COASTLINE CHANGE AT WANGANUI, NEW ZEALAND

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TABLE OF CONTENTS

Table of Contents (Contd.)

Table of Contents (Contd.)

LIST OF FIGURES

List of Figures (Contd.)

LIST OF TABLES

LIST OF PLATES

ABSTRACT

In the last 100 years the coastline adjacent to Wanganui River mouth has changed substantially. Construction of harbour moles at the mouth of Wanganui River iniated these changes.

It is suggested that sediment reaches the mouth of the river in substantial quantities from the north via longshore currents and from the Wanganui catchment via Wanganui River. Interruption of natural by-passing processes resulted in progradation of updrift beaches and erosion of parts of the downdrift coast.

The improved depths found at the entrance in the late 1920's as a result of mole construction deteriorated rapidly in the 1930's, facilitating more rapid by-passing of sediment. Consequently progradation of the updrift beaches and erosion of downdrift beaches slowed.

At present conditions at the harbour entrance are not unlike those encountered by early settlers of the area. Most material reaching the coast is by-passed south of the entrance and present day changes are minimal.

INTRODUCTION

General

Since the beginning of European settlement in New Zealand this country has experienced catastrophic changes in land use, vegetation cover and population density. White settlers arriving in the second half of the nineteenth century were confronted with a small native population, probably 125,000 - 175,000 (Pool, 1964), whose economy was 'essentially conservational' (Cumberland, 1941). More intensive use of the land associated with new settlement resulted in considerable modification of the existing order. Vegetation was burnt, cleared and replaced with pasture plants suitable for grazing animals. Roads, railways and ports were built to link the growing settlements and other natural resources began to be utilized more fully.

Changes in the New Zealand landscape have been accompanied by numerous problems. Vegetation and landuse changes have often resulted in increased erosion. Construction of dams for hydroelectricity and irrigation in areas of high sediment load have necessitated costly dredging and desilting work. Similarly waters laden with sediment are considered of inferior quality for domestic and industrial use. More recently the increasing problem of man-induced pollution has been more widely publicised. Sewerage disposal, industrial and agricultural effluents and atmospheric pollution have all changed the New Zealand environment.

At the land's edge changes have also occurred. Areas, once ocean, have been reclaimed, other areas have been lost to the natural processes of the sea and in places man's actions have, unintentionally, resulted in changes of the foreshore.

In the last decade the New Zealand coastline has become subjected to a sudden increased demand. Greater prosperity and more leisure time has subjected the coast to greater recreational pressures than ever before. Beaches are becoming more crowded, demand for coastal land has increased and amenities for holiday makers are required to a greater extent. The growth of large cities close to the coastline has resulted in other pressures on the coast. The ocean is being used as a giant garbage tip for the increased quantities of sewerage, stormwaters and industrial wastes, material is being removed from the beaches for building and construction purposes and it seems likely that minerals will be extracted from the beaches in the near future.

Despite this demand for coastline relatively little is known about how, why and where the New Zealand coast is changing. Early work by geomorphologists and geologists typified by Adkin (1919, 1921, 1951), Batrum (1916, 1924, 1926, 1935, 1936, 1938, Cotton (1918, 1949, 1951, 1956a, 1956b, 1962, 1963), Jobberns (1928, 1937), King (1930, 1932), King and Jobberns (1933), McKay (1877), Maxwell (1897), Park (1901) and Speight (1930, 1950) described and accounted for the physiographic characteristics of sections of the coast. Engineers working on the coast concerned themselves with specific problems necessitating protective works and harbour works. Early published investigations of port development include Adams (1926, Thames), Baillie (1924, Wellington), Clarke (1921, Timaru), Furkert (1947, Westport), James (1960, Otago) and Simpson (1945, Napier), Campbell (1879), Doidge (1941), Donnellely (1959), Nevins (1938), Scott (1955) and Sharp (1915) have worked on general erosion-protection problems around the coast.

Work on the large areas of sand dunes which back many of New Zealand's beaches is relatively plentiful. Since Cockayne (1909) presented his report on sand country Carnaham (1957), Elser (1969), Logan and Holloway (1934), Pegg (1914) and Williamson (1953) have written describing sand dune vegetation. Brothers (1954), Cowie (1963) and Hocking (1964a) have discussed dune building and Biggs (1947), Field (1892), Fields, (1970), Hocking (1964b), MacPherson (1912), Malt (1938), Marks (1914), Saunders (1968), Sexton (1964) and Whitehead (1964) have written about general sand dune problems. This work has successfully established where areas of dunes are located, what plants cover the dunes and in some cases their geomorphological background.

Re-vegetation of dune areas has also been the subject of much of this and other work, large amounts of which are unpublished.

Studies relating beach or coastline changes with littoral processes are not so numerous. Previously mentioned work by Doidge (1941) and Nevins (1938) were early attempts. More recently Blake (1964), Dingwall (1966), Hodgson (1966), Kirk (1967) and Martin (1969) have examined these problems on the East coast of the South Island while Smith (1968) worked on the Napier Beaches. No recent work has been attempted on any of the West Coast Beaches except in the far north North Island where Schofield (1970) explained beach and nearshore sediments in terms of ocean currents.

Beach and offshore sediments have been the subject of considerable work in recent years. Most work has been performed on the iron sand beaches in an attempt to determine mineralogical content; Beck (1947), Fleming (1946), Gow (1967), Hutton (1940, 1945a, 1945b), Marshall, Suggate and Nicholson (1958), Martin (1955), Munro and Beavis (1945), Nicholson (1959, 1967), Nicholson, Cornes and Martin (1958), Nicholson and Fyfe (1958), Ross (1963) and Wylie (1938) are typical. Studies of grain size properties, sorting characteristics and/or environment differentiation on these grounds are more limited in number. Typical of the New Zealand work are Andrews and van der Lingen (1969), Blake (1968), McLean (1969, 1970), McLean and Kirk (1969),

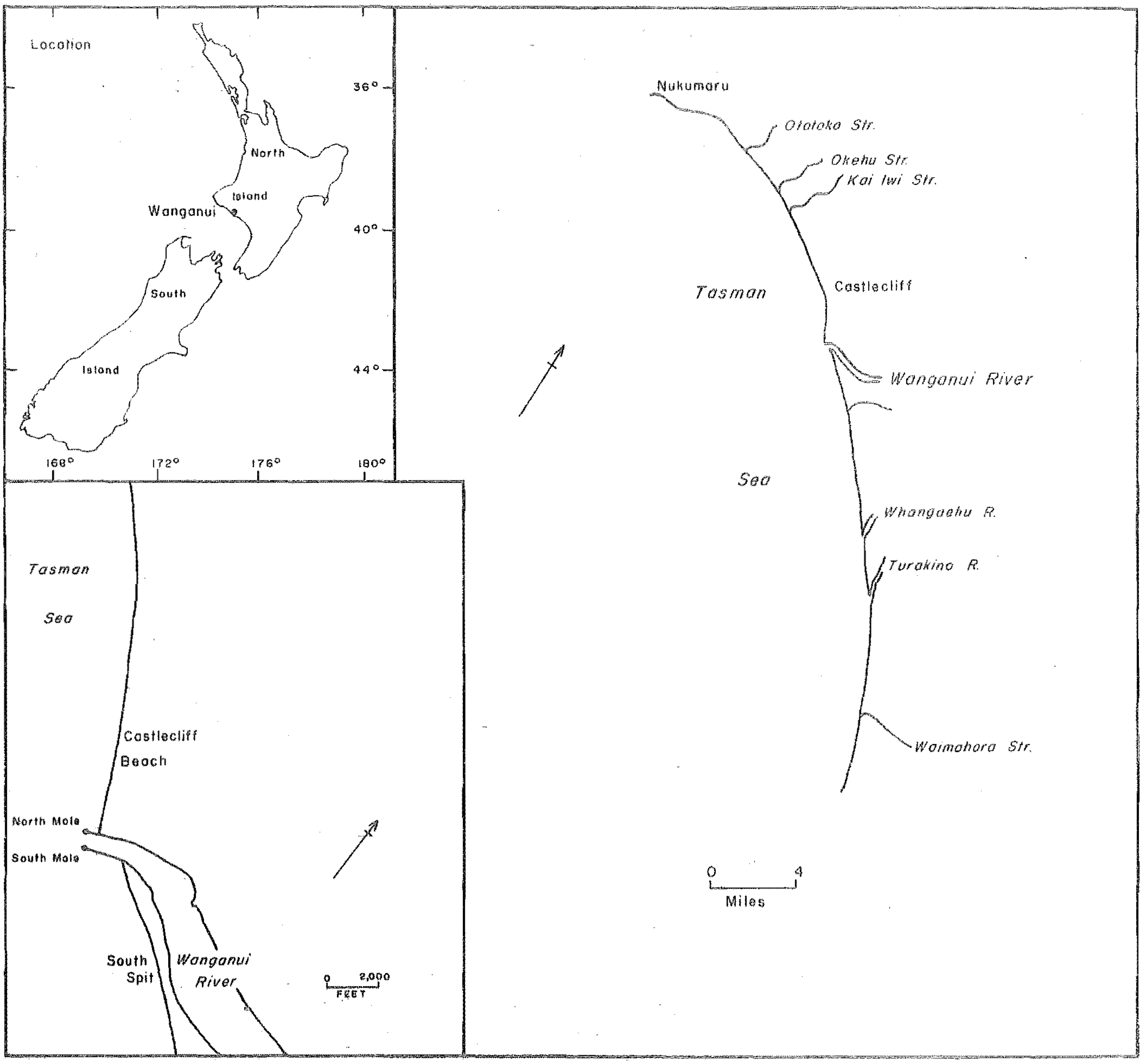


Figure 1 The Wanganui Coast

Marshall (1929) and Sevon (1966a, 1966b). Description of offshore sediments in many areas have been attempted by officers of the New Zealand Oceanographical Institute.

Study Aims

At Wanganui on the west coast of North Island New Zealand it is possible to document coastline changes since the arrival of European settlers in the middle of last century The changes that have occurred are impressive in their magnitude especially at the mouth of the Wanganui River. In this thesis it is intended to examine the changes that have occurred on this small stretch of beach (Figure 1) and relate changes to the geomorphic processes operating on the coast.

These changes are of special interest as they appear to be the result of man's efforts to provide port facilities. The construction of protective moles at the river mouth provided the catalyst needed to iniate massive 'quasi-natural' geomorphic changes (Jennings, 1965). Essentially these changes have resulted from efforts to improve depths at the harbour entrance. Although depths were improved they eventually deteriorated to such an extent that present depths are little different to conditions in the middle of last century. Associated with the improvement and decline in entrance depths has been fluctuation of the beach areas north and south of the entrance.

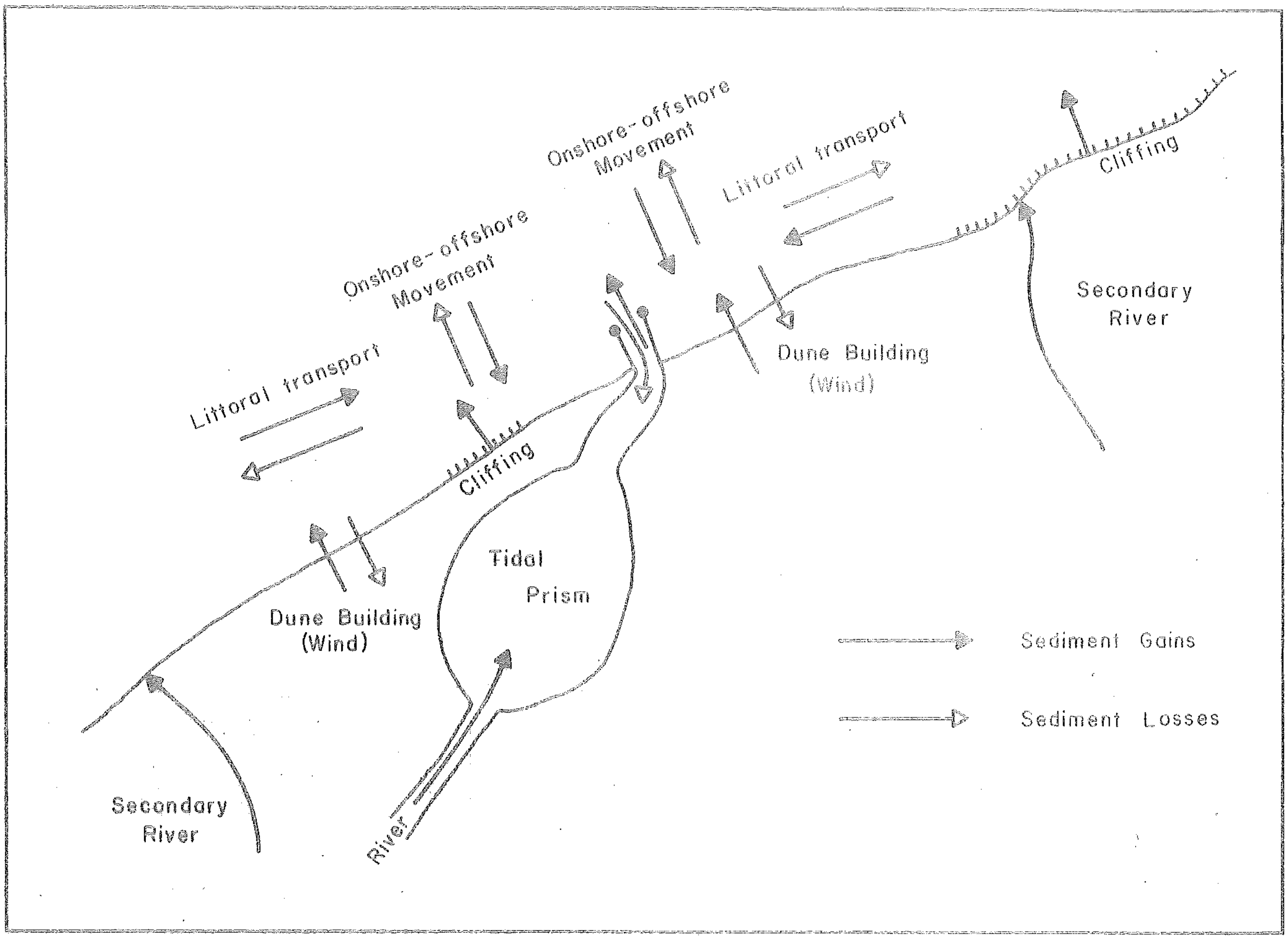


Figure 2 Coastline dynamics -- a conceptual framework

It is hypothesised that the sequence of changes that have occurred at the mouth of the river can be explained by examining the behaviour of the present coast and extrapolating into the past.

Conceptual Framework

The broad conceptual framework within which this study is set is an adaptation of Krumbein's (1963) beach process-response model. With regard to changes at the mouth of Wanganui River it will be assumed that certain geomorphic processes move material into and out of the system. The balance and 'direction' of operation of these process factors will be used to account for physical responses of the system. The possible origin and destination of the inputs and outputs of sediment broaden the framework to include a much larger stretch of coast or coastal compartment. The Wanganui River mouth is located near the centre of a coastal compartment which probably extends from Cape Egmont to Kapiti Island but for convenience in this study the extended coastal compartment to be studied stretches from Nukumaru to Waimahora River (Figure 1).

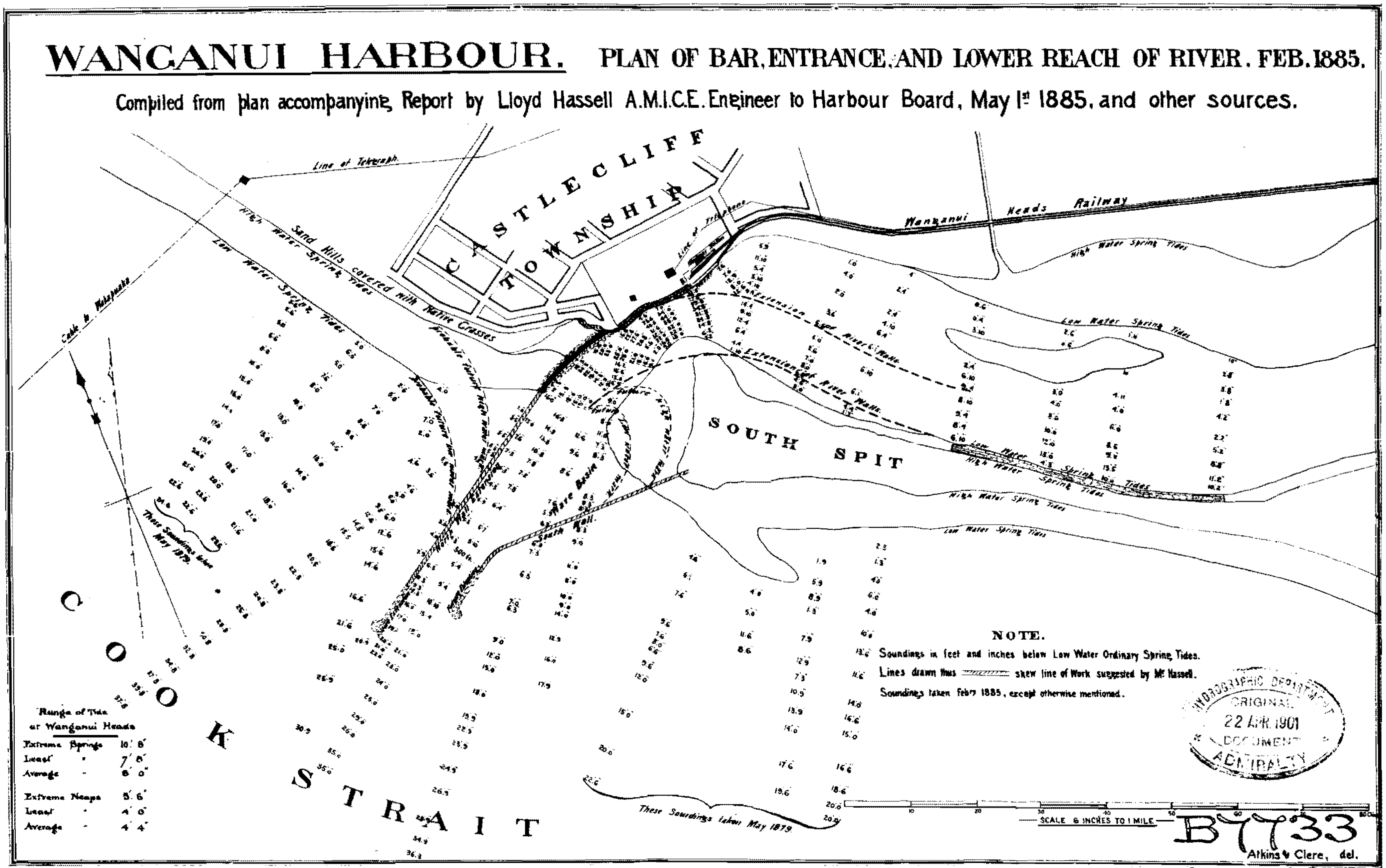
Some of the factors responsible for the systems behaviour are presented in Figure 2. Elucidation of these factors will follow a statement of recorded Wanganui River mouth changes. Possible sources for the sediment accumulating at the mouth of Wanganui River will be established through an examination of the geology and physiography of the coast, the physical attributes of the coastal sediments and the river regime. Processes responsible for moving these sediments from their respective source areas necessitates an examination of the wave environment, ocean currents, wind and river flow. Having established the physical environment in which the coastline changes have taken place a detailed examination of present river entrance dynamics will be made. Finally changes that have taken place over the last 100 years will be re-examined in light of present dynamics.

COASTLINE CHANGE AT WANGANUI

The Wanganui River Mouth

Before the arrival of European settlers at Wanganui the Wanganui River flowed into the Tasman Sea at a position a little seaward of Castle Cliff. Early visitors to the area observed that for the last mile or so of its course the river was separated from the sea by a thin, rather unstable sand spit. North of the river Castlecliff Beach was prograding slowly and as at present was a mass of drifting sand and driftwood debris. Grimstone, writing in 1847, reported that at the mouth of the river an offshore bar formed. This bar was covered by only five-eight feet of water at low tide.

Between 1840 and 1860 numerous small vessels called at Wanganui with supplies and settlers. Typical of the vessels using the river as a port were the Sandfly (16 tons), Gem (70 tons), Black Warrior (9 tons) and Imp (15 tons). During the 1860's the settlement made slow but steady progress and local optimists began to see a future for a port at Wanganui. In 1865 the first recommendations, by a professional engineer, for navigation improvement were made. J.M. Balfour advocated the building of protective walls to protect the sand spit south of the river mouth and the 'clay bluff' to the north of the entrance. Although not important from an engineering standpoint two important facts can be gleaned from the report.



A.D. WILLIS, LITH. WANGANUI.

New Zealand folio 3

Figure 3 Wanganui Harbour – 1885

First, that the southern spit needed protecting indicates existing instability and secondly the mention of the 'clay bluff' at the entrance is an early reference to what is now known as Castle Cliff. It was on this cliff that the Pilot Station and the entrance leading beacons were established.

In 1876 the 'Wanganui Harbour and River Conservators Board Act' constituted an authority responsible for harbour development. Almost immediately the Board engaged Barr and Oliver, consulting engineers. G.N. Barr's report in June 1877 stated that before anything else was done the south spit needed to be further protected to ensure that breakthroughs did not occur 'again'. In August 1877 Barr's second report recommended that training walls should be built in the river to obtain 13 feet of water in the river as on the bar at high water spring tide. Barr's recommendations were accepted and the first major developments began. By 1880 the work was completed. Two training walls 500 feet apart starting a quarter of a mile downstream of the Town Bridge and extending for about four miles were constructed. The south wall was designed to divert the current away from the south spit.

The year 1880 also saw a new engineer in the Harbour Board employ. Lloyd Hassell designed an ambitious project which was only partially completed by 1882 when lack of finance halted development. Figure 3 shows Hassell's plan and gives an indication of the river mouth during these early years. A short 900 foot north mole had been built but the offshore bar still had a minimum depth of three feet in one place.

The completion of the training walls also signified the beginning of dredging work. Between 1881 and 1883 68,000 cubic yards of silt and sand were dredged from the river bed. A large flood on the 23 February 1883 completely undid this work, an early warning to future developers of the river's power. At this time most development work was confined to the river itself so that ships could proceed up the river to Wanganui. Both Barr and Hassell had suggested that depths on the offshore bar could be improved by the construction of breakwaters. Apart from a 900 foot wall from Castle Cliff on the north bank little work was done until 1895 when Leslie Reynolds presented a report to the Board which suggested that an extension of 2400 feet be added tothe north mole and a 2000 foot long south mole be built. A further report by C. Napier Bell in 1899 recommended a similar scheme to that of Leslie Reynolds. Reynolds again presented a report to the Board in 1905 and work on the mole extensions began in 1907. Work proceeded rapidly and both the north and south moles soon reached considerable length. In the period 1920-40 work on the moles was to raise them to their present level, a suggestion made in a report by J. Blair Mason in 1921. This made the moles impervious to wind and water borne sand. Work carried out since 1940 has been minor and of a repair nature. More recently protection work has been carried out

TABLE 1

Development Work at the Port of Wanganui

1878	Training walls in river began.
1880	Training walls completed and north mole started.
1882	North mole 900 feet long. Work stopped.
1907	Mole construction restarted.
1908	North mole 1100 feet long.
1909	South mole started.
1911	North mole 2600 feet long. South mole 3200 feet long.
1915	North mole 2600 feet long, South mole 3200 feet long. 13,400 tons of rubble used in raising North mole, 12,215 tons in raising South mole.
1921	North mole 2840 feet long, South mole 3320 feet long. 9312 tons for raising North mole, 27,830 tons for raising South mole.
1930	North mole 34,276 tons for raising, South mole 4160 tons for raising.
	End of major development
1935-1938	36,000 tons of rubble for heightening and strengthening moles.
1940-1942	Repair work totalling £10,180. 4s. 1d.

along the south spit to combat erosion following breakthroughs in 1946 and 1956. Table 1 tabulates all these developments and adds more detail.

In summary, harbour development can be considered in terms of four phases.

(1) 1870 - 1900 Internal training walls and channel dredging.

(2) 1900 - 1920 Mole extensions.

(3) 1920 - 1940 Mole heightening and internal development at Castlecliff. Increased dredging of the harbour basin.

(4) 1940 - present Dredging of harbour basin and general maintenance.

Unlike many other ports the problem of bar development at Wanganui was never tackled directly by dredging on the bar or in the roadsteads.

Accompanying these harbour developments were changes at the mouth of the river, to the beach to the north and to the southern spit.

Castlecliff Beach

Just north of the Wanganui River Castlecliff Beach has prograded rapidly since European settlement. Early visitors noted that the Wanganui River joined the sea close to Castle Cliff. The river now meets the sea hundreds of feet seaward of this point. Progradation of the beach was most rapid next to the north mole, decreasing northwards so that two

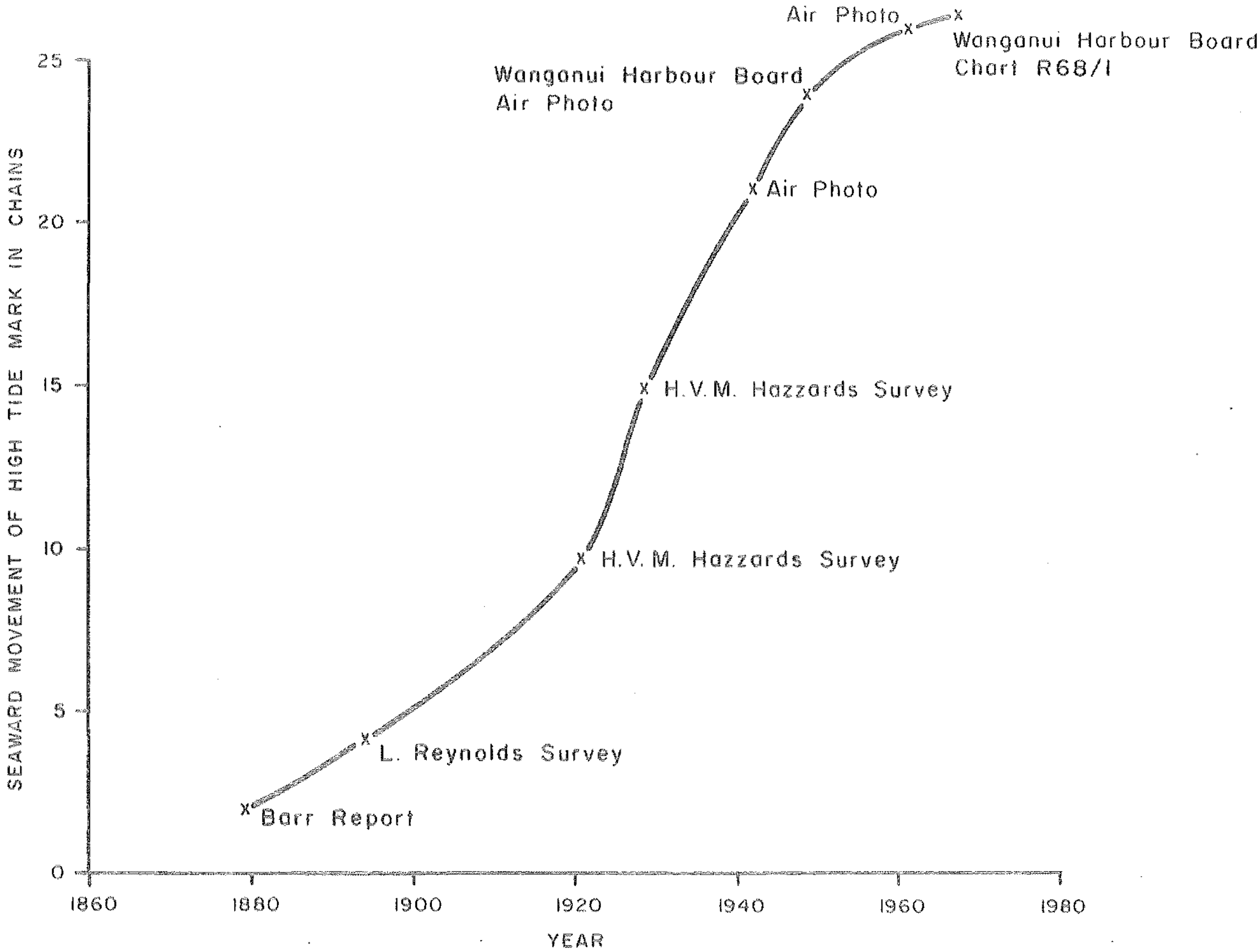


Figure 4 Progradation of Castlecliff Beach

miles further north little change can be detected from map evidence. Field examination of the area between Kai-iwi Beach and Wanganui River reveals that the cliffs up to 3.5 miles northwest of Wanganui River are protected from the sea by backshore accumulation of sediment and driftwood debris. Small dunes (six-eight high) have developed and the area is 20-50 feet wide. The cliffs two miles northwest of Wanganui River when examined by Fleming (1953) in the early 1950's were lapped by the sea. The same area today is characterised by an accumulation of sand at the foot of the cliff line. Figure 4 shows that the high tide mark next to the north mole moved seaward 2.5 chains in the period 1880-1900, five chains from 1900-1920, 10 chains 1920-40, five chains between 1940-60 and very little since 1960.

