling £19,250; but 1,000 ft. is inadequate and the period assumed, 30 years, may well be too long. (Some authorities have estimated the life of the improvement at only seven years.)

Island Breakwater.

With respect to the island breakwater, Vizagapatam moves about 1,000,000 cubic yards per annum, while at Westport five times that quantity may have to be moved, and capital cost and the expense in perpetuity for the dredging plus the interest and sinking fund charges on the breakwater would much exceed the cost of other methods, while the method itself would be highly speculative and might be quite unsuccessful. The capital cost would not be less than £500,000 and annual charges perhaps £45,000.

Groyne from Tauranga Point.

The Groyne from Tauranaga Point involves less capital expenditure than extension of the moles or the purchase of dredgers, and if its beneficial effects lasted 30 years the annual charges would be about half those of the mole extension and a quarter of those of the two large dredgers which have been suggested. The charges on account of the tidal compartment enlargement would be slightly less than those of the Tauranga Point groyne, but the beneficial effect would be less than that obtainable otherwise and would not be adequate to satisfy local aspirations for port improvement. Analysis of coastal conditions justify the belief that the beneficial effects of the Tauranga Point groyne would last 60 years or more, but even if all benefit had passed away in 15 years the annual charges would be less than those anticipated with other solutions. It is realised that even a groyne half a mile long will not intercept all coastal drift, but as it will end in water between five and six fathoms deep its effect will be much more marked than that of the Westport entrance moles which, although only extending into about three fathoms, have had a profound effect. A length of 2,500 ft. of groyne has been estimated to cost £280,000, but even if it was taken at £300,000, then the annual charges would be £16,500 if we assumed only 30 years of life, while if 50 years were taken, during the last 20 years of which there would be no capital charges, then the real annual cost would be under £10,000.