If it is assumed that rate of progradation decreased in a linear fashion away from the moles (the area added is roughly right angle triangular) and that progradation ceased two miles north of the river, the area involved in the progradational process since 1880 is approximately 185 acres or a little more than 2.3 acres per year. Maximum progradation occurred between 1920-40 when 80 acres or four acres/year were added. Quantity surveys of the volumes of material involved are not available but a series of six profiles surveyed across the area of progradation suggests that average accumulation is approximately 30 feet. At this rate of change average accumulation on Castlecliff Beach in

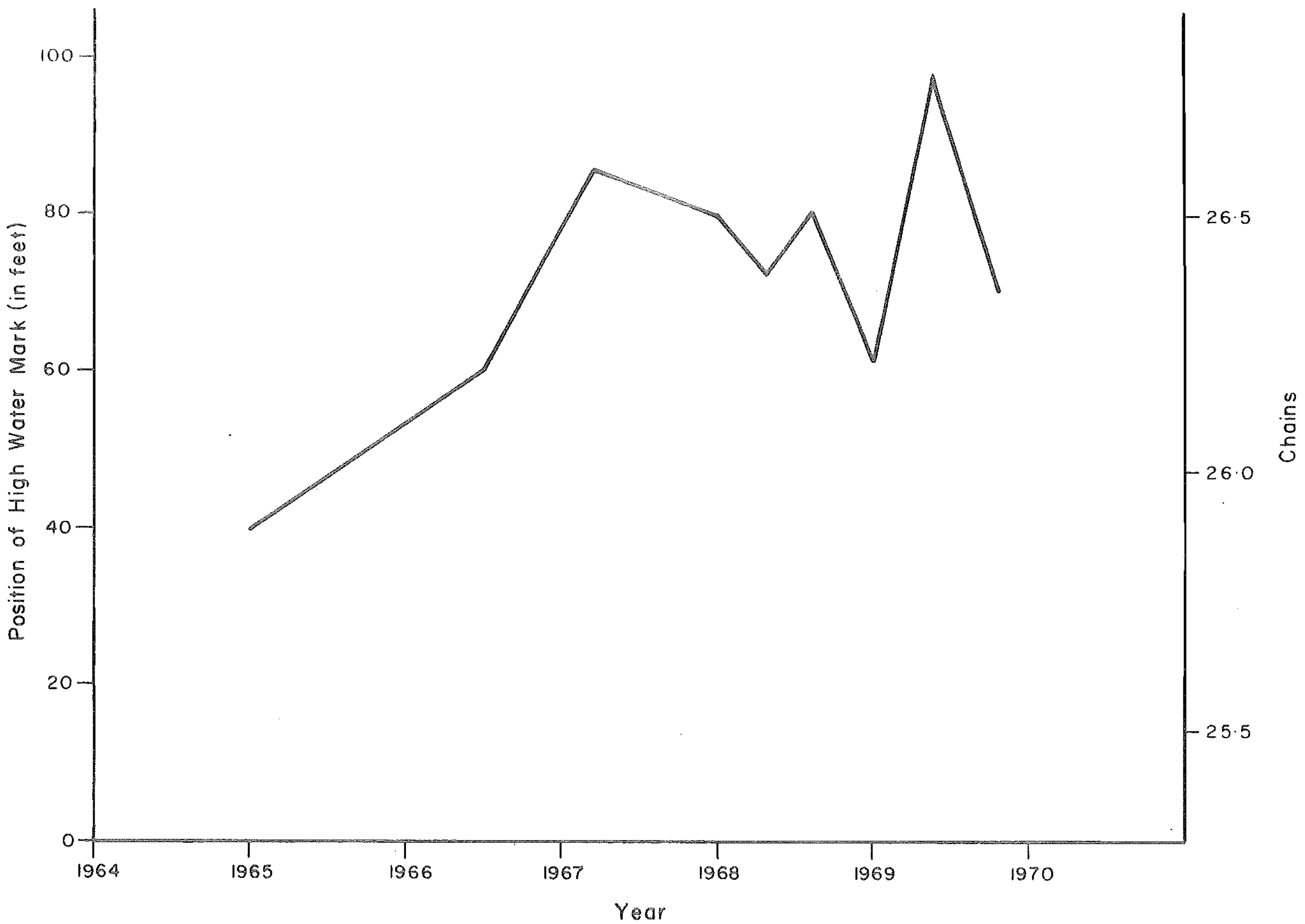


Figure 5 Recent fluctuations of the high water mark on Castlecliff Beach

the period of most rapid progradation (1920-40) would involve volumes in the order of 200,000 cubic yards per year.

More recent changes in the foreshore suggest that the progradational trend of the coast has ceased or is continuing only slowly. Figure 5 shows the position of the high tide mark next to the north mole at various times since 1967. These trends superimposed upon the longer term changes described above suggest that Castlecliff Beach is now fluctuating around some equilibrium position.

In summary, the behaviour of the beach can be conveniently divided into four time periods.

(1)	Pre 1900	Slow progradation.
(2)	1900 - 1940	A period of rapid progradation. Maximum change probably occurring about 1930.
(3)	1940 - 1960	Decreasing rates of progradation.
(4)	Post 1960	Progradation very slow and not detectable on a year to year basis.

South Spit

The sand spit south of the Wanganui River mouth has also changed considerably in European times and has had a long history of instability. Balfour, Barr, Hassell, Hazzard, Reynolds, Lee, Clay and Riddell, all engineers to the Wanganui Harbour Board, in various reports on harbour development, have warned of potential instability. Field (1892) states that between 1851 and 1892 the spit grew

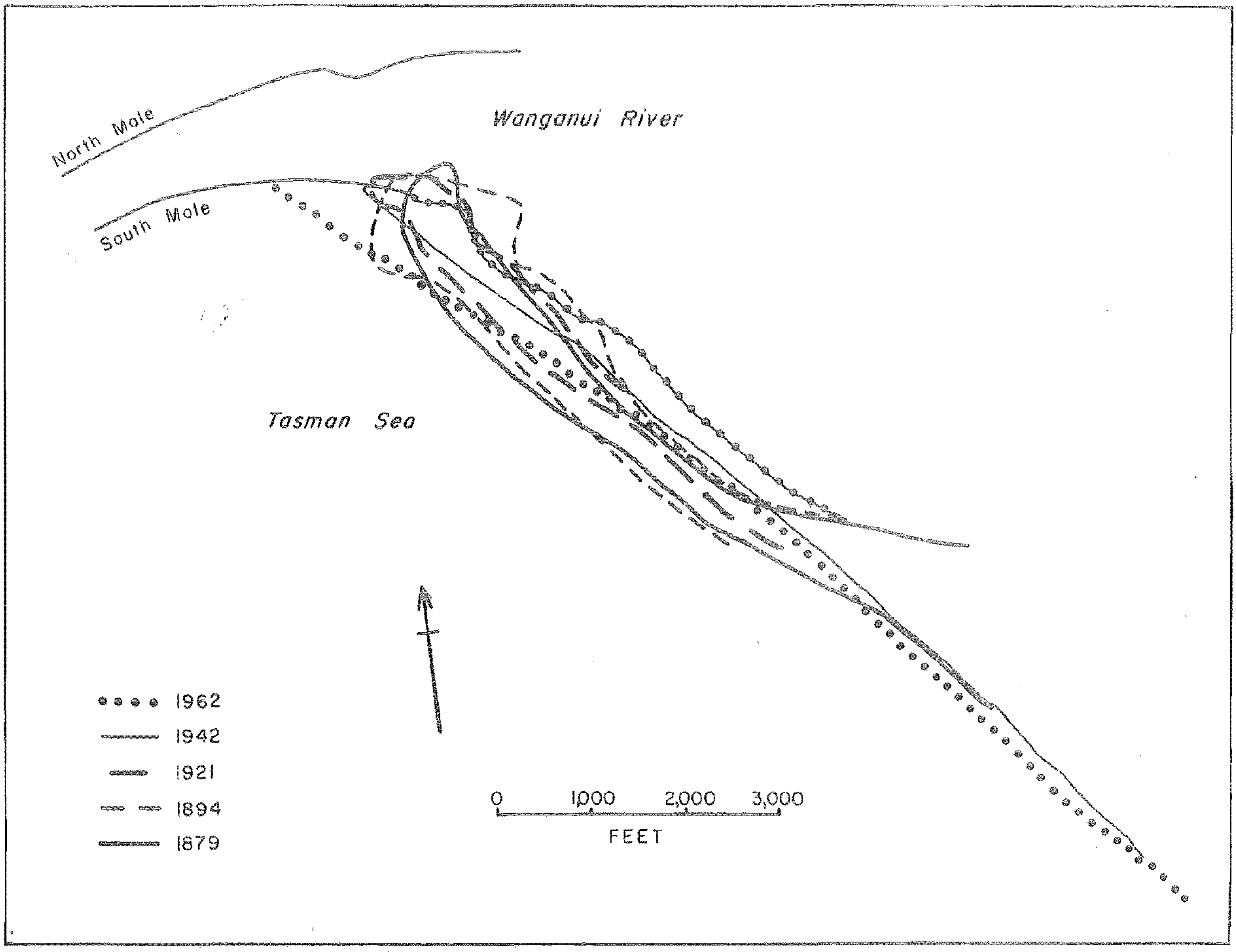


Figure 6 Changes of Wanganui south spit

northwards several hundred yards. This seems likely as it was in this period that erosion of Castle Cliff by the river took place. Maps and charts of the area since 1879 show that this northwards movement soon ceased and more recent changes have been in breadth and shape. The available information is presented in Figure 6. Two major points are apparent from this diagram. First, the hooked tip of the 1879 spit was soon replaced and by 1962 the spit terminated as a concave accumulation of sand against the south mole. Secondly, the whole spit moved landward by several chain over the period. Each successive survey of the spit shows it to have grown smaller except in the last survey (1962) when an increase in size occurred.

The spit's long history of instability is reflected in the numerous reports of breaching. Field (1892) observed that between 1851 and 1892 the river had broken over the spit two or three times. Barr (June 1877) noted in his report the possibility of further breaching of the spit. It is therefore obvious that this narrow stretch of sand was unstable even in the earliest European times. Instability continued throughout the first half of this century culminating in breakthroughs in 1946 and 1956 necessitating further protection work. The protective walls built during early port development had to be modified, strengthened and supplemented. Protection also took the form of three groins on the beach, an attempt to induce accumulation on the seaward side of the spit.

King (1964, p.73) estimates that the cost of protective works to this area, carried out by the Wanganui Harbour Board to be in the vicinity of $224,000. This figure, high as it is, is probably still a little conservative as it takes no account of the numerous plantings of sand binding plants during this century.

Although in recent years the spit has appeared to be considerably more stable its safety is far from assured as ¾ mile from the mole the neck of the spit is still very thin. Present trends suggest increasing stability and two major areas of spit behaviour can be isolated:

(1) Pre 1956 Instability culminating in the 1956 breakthrough.

(2) Post 1956 Tenous stability.

Entrance Depths

Earliest visitors to Wanganui were aware of limited depths of water at the river mouth caused by the formation of a sand bar a little way offshore. Grimstone (1847, p.20) reported that at the mouth of the river an offshore bar formed and was covered by five to eight feet of water at low tide. Barr's August 1877 report recommended training walls in the river so that depths there would be the same as on the bar (13 feet at high water spring tide or five feet at low water spring tide). Lloyd Hassell's 1885 (Figure 3) chart of the river mouth shows similar depths to those quoted by Grimstone

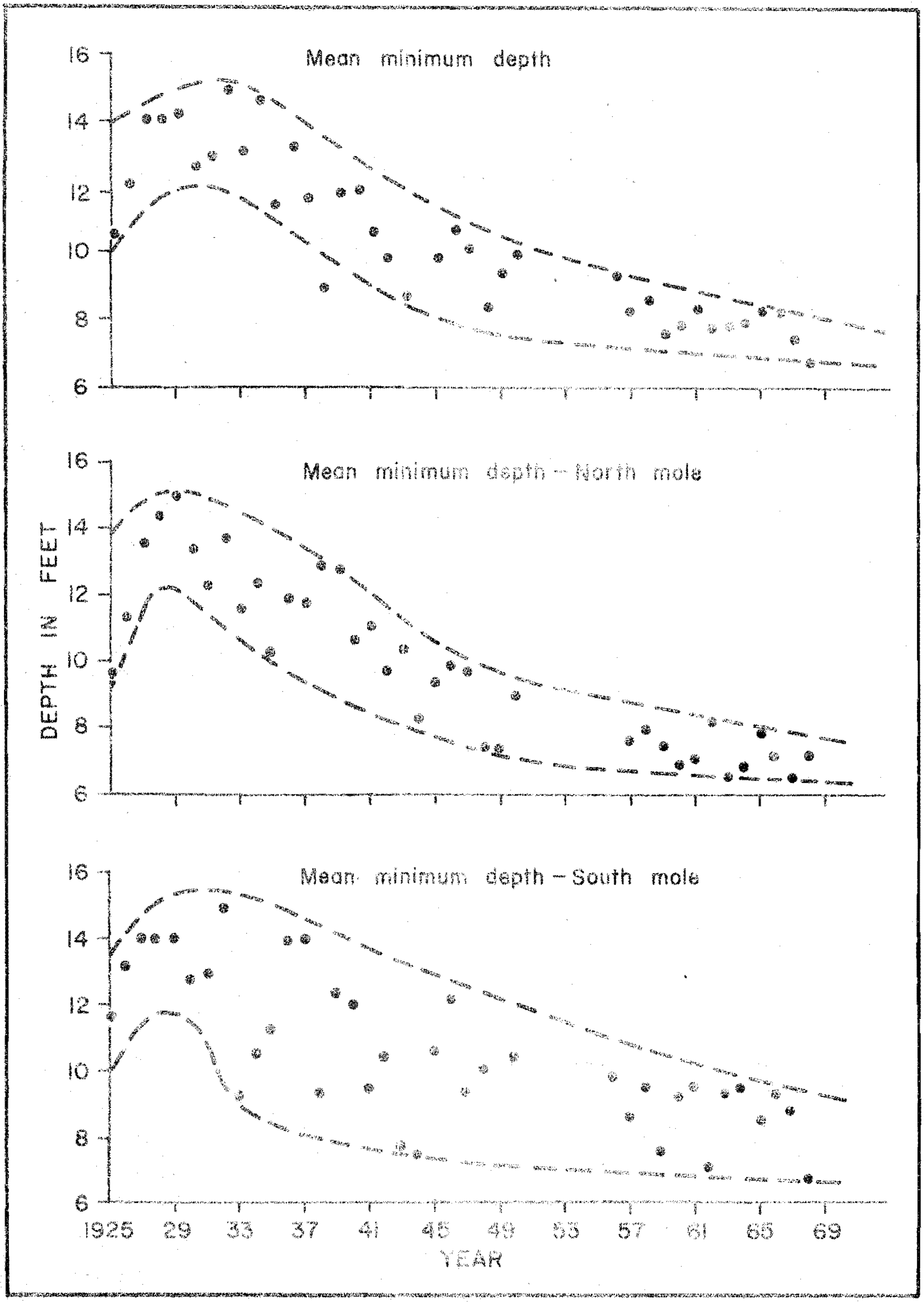


Figure 7 Fluctuation of mean annual minimum water depths at the entrance to Wanganui Harbour

and Barr. In sailing instructions for mariners issued by T. Low, the Harbour Master, in 1889 it is stated that, 'there is 11 feet to 14 feet on the bar at high-water springs', giving three feet to five feet at low water springs. This evidence makes it clear that at the time of first European settlement minimum depths at low water spring tides varied somewhere between three feet and eight feet.

Quantities of sounding charts of the entrances have been held in the archives of the Wanganui Harbour Board since 1925 so depth conditions since that date are more firmly based. For each chart lines were drawn following the line of the north mole, the south mole and midway and parallel to the two moles. The minimum depth occurring along each line was recorded and for each year's data the mean depth along the north mole line and the south mole line was calculated. A mean annual depth for the entrance as a whole was calculated by averaging all the depth figures. For each year between 10 and 20 sounding charts were available. These data (mean depth is in fact at LWOST) are graphed and presented in Figure 7. The dashed lines enclosing the data points were drawn by eye to form an envelope curve to assist in detecting major trends. By 1930 minimum depths at the entrance had increased to about 13 feet at low water spring tide (21 feet HWST). Depths off the entrance as a whole and off the north mole in particular declined rapidly after this date and by 1940 were of the order of 10 feet (LWOST). Change since 1940

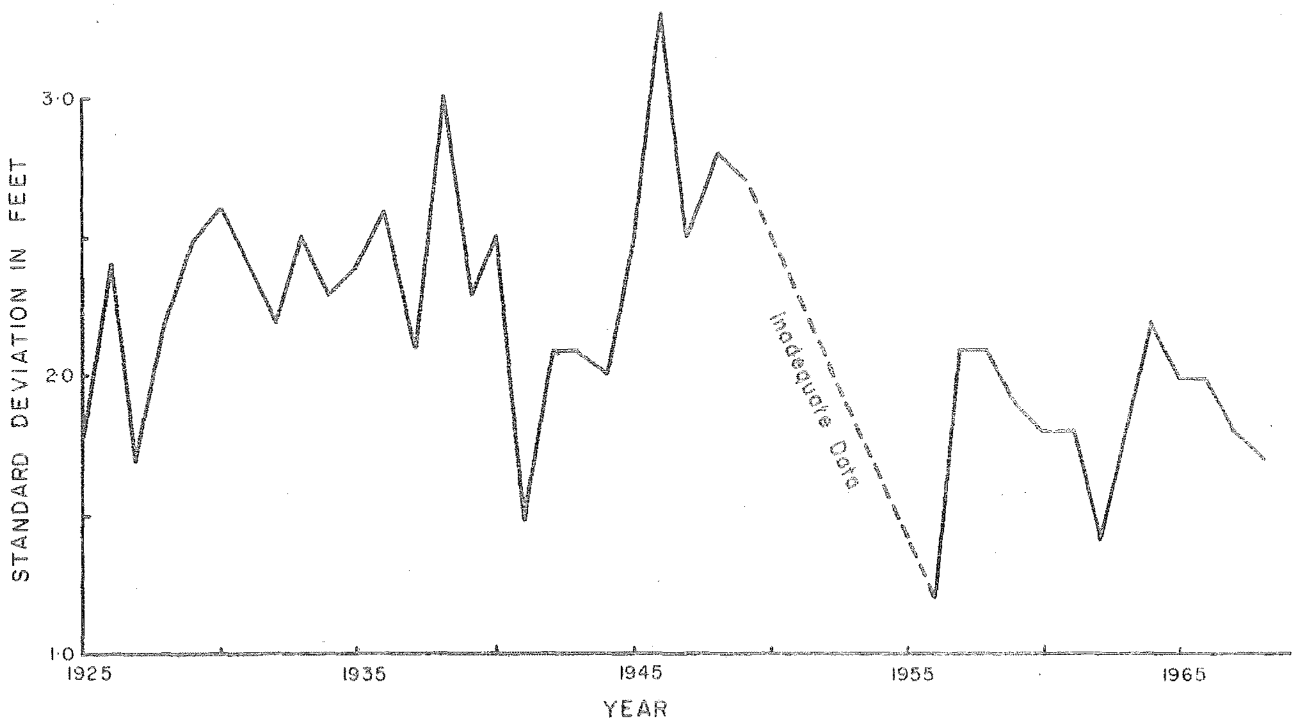


Figure 8 Annual fluctuations of entrance depths at Wanganui

was less spectacular and was rather a slow fluctuating decline. Depth deterioration off the south mole has been less consistent than that off the north mole or for the entrance as a whole. Water depths there have fluctuated more widely and have not reached the consistent low levels characteristic of north mole depths. Although Figure 7 shows mean annual depth since 1925 fluctuations occurring within any one year of data are not shown. Figure 8 gives some indications of these fluctuations by graphing the standard deviation for each year's data. The standard deviation has fluctuated widely from year to year. In recent years (post 1955) depth fluctuations have been less severe and have generally been less than two feet. Behaviour of the entrance between 1950-55 is unknown because of lack of sounding information for that period.

Although information similar to that presented in Figure 7 is not available for the entire period of European occupation a number of distinct entrance depth environments can be detected:-

(1) Pre 1890. Depths low fluctuating below eight feet.

(2) 1890 - 1930 Increase in water depths, probably suddenly between 1910 - 1930.

(3) 1930 - 1940 Rapid decline in depths from 13 - 14 feet to nine - ten feet.

(4) 1940 - Present Slow fluctuating decline in water depths to about six - eight feet at present.

Tidal Prism

The lower reaches of the Wanganui River is tidal and considerable quantities of water are stored as a tidal prism. Work by Sir Alexander Gibb and Partners (1959) suggests that the tidal compartment of the Wanganui River was approximately the same size as it was in 1876 when first determined. Gibb also states that the river is still tidal for 23 miles above its mouth as it was in 1895 and that over that period has shown no sign of aggrading. Depending upon height of tide the tidal compartment is approximately 255 million cubic feet (6.8 feet tidal range and river flow 11,000 cusecs) giving a maximum ebb flow in the vicinity of 30,000 cusecs.

Summary

Since European settlement the mouth of Wanganui River has changed considerably. Harbour improvement schemes increased depths to the stage where minimum low spring tide depths were 13 feet in 1930. Major development work had been completed by this date and harbour depths rapidly deteriorated so that at present depths fluctuate between six - eight feet. Castlecliff Beach north of the river began prograding rapidly during the period of harbour improvement but since 1940 rate of change has decreased. To the south of the river the sand spit separating the river from the Tasman Sea has been instable since European settlement and only in the last decade has stability improved.

GEOLOGY AND PHYSIOGRAPHY OF

THE WANGANUI COAST

General

The geology of the Wanganui area has been the work of Dr. C.A. Fleming for several decades. "The geology of Wanganui Subdivision" in 1953 is probably one of the most important pieces of geology attempted in this country. This present discussion of the geology and physiography of the Wanganui coast leans heavily on Fleming's work.

Geologic History

The coastline between Nukumaru and Waimahora River (Figure 1) forms part of the landward edge of an incomplete basin called the Wanganui Basin. The basin is a geosynclinal structure of Pliocene age and all exposed rocks are of recent origin. Three series are distinguished by Fleming:-

(1) Recent series: Beach and dune sands, alluvium and volcanic ash showers.

(2) Hawera Series: Marine, fluviatile and terrestrial deposits on elevated coastal and river terraces, believed to be Pleistocene, with a thickness seldom exceeding 150 feet.

(3) Wanganui Series: Marine and estaurine geosynclinal

sediments, usually correlated with the Pliocene.
Thickness may reach in excess of 8000 feet.

Fleming notes that the decipherable geologic history of the Wanganui Basin opens in the early Pliocene with deposition of marine sediment. A great thickness of sediment was deposited because of geosynclinal sinking of South Taranaki and West Wellington. Periodic tilting pushed shore-lines towards the centre of the basin. Older sediments were wave scoured and covered by littoral deposits (pebble beds, shellbeds and estaurine sands) followed by silts and muds as sinking continued.

During the Waipipian and Mangapanian similar conditions of deposition continued. Diastrophic pulses preceding deposition of Marahauan sediments were more acute than earlier ones and coarser sediments came into the basin. Abundance of sandy material led to widespread estaurine conditions. In the later Marahauan estuarine conditions continued and rhyolite eruptions to the north-east supplied pumiceous sediments.

The Okehuan opened with violent rhylotic eruptions in the north-east with the result that the basin was flooded with pumiceous sediment. Activity on the Nukumaru Fault zone and tilting on the west side of the basin allowed the sea to scour into the Marahauan sediments depositing shell conglomerates. Further east thick estuarine and deltaic, pumiceous sands, silts and muds were deposited. Large quantities of pumiceous sediment again flooded the basin in the middle of the Okehuan. Diastrophic tilting at the margins of the basin during the period resulted in shoreline fluctuations, deposition of beach sediment and then burying of platform and beach sediment by fine silt and mud. These processes continued in the Putikian deformation, quickened, and marine deposition was restricted to the centre of the basin.

Geological history in Hawera times explains most present physiographic development. Areas of softer rock were peneplained, then warped and rivers intrenched. Fleming notes a number of stages.

(1) The sea nicked the gently-tilted peneplain west of Wanganui River and deposited a veneer of marine sediments. To the east cliff-cutting was prevented by the river deltas.

(2) Uplift exposed the lower Brunswick marine sediments as a coastal plain. Ash showers were deposited, followed by dissection of the uplifted plain.

(3) The coastline prograded in response to an increased supply of volcanic sediment from Taranaki and Ruapehu. Sand dunes advanced and buried the coastal plain and the rivers aggraded.

(4) Planation of the coastal to form the surface of the Brunswick Terrace.

(5) Cliffing of the Brunswick Terrace and valley cutting.

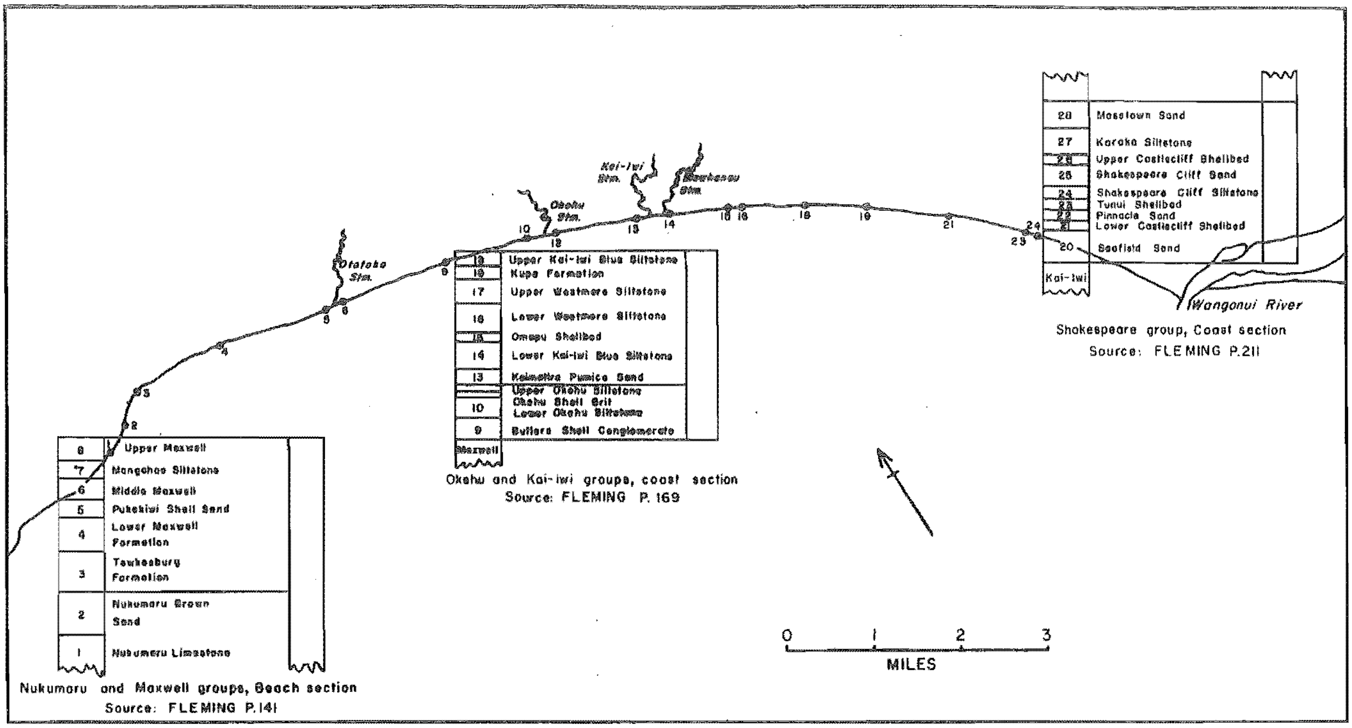


Figure 9 . Stratigraphic expression of the geologic history of Wanganui Coast

(6) Uplift exposed the Rapanui Marine sand as a coastal plain into which the rivers cut valley 100 feet deep.

(7) Taranaki and Ruapehu volcanoes supplied vast quantities of sediment leading to a further advance of sand dunes and blanketing of the coastal plain with alluvium.

(8) Decrease in waste and planning of dune sands to form the Rapanui Terrace.

(9) Cliffing and valley cutting of the Rapanui Terrace.

(10) Aggradation of the Wanganui River in response to pumiceous alluvium from Taupo Pumice shower.

The above sequence of events adequately describes events west of Wanganui. East of Wanganui greater quantities of river derived sediment hindered cliff cutting in (1) and (5) so that the coastal terraces are harder to distinguish, making the physiography quite different.

Stratigraphic expression of the geological history is summarised in Figure 9. The structure of the exposed sediments is simple. The beds strike north-eastward or eastward and dip south-eastward or south at low angles (3° - 7°). Cliffing of the coast north of Castlecliff exposes these sediments along the length of the coast. Dip of the strata means that south from the Nukumaru fault zone sediments exposed at beach level become progressively younger. Sediments exposed at beach level are also noted in Figure 9. South of the Wanganui River near Kaitoke coastal cliffs reappear briefly but for most of the coast large areas of sand dunes occur.

Recent Coastline Change North of Wanganui River

The coastline north of Castlecliff Beach is characterised by high cliffs cut in often unconsolidated siltstones and sandstones of the Nukumaruan Stage of the Wanganui Series (Lower Pleistocene). At the northern extremity of the study area the cliffs are cut in the more resistant Nukumaruan Limestone which is eroded only slowly. South from Nukumaru to Ototoka Stream the cliffs are protected from the sea by a debris slope composed of slumped cliff and wind blown sand. On these debris accumulations vegetation has become established giving the whole area, which was obviously being eroded by the sea at some time in the last few centuries, the impression of stability.

Moving south the coastline is broken by the deeply entrenched Okehu Stream. The mouth of this river moves in position on the beach and at times of high wave activity may run almost parallel with the cliff line for several chains before reaching the sea. This tendency, despite the small size of the river, has resulted in the removal of debris backing the cliff and allows the sea and river to attack directly the unconsolidated cliff material resulting in localised cliff erosion.

TABLE 2

Coastline Retrogradation Near

Mowhanau Stream

1876-1893	5.00 feet/annum	(Source: Fleming p.22)
1893-1916	1.43 feet/annum	(Source: Fleming p.22)
1942-1953	2.23 feet/annum	(Air Photo)
1953-1962	1.50 feet/annum	(Air Photo)
1962-1969	2.22 feet/annum	(Field Survey)

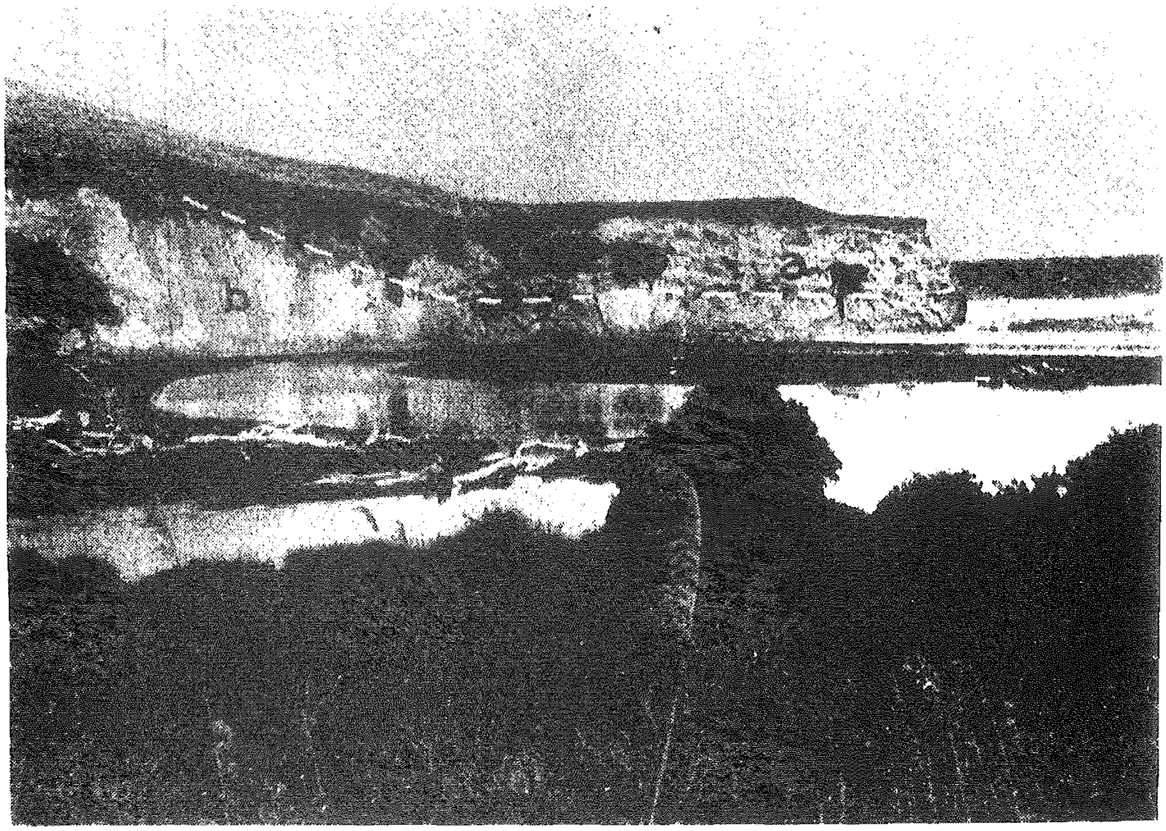


Plate 1 (a) Kai-iwi Beach (1950) — Photo (C.A. Fleming)

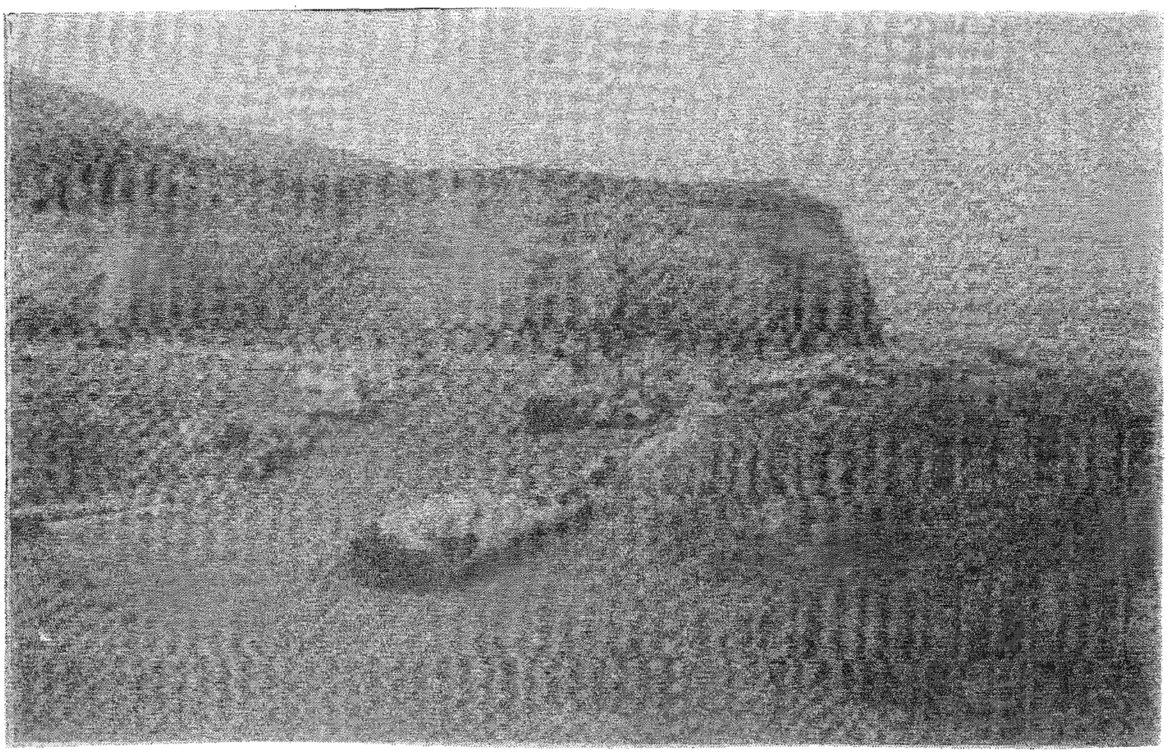


Plate 1 (b) Kai-iwi Beach (1970)

South of the Okehu river a debris slope again forms in front of the cliff. The cliff is still being eroded at the mouth of Ototoka Stream but generally the coast between Ototoka and Okehu streams is stable. Local inhabitants claim that the remnants of an old fenceline 50-60 years old is still approximately the same distance from the cliff edge now as it was when originally built.

From Kai-iwi River south to a little south of Omapu Stream two miles from Kai-iwi Beach impressive erosion of the sea cliffs is taking place. More exact survey data allows erosion rates to be calculated. Table 2 tabulates recession of the cliff just south of Mowhanau Stream for a period of 90 years. Rates of erosion have fluctuated over the years and at present show little sign of slowing. Plate 1 demonstrates photographically the very rapid rate of erosion. Little accumulation of the debris material occurs at the foot of the cliffs as happens further north and consequently erosion continues unimpeded.

A few chain south of Omapu Stream the coast is no longer being eroded. A few decades ago waves were able to reach the cliff but today the same areas are protected from further attack by accumulations of dry sand and driftwood.

Coastline Change South of Wanganui River

South of the Wanganui River the large area of sand dunes backing the coast have been modified only slighly by the sea.

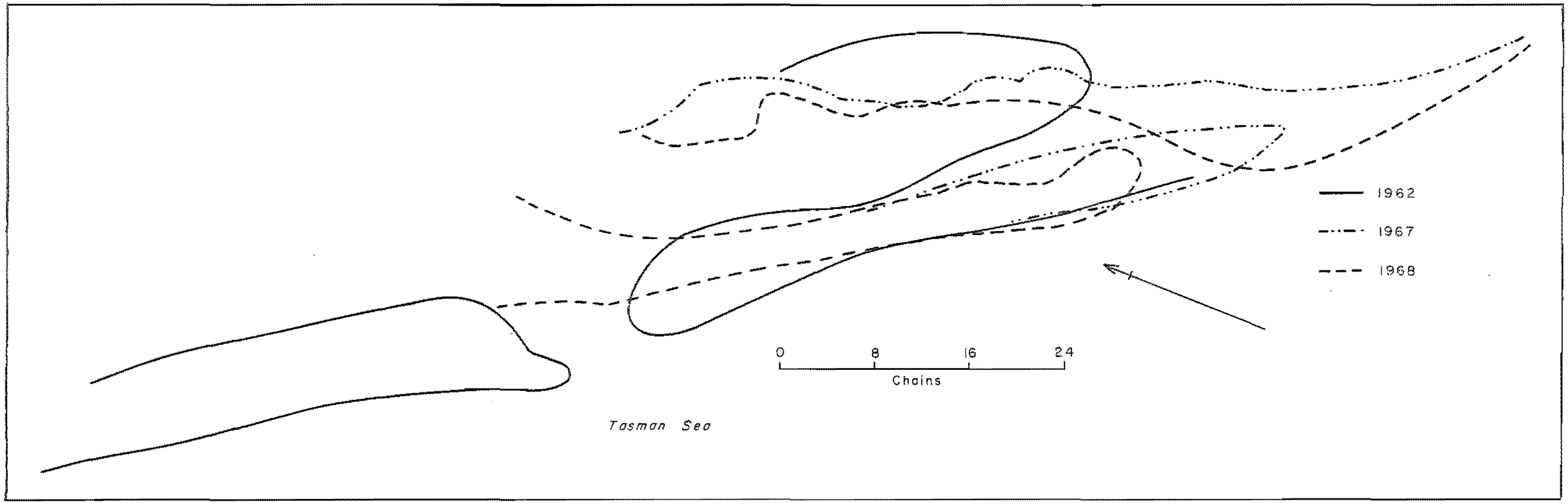


Figure 10   Coastline changes at the mouth of Turakina River

From Wanganui Airport to just north of Whangaehu River the beach is narrow and backed by a sandbank which varies in height from 5-35 feet. 3½ miles north of Whangaehu River the Rapanui Surface is again exposed at the coast. This bluff and the sandbank are occasionally undermined by large seas but changes are not great. South of Whangaehu River a wider beach, backshore and sand dunes are little effected by the sea. At the mouths of the Turakina and Whangaehu Rivers, however, the position of the outlets have changed frequently as have the length and shape of the sand spits forming at the mouths. Figure 10 shows a typical set of changes at the mouth of the Turakina River. This does not suggest any long-term progradation or retrogradation but further south at Santoft the beach has prograded 200 feet since the Fusilier was wrecked there 80 years ago.

Coastal Vegetation

Most of the Wanganui Coast has been classified by Hocking (1964a) as sand country. Hocking suggests that the original vegetation of the sand country has been removed in the last century as a result of over-grazing and burning. Problems associated with the resulting drifting sand have been encountered throughout New Zealand resulting in Acts of Parliament as early as 1908 (1908 Sand Drift Act). Cowie (1963) suggests that modification of the natural vegetation probably iniated a recent (European times) dune-building phase known as the Waitarere Phase. Active areas of sand dunes occur along a considerable stretch of Wanganui Coast from Waitotara southwards.

Summary

The coast north of Wanganui River is characterised by high 100-200 foot cliffs backing the beach. These cliffs are in easily erodable unconsolidated siltstones and sandstones and date from the Lower Pleistocene. Recent accumulation of cliff debris and sand blown from the beaches by wind protects most of the coast from further erosion except in the vicinity of Kai-iwi Stream where rapid erosion of the cliffs continues to take place.

Large inputs or material to the coast during the Late Pleistocene from rivers especially Wanganui River resulted in large accumulations of dunes south of the Wanganui River. Removal of vegetation during European settlement of the area encouraged dune instability but recent policies of dune fixation has successfully stablised much of the coast. The natural coastline protection afforded by these dunes has prevented any serious coastal erosion and further south there are reports of recent progradation.

The geologic and physiographic nature of the present coast suggests a continuing ample supply of sedimentary material.

BEACH SEDIMENTS

General

Work on sediments along the Wanganui Coast has previously been attempted by Finch (1947), Fleming (1953) and Willett (1959), working on mineralogy, and McDougall and Gibb (1970) who worked on offshore sedimentation. This previous work will be first summarised and then complemented by an examination of size sorting of sediments on the beaches and the nearshore.

Previous Work

Offshore Sediments:

Work by McDougall and Gibb (1970) shows that off the Wanganui coast the sea bed is gently shelving (50 fathom contour 12-13 miles off the Wanganui River Mouth). The sediments covering the shelf are mainly medium to fine sand in depths less than 50 fathoms with quantities of organic carbonate remains and finer sediments at greater depths. Just north of the Whangaehu River Mouth offshore sediments become finer and are characterised by muds and greater quantities of organic carbonate remains.

Mineralogy:

Mineralogy of coastal sediments has been studied by

Finch (1947) and later by Willett (1959). Fleming (1953) following Finch makes the following comments:

(1) Beach sand is essentially similar to adjacent dune-sand except that it contains concentrates of heavy minerals, mainly magnetite.

(2) Beach sand from Nukumaru contains 65% of magnetite amongst its grains, at Kai-iwi Beach 31.8% and at Castlecliff 6.4%.

Finch notes that titaniferous iron-ore similar to that at Fitzroy, Patea and north-west of Wanganui River mouth occurs south of Wanganui River but in much lower quantities. He also found that south of Wanganui River high percentages of quartz, feldspar and hypersthene occurs. North of the river hypersthene is relatively uncommon in the beach sands.

Willett (1959) examined a number of samples collected in the vininity of Wanganui River mouth and up the river at Whakaihuwaka, Matahiwi, and Pipiriki. Size analysis of this limited suite of sediments suggests that sediment of the Wanganui River is marginally finer than beach and bar sediments. These sediments cannot, however, be considered representative of the entire river bed. Local Wanganui sand and shingle merchants (Bullocks) obtain fine sand, coarse sand and shingle from the river a short distance from Wanganui. Willett suggests that the majority of sediments carried by the river are fine and are probably washed out to sea past the bar. He does not preclude the possibility of

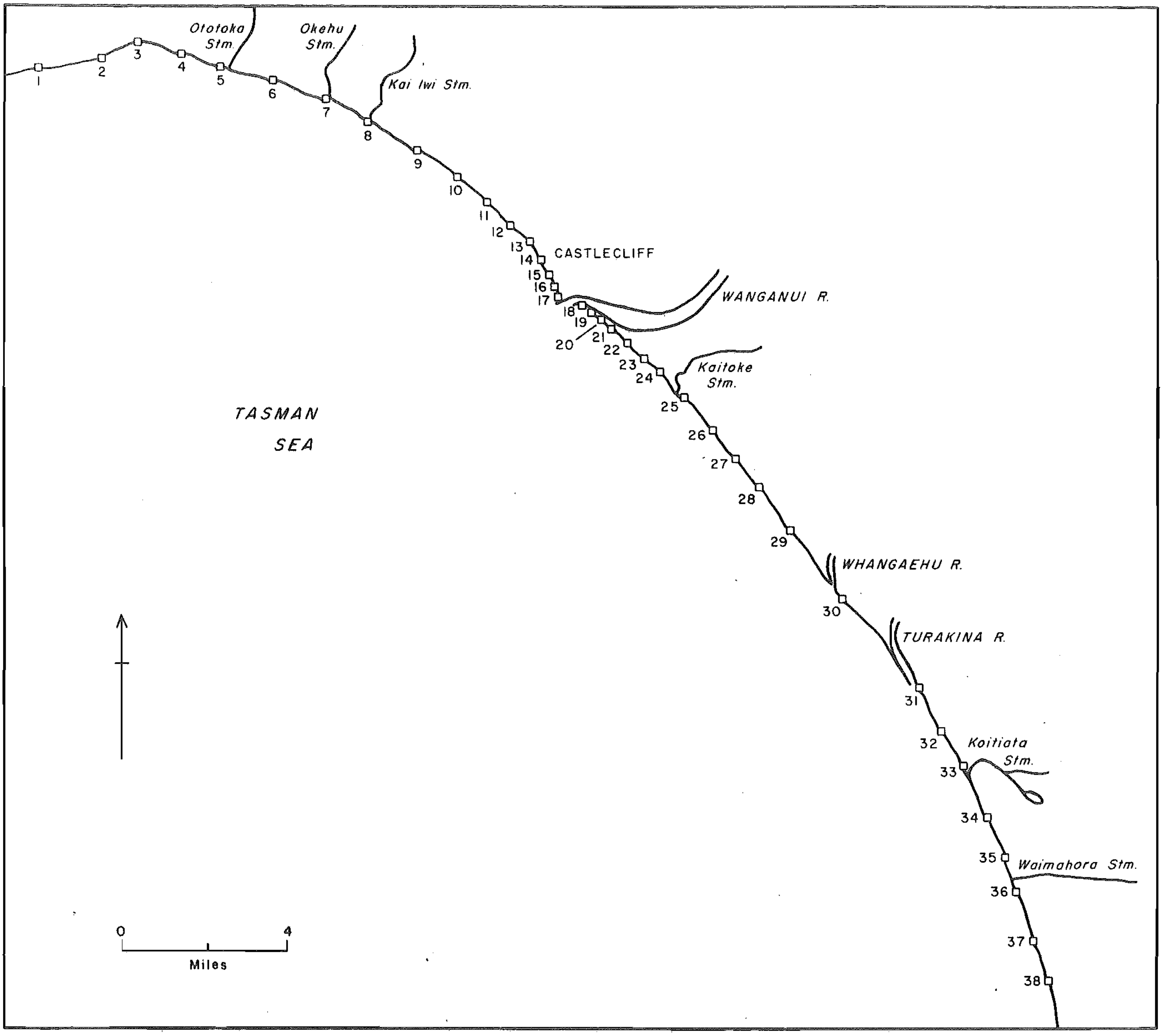


Figure 11 Location of sample stations

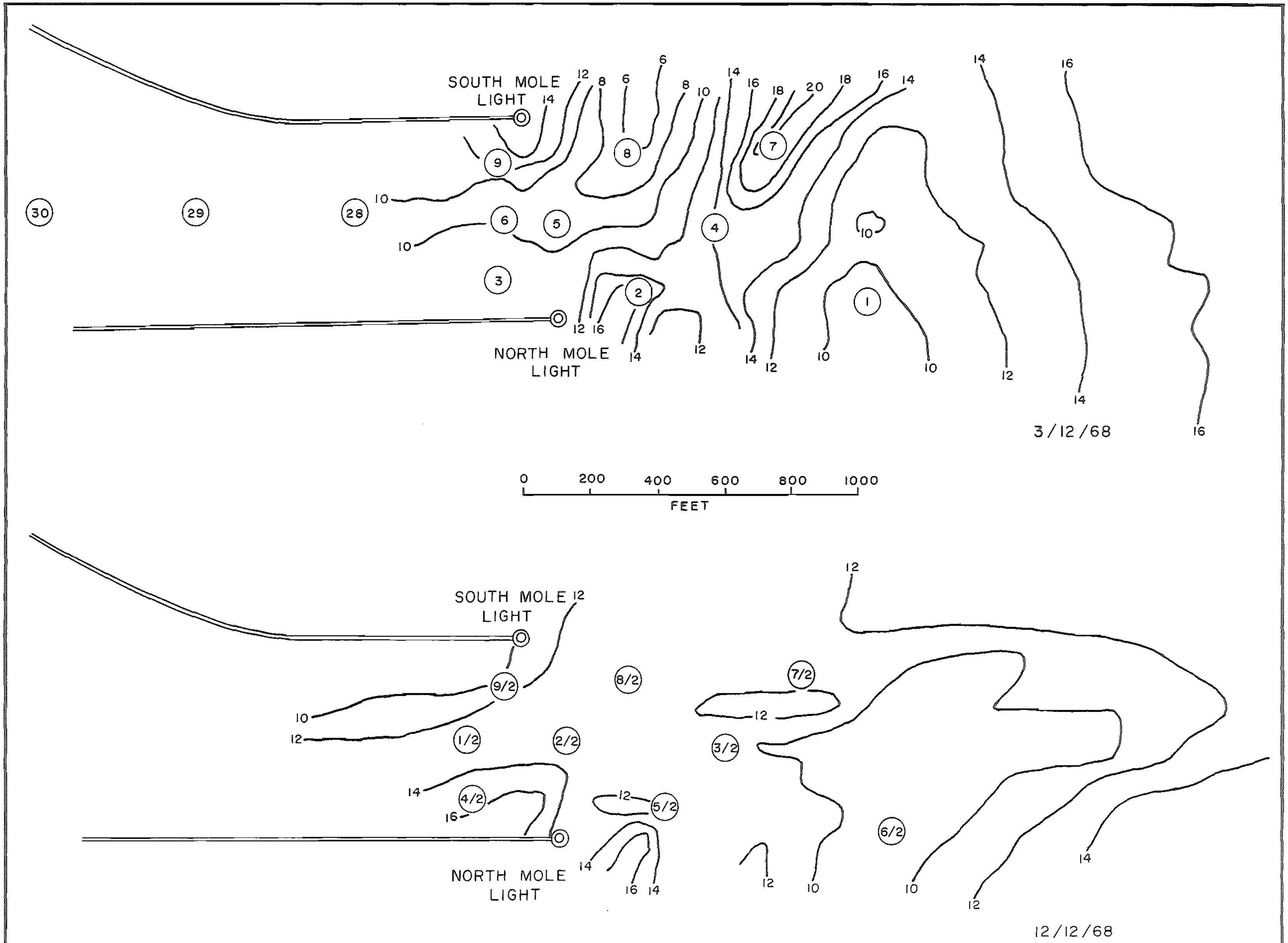


Figure 12 Entrance Wanganui Harbour – December 1968 (Figures in circles refer to sample numbers, other figures to water depth in feet LWOST)

material being deposited in shallower water. Willett also comments on the increased quantity of hypersthene south of the river mouth and states that this evidence further suggests input of sediment to the beaches and nearshore from the Wanganui River.

Grain Size Examination

Collection and Laboratory Analysis:

Between 27 November and 3 December 1968 samples of beach sediments were collected between the Waimahora Stream and the Waitotara River. Sample stations were spaced approximately one mile apart except near the Wanganui River where distance between sample stations was decreased to a minimum of 24 chains. A distance of 36 miles of beach was covered (see Figure 11 for station location). Additional samples were collected from the offshore zone and from the Wanganui River Mouth on 3 December and again on 12 December. The locations of these sample stations are shown in Figure 12).

At each of the 38 beach stations four samples were collected to correspond with:

(a) the dune area behind the beach (labelled A);

(b) the backshore or berm area (labelled B);

(c) the mid-tide point (labelled C); and

(d) the low-tide point (labelled D).

Approximately 400 grams of sediment was scraped from the beach surface at each point. At some points samples were not taken because of the nature of the material (e.g. hard-rock cliffs). Samples were collected offshore and in the river from the Wanganui Harbour Board Pilot vessel with a U.S.B. M54 sampler (weight 150 pounds) lent by the Ministry of Works.

In addition five samples were collected 50 yards from the high tide mark at stations 13, 14, 15, 16, and 17 (Castle-cliff Beach area) and one sample was collected in the river bed of the Whangaehu River at the main highway roadbridge. These samples are labelled 13X, 14X etc. and the Whangaehu River bed sample labelled 'Whangaehu River bed'.

Samples were washed, dried and then split to about 100 grams. Sieving was carried out on sieves conforming to the British Standard Code of Practice No. 410. The sieve gradation was $\frac{1}{4}\emptyset$. Each sample was shaken for 15 minutes on an 'Endrock' shaker and the contents of each sieve weighted to the nearest hundredth of a gram. Cumulative frequency curves were drawn on logarithmic probability paper and the percentile values necessary for calculation of mean grain size, sorting, skewness and kurtosis parameters read off. Calculation of the various parameters was according to the formulae of Folk and Ward (1957). Formulae used and grain size statistics calculated are recorded as an Appendix. Where sediments contained silt and clay sized material analysis was by a combination of sieving and hydrometer size determination.

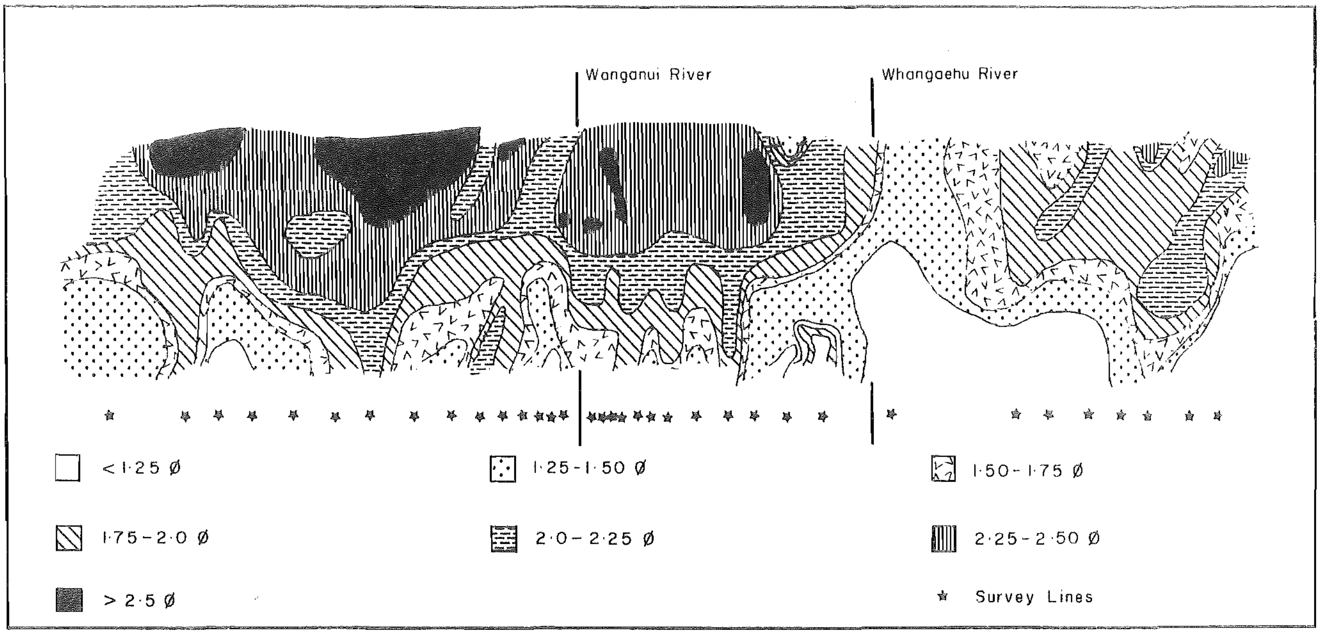


Figure 13 Variation in mean grain size along Wanganui Coast

Beach Sediments

(1) Mean Size

Grain size characteristics vary considerably along the Wanganui Coast. Figure 13 shows variation in graphic mean size. For ease of interpretation the coastline has been 'straightened' so that the coast is presented in stylised form. Distances between stations have been drawn to scale. Distances between samples at the individual stations are not at scale. A number of broad trends emerge from this diagram.

(a) Mean grain size increases towards the low tide mark.

(b) Mean grain size increases southwards.

(c) Considerable local variation occurs.

To help isolate trends in grain size, trend surface analysis was performed on the data (Chorley and Haggett, 1965). Essentially trend surface analysis is a procedure by which broad trends can be isolated from data which contains considerable background noise. The method is analogous to two-dimensional regression of graphic data except that three-dimensional regressions are calculated. The degree of explanation, or fit, is expressed in the same way as two-dimensional regressions, percentage reduction in total sum of squares. The choice of surfaces fitted to the data was restricted to the first three orthogonal polynomials (linear, quadratic and cubic) because of their mathematical simplicity. Small scale variations in the data are reflected

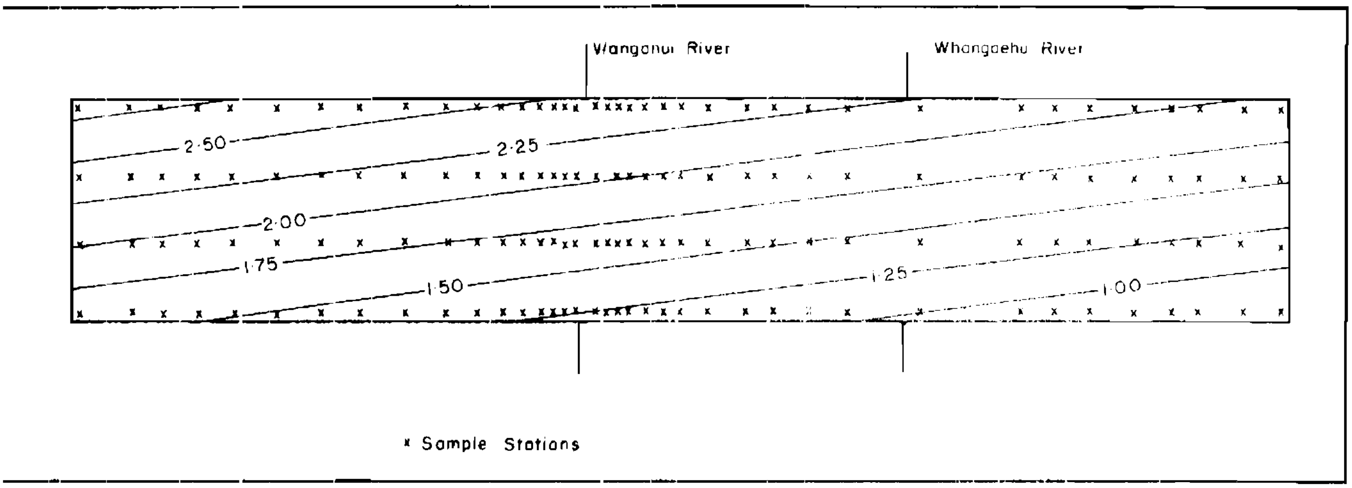


Figure 14 Mean grain size trend surface

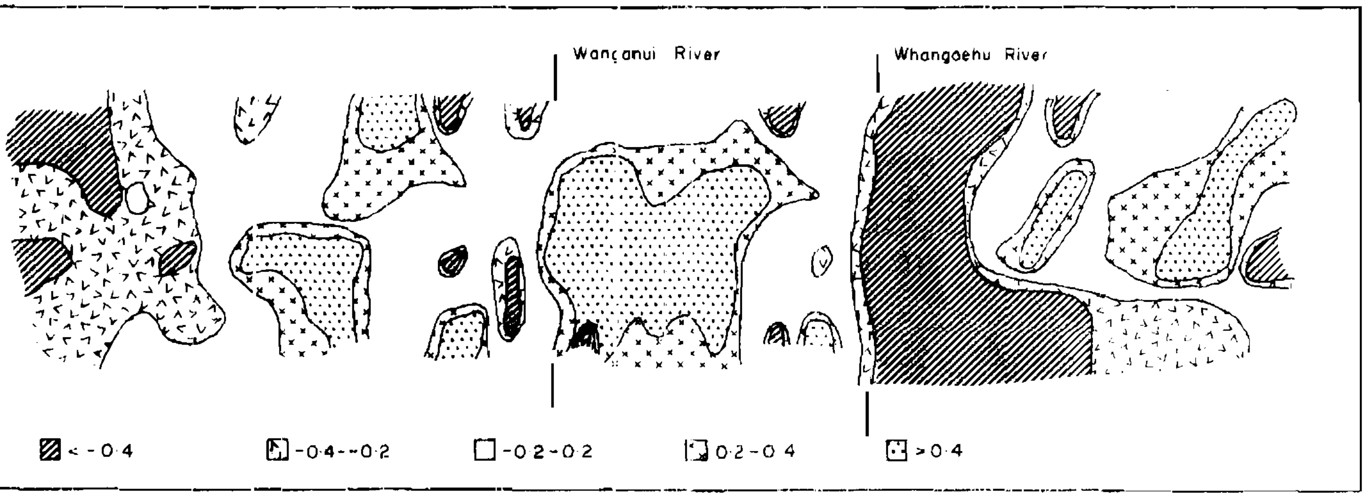


Figure 15 Residuals from trend surface (mean grain size)

in residual values. As considerable internal variation occurs on a beach the technique is well suited to dealing with beach data.

Trend surface analysis confirmed the above mentioned trends. A linear surface (Figure 14), explaining 25.82% of the variance, suggests that sediment size increases southwards and towards the low tide mark. Higher order surfaces explained little more of the variance (quadratic 28.6% and cubic 34.5%). A map of the residuals (deviation of actual grain size from that predicted by the trend surface) is presented in Figure 15. Two major points emerge as potentially significant.

(a) An area of high positive residuals (finer sediments than predicted) occurs just south of the Wanganui River.

(b) Just south of the Whangaehu River an area of high negative residuals (coarser sediments than that predicted) occurs.

Further examination of the coast was attempted by splitting the beach into two sections (north and south of the Wanganui River) and repeating the trend surface analysis for each area. North of the river the linear surface explained 42.8% of the variance, higher order surfaces increasing the explanation little more (quadratic 50.7%, cubic 52.4%).

Longshore differences in sediment size on the north beach are not distinct. Trend surfaces analysis suggests that sediment possibly fines towards the Wanganui River but

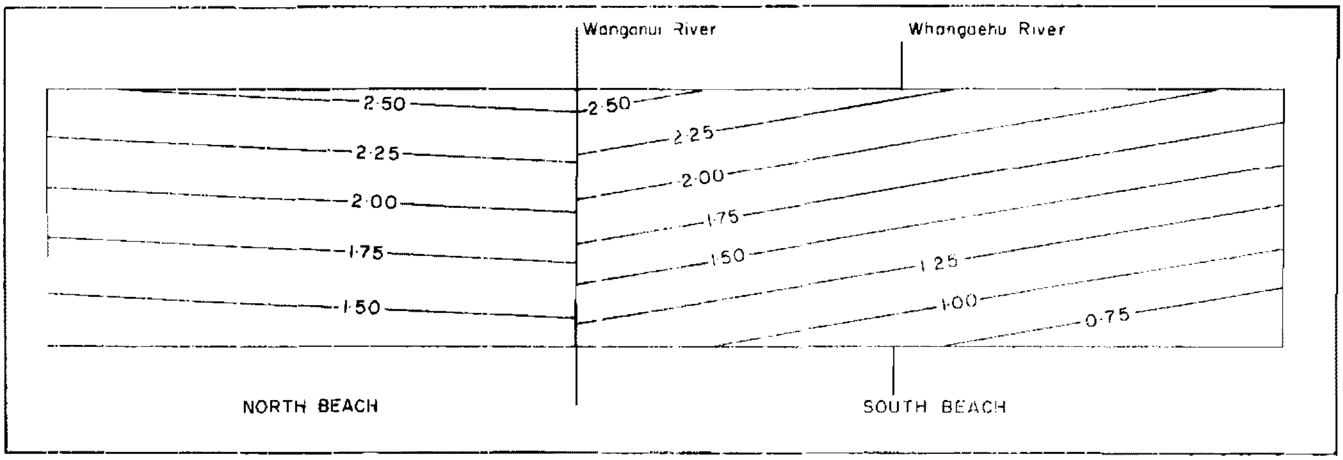


Figure 16 Trend surface north and south of Wanganui River

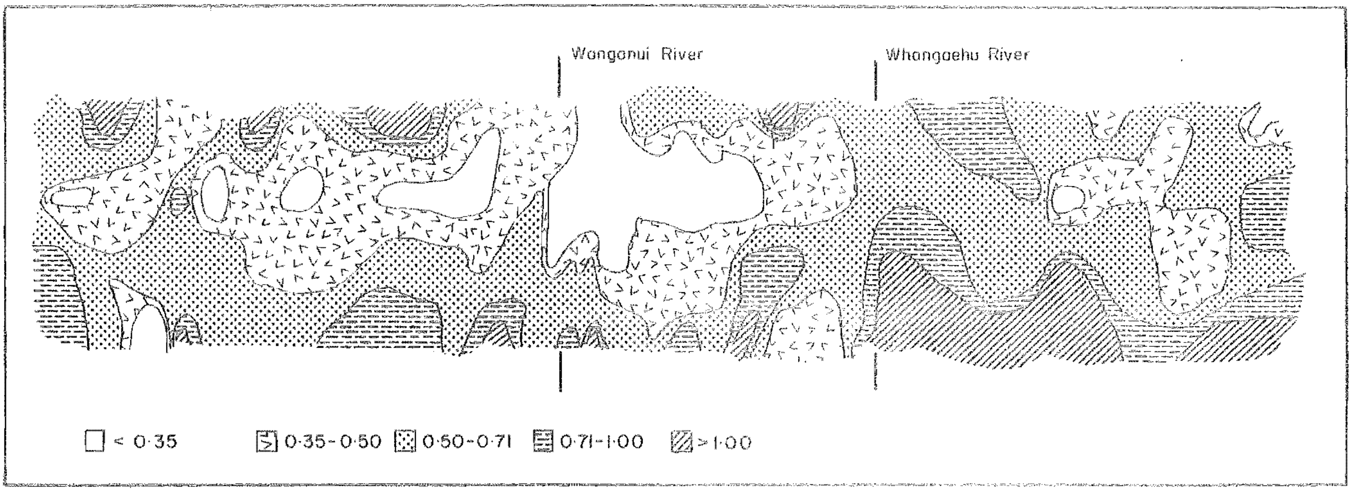


Figure 17 Variation in grain size sorting along Wanganui Coast

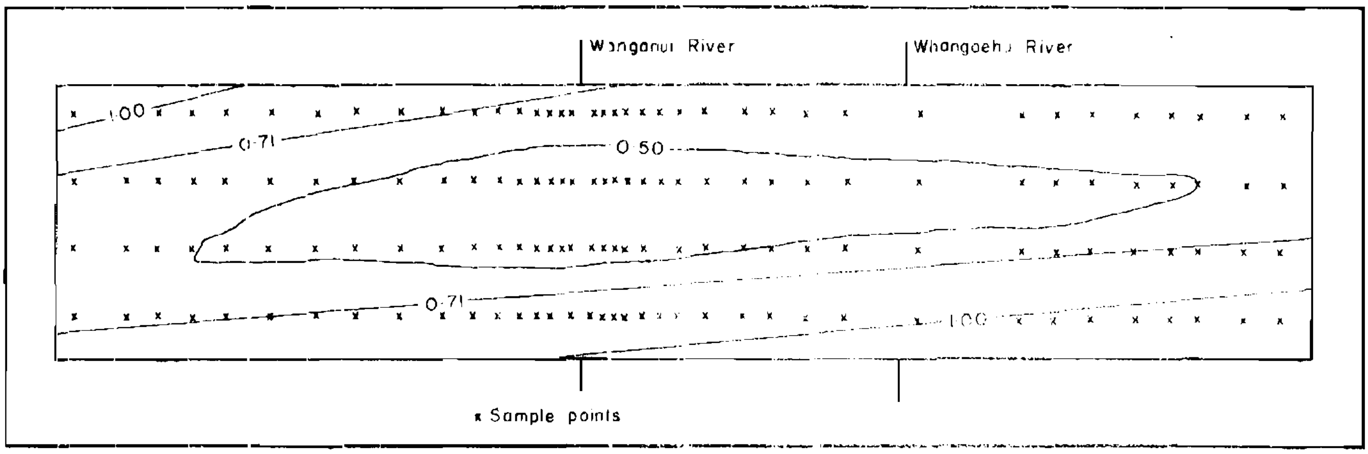


Figure 18   Mean sorting trend surface

this is by no means an established trend. Size variation that did occur north of the river mouth was essentially shore normal (Figure 16). South of the Wanganui River trend surface analysis explained less variance than north of the river (linear 24.4%, quadratic 32.7% and cubic 34.0%). The linear surface (Figure 16) suggests that sediment is coarser towards low tide and southwards.

(2) Size Sorting

Size sorting characteristics of beach sediments were investigated in a similar manner to mean grain size. Data (mapped Figure 17) were subjected to trend surface analysis, the beach was split into two at Wanganui River, and the data re-analysed. The linear surface explained only 2.7% of the variance for the whole beach. The quadratic surface increased the explanation to 22.7% (Figure 18). Similarly the quadratic surface provided the best fit to both north and south beaches, (north beach, linear 1.4%, quadratic 21.8%; south beach, linear 18.5%, quadratic 36.9%).

This analysis suggests the following points:

(a) Sorting values decrease from the dune and backshore areas to the mid-tide line where the best sorted sediments are found and then increase towards the low-tide mark.

(b) On the south beach sorting improved northwards towards Wanganui River.

(c) On the north beach sorting improved southwards towards Wanganui River.

(3) Other Sediment Parameters

Analysis for trend of skewness and kurtosis values failed to reveal any definite areal trends. Neither the linear, quadratic nor the cubic surfaces explained more than about 5% of the variance.

Offshore Sediment

Offshore samples were collected at depths of 10 and 20 feet below mean low water (spring tide) at stations 13, 14, 15, 16, 17, 19, 21 and 23. The precise location of these stations is held in the archives of the Wanganui Harbour Board. Mean size of these sediments ranged from 2.57ϕ to 3.05ϕ and size sorting values varied between 0.26 and 0.60. Offshore sediments are therefore quite different in size and sorting characteristics than beach samples. Sediments were generally finer and better sorted. Also noticeably different were colour characteristics. Beach sands along the Wanganui Coast, especially north of Wanganui River, are typically black in colour as a result of high concentrations of magnetite. Offshore samples were much lighter in colour. A simple bromoform split of heavy and light minerals for two representative samples (Nos. 17 and 22) revealed that offshore sediments contain less than 5% heavy minerals.

TABLE 3

Offshore Sediment Samples

Sample No.	M_z	3/12/68	Water Depth	Topography
1	2.68	0.68	9' 3"	Bar offshore
2	1.93	0.75	18' 0"	Trough close to N.Mole
3	2.40	0.35	11' 6"	Just inside entrance
4	2.92	1.06	14' 3"	Trough
5	1.07	0.96	8' 6"	Barr offshore
6	1.78	0.50	9' 9"	Just inside entrance
7	2.58	0.34	21' 0"	Trough
8	1.78	0.49	7' 0"	Bar
9	2.40	0.35	12' 6"	Just inside entrance
		12/12/68		
1/2	2.52	0.41	12' 0"	Inside entrance
2/2	1.60	0.69	12' 9"	Just outside entrance
3/2	1.85	0.72	10' 9"	Shoal
4/2	-1.07	1.70	17' 6"	Inside entrance
5/2	2.50	0.39	11' 6"	Just outside entrance
6/2	2.70	0.56	10' 0"	Shoal
7/2	3.55	1.24	12' 0"	Shoal
8/2	1.47	0.90	13' 3"	Just outside entrance
9/2	2.43	0.49	10' 0"	Inside entrance

Entrance Sediment

Two sets of samples were collected at the mouth of the Wanganui River. The first set was collected on 3 December 1968. Conditions in the week preceding the collection were mild and fine. Wave height ranged from 5.0 feet on 1 December to 0.4 feet on the day of collection. Wave period was between 10 and 12 seconds and the wave train approached from the south. River flow was normal.

The second set of samples was collected on 12 December. Between 3 and 12 December conditions changed considerably. Southerly waves predominated with a few days of northerly conditions. Wave height fluctuated from 2.5 feet to 8.7 feet and period from eight to 10 seconds. On 7 December a very large flood (peak 100,500 cusecs) caused considerable change at the entrance. Figure 12 shows the locations of the samples and demonstrates the morphological changes that occurred.

Size and sorting characteristics of entrance sediments varied widely. Mean size ranged from 1.07ø to 2.92ø on 3 December and from -1.07ø to 3.55ø on 12 December. Sorting varied from 0.34 to 1.06 on 3 December and from 0.28 to 1.70 on 12 December. Table 3 presents grain size characteristics of the sediments, depth of water where they were collected, and the morphological characteristics of the bottom at the collection point.

(1) Pre-flood samples

As expected both samples collected from the inner bar (5 and 8) were characterised by relatively coarse sediments. The sample collected on the bar further offshore (1) was collected from deeper water and was understandably finer. Samples collected in the offshore trough were finer than the bar samples except in the case of sample (2) which was located in deep water near the north mole, an area which is often described as a scour hole. Sediments collected inside the entrance were not as fine as those found in trough areas but finer than those on the bars. Sediments (3) and (9) collected at the edges of the channel were finer than sample number (6) collected in shallower water in the middle of the channel.

(2) Post-flood Samples

Sediments collected after the December 7 flood are quite different to those collected previously. The bar-trough topography of 3 December was absent on 12 December. Sediments inside the entrance are not greatly dissimilar to those collected earlier except sample (4). On 3 December 11.5 feet of water existed at this site but by 12 December 17.5 feet of water covered the area and the sediment was much coarser and very poorly sorted. Outside the entrance sediment characteristics varied. Samples (6/2) and (7/2) located on the large shoal were fine and poorly sorted.

Castlecliff Dune Samples

The five samples collected in the dune area backing

TABLE 4

Differences in Grain Size Characteristics on Castlecliff Beach

	Rear Dunes	Dunes	Backshore
M_z	2.10	2.18	2.22
σ_I	0.47	0.41	0.47

't' Values

	Rear Dunes	Dunes	Backshore
Rear dunes	-	2.86 *	0.00 *
Dunes	2.35 **	-	0.17 *
Backshore	1.16 **	0.37 **	-

Left triangle mean size

Right triangle sorting

* Not significant at .05 level

** Not significant at .01 level

Castlecliff Beach were little different in size, sorting and visual characteristics from the berm and dune samples collected in front of them. Differences in size and sorting characteristics between inland dune, foredune and berm were insignificant using a Student's 't' test. The results of the Student's 't' test are shown in Table 4.

Whangaehu River Sample

Unfortunately only one sample was collected from the bed of the Whangaehu River. This lone sample tells very little about the nature of bed material in the river except that at the point of collection, which is not far from the mouth, a wide range of size grades exist. Material size in this one sample ranged from very fine sand sized material to shingle sized material.

Summary and Conclusions

Previous investigations of Wanganui Coast sediments conclude that the quantity of magnetite in beach sands decreases south from Taranaki suggesting that the sediment moves predominantly in a southerly direction and that it probably has its source near Taranaki. South of the Wanganui River mouth both Finch (1947) and Willett (1959) found increasing quantities of minerals which probably had their origin in the catchment of the Wanganui River.

Grain size and sorting of beach sediments varied greatly from sample to sample but trend surface analysis suggested that sediment fined towards the Wanganui River. South of the Wanganui River this trend was quite distinct but north of the river it was not well defined. Examination of residuals from trend surface analysis of the entire suite of beach samples showed the most important departures from the predicted trend occurred just south of the Wanganui River and again just south of the Whangaehu River. That sediment was finer than predicted south of the Wanganui River could be attributed to a barrier effect caused by the river and moles or possibly to input of finer sediment from the Wanganui River. Both hypotheses have credit and will be discussed more fully in a later section on entrance dynamics.

Examination of sediment at the mouth of Wanganui River in the course of this study and previously by Willett (1959) reveals that entrance sediments bear marked similarities to neither the beach sediments north or south of the entrance nor to offshore or river sediments but instead suggest a mixing of river and beach sediments.

By combining previous mineralogical studies with this grain size analysis it seems reasonable to suggest that beach sediments moving along the coast have their origin in two major source areas. First, sediment is moved south from a Taranaki source area either directly alongshore or offshore and eventually onshore and secondly, large quantities of material are added from the catchments of the larger rivers.

The mouth of the Wanganui River is a major mixing area for sediments from both sources.

ENVIRONMENTAL CONDITIONS OF WANGANUI COAST

In this section various factors likely to effect coastline development will be discussed. First the Wanganui wave environment will be described, followed by a brief statement of probable coastline currents. The likely effect of various climatic factors are then considered and finally the flow regimes of the important rivers, especially Wanganui River, will be mentioned.

Wanganui Wave Environment

Little published information describing the wave environment of the New Zealand coast exists. Comments on the nature of the wave environment at Wanganui have been restricted to mentions in the Gibb Report (1962) and a report from the Hydraulics Research Station at Wallingford (1966). The Gibb report makes little comment on wave characteristics other than to mention that prevailing waves approach from the WSW. The Wallingford report divides waves into two types:

(a) waves generated by local winds; and

(b) waves generated in the Pacific Ocean.

They also state that local wind direction data suggests that the westerly and north-westerly directions will be of greatest importance.

(1) Data

For this study wave data were obtained from a site just north of the Wanganui River (collected by Wanganui Harbour Board) and from an oil rig offshore (Shell BP Todd).

(a) Wanganui Harbour Board data:

Wave data were collected by a Wanganui Harbour Board employee twice daily from a lookout station located on a high cliff a little north of the Castlecliff Surf Club. Wave height was calculated trigonometrically with the aid of a fixed buoy and theodolite. The difference in angle between the wave trough and the wave crest allowed wave height to be calculated. The observer took readings from a number of waves over a three to five minute period so that the height he obtained was a maximum. Wave period was calculated by counting the number of waves passing the buoy in a two minute period. The direction of approach and angle of the wave crest with the shore at break point was estimated by eye. Wave records were kept from October 1968 to December 1969 and the originals are held in the archives of the Wanganui Harbour Board.

(b) Shell BP Todd data:

Between October 1969 and February 1970 (five months) wave records were kept on board the Sedco 135F drilling rig. During October, November and December the rig was located at 39° 36' 45" S and 173° 26' 58" E in 259 feet of water (Maui 2) and during January and February at 39° 32' 11" S and 173° 27' 05" E in 360 feet of water (Maui 3).

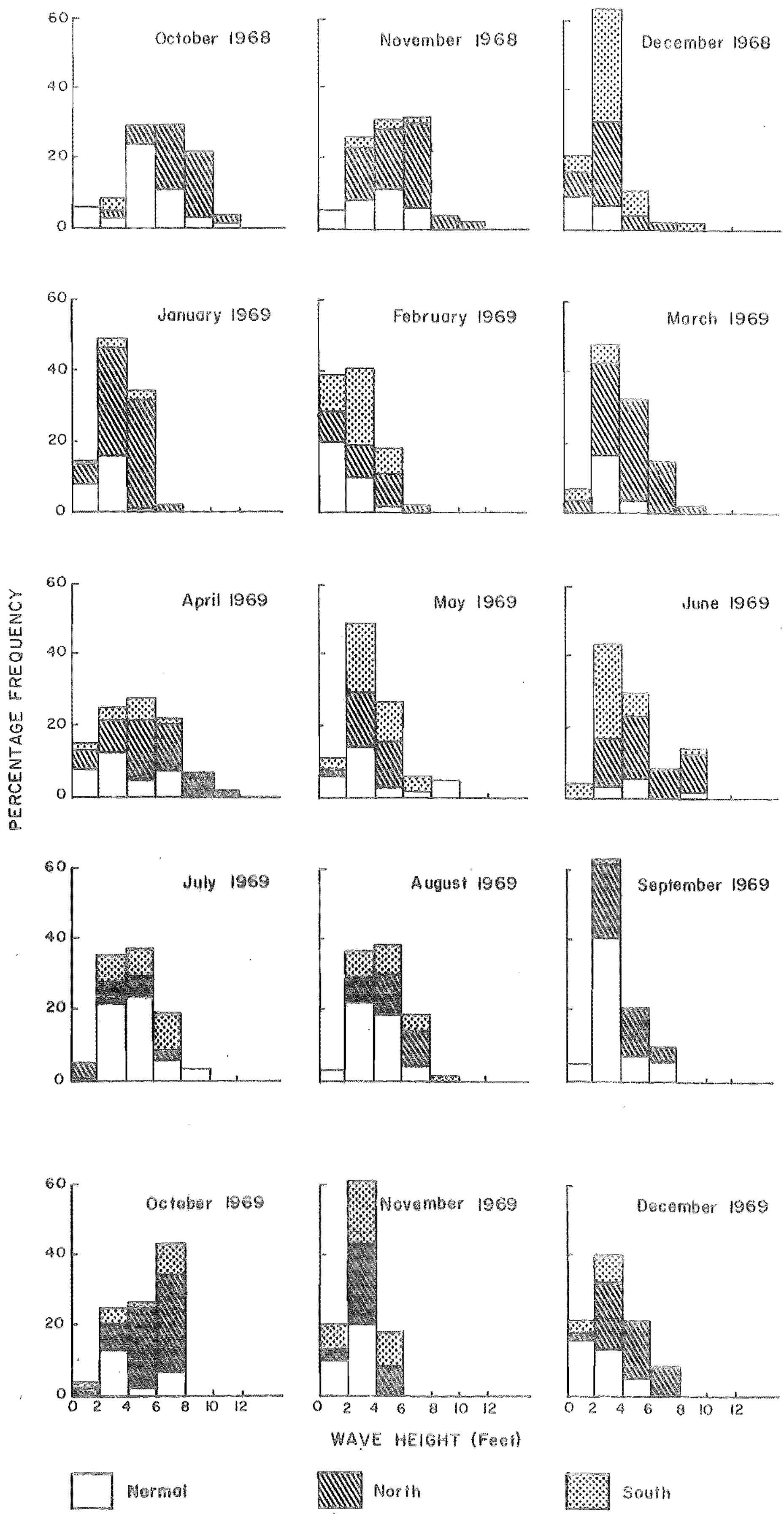


Figure 19 Wave height at Castlecliff Beach

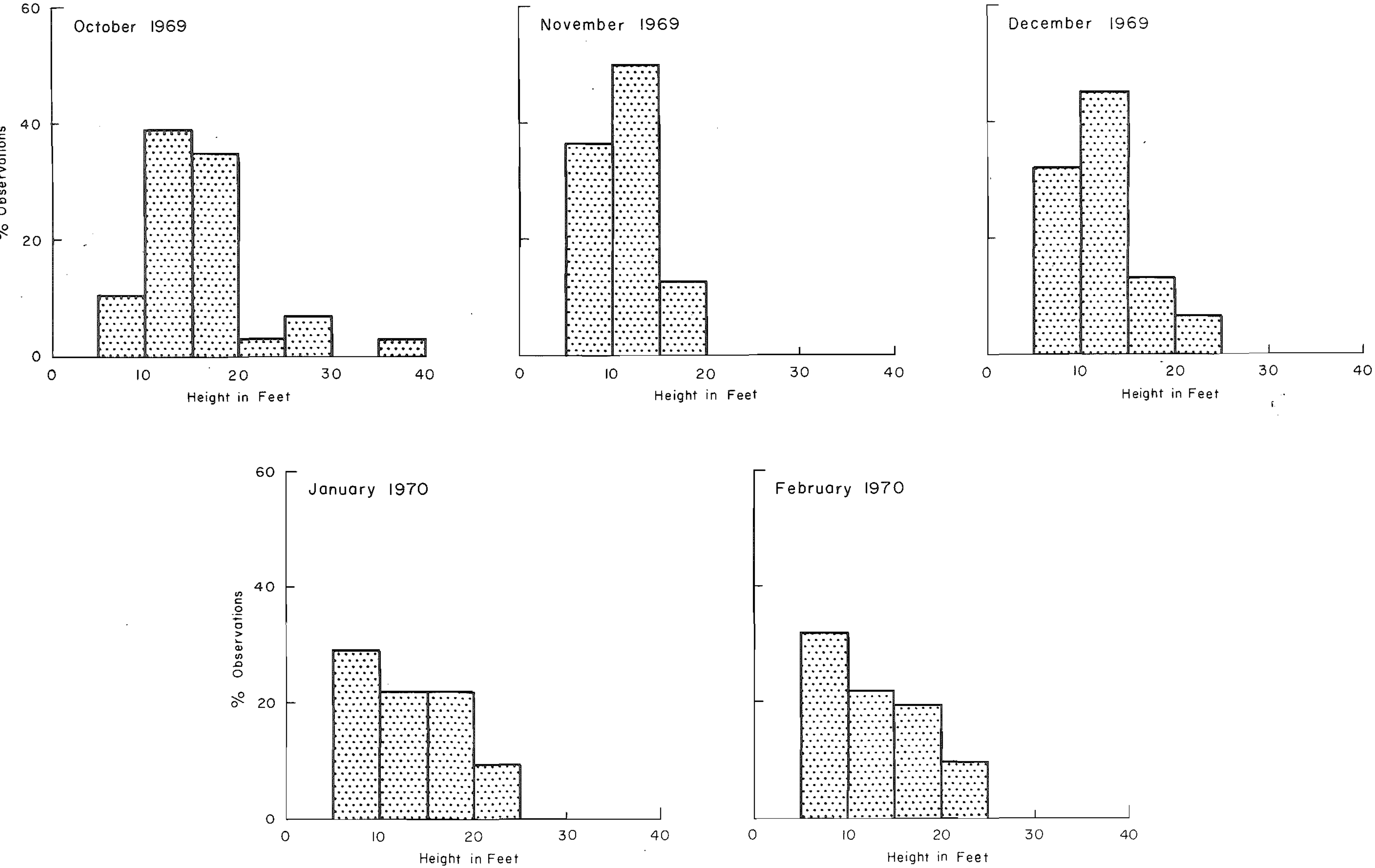


Figure 20 Offshore wave height

Wave height, direction and period parameters were all measured visually with the aid of a fixed guage. Six observations were made each day.

(2) Wave Height

Wave height at shore just north of Wanganui River fluctuated widely from day to day. Height sometimes fell to less than one foot and on occasions exceeded 10 feet. Mean wave height for the 15 months data was close to four feet. The available data are presented diagramatically in Figure 19. Although only 15 months data are available this is sufficient to suggest that any clearly defined seasonal differences in wave height do not exist. Both large and small waves occurred in winter and summer months. Figure 19 does, however, suggest that perhaps the period December - March is the period of lightest wave conditions.

On the Sedco rig offshore of Wanganui wave height in excess of 35 feet was recorded on one occasion. At other times wave height fell below one foot. Figure 20 shows offshore wave height for the five months of records. Mean wave height was about 11 feet, almost three times as great as wave height at shore.

The two sets of data were comparable only for the period October 1959 - December 1969. Certain similarities are apparent even from these limited data. Close to shore less than 30% of observations in October were less than four feet (annual mean). Offshore 13% of observations were less

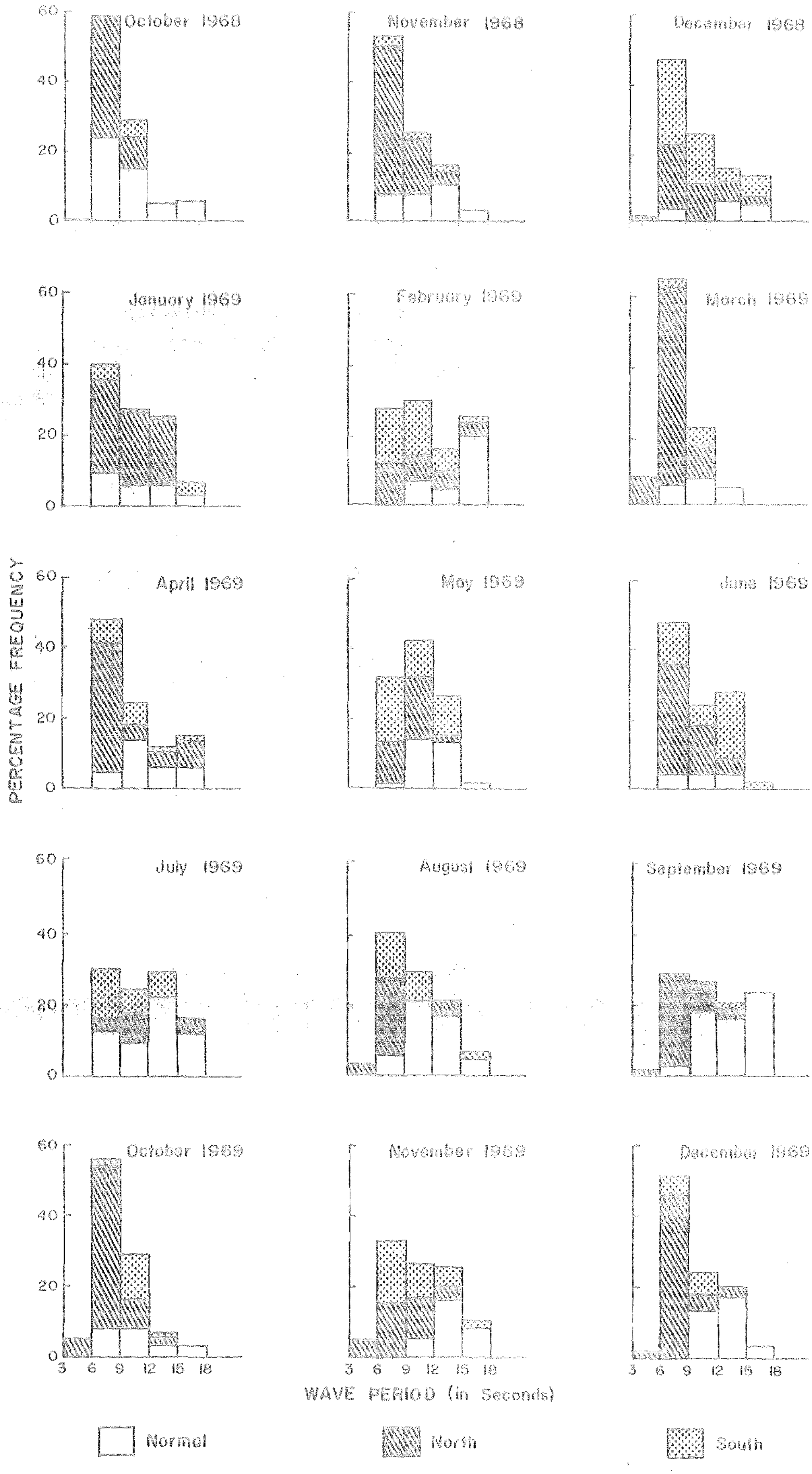


Figure 21 Wave period at Castlecliff Beach

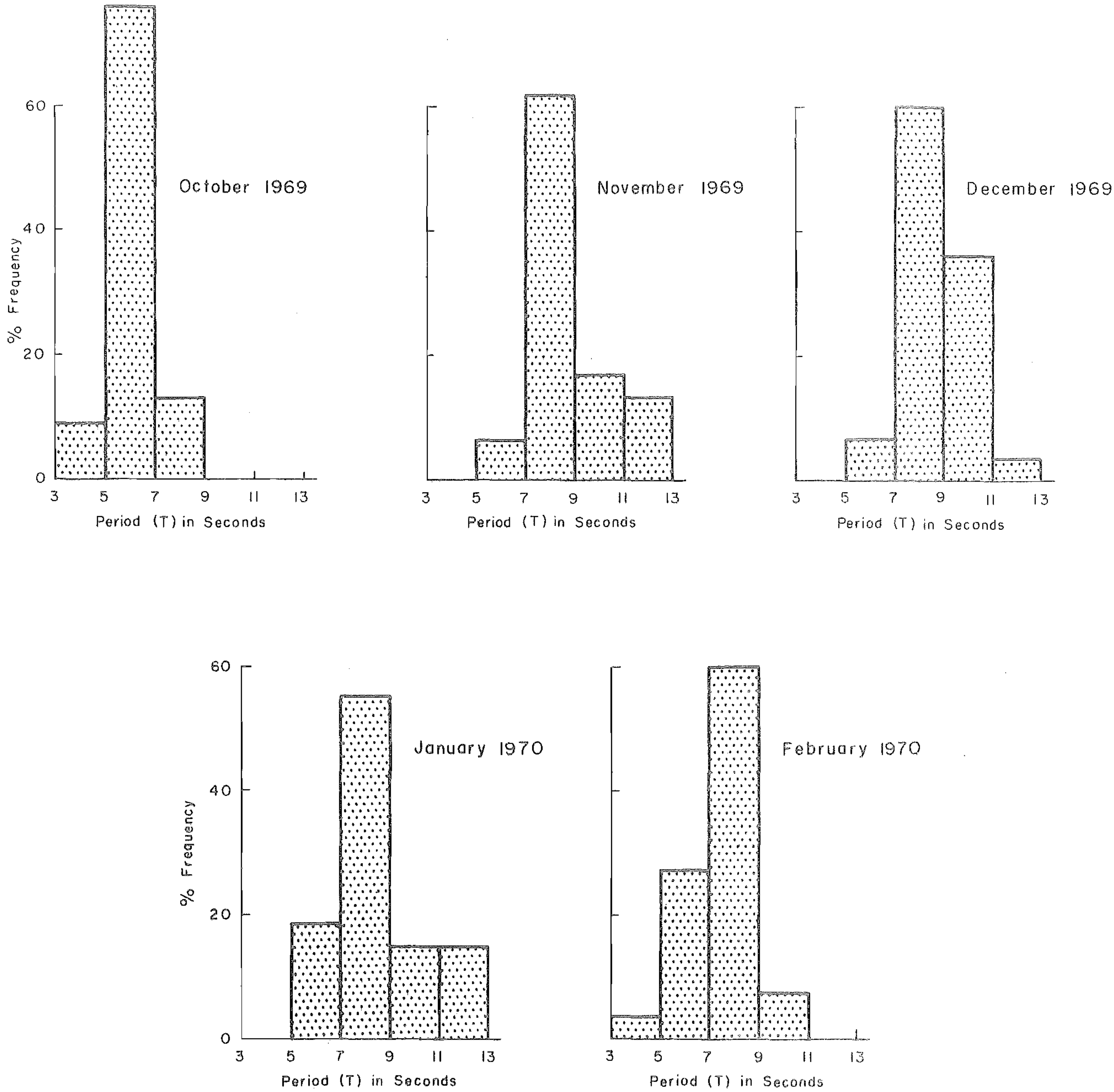


Figure 22 Offshore wave period

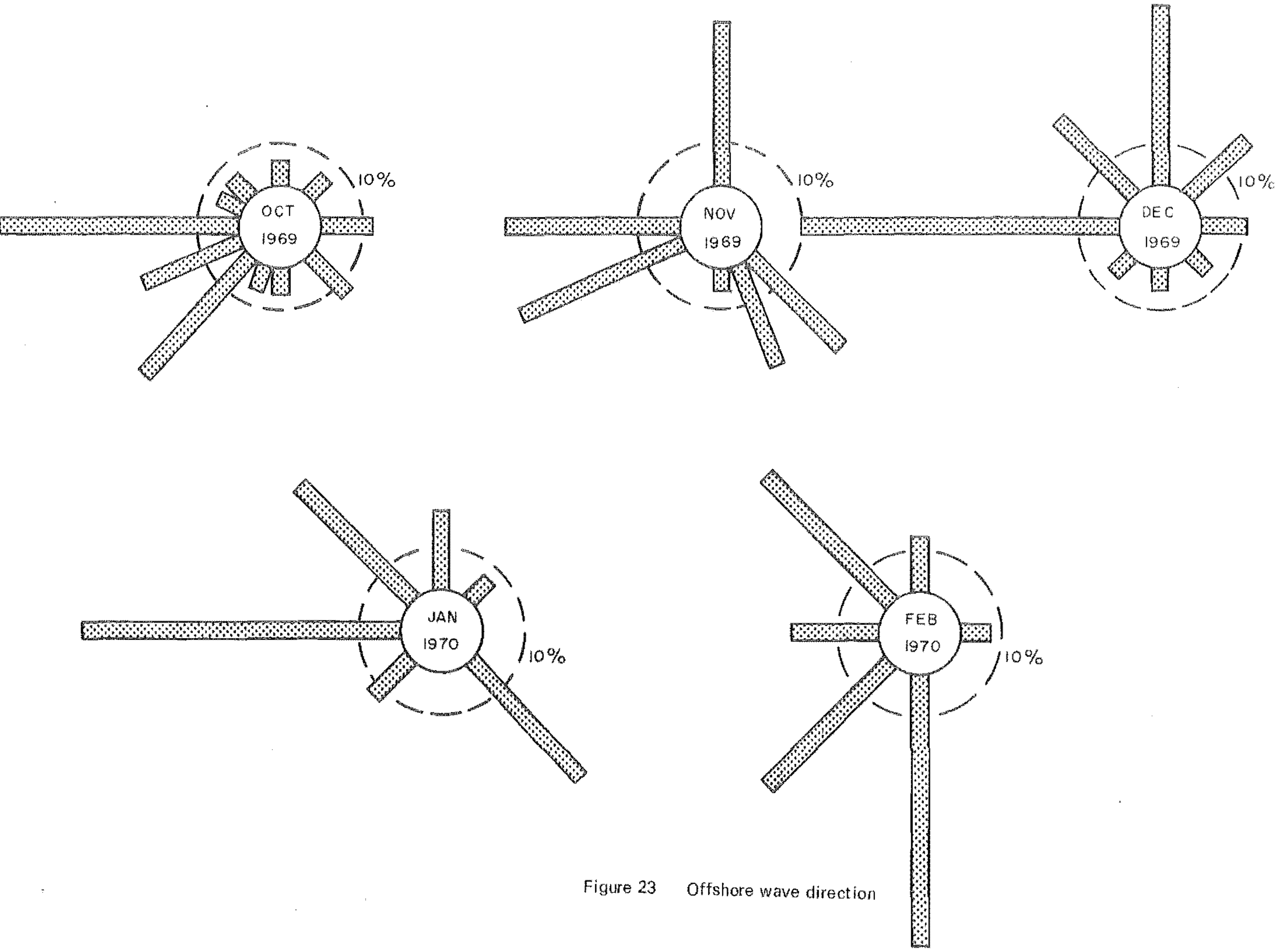


Figure 23 Offshore wave direction

than the survey mean of 11 feet. In November wave conditions were considerably lighter onshore (80% less than four feet). A similar pattern was also observed offshore (53% less than 11 feet). During December a wide range of conditions were observed at both and onshore stations. Periods of high waves offshore (in excess of 20 feet - October 10, 19, 20, December 25, 26) were also periods of high waves onshore (October 10 - 9.1', 6.4'; 19 - 4.9', 7.7'; 20 - 4.9', 7.7'; December 25 - 7.6', 7.8'; 26 - 7.6', 7.8')

(3) Wave period

Wave period at the shore ranged from five seconds to 18 seconds. Figure 21 shows that the majority of observations were between six and 12 seconds. An examination of Figure 21 reveals that the six to nine second group was the modal class for all months except February and May, mean period being approximately nine seconds for the year 1969. Figure 22 presents wave period data from the Sedco rig. Periods ranged from three seconds to 12 seconds and the modal class was the seven to nine second grouping. Mean period for the survey period was 7.5 seconds.

(4) Direction of Wave Approach

Waves approached the offshore Sedco rig from most quarters of the compass. Figure 23 suggests that most waves approached the rig from northwest to southeasterly directions, westerly quarters being the most common quarter

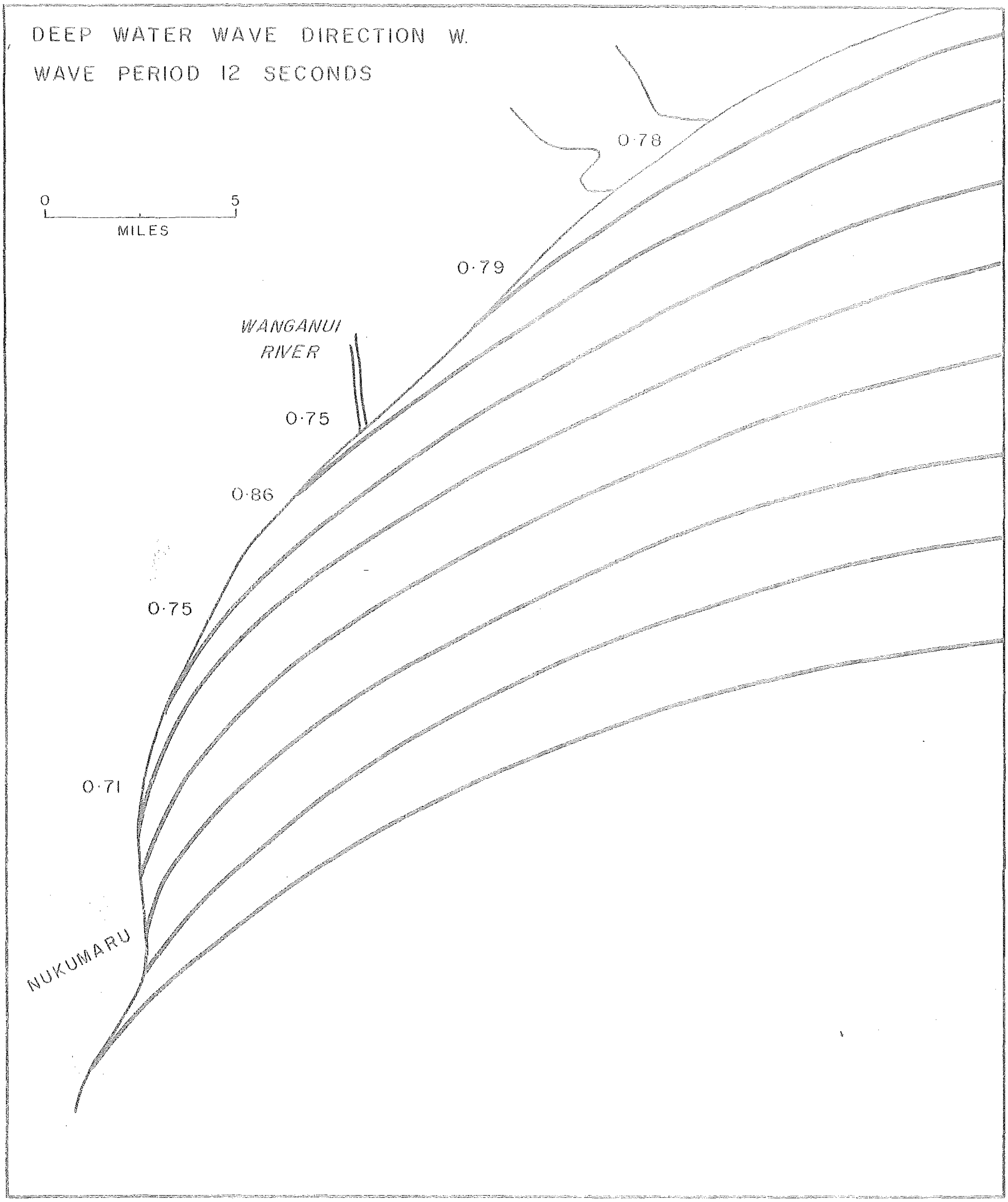


Figure 24 (a) Refraction of a westerly wave train

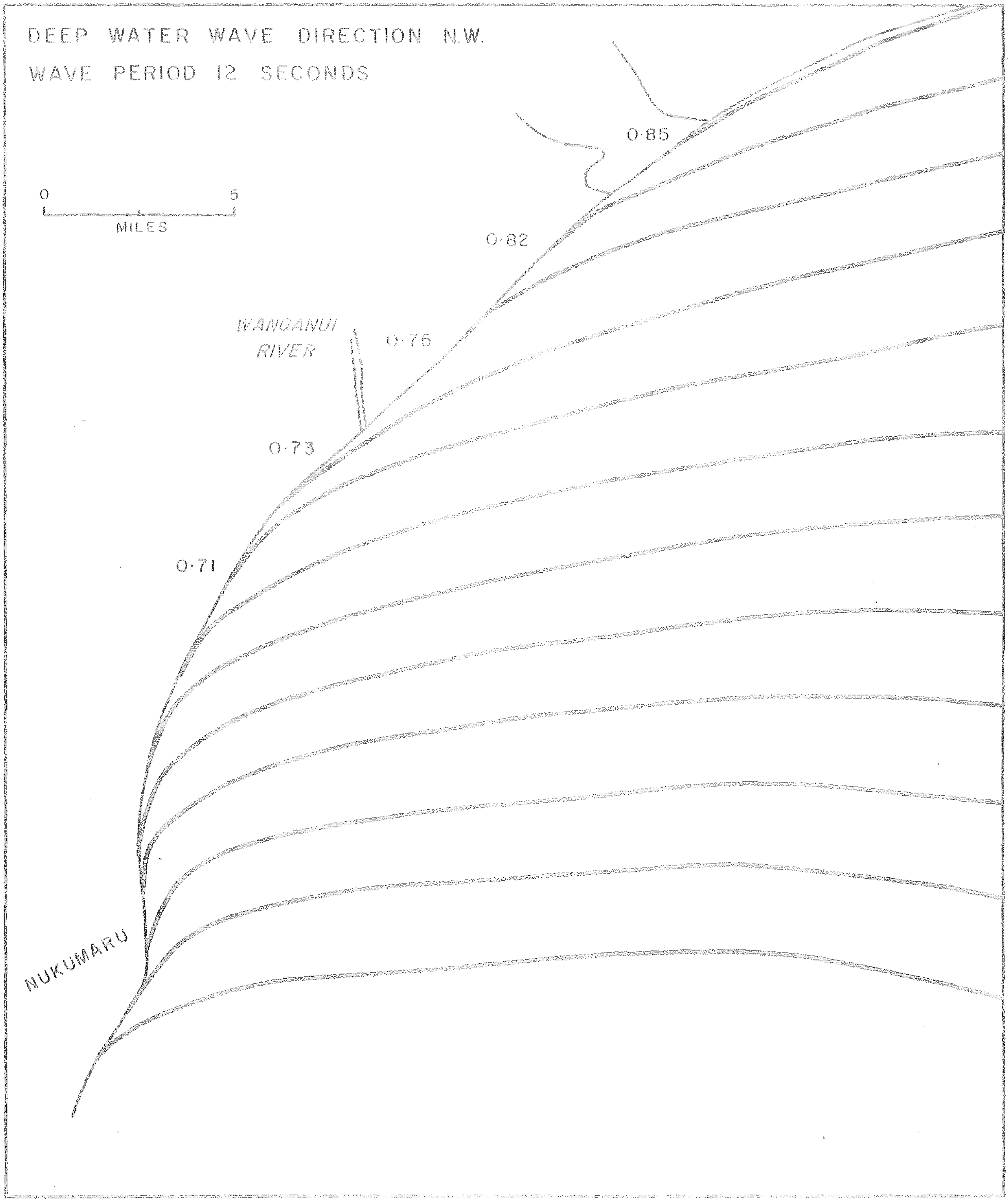


Figure 24 (b) Refraction of a northwesterly wave train

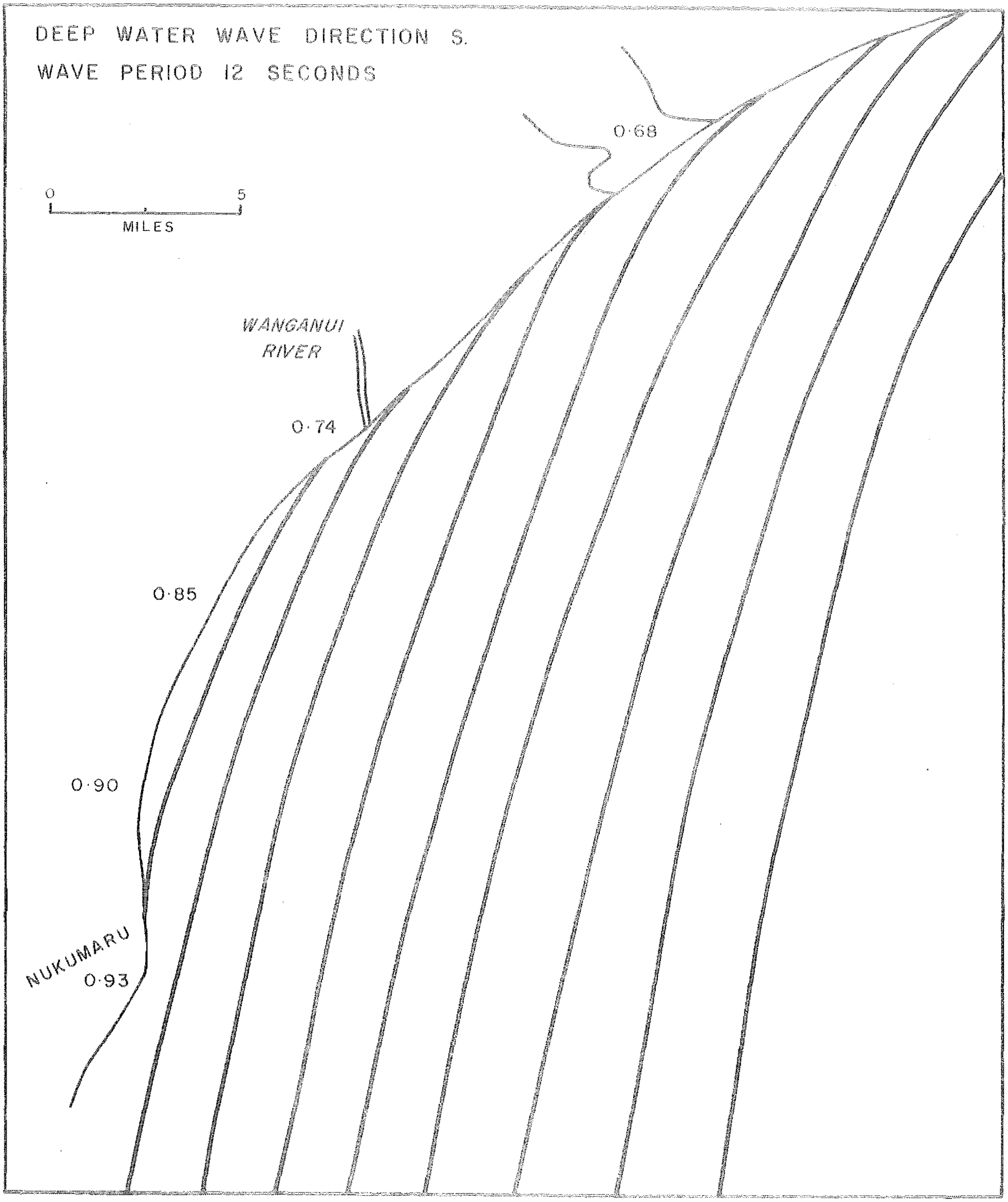


Figure 24 (c) Refraction of a southerly wave train of approach. As wave trains move from deeper water towards the shallower coastal waters wave height decreases, period increases and the waves are refracted so that they approach more or less shore-normal. At Wanganui the very shallow depths for considerable distances offshore ensures that refraction is almost complete and consequently waves rarely break at angles greater than five degrees to the shoreline. Figures 24a, 24b, and 24c show broad refraction patterns for the Wanganui Coast.

On the wave refraction diagrams refraction coefficients are presented for various parts of the coast. Because of the gently shelving nature of the coast refraction of wave crests begins well offshore of the area shown in Figure 24. The refraction coefficient is defined as:

$$K_b = (S_d / S_b)^{1/3} \qquad \text{(Shepard, 1963, p.73)}$$

where K_b = refraction coefficient

S_d = distance between wave rays in deep water, and

S_b = distance between wave rays.

Deep water is defined as:

$$h = 1/2\ L_d$$

where h = depth of water, and

L_d = wave length.

Wave length is defined as:

$$L_d = 5.12\ T^2$$

where T = wave period.

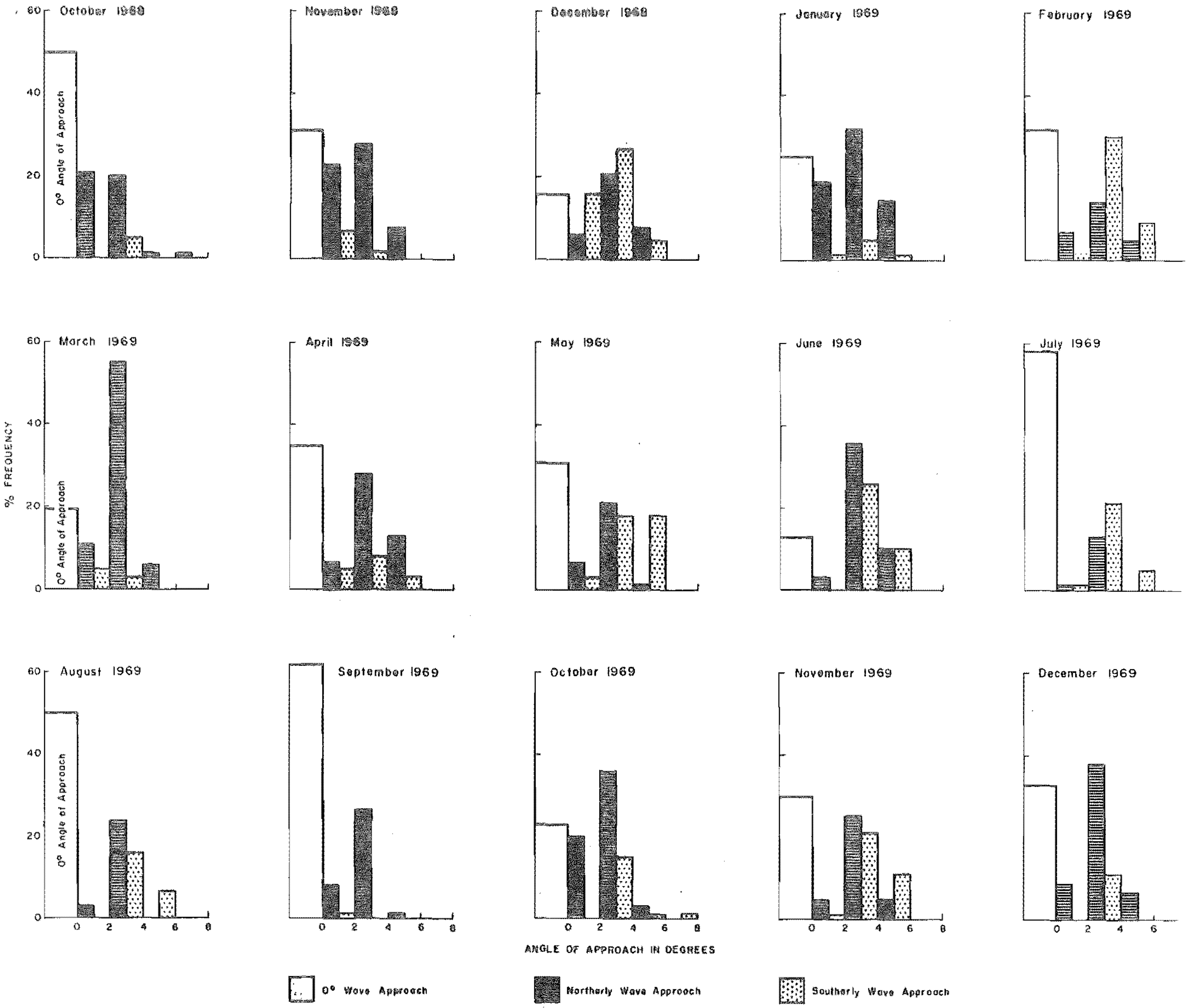


Figure 25 Direction of wave approach at Castlecliff Beach

A coefficient (K_b) of less than 1.0 indicates that divergence has occurred and a coefficient of greater than 1.0 indicates convergence. Having calculated wave refraction coefficients it is possible to predict height at shore:

$$H_b/H_d = 0.30 \, (L_d/H_d)^{1/3} \, K_b \quad \text{(Shepard, 1963, p.73)}$$

where H_d = deep water wave height

Applying this relationship for a westerly wave train, period 12 seconds deep water height 10 feet, height at shore will be a little over eight feet a theoretical reduction of 20%

From the wave refraction diagrams it is possible to deduce that energy delivered to the nearshore will decrease northwards for northwesterly wave train and southwards for a southerly wave train. Maximum energy during westerly waves is delivered to the coast in the vicinity of Kai-iwi River.

At the coast the angle of the breaking wave with the shore was measured by eye. These data are presented in Figure 25. Most waves approached the coast at zero or close to zero angles. The diagram also clearly indicates that the majority of waves not arriving parallel to the coast approach from northerly quarters. Significant periods of waves from southerly directions did occur especially in December 1968, February, May, June, July and November 1969.

(5) Wave Energy

When waves reach the coast a certain amount of energy is transmitted with each wave. This energy can, for convenience, be considered as comprising two components; a shore-normal energy component and a alongshore energy component. Both these energy components are important as sediment is able to be moved by either.

Calculation of the longshore energy component is possible using the Adachi et.al. (1959) modification of Caldwell's (1956) formulae. Adachi's modification of the well-known Caldwell's formulae is used because it allows the calculations to be performed using shallow water wave data. The equation is:

$$E_i = 1/16\ W\ H_b^{\ 2}\ (L_b/T)\ \mathrm{Sin}\ 2\phi$$

where E_i = alongshore component of wave energy in foot pounds per minute per foot of beach

W = specific weight of sea water

H_b = average breaker height

L_b = wave length at breaking

T = wave period

ϕ = angle of wave incidence at breaking

To enable E_i to be calculated on a daily basis three assumptions have to be made. First the calculation of L_b depends upon the depth of water that wave height was recorded in. Depth records were kept for a period of only ten days but as they all fell between 12 and 18 feet a depth of 15 feet was considered to be reasonably representative of all observations. Secondly, wave observations were only made twice daily. Each of these observations was assumed to represent a period of 12 hour. Thirdly, the wave height measurement was a maximum for the three minute period of observation. This value is assumed to represent mean height for the 12 hour period.

The precise relationship between this longshore energy component and longshore littoral transport of sediment is very much in doubt. Work by Caldwell (1956) and Ingle (1966) has shown that a close relationship does exist between the alongshore component of wave energy and volume of sand transported. Numerous expressions of this relationship are available, the most common being that suggested by the U.S. Army (1966, Shore Protection, Planning and Design):

Equation (2)

$$Q_o = 210\ (E_i/10^6)^{0.8}$$

where Q_o = longshore littoral transport in cubic yards per day

E_i = longshore energy in foot pounds per foot of beach per day.

Working with Wanganui Harbour Board wave data for the period October 1968 - October 1969 a ratio of north to south alongshore energy to south to north alongshore energy of 2.5 : 1 was calculated. The ratio of north-south to south-north Q_o was 2.4 : 1 calculated for the 15 foot contour.

Expression of total wave energy is usually given as:

$$E = 41\ H^2\ T^2 \qquad (3)$$

where E = energy (kinetic and potential) in foot pounds per foot of wave crest

H = wave height

T = wave period

Comparison of equation (1) and equation (3) makes it obvious that the alongshore energy component of any wave train is only a fraction of the total energy delivered to the shore.

(6) Summary

Wave data collected at Wanganui and offshore confirms that the coast is subjected to a variety of wave conditions. Wave height at shore frequently exceeds four feet, consequently the coast can be considered a moderate to high energy coast. Offshore topography and refraction of wave crests ensures that wave trains approach the shore at angles generally less than five degrees. Application of formulae derived by Caldwell (1956) and Adachi et.al. (1959) show that available alongshore energy favours littoral movement of sediment from north to south.

Coastal Currents

Brodie (1960) in his paper on coastal current around New Zealand detects a current (D'Urville current) moving southwards along the Wanganui-West Wellington Coast. This current moves in the opposite direction to the Westland Current and this he attributes to the orientation of the coastline and the effect of the local wind environment.

Small scale experiments investigating inshore coastal currents were conducted during this study using bottles weighted so that they floated beneath the surface and

Whitehead sea-bed drifters weighted so that they dragged along the bottom. Bottles and drifters were liberated under a variety of northwesterly conditions and the beaches adjacent to the release points searched. Twice weighted bottles were liberated outside the surf zone, once opposite Castlecliff Beach and once just north of the river mouth. Bottles were also liberated in the river and sea bed drifters were liberated from the end of the north mole. Personal searching of the nearby beaches ensured high returns of bottles and drifters (75% over all). Bottles and drifters released in the river were recovered south of the river mouth up to 2.5 miles from the release point after 24 hours. Conditions were north-westerly and wave height varied from four to eight feet. Of four dozen bottles released from Castlecliff Beach on 13 October 1969 75% were recovered south of the river entrance next day. On 13 October some of the bottles were noted on Castlecliff Beach just north of the north mole. They were left on the beach and by next morning had disappeared, presumably southwards.

These experiments were too small-scale to be of any great use in describing current patterns near Wanganui but they were useful in that they show that sedimentary material would have little difficulty bypassing the river mouth. Brodie's (1960) work had already shown that a coastal current moves north to south along the coast in the same direction as predominant wave induced current.

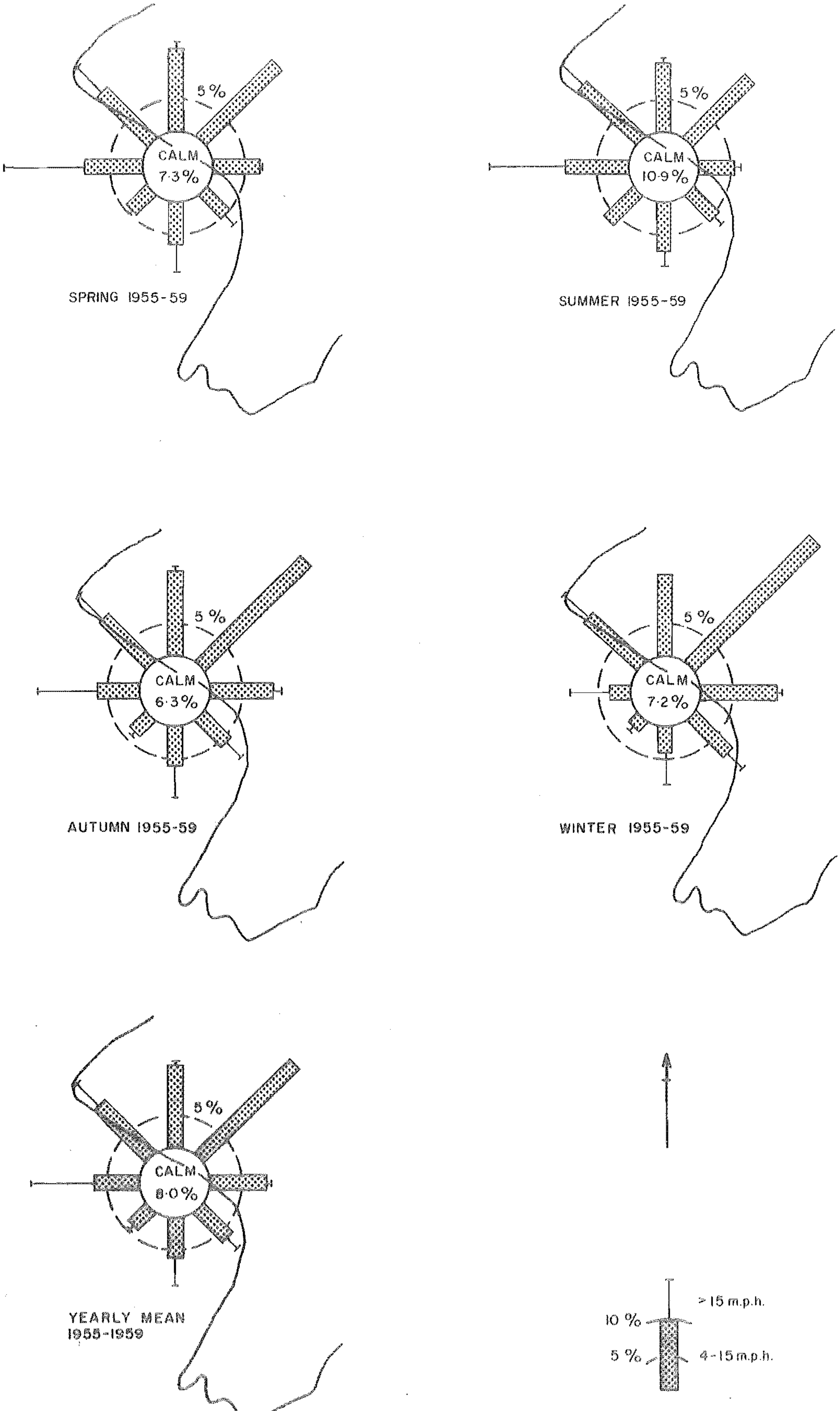


Figure 26 Wind direction at Wanganui Airport

Meteorologic Conditions

New Zealand Meteorological Service data collected at Wanganui shows that rainfall is spread over the entire year. Rainfall increases inland and to the south ranging from just below 35 inches (annual mean) at Wanganui to over 100 inches. Although rainfall tends to be uniformly spread over the entire year the catchments are occasionally subjected to prolonged heavy rains when warm, moist northwesterly air associated with a warm front, comes into contact with the high country of the interior.

Mean temperatures are not unlike other coastal areas of New Zealand. Monthly minima occur in July (47.4°F) and reach maxima in February (64.6°F).

Wind speeds at Wanganui (Figure 26) vary from season to season. Spring and Summer months are characterised by higher percentages of winds in excess of 15 m.p.h. approaching from the west and northwest. During Autumn and Winter the predominant wind direction is northeast. The more frequent occurrence of higher speed winds from the west and northwest during the hotter spring and summer months promotes greater movement of dry sand on the foreshore, by wind, at this time of year.

River Flow

Between Nukumaru and Waimahora Stream 11 rivers discharge water to the coast. From north to south they are Ototoka

Stream, Okohu Strea, Kai-iwi Stream, Mowhanau Stream, Omapu Stream, Wanganui River, Kaitoke Stream, Whangaehu River, Turakine River, Koitiata Stream and Waimahora Stream. The most important of these rivers are Wanganui, Whangaehu and Turakina.

(1) Wanganui River

The Wanganui River is 195 miles long and drains an area of 2,850 square miles. The gradient of the river is very gentle and in the lower reaches it is only 1:26,000 (Krenek, 1968). The volume of water carried by the river varies considerably, flows between 1,500 and 200,000 cusecs being recorded. Mean annual flow for the period 1958-1964 at Paetawa was 8,328 cusecs. For a greater part of its course the river flows through a catchment of soft easily erodable Tertiary sandstones and mudstones and even at times of low flow the water has a muddy appearance.

New Zealand Hydrological Survey information on quantity of sediment carried by the river is restricted to suspended load. Examination of their rating curve reveals that an exponential relationship exists between daily river discharge and sediment discharge. A flow of 8,000 cusecs (normal) gives a 2,000 tons per day discharge of sediment. A five-fold increase in flow to 40,000 cusecs increases computed sediment discharge to 200,000 tons per day (ten-fold increase) and if flow is increased ten-fold to 80,000 cusecs sediment discharge increase 500 times to 1,000,000 tons per day.

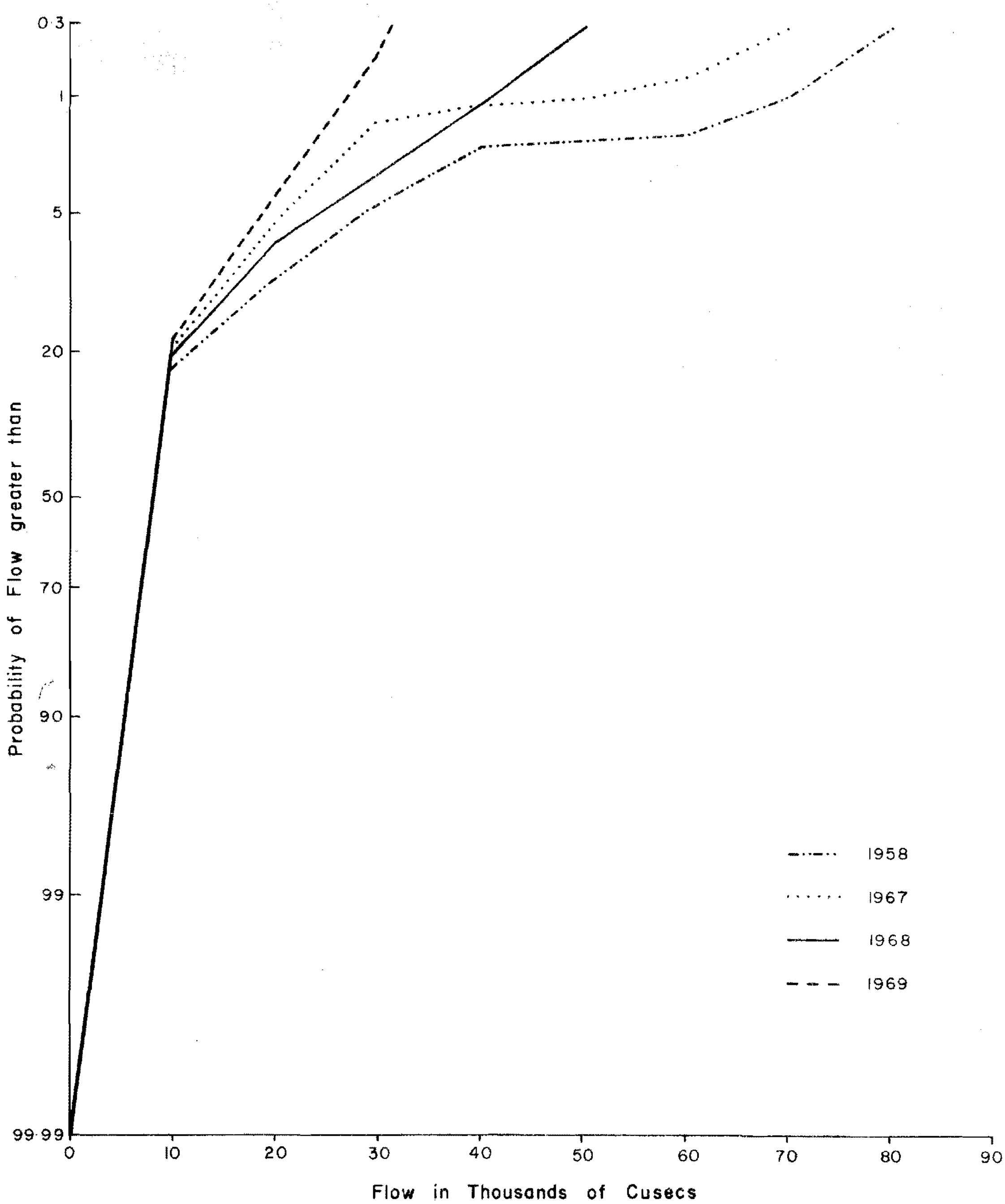


Figure 27 Daily discharge of Wanganui River 1958, 1967 – 69

Figure 27 shows the probability of a river discharge exceeding a particular flow on any day during 1958, 1967, 1968 and 1969. A probability plot has been used to emphasise high flow as it is these flows which potentially carry the most material. The probability of flows less than 10,000 cusecs occurring in the years examined was similar consequently the individual curves join the lower flow regimes.

(2) Whangaehu and Turakina Rivers

Gauging of the Whangaehu and Turakina rivers near the mouths has not been attempted by the Hydrologic Survey on the same scale as in the Wanganui River. Some gauging has been done and flows of 1,000 to 8,000 cusecs were recorded in Whangaehu River and 30 to 600 cusecs in the Turakina River. Computed discharge of suspended sediment at flows of 1,000 and 8,000 cusecs in Whangaehu River was 400 and 30,000 tons per day. For flows of 30 and 400 cusecs in Turakina River discharge of sediment was one and 1,000 tons per day. Turakina River therefore carries little material in suspension but the Whangaehu River carries relatively large quantities. At a flow of 8,000 cusecs Wanganui River carries a computed suspended load of 2,000 tons per day. At the same flow the Whangaehu River carried 15 times as much material.

The gradients of these two rivers is substantially greater in the lower reaches than Wanganui River. Whereas Wanganui River has a gradient of less than two feet per mile in the last 20 miles of its course Whangaehu River has a gradient of 10 feet per mile and Turakine River 11 feet per mile

(3) Other Rivers

Other rivers discharging into the ocean along the Wanganui Coast may be locally important. They are not, however, sufficiently large to play more than a minor part in coastline dynamics.

Summary

Figure 2 presents in a conceptual form factors which collectively operate on the Wanganui Coast. An examination of these factors reveals that ocean waves generated offshore in the Tasman Sea lose height, increase in period and approach the Wanganui Coast more or less shore-normal. Waves reaching the shore are still sufficiently large to subject the coastline to a moderate to high wave energy attack and incomplete refraction of the crests results in a not inconsiderable north to south energy balance. Coastal currents also operate in the same direction and the movement of sediment by wind in onshore and north to south directions is favoured by climatic conditions.

Wanganui and Whangaehu rivers are sufficiently large to discharge considerable quantities of sediment into the nearshore zone and although large amounts of fine material are probably lost offshore circumstantial evidence suggests that large volumes are added, on occasions, to the nearshore littoral system.

ENTRANCE DYNAMICS

General

The preceding discussion of sediment characteristics, coastline physiography, wave environment, meteorologic conditions, river flow and coastline change make it obvious that, potentially, the entrance to Wanganui Harbour is subjected to large quantities of sediment which reaches the harbour entrance by river, wind and wave transport. Rapid accumulation of material earlier this century when the moles were most effective as trappers of sediment indicates the possible magnitude of sediment quantity involved. At present little accumulation of sediment occurs up-drift of the moles probably resulting in larger quantities of material by-passing the entrance. Possible reservoirs of sediment involved include the coastal cliffs to the north which are being actively cliffed at present, the inner continental shelf and the catchments of rivers discharging into the South Taranaki Bight. Examination of sediment on the Wanganui Beaches and at the entrance to the harbour does not preclude any of these source areas.

In this section an area of the harbour entrance will be examined in an attempt to establish what are the important sediment moving processes operating at the river mouth and what volumes of material are involved.

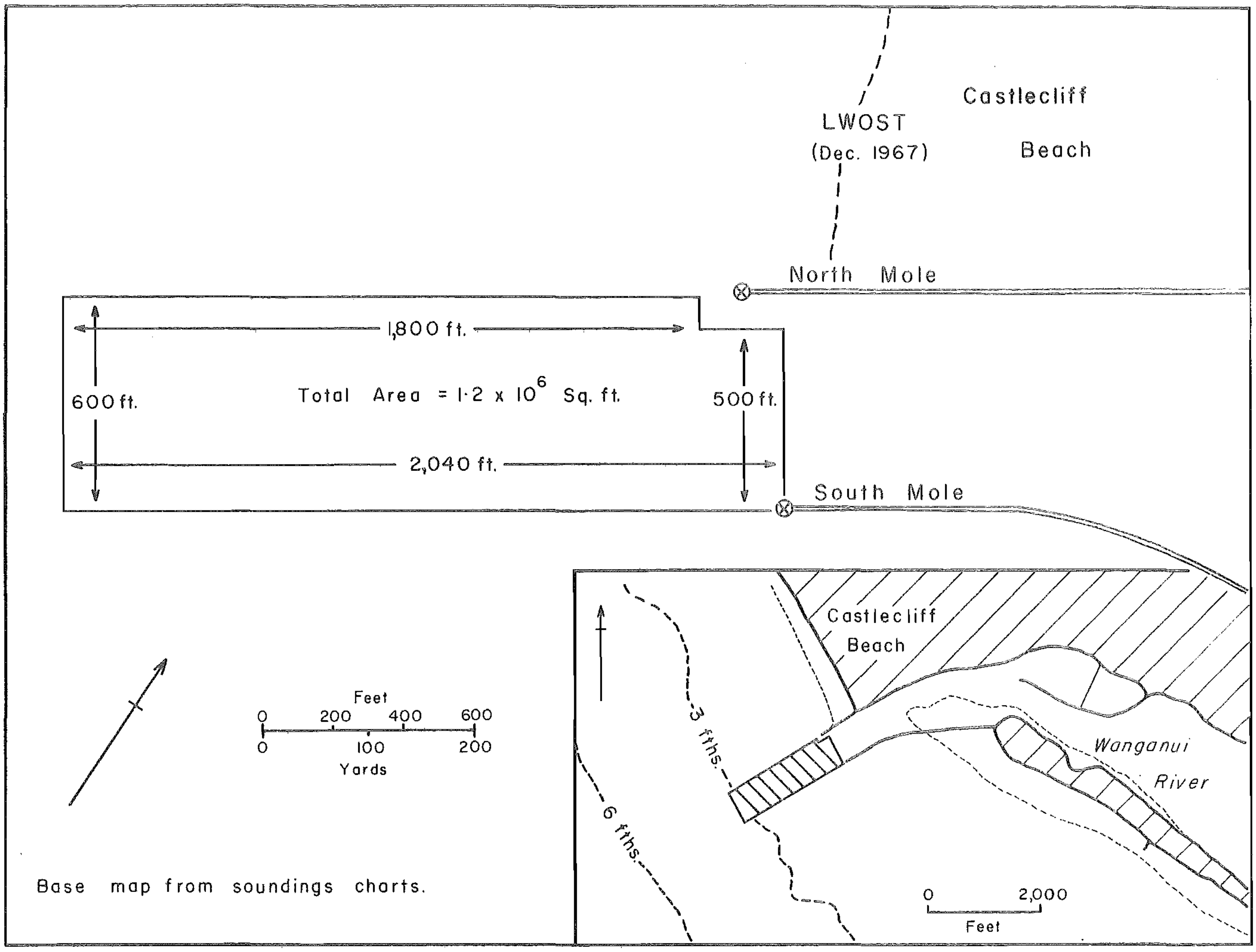


Figure 28 Location of area investigated for volumetric changes

Study Area and Data

In a forerunner to this study sounding charts of the harbour entrance were examined for the years 1958 and 1967 (McLean and Burgess, 1969). These data are re-presented here along with data for 1968 and 1969. In total 99 charts were analysed; 22 for 1958, 21 for 1967, 28 for 1969 and 28 for 1969.

The charts used were all constructed at a scale of 1 inch to 200 feet. Each chart was contoured at a 1 foot contour interval, level being in terms of the local gauge zero which is one foot below mean low water spring tide. The location of the area examined in this study is shown in Figure 28. This area of 1.2 million square feet was chosen because of the consistency of detailed soundings in the area. For each chart the area enclosed by each contour was calculated. If the combined individual contour areas did not total $\pm$ 1% of 1.2 million square feet the areas were re-calculated. To avoid error caused bias in total volume calculation any error in area calculations was 'distributed' throughout the entire range of depths depending on size of the area in relation to total area. Areas between contours were then converted to volumes. Certain error was inherent in the calculation of these volumes. Besides error in area calculation, difficulties occur in accurately sounding the sea bed. The sounding team led by Captain K.F. Davies have worked together for a long period of years, are well equipped

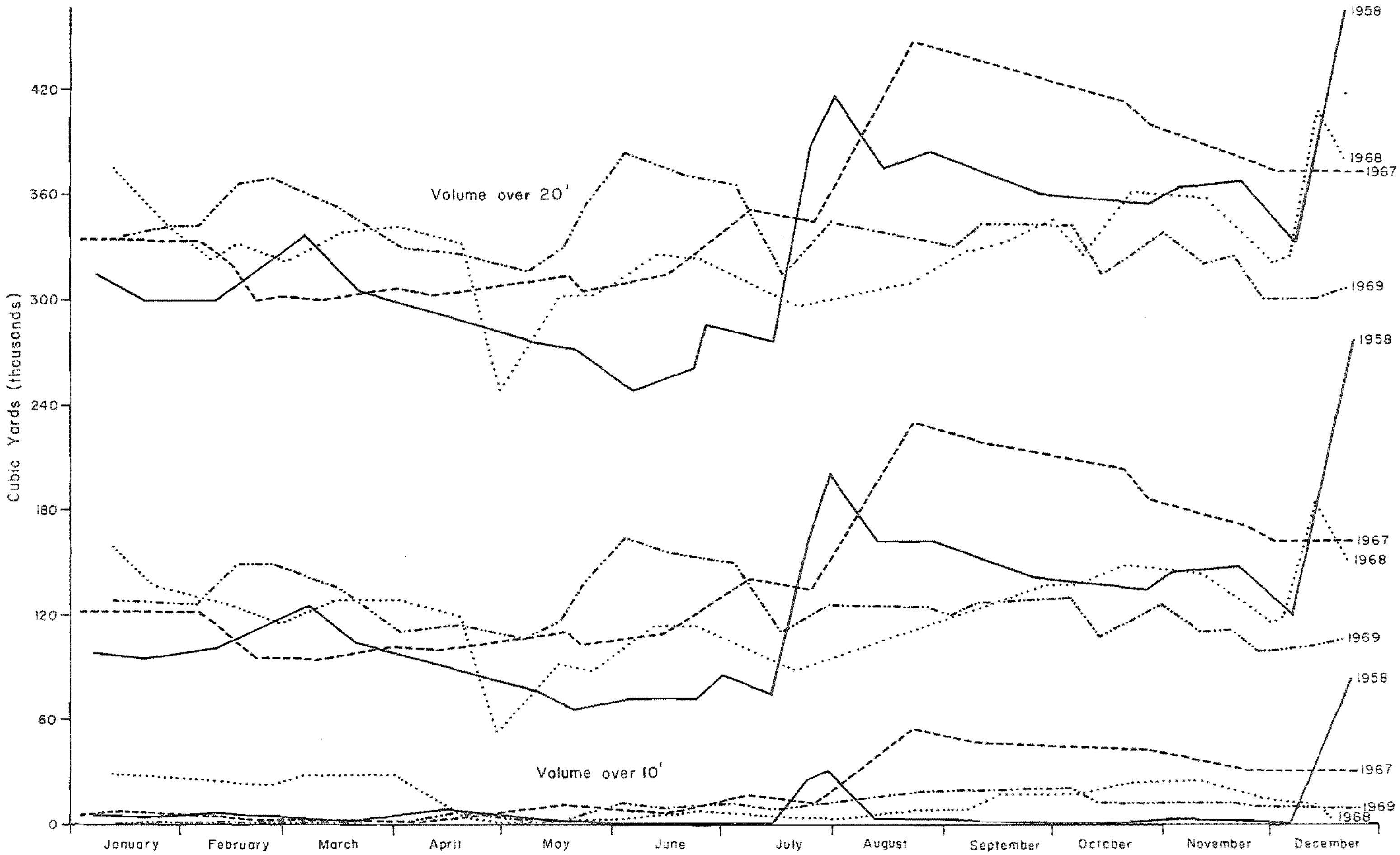


Figure 29 Fluctuation in volume of material above the 10, 15 and 20 foot contours
1958, 1967 – 1969

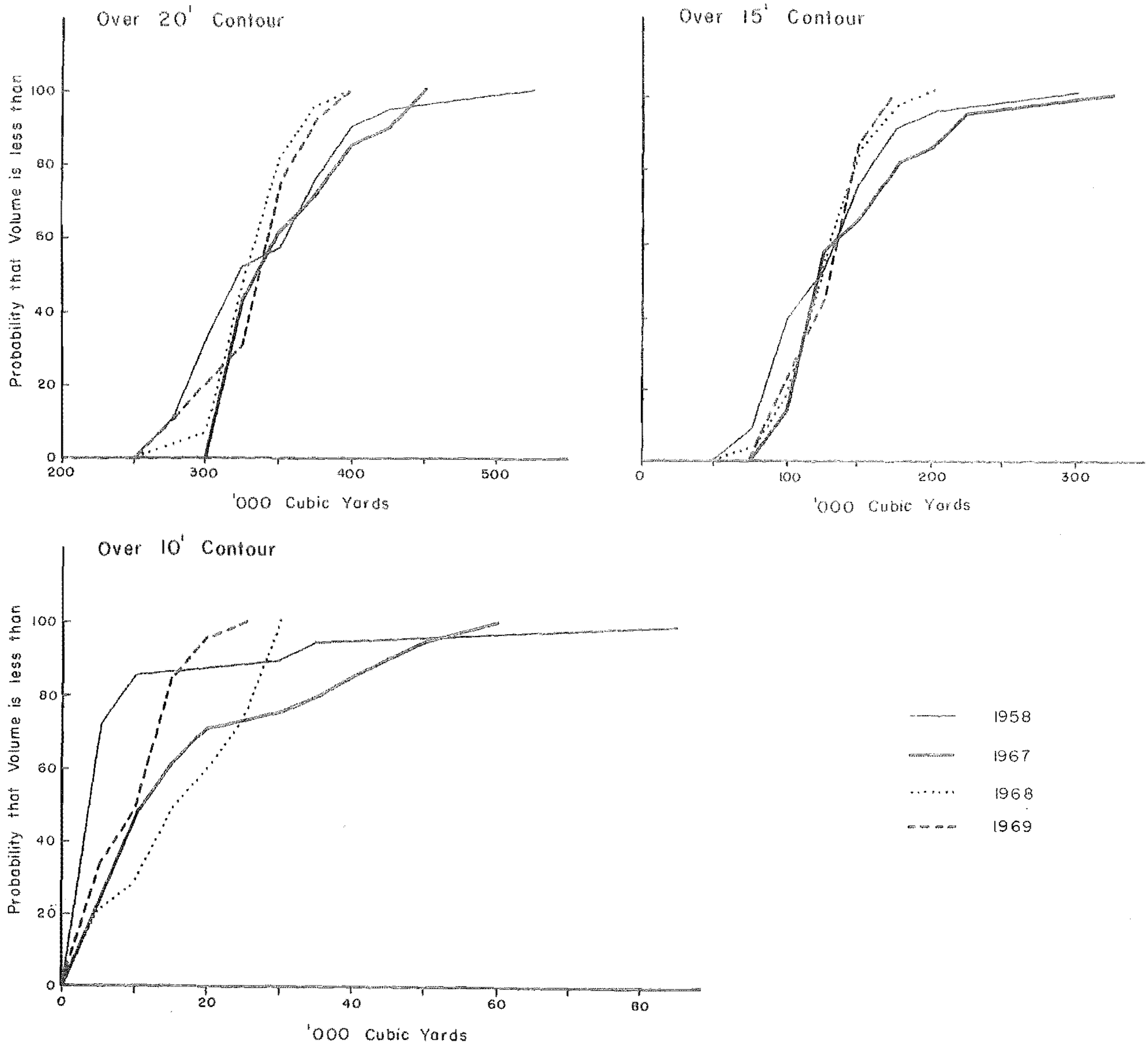


Figure 30 Frequency distribution of volumes of material above the 10, 15 and 20 foot contours 1958, 1967 – 1969

TABLE 5

Volumes of Material Above 10ft., 15ft., 20ft. Depth Contours

(Thousands of Cubic Yards)

1958				1967				1968				1969			
	10	15	20		10	15	20		10	15	20		10	15	20
/1	6	77	315	3/1	5	122	335	12/1	29	159	374	2/1	3	148	366
2/1	10	96	299	15/1	6	123	334	23/1	26	138	349	13/1	1	128	337
0/2	6	101	301	6/2	5	121	333	9/2	23	119	323	28/1	2	127	343
/3	4	126	338	14/2	5	111	320	16/2	25	125	333	5/2	1	126	343
0/3	3	95	307	21/2	2	96	300	28/2	23	115	322	17/2	2	149	367
5/4	9	89	291	28/2	4	96	302	6/3	28	123	327	26/2	1	150	369
/5	4	78	277	9/3	2	95	300	15/3	28	129	338	14/3	2	137	356
0/5	2	67	273	30/3	2	103	307	27/3	28	128	341	1/4	1	111	330
/6	0	72	249	10/4	3	100	303	1/4	28	129	341	18/4	8	115	328
3/6	0	73	260	18/5	13	112	315	18/4	7	120	333	30/4	5	110	320
0/6	0	86	287	22/5	12	106	305	29/4	1	53	250	6/5	3	107	318
4/7	0	77	277	14/6	8	110	315	16/5	3	93	304	17/5	2	118	331
4/7	27	167	386	8/7	17	141	350	25/5	3	90	303	23/5	6	139	355
0/7	31	201	419	25/7	13	136	346	12/6	8	113	327	3/6	13	167	385
3/8	4	162	378	22/8	55	230	448	24/6	11	113	325	15/6	9	156	375
7/8	4	164	381	9/9	48	220	438	20/7	4	91	298	4/7	13	152	368
6/9	0	144	362	19/10	45	203	419	29/7	4	95	301	17/7	10	110	313
6/10	1	136	355	26/10	44	189	398	22/8	11	111	312	29/7	14	129	344
/11	2	146	364	22/11	38	170	380	6/9	11	121	329	26/8	19	125	335
1/11	1	149	367	1/12	29	162	373	16/9	19	127	334	2/9	18	120	330

Table 5 (Contd.)

	1958				1967				1968				1969		
	10	15	20		10	15	20		10	15	20		10	15	20
/12	0	120	331	20/12	30	161	376	29/9	18	138	346	10/9	19	128	342
2/12	82	276	495					8/10	19	138	341	5/10	21	131	340
								21/10	24	150	363	13/10	12	108	315
								11/11	24	145	357	30/10	13	127	338
								29/11	14	116	322	10/11	13	113	320
								4/12	13	119	325	19/11	13	113	325
								12/12	12	184	403	26/11	10	101	301
								19/12	3	155	374	11/12	10	103	301
												31/12	3	111	316
lean Vol.	8.9	119.5	332.4		18.4	138.4	347.5		16.0	122.5	332.0		8.7	125.4	337.3
lini-mum	0	67	249		2	95	300		1	53	250		1	101	301
laxi-mum	82	276	495		55	250	448		29	184	403		21	167	385

TABLE 6

Intersurvey Time Periods

Year	Mean Intersurvey Period	Minimum Intersurvey Period	Maximum Intersurvey Period
1958	16 days	6 days	30 days
1967	17 days	4 days	40 days
1968	13 days	5 days	26 days
1969	13 days	6 days	25 days

and know the entrance area particularly well. Error in volumes, therefore, probably do not exceed ± 10%. Table 5 lists the sounding charts examined and the volumes of material above the 20, 15 and 10 foot contours. The dates on which soundings of the entrance were made depended on weather conditions but where possible were spread throughout the year. Table 6 indicates time between surveys for the four years of records examined. The original sounding charts are held in the archives of the Wanganui Harbour Board.

Volumetric Changes

(1) Total Volume

The information contained in Table 5 and re-presented in Figures 29 and 30 shows that mean volume of material above the 20 foot contour fluctuates around 330-350,000 cubic yards. Minimum volume recorded was 249,000 cubic yards on 5/6/58 and maximum recorded volume was 495,000 cubic yards on 22/12/58. On only 14 occasions did total volume exceed 375,000 cubic yards or fall below 275,000 cubic yards. Intersurvey change in total volume did fluctuate widely, however. The largest change in total volume was of 164,000 cubic yards between 6/12/58 and 22/12/58. This change represented a change in total volume of approximately 50%. Most changes did not compare with this change and positive changes in excess of 30,000 cubic yards were recorded on only 10 occasions during the four years of records. Negative changes of large magnitude were recorded less frequently and only six surveys resulted in decreases of volume greater than 30,000 cubic yards. The maximum recorded negative change was 83,000 cubic yards, half that of the largest positive change.

(2) Volumes above the 15 and 10 Foot Contours

Maximum volumes recorded above the 15 and 10 foot contours were 276,000 and 82,000 cubic yards. Minimum values were 53,000 and zero cubic yards. Examination of Figures 29 and 30 show that fluctuations in volumes above the 15 foot contour are not too dissimilar to fluctuations in total volume. Changes above the 15 foot contour, like changes in total volume, rarely exceeded 20% of the previous volume. Volumes above the 10 foot contour had relative changes which greatly exceeded relative volume changes above the 15 and 20 foot contours. Volume changes of the order of 50% were not uncommon.

These changes in shallower depths, although not involving large absolute quantities of material, are particularly important for a number of reasons. First, it is the shallower areas which limits the draught of ships able to use the port. The total volume of material in the entrance may be low yet material can accumulate in the form of a bar which would limit shipping more than if the entrance was characterised by a large quantity of material and no bar. Accumulation of material in shallower depths is also important for the process of by-passing. Bruun and Gerritson (1960) suggest two methods whereby material may by-pass a river mouth or tidal inlet:

(a) bar by-passing and

(b) tidal flow by-passing.

Obviously an accumulation of material in shallower depths in the form of a bar will assist in the by-passing process. The processes responsible for the accumulation of material in shallower water are somewhat different to the processes responsible for accumulation of material in the whole entrance. For this reason they will be studied separately.

Factors Influencing Total Volume Change

The explanation of fluctuation in the volume of material above the 20 foot contour is hampered by several unavoidable difficulties. First is the previously mentioned error factor in calcuation of the actual volumes. To be safe the volumes are said to be within $\pm$ 10% of the actual volume. Working with a volume of 300,000 cubic yards the error at 10% is $\pm$ 30,000 cubic yards. Most volume changes were less than 30,000 cubic yards and consequently must be treated with caution. The second difficulty also relates to the size of this error margin. Longshore transport of material into the study area may not be sufficiently large to overshadow the error margin. For example, a wave approaching and breaking at an angle of 2.5°, height 5.4 feet, period 10 seconds and

TABLE 7

Large Positive Volume Changes

Date	Volumes (Yards)	Change	Max.River Flow(cusecs)
6/12/58-22/12/58	331,000-495,000	164,000	72,000
14/7/58-24/7/58	277,000-389,000	112,000	62,000
25/7/67-22/8/67	346,000-448,000	102,000	72,000
4/12/68-12/12/68	325,000-403,000	78,000	100,000
29/4/68-16/5/68	250,000-304,000	54,000	16,000
10/2/58-7/3/58	301,000-338,000	37,000	125,000
14/6/67-8/7/67	315,000-350,000	35,000	26,000
24/7/58-30/7/58	386,000-419,000	33,000	21,000
17/7/69-29/7/69	313,000-344,000	31,000	4,000
23/5/69-3/6/69	355,000-385,000	30,000	22,000

water depth 15 feet will (theoretically) transport 92 cubic yards/day/foot of beach (Adachi, 1959; U.S. Army Coastal Engineering Research Centre, 1964). Over a two week period this amounts to 1,648 cubic yards. If transport is assumed to be constant from the 20 foot contour to the shore then the amount would be 33,000 cubic yards in two weeks, little more than the 10% error margin.

Examination of the larger changes does help with the understanding of entrance dynamics. Table 7 lists all positive changes in excess of 30,000 cubic yards. Included in this table is maximum river flow for the intersurvey period. It is immediately obvious that large volume increases are associated with higher flow although the relationship is not a simple one. This premise, that high volume increases are associated with high river flow, has much to recommend it. Examination of river flow in an earlier section indicated that Wanganui River was capable of transporting large quantities of material at times of high flow. Reinforcing this hypothesis are numerous observations of similar occurrences made throughout the history of the port. In the 'Wanganui Chronicle' 15 March 1958 it was reported that after the large 25 February flood considerable shoaling occurred at the basin entrance. It was reported by the Wanganui Harbour Board Engineer of that time that 60,000 cubic yards of silt was deposited in the tidal area of the basin. Similarly it was reported in the 'Wanganui Chronicle' 20 October 1942 that,

TABLE 8

Survey Periods with River Flow Exceeding 20,000 Cusecs

Date	Volume in Cubic Yards	Change in Cubic Yards		River Flow in Cusecs
10/2-7/3/58	301-338,000	+ 37,000	*	125,000
15/4-9/5/58	291-277,000	- 14,000	$	40,000
9/5-20/5/58	277-273,000	- 4,000		27,000
20/5-5/6/58	273-249,000	- 24,000	$	41,000
23/6-30/6/58	260-287,000	+ 17,000	*	26,000
14/7-24/7/58	277-386,000	+ 112,000	*	62,000
30/7-13/8/58	419-378,000	- 41,000	$	28,000
13/8-27/8/58	378-381,000	+ 3,000		26,000
6/12-22/12/58	331-495,000	+ 164,000	*	72,000
15/1-6/2/67	334-333,000	- 1,000		85,000
8/7-25/7/67	350-346,000	- 4,000		20,000
25/7-22/8/67	346-448,000	+ 102,000	*	72,000
22/8-9/9/67	448-438,000	- 18,000	$	25,000
26/10-22/11/67	398-380,000	- 18,000	$	29,000
1/12-20/12/67	373-376,000	+ 3,000		31,000
16/5-25/5/68	304-303,000	- 1,000		31,000
25/5-12/6/68	303-327,000	+ 24,000	*	36,000
24/6-20/7/68	325-298,000	- 27,000	$	50,000
21/10-11/11/68	363-357,000	- 6,000		27,000
11/11-29/11/68	357-322,000	- 35,000	$	21,000
4/12-12/12/68	325-403,000	+ 78,000	*	100,000
5/2-17/2/69	343-367,000	+ 24,000	*	24,000
17/2-26/2/69	367-369,000	+ 2,000		29,000
6/5-17/5/69	318-331,000	+ 23,000	*	37,000
17/5-23/5/69	331-355,000	+ 24,000	*	23,000
23/5-3/6/69	355-385,000	+ 30,000	*	22,000
15/6-4/7/69	375-368,000	- 7,000		27,000
29/7-26/8/69	344-335,000	- 2,000		26,000
10/9-5/10/69	342-340,000	- 2,000		23,000

* Positive change over 10,000 cubic yards

$ Negative change over 10,000 cubic yards

TABLE 9

Large Negative Volume Changes

Date	Volumes (Yards)	Change	Max.River Flow(cusecs)
18/4/68-29/4/68	333,000-250,000	-83,000	7,000
4/7/69-17/7/69	368,000-313,000	-45,000	15,000
30/7/58-13/8/58	419,000-378,000	-41,000	28,000
21/11/58-6/12/58	367,000-331,000	-36,000	3,000
11/11/68-29/11/68	357,000-322,000	-35,000	21,000
7/3/58-20/3/58	338,000-307,000	-31,000	16,000

'because of a series of freshes in the river the dredge Kaione had worked over the same ground'. An even earlier reference to the power of the river as a sediment transporter was 23 February 1883 when dredging work was undone by a large flood (King, 1964).

This hypothesis of high volumes being associated with high river flow is further supported by an examination of Figures 27 and 30. In 1958 and 1967 larger numbers of high flows were recorded. Similarly higher volumes were recorded in those years. Similarity in the important upper sections of the two sets of curves is apparent. Unfortunately this simple hypothesis breaks down when examined in reverse. High volume changes are (Table 7) invariably associated with high river flow but high river flow is not always associated with large positive volume changes. Table 8 lists all survey periods during which maximum daily river flow, on some occasion, exceeded 20,000 cusecs. Positive changes in excess of 10,000 cubic yards are marked with an asterisk (*) and negative changes in excess of 10,000 cubic yards are marked with a dollar sign ($). 11 positive changes and seven negative changes in excess of 10,000 cubic yards occurred.

Even large negative changes occurred at times of high flow. Table 9 lists the six occasions when in excess of 30,000 cubic yards of material was lost from the entrance. On two occasions river flow had been in excess of 20,000 cusecs. Other factors are, therefore, involved.

(1) Lagging

Attempting to relate environmental conditions to volume changes is made more difficult because of an inter-correlation problem. Figure 20 shows that large changes are invariably followed by changes in the reverse direction. Of the 10 positive changes above 30,000 cubic yards eight were followed by negative changes. Five of the six negative changes were followed by positive changes. Not only were large changes reflected in the next immediate survey, losses or gains were often recorded for some time. On 22/8/67 102,000 cubic yards of material was added to the entrance area. Losses were then recorded for the next five surveys and a decline in volumes continued until 9/2/68 when volumes were again similar to the pre-flood period. Obviously, therefore, considerable care must be taken when attempting to relate volume changes with river and wave processes.

(2) Environmental Conditions

Although wave records are only available from October 1968 the sounding charts for the earlier period contain information on weather conditions. As strong winds tend to generate waves from the same quarter conditions for the period before October 1968 can be roughly deduced. Table 10 tabulates the volume lost or gained at the entrance and notes the weather conditions in the intersurvey period. An examination of the conditions associated with the large

TABLE 10 (a)

Intersurvey Volumetric Change 1958

Date	Volume Lost or Gained Above 20' Contour	Weather Conditions
22/1/58	- 16,000	Fresh WNW and light W and NW.
10/2/58	+ 2,000	Light S. Calm.
7/3/58	+ 37,000	Southerly Gale, light and clam.
20/3/58	- 31,000	1 day Mod-Fresh N. 2 days Strong W - Calm.
15/4/58	- 16,000	1 day Fresh-Str. S. 1 day Fresh-Str. NW. 1 day Fresh-Str. W. Calm.
9/5/58	- 14,000	1 day Mod.-Fresh NW. 1 week Fresh-Str.NW. Calm.
20/5/58	- 4,000	2 days Fresh S. Calm.
5/6/58	- 24,000	Fresh-Str. NW for period.
23/6/58	+ 11,000	3 days Fresh-Str. WNW. Calm and light.
30/6/58	+ 27,000	Light and calm.
14/7/58	- 10,000	Light and calm.
24/7/58	+ 112,000	Light and calm.
30/7/58	+ 33,000	12 hours Fresh SE. Light and calm.
13/8/58	- 41,000	18 hours Mod.-Fresh SW. 2 days Fresh NW. 1 day Mod.-Fresh S. Light-Mod. N and SE.
27/8/58	+ 3,000	Mod.-Light and calm.
26/9/58	- 19,000	36 hours Mod.-Fresh NW. 12 hours Fresh-strong W. Calm.
26/10/58	- 7,000	24 hours Fresh WNW. 12 hrs. Mod.-Fresh NW.
3/11/58	+ 9,000	Light and calm.
21/11/58	+ 3,000	Light - Moderate.
6/12/58	- 36,000	36 hours Fresh WNW. 12 hours Mod.-Fresh S. Calm.
22/12/58	+ 164,000	Mainly light and calm.

TABLE 10 (b)

Intersurvey Volumetric Change 1967

Date	Volume Lost or Gained Above 20' Contour	Weather Conditions
15/1/67	- 1,000	Mainly light or moderate winds.
6/2/67	- 1,000	Fresh WNW for 1½ days, 18 hrs. strong S.
14/2/67	- 13,000	2 days fresh W. Light and Moderate.
21/2/67	- 20,000	NW freq. Fresh to Fresh-Strong.
28/2/67	+ 2,000	Light-Moderate.
9/3/67	- 2,000	Light-Moderate.
30/3/67	+ 7,000	Occ. Fresh SE or S. Light.
10/4/67	- 4,000	12 hrs. Fresh-Str. NW. Light-Mod.
18/5/67	+ 12,000	Until 26/4/58 NW. 12 hrs. S Fresh-gale. 4 days Strong-Gale NW.
22/5/67	- 10,000	Light-calm.
14/6/67	+ 10,000	12 hrs. Strong S. Light-Mod.
8/7/67	+ 35,000	4 hrs. Fresh SSW. 72 hrs. Mod.-Fresh SE. Light-Moderate.
25/7/67	- 4,000	8 hrs. Mod. NW. 24 hrs. Mod. SE. Slight.
22/8/67	+ 102,000	30 hrs. Fresh-Strong S. 12 hrs. Fresh NNE. Light.
9/9/67	- 10,000	24 hrs. Fresh-Strong SE. 12 hrs. Mod.-Fresh NW. 24 hours Fresh S.
9/10/67	- 19,000	8 hours Fresh-Strong S. 8 hours Fresh WNW. 26 hours Fresh NW.
26/10/67	- 21,000	8 hours Fresh-Strong S. Light-Mod.
22/11/67	- 18,000	12 hrs. Fresh W. 1½ days Fresh-Strong WNW. 4½ days Strong NW. 8 hours Fresh N. Light-Mod.
1/12/67	- 7,000	1 day Fresh-Strong WNW. Light-Mod.
20/12/67	+ 3,000	24 hrs. Fresh-Strong NW. 12 hrs. Strong NW. 24 hrs. Fresh NW. 10 hrs. light-fresh NNW.

TABLE 10 (c)

Intersurvey Volumetric Change 1968

Date	Volume Lost or Gained Above 20' Contour	Weather Conditions
23/1/68	- 23,000	3 days Mod.-Strong NW. 12 hours fresh-strong S. 18 hours fresh WNW.
9/2/68	- 26,000	1 day Fresh-Strong WNW. 1 day Fresh-Strong NW. Light-Moderate.
28/2/68	+ 16,000	8 hours Fresh NW. 10 hours Fresh SE. Light-Moderate.
28/2/68	- 11,000	Light.
6/3/68	+ 5,000	Light.
15/3/68	+ 11,000	8 hours Mod.-Fresh NW. Light.
27/3/68	+ 3,000	Light.
1/4/68	0	Light.
18/4/68	- 8,000	14 hours Fresh-Strong SE. 20 hours Mod.-Fresh. 6 hours hurricane SSW. 12 hours Mod.-Fresh W. 8 hours Mod.-Fresh SW. 10 hours Mod.-Fresh WNW. 24 hours Fresh-Strong Westerly.
29/4/68	- 83,000	12 hours Mod.-Fresh WNW. 12 hours strong WNW. 2½ days gale S. 16 hpurs Fresh S.
16/5/68	+ 54,000	24 hours Fresh-Strong NW. 2¼ days Strong-Gale S. Light-Moderate.
25/5/68	- 1,000	18 hours Fresh WNW. Light.
12/6/68	+ 24,000	12 hours Fresh NW. 20 hours Mod.-Strong NW. 8 hours Fresh-Strong S.
24/6/68	- 2,000	34 hours Fresh-Strong SSE. 12 hours Fresh Strong SE. 12 hours Strong S. 10 hours Strong WSW.

Table 10 (c) (Contd.)

20/7/68	- 27,000	30 hours Fresh-Strong NW. 6 hours Strong WNW. 12 hours Fresh WNW. 24 hours Mod.-Fresh S. 8 hours Fresh SSW. 6 hours Fresh-Strong W. 12 hours Strong-Gale SW. 12 hours Strong S.
29/7/68	+ 3,000	Mainly light-moderate.
22/8/68	+ 11,000	52 hours Fresh NW. 18 hours Fresh-Strong SSW. 52 hours Fresh-Strong SE.
6/9/68	+ 17,000	12 Fresh NW. Light-Moderate.
16/9/68	+ 5,000	16 hours Fresh N. 4½ days NW. Moderate-Fresh.
29/9/68	+ 12,000	12 hours Fresh WNW. 10 hours Fresh-Strong S. 10 hours Fresh NW. 22 hours Strong-Gale S.
8/10/68	- 5,000	20 hours Fresh WNW. 12 hours Fresh-Strong SE. Mean height 4.53. Mean Adachi 108,958.
21/10/68	+ 22,000	3 days Mod.-Gale NW. 4 hours Fresh-Strong S. 16 hours Fresh-Strong NW. Mean height 6.72. Mean Adachi 441,030.
11/11/68	- 6,000	3½ days Fresh-Strong NW. 8 hours Fresh S. Mean height 5.70. Mean Adachi 108,015.
29/11/68	- 35,000	8 hours Fresh NW 10 hrs. Fresh WNW. 18 hrs. Strong-Gale WNW. 12 hrs. Strong NW. 40 hrs. Strong WNW. 12 hrs. Strong NW. 12 hrs. Gale NW. Mean height 5.44. Mean Adachi 457,727.
4/12/68	+ 3,000	Light-Mod. Mean height 2.80. Mean Adachi -50,023.
12/12/68	+ 78,000	12 hrs. Strong NW. Light-Mod. Mean height 3.92. Mean Adachi 28,495.
19/12/68	- 29,000	2½ days Light-Mod. S. 12 hrs. Light S. 2½ days Fresh-Strong SE. 1 day Light SE. Mean height 2.42. Mean Adachi -80,256.

TABLE 10 (d)

Intersurvey Volumetric Change 1969

Date	Volume Lost or Gained Above 20' Contour	Weather Conditions
2/1/69	- 8,000	Light-Moderate. Mean height 2.38. Mean Adachi -14.
13/1/69	- 29,000	10 hours Fresh WNW. Light-Moderate. Mean height 3.12. Mean Adachi 119,766.
28/1/69	+ 6,000	12 hours Fresh NW. 12 hours Fresh-Strong WNW. Mean height 3.51. Mean Adachi 167,533.
5/2/69	0	Light-Moderate. Mean height 3.45. Mean Adachi 103,971.
17/2/69	+ 24,000	3 days Fresh-Strong SE. Light-Moderate. Mean height 2.43. Mean Adachi -80,130.
26/2/69	+ 2,000	10 hours Fresh SE. Light-Mod. Mean height 3.04. Mean Adachi 2435.
14/3/69	- 13,000	96 hours Fresh-Strong NW. 24 hrs. Fresh-Strong WNW. Mean height 4.20. Mean Adachi 322,900.
1/4/69	- 26,000	23 hrs. Fresh-Strong NW. 26 hrs. Fresh W. Mean height 3.60. Mean Adachi 150,152.
18/4/69	- 2,000	8 hrs. Mod.-Fresh SW. 54 hrs. Fresh-Strong NW. 40 hrs. Strong WNW. 24 hrs. NW. Gale. 4 hrs. Fresh-Strong W. 24 hrs. Fresh WNW. 24 hrs. Strong-Gale NW. 8 hrs. Fresh WSW. Mean height 5.17. Mean Adachi 465,934.
30/4/69	- 8,000	Light-Mod. Mean height 4.11. Mean Adachi -135,167.
6/5/69	- 2,000	Light. Mean height 2.54. Mean Adachi 34,508.
17/5/69	+ 13,000	12 hrs. Strong-Gale SW. 16 hrs. Fresh-Strong SW. 12 hrs. Fresh NW. Mean height 4.70. Mean Adachi 19,899.
23/5/69	+ 24,000	Light-calm. Mean height 2.37. Mean Adachi -35,978.

Table 10 (d) (Contd.)

3/6/69	+ 30,000	12 hrs. Strong SSW. Light. Mean height 3.70. Mean Adachi -202,797.
15/6/69	- 10,000	2 days Fresh SE. 2-3 days Fresh NW. Mean height 4.07. Mean Adachi 138,008.
4/7/69	- 7,000	2-3 days Fresh S. 3 days Fresh-Strong NW. Mean height 5.76. Mean Adachi 184,161.
17/7/69	- 45,000	Ligh-Mod. 2 days Fresh NW. 2 days Fresh SE. 12 hours Strong S. Mean height 4.68 Mean Adachi -126,329.
29/7/69	+ 31,000	24 hrs. Fresh NW. 3 days Fresh SE. 12 hrs. Strong S. 1 day Fresh S. Mean height 4.15. Mean Adachi - 154,922.
26/8/69	- 9,000	6 days Fresh W. 2½ days Fresh-Strong NW. 2½ days Strong S. 2 days Fresh SE. Mean height 4.74. Mean Adachi -27549.
2/9/69	- 5,000	1 day Fresh NW. Light-Moderate. Mean height 3.49. Mean Adachi 109,420.
10/9/69	+12,000	1 day Fresh NW. Light-Moderate. Mean height 3.57. Mean Adachi 59,016.
5/10/69	- 2,000	8 hrs. Fresh SE. Light-Moderate. Mean height 3.99. Mean Adachi 43,690.
13/10/69	- 25,000	48 hrs. Fresh-Strong NW. 24 hrs. Strong-Gale S. Mean height 4.84. Mean Adachi 154,489.
30/10/69	+ 23,000	4 days Light-Moderate. Remaining Fresh-Strong NW. Mean height 5.76. Mean Adachi 370,870.
10/11/69	- 18,000	10 hrs. Fresh NW. Light. Mean height 3.00. Mean Adachi 40,865.

Table 10 (d) (Contd.)

19/11/69	+ 5,000	6 hrs. Fresh S. Light. Mean height 2.42. Mean Adachi 27,491.
26/11/69	- 24,000	Mainly light-Moderate. Mean height 2.94. Mean Adachi 103,449.
11/12/69	0	Light-calm. Mean height 3.10. Mean Adachi 51,754.
31/12/69	+ 15,000	6 hrs. Strong NW. 16 hrs. Fresh-Strong NW. Mean height 3.46. Mean Adachi 149,748.

N.B. Mean Adachi: Negative value indicates south-north energy balance

Positive value indicates north-south energy balance volume gains reveals that of the 10 observations seven were associated with southerly conditions, two with calm conditions and one with light northerly conditions. In the case of the six large negative changes two were associated with northerly conditions, three with mixed conditions and one with mixed but predominantly southerly conditions.

Returning to Table 8 it has been previously noted that although large volume increases are associated with high river flow the occurrence of a high flow is not necessarily associated with high volume increase. Of the positive volume increases over 10,000 cubic yards not yet discussed (six observations) two were characterised by southerly conditions, two by calm conditions and two by mixed conditions. Of the other changes noted in Table 8 eight were accompanied by northerly conditions, five by mixed conditions, one calm conditions and one southerly conditions.

Attempts to establish more closely relationships between total volume changes and wave conditions were unsuccessful. Using volumetric and wave data collected between October 1968 and December 1969 correlation coefficients were calculated using volume as the dependent variable and intersurvey wave energy, wave height, alongshore energy and the same variables calculated for the five days immediately preceeding the survey. No singificant relationships were detected.

This evidence tends to suggest that large inputs of material into the entrance area occurs at times when high river flow coincides with southerly or calm conditions. Northerly or mixed northerly and southerly conditions coinciding with higher river flow usually results in loss of material. No large accumulation of material in response to a particular wave environment unaccompanied by high river flow were noted.

The evidence presented has shown that accumulation of material occurs during southerly conditions and high flow. This accumulation could have occurred because:

(a) During southerly conditions littoral drift material is unable to by-pass the entrance.

(b) The river carries greater quantities of material as a result of southerly conditions.

(c) Southerly wave conditions are more conducive to deposition of material at the entrance.

(d) Tidal currents favour north to south transfers.

The first suggestion (a) can be partially discounted as there seems no reason why material should not be by-passed from south to north under southerly conditions if north to south by-passing occurs under northerly conditions. Suggestion (b) has possible merit. It is conceivable that southerly storms cause more damage in the catchment area and subsequently increase sediment load. Evidence to support this hypothesis has not been collected. The third suggestion is also a possibility but the most plausable explanation is that, off the coast adjacent to the harbour, the tidal stream sets northwards with the rising tide and southwards with the falling tide. This southwards ebbing would be acting in the opposite direction to a southerly wave train. The direction of longshore drift plus the ebbing tide under northly conditions would ensure that material is rapidly moved south of the harbour entrance.

Volume Changes Above the 10 Foot Contour

The Walrus and the Carpetner
Were walking hand and hand.
They wept like anything to see
Such quantities of sand,
'If only this were swept away',
They said, 'it would be grand'.

'If seven maids and seven mops
Swept it for half a year,
Do you suppose', the Walrus said,
'That they could keep it clear?'
'I doubt it', said the Carpenter,
And shed a bitter tear.

'I'm not so sure', the Walrus said,
'I've got a little scheme;
In place of seven maids and mops,
We'll concentrate the stream,
And then the sand will surely go
Much further than you dream'.

<u>Wanganui Chronicle</u> 19/6/1923

The method of improving depths at the harbour entrance envisaged by the Walrus has its origin in a number of observations that suggested that high river flow swept away the bar forming at the entrance. Work done by Sir Alexander Gibb and Partners (1962) also suggests that higher river flow results in improved depths. A somewhat anomalous situation therefore exists. Evidence presented in the previous section shows that high volumes of material in the entrance are associated with high river discharge yet observations by Gibb and others suggest that depth conditions improve under the same circumstances. Examination of changes in volume following river flow in excess of 20,000 cusecs further confuses the issue. On 14 occasions losses in volume of material above the 10 foot contour were incurred. On 11 occasions gains were recorded and four surveys showed no change. Closer examination reveals that 72,000 cubic yards of material was lost from above the 10 foot contour during the 14 flows (average loss 5,000 cubic yards) and 180,000 cubic yards gained during the 11 flows (average gain 16,500 cubic yards). On a number of occasions the top of the bar was removed consequently increasing minimum depths at the entrance but frequently this decapitation process merely involved redistribution of sediment in the entrance area and the volume of sediment in shoal depths did not decrease. This evidence suggests that the premise that the bar improves during high flow appears to be shakily based. The sounding charts examined here for the years 1958, 1967, 1968 and 1969 fail to confirm the hypothesis.

The failure of a river flow hypothesis to explain volume changes in shallow water off the entrance to Wanganui Harbour prompted the use of simple correlation analysis in an attempt to isolate possible causal factors. Volume of material above

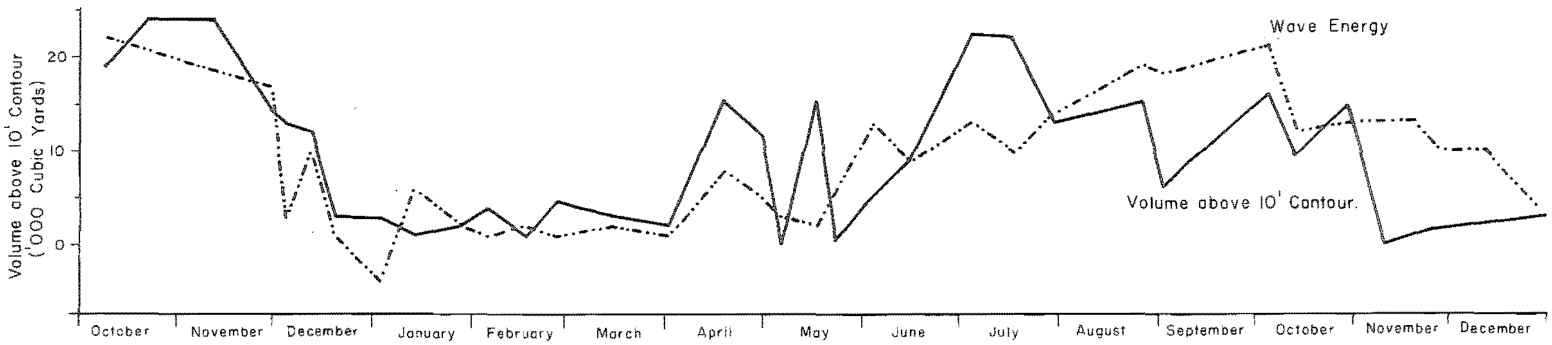


Figure 31 Fluctuation of wave energy in relation to volume of material above the 10 foot contour

the 10 foot contour was correlated with a number of wave parameters (mean intersurvey wave height, wave energy ($41H^2T^2$), longshore energy (E_i=1/16W H_b $^2(L_b/T)$ Sin2$\emptyset$) and the same variables calculated for the five days preceeding the survey.)

First, a close relationship existed between volume of material and mean intersurvey wave energy (r=0.56). This relationship is shown in Figure 31. Also significantly important was the relationship between volume of material and the volume of material in the entrance area at the time of the previous survey (r=0.84). Using a multiple stepwise regression technique (Ezekiel and Fox, 1966) 74% of the variance was explainable. The regression equation was:

$$Y = -0.313 + 0.043X_1 + 0.732X_2$$

where Y = volume of material above the 10 foot contour,

X_1 = volume of material at time of previous survey and

X_2 = mean intersurvey wave energy.

This analysis left some 26% of the total variance unaccounted for but in view of previously mentioned error factors the result is satisfying.

Before this analysis was begun it was tentatively hypothesised that the amount of material found at the entrance to the harbour would be related in some way to the magnitude of littoral drift. In the correlation analysis Aduchi's expression for longshore energy was correlated against volume of material. No significant relationships were found to exist. It could be argued from this evidence that longshore drifting of material is not important in supplying material to the entrance. Following this line of argument it is also possible to suggest that the large volume of material which has accumulated north of the entrance is not a product of longshore drifting. This argument is, however, invalid. Previously mentioned work by Bruun and Gerritson (1960) suggested that material by-passes tidal entrances by either tidal flow by-passing, or bar by-passing, or a combination of the two methods. Whether predominant bar or tidal flow by-passing occurs depends on the ratio of littoral drift to tidal flow. Bruun and Gerritsen describe by-passing with the expression:

$$r = M_{mean} / Q_{max}$$

where: r is the by-passing factor

M_{mean} is predominant littoral drift in cubic units/year, and

Q_{max} is maximum tidal flow at spring tide in cubic units/second.

If r is between 200-300 bar by-passing predominates, and if r is between 10-20 tidal flow by-passing predominates. If predominant littoral drift at Wanganui is taken as 200,000 cubic years/year and tidal flow as 30,000 cusecs:

$$r = 200{,}000 / (30{,}000/27)$$

$$= 180$$

Bruun and Gerritson also point out that the more regularly the transport of material by moderate to heavy wave action takes place the better are conditions for by-passing.

The Wanganui situation is one, therefore, of combined bar and tidal flow by-passing. During periods of high waves bar by-passing can be expected to predominate while during calmer conditions tidal flow will be important. In view of the already described relationship between volume of material above the 10 foot contour and mean intersurvey wave energy this explanation seems sound. Increases in the volume of material in shallow water during periods of high wave energy reflect the greater importance of bar by-passing. Loss of material from shoal depths during calmer periods reflect the increased importance of tidal by-passing. During periods of greater sediment availability due to increased longshore drifting, conditions at the entrance will also be more favourable to by-passing. Consequently large accumulations of material from longshore sources will be unlikely.

Summary

The entrance to Wanganui Harbour fluctuates widely and in many different ways due to wave and river processes. The volume of material above the 20 foot contour in the small area (1.2 million square feet) studied fluctuated from as low as 249,000 cubic yards to as high as 495,000 cubic yards. The distribution of sediment within the entrance also changed markedly from survey to survey. Quantities of sediment in shallower depths fluctuated (relatively) even more than total volumes. Examination of volumetric changes suggested that large additions of material to the entrance area could be attributed to high river flow and presumably part of the large sediment load associated with the high flow was deposited at the entrance. Deposition of large amounts of material disrupt the equilibrium balance at the entrance until the extra sediment is transported to the down-drift beaches.

Additions of material at times most likely to be conducive to longshore drifting were difficult to detect. This is attributed to the ability of the entrance to by-pass littoral drift material suggesting that although large amounts of material may reach the entrance area and although accumulation occurred in the past, at present an equilibrium situation exists and material by-passes the entrance with resulting short term changes but long term stability.

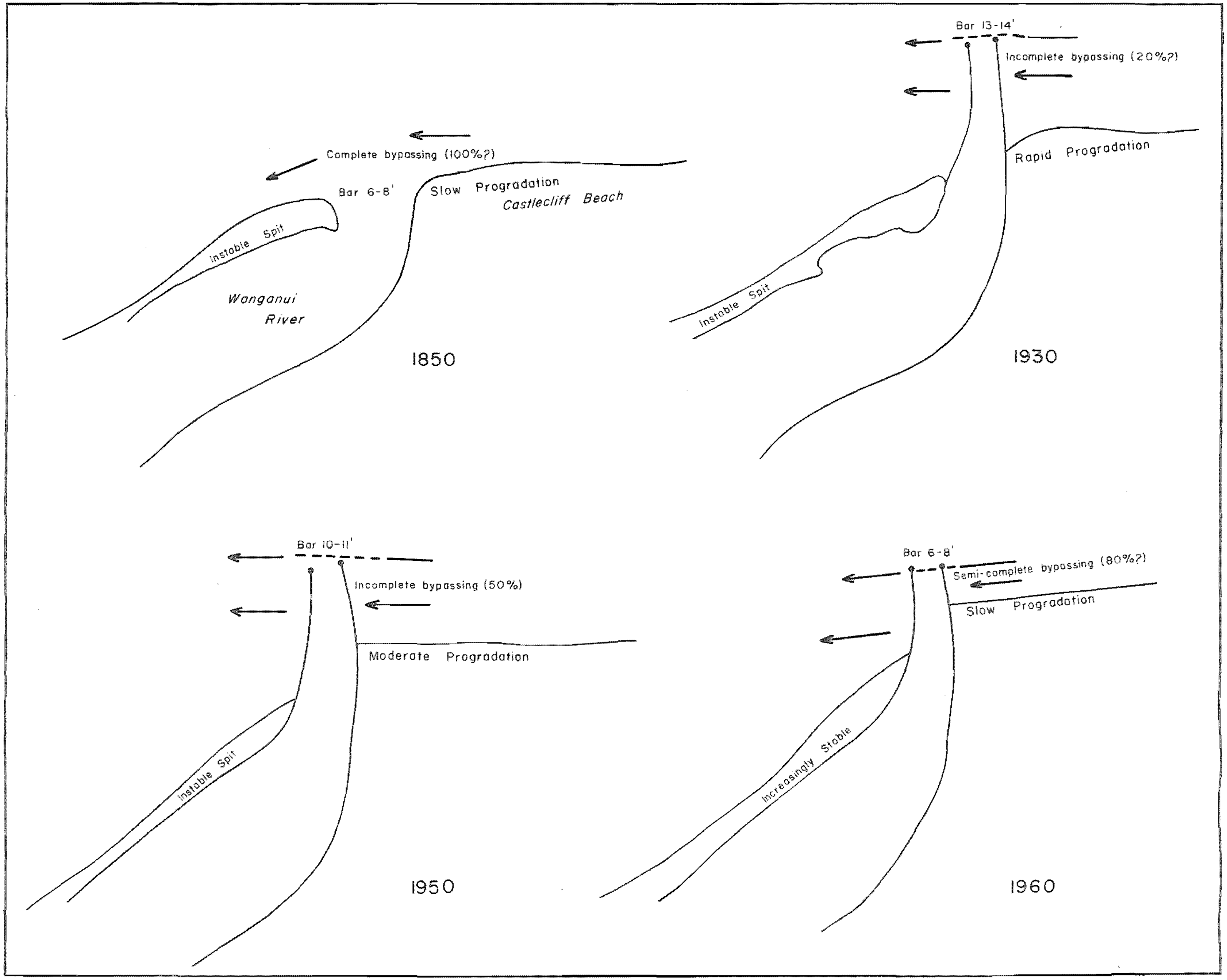


Figure 32 Schematic reconstruction of sand movement in the past 100 years

RECONSTRUCTION OF SEDIMENT MOVEMENT PATTERNS OF THE LAST 100 YEARS

General

The coastline adjacent to the mouth of Wanganui River has changed considerably in the last 100 years. In previous sections it has been shown how entrance depths were improved from six - eight feet in the early 1960s to 13-14 feet by 1930. Since 1930 depths deteriorated to such an extent that today depths are little different to when the first European visited New Zealand. Improvement in depths has been attributed here to the building of rock and rubble moles which pushed the entrance out into deeper water. Deterioration has been attributed to vast accumulation of sediment.

Pre-development Phase

Figure 32 schematically reconstructs how coastline probably took place. Before 1870 material moved along the coast until it reached the Wanganui River. At the mouth of the river an offshore sand bar covered by six-eight feet of water at low tide facilitated the transfer of material from north to south. It has been suggested that Castlecliff Beach was prograding slowly, meaning that not all of the littoral drift material by-passed the entrance.

However, it seems likely that most littoral drift material did find its way south of the entrance. No evidence to suggest that material was accumulating in the entrance can be found, so that it appears that the only losses of material would have been the sediment accumulating on Castlecliff Beach and the material being blown from the backshore inland.

The Years of Development - 1870-1935

Attempts to improve harbour entrance depths began in the 1870's. Construction of moles early this century iniated major improvements in entrance depths and also started considerable change in the adjacent coastline. By 1930 depths at the entrance had reached a maximum (minimum mean depth at low water spring tide 13 feet). Rate of progradation on Castlecliff Beach also reached a maximum about this time. The beach had prograded five chain between 1900-1920. This rate sped up in the next two decades and the shoreline advanced 10 chains. South of the river mouth the long unstable sand spit separating the river from the Tasman Sea changed from the hooked shape of earlier years to a less stable form bounded at its northern extremity by the south mole. At the same time the seaward boundary of the spit retreated.

This pattern of events can be attributed to the interruption of littoral drift by the harbour moles. Material by-passing the entrance before mole construction encountered depths of six-eight feet. By 1930 the minimum depths were 13-14 feet with the consequence that sediment transfer was less easily accomplished. Material which had previously by-passed the entrance began accumulating on Castlecliff Beach. Although considerable quantities of material were prevented from reaching the beaches south of the river it seems likely that at least some material must have by-passed the entrance as erosion of the down-drift beaches was not as substantial as would have been expected if total interruption had occurred. Examples of similarly caused erosion reported in the literature normally resulted in quite substantial retreat of the coastline. At Durban, South Africa, 400 feet of beach was lost at Rutherford Street in the space of 20 years (National Mechanical Engineering Research Institute, 1963). In Figure 32 it is suggested that in 1930 about 20% of total littoral drift probably by-passed the entrance. This figure is an estimation based on the magnitude and the nature of the changes taking place. It was previously mentioned that maximum accumulation of material on Castlecliff Beach at this time was approximately 200,000 cubic yards per year. Allowing an extra 20% for sediment that by-passed the entrance net drift is likely to be of the order of 240,000 cubic yards per year. Total drift would of course be of greater magnitude. Wave records show that north to south wave energy is 2.5 times greater than south to north movement. Using equation (1) (p. 47) and equation (2) (p. 48) it was possible to calculate approximate quantities for longshore drift. North to south drift was found to be approximately 400,000 cubic yards/year and south to north drift 160,000 cubic yards/year. These figures, perhaps fortuitously, result in a net drift of 240,000 cubic yards/year and a gross drift figure of 560,000 cubic yards/year." Ingle (1966) working on Californian beaches obtained annual net transport rates of 259,000 cubic yards at Goleta Point Beach, 333,000 cubic yards at Trancas Beach, 246,000 cubic yards at Santa Monica Beach, 192,000 cubic yards at Huntington Beach and 115,000 cubic yards at La Jolla Beach." Ingle does not summarise wave conditions for the beaches he worked on so comparisons between littoral drift at Wanganui and these Californian Beaches is not really possible. Conditions during tracer tests performed on the beaches are mentioned by Ingle and suggest that wave energy conditions are moderate to high." The littoral drift figure of 240,000 cubic yards per annum for Wanganui would therefore appear to compare with Ingles' drift volumes.

In addition to material reaching the entrance by littoral drifting large quantities reach the entrance from the catchment of Wanganui River. Table 6 shows that on the average two occasions per year will result in large deposits of material from the river. Obviously some of the sediment accumulating will be littoral drift material. Assuming that littoral drift material moves along the coast at a constant rate (net weekly rate 4,800 cubic yards) the average amount of material accumulating in the entrance area studied, per annum, attributable to river flow is approximately 120,000 cubic yards. This volume could be higher if it was possible to examine a larger area at the entrance. It is probable that most sediment effecting change on the beaches is deposited in the area studied. A certain amount could be lost immediately north and south of the entrance but the orientation of the moles with the shoreline would minimise this loss and most finer material would be lost offshore.

The Years of Deterioration - 1935 - Present

Rapid progradation of Castlecliff Beach resulting from mole construction began to slow after 1935. Accompanying this decreased rate of progradation was increased sedimentation at the harbour entrance. Material which before 1935 accumulated on Castlecliff Beach started to leak around the end of the moles and began to accumulate in the vicinity of the entrance. The large quantities of material involved caused rapid decline in depths. Figure 32 suggests that by 1950 depths at the harbour entrance would have deteriorated to such an extent that only 10-11 feet of water (minimum LWOST) existed whereas it was 13-14 feet in 1930. Shallower depths at the entrance facilitated more rapid transfer of sediment and consequently rate of depth decline decreased. In Figure 32 the amount of material by-passing the entrance is put at 50%. This figure is again an estimation made with respect to the magnitude of changes taking place, on Castlecliff Beach, at the entrance and on the south spit.

By the 1960s entrance depths had declined to six-eight feet, progradation of Castlecliff Beach was minimal and the south spit was increasingly stable. This pattern of events suggests that material was, as in the middle of the nineteenth century, by-passing the entrance relatively easily. In Figure 32 it is suggested that 80% of littoral drift material finds its way to the down-drift beaches. Evidence to suggest that a considerable percentage of littoral drift moves uninterrupted along the coast includes the relative stability of Castlecliff Beach at present, the poor depths at the river mouth and the stability of the southern spit. In addition sediment characteristics north and south of the river are only marginally different in terms of size and sorting characteristics.

At present the coast in the immediate vicinity of the harbour entrance is in some sort of dynamic equilibrium not unlike that in the pre-development years. Material is transported along the shore by a predominantly north to south littoral drift. Upon reaching the river entrance material is transferred to the southern beaches by either bar by-passing or tidal flow by-passing or a comination of both. Under favourable conditions no problems are encountered in by-passing all available sediment but sudden influxes of material do sometimes occur which are too large for the by-passing mechanisms. In such circumstances temporary accumulation occurs. Changes in the beaches north and south of the entrance also occur but they too are essentially short term.

CONCLUSIONS

Previous examinations of coastline changes and the geomorphic processes responsible for those changes along the New Zealand Coastline have been limited both in areal extent and detailed explanation. Overseas coastal erosion problems, often caused by human interference with the littoral zone, has initiated numbers of detailed studies of coastal dynamics. Limited utilisation of the New Zealand coastline has not resulted in such concern but growing population numbers will undoubtedly eventually result in many of the overseas problems being, again, encountered here.

This study has examined in detail the changes that have taken place on a small stretch of coast near Wanganui over the last 100 years. In terms of Krumbein's process-response model, the framework for this study, changes that have occurred are considered the physical responses to the large number of processes acting on the coast. These changes are probably best described as 'quasi-natural' as they resulted naturally as a consequence of port development. In early European times the coastline and Wanganui River mouth were in dynamic equilibrium with wind, wave and river processes. The interruption of littoral drift resulting from the construction of moles, designed to improve harbour entrance depths, drastically altered the balance that had existed between geomorphic processes and the coastline. Depths at the harbour entrance were greatly increased but the interruption of movement of littoral material began a period of 40-50 years of rapid progradation of the updrift beaches. The long moles in effect provided a large storage trap for littoral drift material which had previously by-passed the entrance to the southern beaches. Downdrift beaches suffered as a result of 'starvation' of littoral drift material but circumstances (incomplete interruption of littoral drift and substantial inputs of sediment from catchment sources) prevented damage to the coast being as great as frequently described in the overseas literature.

The 'storage' capacity of the updrift beaches rapidly declined under the high drift load and material began accumulating at the river entrance resulting in increased quantities of material by-passing the entrance. No attempts were made to remove this material by dredging and eventually conditions began to return to those similar to a century ago. Today equilibrium conditions not unlike those of a century ago exist. The differences: 20 chains of additional beach at Castlecliff; two moles designed to reach deep water but now ending in water no deeper than found at the river mouth a century ago; and a south spit which has received $224,000 worth of protection and wh ch is now naturally relatively stable.

As a result of this study it is possible to ascertain the probable magnitude of coastline change resulting from interruption to littoral drift in New Zealand conditions. At Wanganui it was estimated that net littoral drift was in the vicinity of 240,000 cubic yards per year and gross drift in the vicinity of 560,000 cubic yards per year. In addition it was ascertained that roughly 120,000 cubic yards of material was deposited at the entrance per annum from the catchment of the Wanganui River.

In conclusion the behaviour of the Wanganui Coast over the last 100 years can be considered a battle of man against nature with nature finally the victor.

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APPENDIX

Formulae used in Calculation of Grain Size Parameters

Formulae and notation used are taken from Folk (1965)

Graphic Mean (M_z) :

$$M_z = \frac{16\,\phi + 50\,\phi + 84\,\phi}{3}$$

Inclusive Graphic Standard Deviation $(\ _1)$:

$$= \frac{84\,\phi - 16\,\phi}{4} + \frac{95\,\phi - 5\,\phi}{6.6}$$

under	0.35 ϕ	very well sorted
	0.35 to 0.5 ϕ,	well sorted
	0.50 to 0.71 ϕ,	moderately well sorted
	0.71 to 1.0 ϕ,	moderately sorted
	1.0 to 2.0 ϕ,	poorly sorted
	2.0 to 4.0 ϕ,	very poorly sorted
	Over 4.0 ϕ,	extremely poorly sorted

Inclusive Graphic Skewness (SK_I) :

$$SK_I = \frac{16\,\phi + 84\,\phi - 2\,(50\,\phi)}{2\,(84\,\phi - 16\,\phi)} + \frac{5\,\phi + 95\,\phi - 2\,(50\,\phi)}{2\,(95\,\phi - 5\,\phi)}$$

SK_I from	1.0 to 0.30,	strongly fined skewed
	0.3 to 0.10,	fine skewed
	0.1 to -0.10,	near symmetrical
	-0.1 to -0.30,	coarse skewed
	-0.3 to -1.00,	strongly coarse skewed

<u>Graphic Kurtosis</u> (K_G) :

$$K_G = \frac{95\,\phi - 5\,\phi}{2.44\,(75\,\phi - 85\,\phi)}$$

K_G	under		0.67 ,	very platykurtic
	from	0.67 to	0.90 ,	platykurtic
		0.90 to	1.00 ,	mesokurtic
		1.11 to	1.50 ,	leptokurtic
		1.50 to	3.00 ,	very leptekurtic
	over		3.00 ,	extremely leptekurtic

GRAIN SIZE STATISTICS

Sample No.	M_z	I	SK_I	K_G
1A	2.08	0.52	-0.04	1.26
1B	2.22	0.33	0.17	1.18
1C	1.05	0.82	0.07	1.31
1D	1.40	0.79	-0.27	1.02
2A	3.30	1.62	0.62	2.65
2B	1.87	0.38	-0.16	1.23
2C	1.77	0.51	-0.14	1.07
2D	1.33	0.65	-0.10	0.72
3A	Sample not collected		(Rock cliff)	
3B	2.53	0.44	-0.25	0.88
3C	1.80	0.00	-0.11	0.97
3D	2.32	0.33	0.08	1.00
4A	2.68	0.40	0.16	1.01
4B	1.98	0.74	0.00	1.18
4C	1.40	0.68	0.04	0.72
4D	-0.13	1.38	0.05	0.76
5A	Sample not collected		(Rock cliff)	
5B	2.30	0.31	0.07	1.08
5C	1.95	0.54	-0.17	1.08
5D	1.27	0.53	-0.07	0.87
6A	2.42	2.73	-0.24	1.16
6B	2.20	0.43	0.21	1.08
6C	2.25	0.48	0.20	1.10
6D	1.62	0.63	-0.13	0.89
7A	2.62	0.48	0.18	0.98
7B	2.07	0.33	0.26	0.96
7C	2.35	0.42	-0.16	1.15
7D	1.77	0.54	-0.09	1.02

Sample No.	M_z	$_I$	SK_I	K_G
8A	Sample not collected (Rock cliff)			
8B	2.53	0.39	0.21	1.15
8C	2.30	0.35	0.02	0.94
8D	2.05	0.85	-0.31	1.43
9A	3.60	1.68	-0.35	1.24
9B	2.33	0.35	0.14	1.05
9C	1.80	0.67	-0.20	1.01
9D	1.52	0.88	-0.26	1.10
10A	3.57	2.50	0.22	1.68
10B	2.25	0.34	0.00	0.90
10C	1.87	0.56	-0.12	1.04
10D	1.47	0.98	-0.28	1.13
11A	2.00	0.48	-0.03	1.39
11B	2.27	0.28	0.12	0.97
11C	1.38	0.65	0.11	0.78
11D	2.25	0.59	-0.33	1.08
12A	2.53	0.37	0.19	1.18
12B	2.23	0.29	-0.05	1.02
12C	1.95	0.44	-0.05	0.99
12D	1.87	0.80	-0.38	1.54
13A	2.40	0.35	0.12	1.18
13B	2.07	0.45	0.00	0.94
13C	1.50	0.64	0.03	0.68
13D	1.55	1.10	-0.41	1.43
14A	2.15	0.39	0.27	1.23
14B	2.08	0.36	-0.24	0.93
14C	1.02	0.61	0.30	1.13
14D	0.85	0.99	-0.19	1.00
15A	1.90	0.41	-0.07	1.15
15B	2.08	0.38	0.15	0.82
15C	1.58	0.58	-0.01	0.90
15D	1.82	0.64	-0.31	0.58

Sample No.	M_Z	I	SK_I	K_G
16A	2.18	0.49	-0.01	0.61
16B	2.57	0.81	-0.13	1.03
16C	1.68	0.67	-0.43	0.93
16D	1.50	0.61	-0.19	0.87
17A	2.28	0.43	-0.08	1.08
17B	2.33	0.34	0.03	1.05
17C	2.10	0.27	0.26	0.87
17D	1.38	0.54	-0.08	0.96
18A	2.23	0.46	-0.11	1.13
18B	2.60	0.30	-0.05	1.02
18C	2.13	0.55	-0.25	1.26
18D	1.60	0.80	-0.29	1.33
19A	2.52	0.29	0.15	1.02
19B	2.42	0.33	0.08	1.13
19C	2.08	0.42	-0.07	1.04
19D	1.42	0.67	0.07	0.75
20A	2.67	0.30	0.40	1.57
20B	2.42	0.34	0.00	1.28
20C	1.68	0.55	-0.15	1.18
20D	0.82	1.14	-0.17	1.74
21A	2.48	0.34	-0.06	1.05
21B	2.50	0.30	0.00	1.02
22C	2.12	0.33	0.08	1.13
21D	1.80	0.54	-0.17	1.17
22A	2.30	0.34	0.05	1.00
22B	2.49	0.31	0.02	1.01
22C	2.22	0.31	0.09	1.02
22D	1.88	0.62	-0.20	1.23
23A	2.27	0.68	-0.10	1.37
23B	2.35	0.29	0.03	0.97
23C	2.00	0.42	-0.02	1.08
23D	1.48	0.65	-0.12	0.78

Sample No.	M_z	$_I$	SK_I	K_G
24A	2.10	0.55	-0.14	1.20
24B	2.28	0.32	0.08	1.00
24C	2.13	0.49	-0.16	1.09
24D	1.92	0.49	-0.18	1.20
25A	2.38	0.35	0.18	1.05
25B	2.32	0.28	0.07	1.11
25C	1.90	0.39	0.00	0.85
25D	1.28	0.85	-0.10	0.95
26A	2.30	0.59	-0.08	1.04
26B	2.45	0.33	0.25	0.90
26C	2.08	0.41	-0.15	0.89
26D	2.02	0.53	-0.17	1.17
27A	2.55	0.38	0.24	1.70
27B	2.52	0.30	0.12	1.08
27C	1.57	0.77	0.06	0.75
27D	1.03	1.07	-0.07	1.56
28A	-1.10	2.55	0.07	0.49
28B	2.10	0.40	-0.20	1.21
28C	1.65	0.87	-0.31	0.90
28D	-5.7	0.42	-0.34	1.23
29A	2.17	0.45	0.06	1.09
29B	2.10	0.44	-0.19	1.23
29C	1.22	0.59	0.25	0.82
29D	2.30	0.41	-0.22	1.19
30A	1.68	0.70	-0.20	0.88
30B	1.15	0.67	0.12	0.99
30C	0.05	1.11	-0.41	0.91
30D	0.40	1.41	-0.10	0.86
31A	1.43	0.70	0.03	0.73
31B	1.69	0.60	-0.17	0.86
31C	1.62	0.52	0.11	0.96
31D	-1.22	1.70	0.51	0.97

Sample No.	M_z	σ_I	SK_I	K_G
32A	2.18	0.54	-0.18	1.37
32B	1.82	0.72	-0.55	2.15
32C	1.75	0.50	-0.14	1.00
32D	0.33	1.49	-0.20	0.66
33A	1.28	0.61	0.31	1.56
33B	2.20	0.21	-1.90	0.23
33C	1.28	1.08	-0.23	1.34
33D	0.10	1.51	-0.24	0.74
34A	2.02	0.41	0.07	0.97
33B	1.87	0.49	0.01	1.13
34C	1.47	0.66	0.08	0.73
34D	0.67	1.05	-0.17	1.62
35A	1.79	0.66	-0.21	0.94
35B	1.92	0.50	-0.13	1.13
35C	1.58	0.59	0.02	0.95
35D	1.10	0.73	0.40	0.94
36A	2.36	0.36	0.15	0.98
36B	1.88	0.51	-0.27	1.42
36C	2.17	0.36	-0.11	1.09
36D	1.68	0.72	-0.20	0.88
37A	1.72	0.74	-0.33	0.94
37B	2.08	0.51	-0.29	1.26
37C	2.15	0.45	-0.21	1.00
37D	0.52	1.52	-0.27	0.71
38A	2.38	0.34	-0.04	1.00
38B	1.77	0.85	-0.53	0.84
38C	-0.52	0.67	0.30	1.88
38D	-0.98	1.17	0.48	1.73
1	2.68	0.68	-0.25	1.98
2	1.98	0.75	-0.31	0.99
3	2.40	0.85	-0.02	1.05

Sample No.	M_z	I	SK_I	K_G
4	2.92	1.06	0.27	0.70
5	1.07	0.96	-0.15	1.00
6	1.78	0.50	-0.11	1.39
7	2.58	0.34	-0.15	1.05
8	1.78	0.49	-0.10	1.13
9	2.40	0.35	-0.02	1.11
10	2.75	0.35	-0.06	1.43
11	2.70	0.34	0.27	1.38
12	2.78	0.38	-0.02	1.22
13	2.52	0.45	-0.17	1.35
14	2.85	0.37	-0.02	1.49
15	2.43	0.41	-0.15	1.32
16	2.80	0.30	0.07	1.85
17	2.37	0.59	-0.26	1.54
18	2.78	0.31	0.02	1.18
19	2.57	0.51	-0.12	1.38
20	3.05	0.37	0.18	1.41
21	2.57	0.60	-0.25	1.67
22	3.02	0.35	0.25	1.57
23	2.83	0.29	0.24	1.59
24	2.97	0.26	6.13	1.56
25	2.77	0.32	0.13	1.23
27	1.70	0.64	-0.23	1.20
28	2.35	0.35	-0.02	1.05
29	1.87	0.66	-0.27	1.35
30	0.69	0.78	-0.20	1.87
31	1.15	0.71	0.07	0.99

Samples Collected After December 7 Flood

Sample No.	M_z	I	SK_I	K_G
1/2	2.52	0.41	0.15	1.19
2/2	1.60	0.69	0.00	0.92
3/2	1.85	0.72	-0.26	0.95
4/2	-1.07	1.70	-0.02	0.84
5/2	2.50	0.39	-0.06	1.02
6/2	2.70	0.56	-0.15	1.79
7/2	3.55	1.24	0.02	1.23
8/2	1.47	0.90	0.96	0.88
9/2	2.43	0.49	0.00	1.48
10/2	1.98	0.40	-0.16	1.46
11/2	2.63	1.20	0.05	1.00
12/2	2.07	0.28	0.07	1.11
	Castlecliff Dune Samples			
13X	2.03	0.50	0.08	0.82
14X	2.37	0.51	0.25	1.16
15X	1.87	0.48	0.20	0.88
16X	2.05	0.49	-0.10	0.88
17X	2.20	0.37	-0.07	0.96

Whanguehu River bed Sample

-1.07	2.81	0.37	0.66