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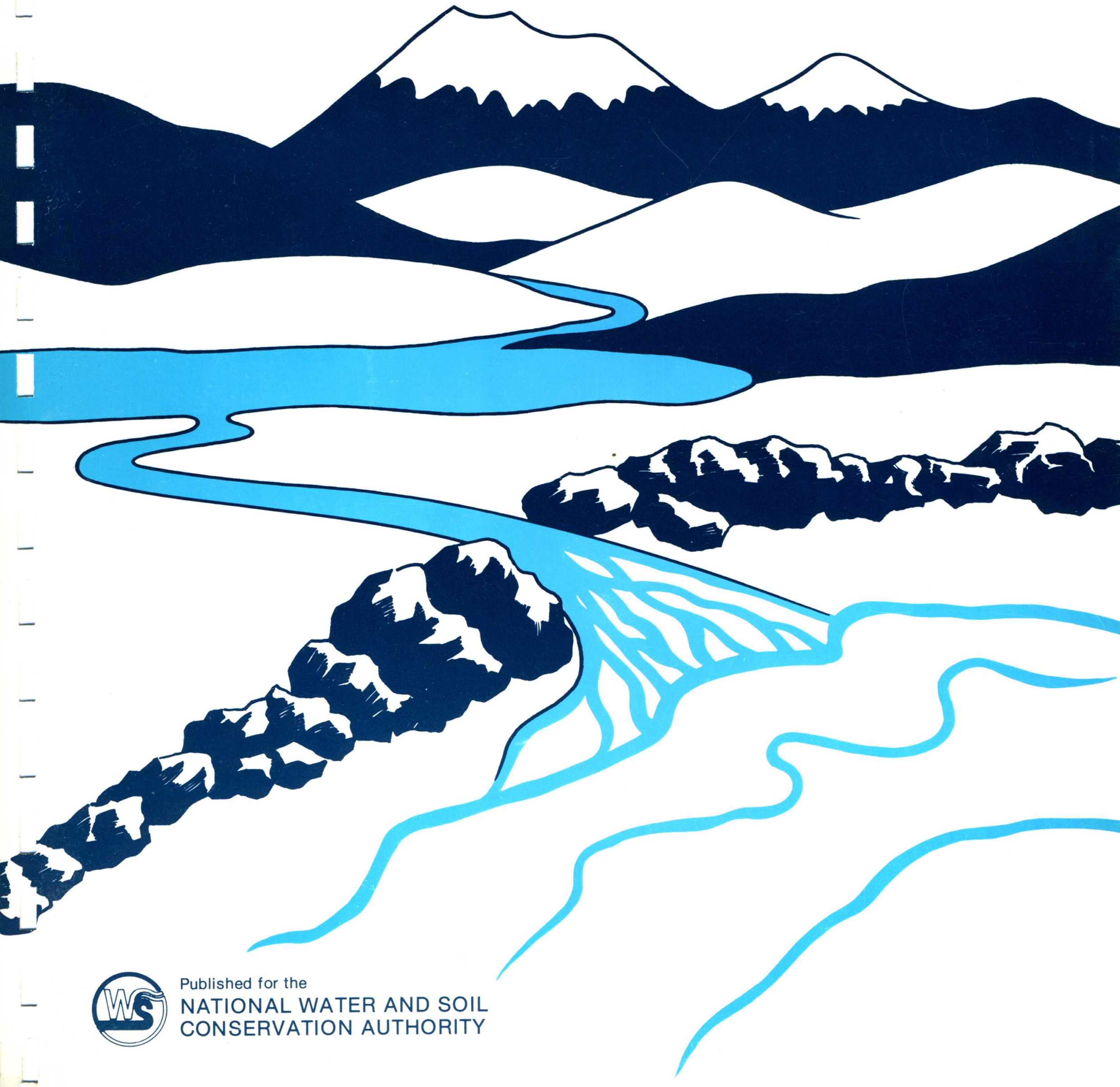
Publication No. 5

BEACH CHANGES BETWEEN NAPIER and CLIFTON

SOUTHERN HAWKE BAY



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BEACH CHANGES BETWEEN NAPIER AND CLIFTON, SOUTHERN HAWKE BAY

by

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INTRODUCTION

The length of coast between Waitangi and Clifton has had a history of recession (Dinnie, 1939; Batten, 1943; Lindup 148; Smith, 1968; Gibb 1973) (Fig. 1). The most serious erosion has been between the mouth of the Ngaruroro River and Haumoana. Survey information from Hastings City Council has shown that recession of the coast in the vicinity of the Hastings sewer outfall has continued for many years. Recession of the beach at East Clive has progressed to the stage where the retreat of the beach barrier is now threatening the security of the stopbank backing the beach. Should this stopbank be breached there is a real danger of salt water flooding over the low lying land between Clive and the sea, as occurred in 1974 (Powell, Fenwick and Johnson, 1974).

A number of alternative strategies for shore protection have been proposed for the length of foreshore known as East Clive, which lies between the mouths of the Ngaruroro and Tukituki rivers. All methods are aimed at strengthening the beach barrier to prevent wave overtopping, the flooding of salt water onto the farm land, and at the same time preserving the existing Muddy Creek drainage scheme. One scheme envisages the use of spur groynes to trap shingle on the beach face which will cause the barrier to widen sufficiently to prevent waves washing down the back slope. Waves reaching the crest of the widened barrier would deposit shingle causing the structure to gain height. As a further security measure the existing stopbank is to be repositioned inland on the western side of the old Tukituki River channel and would prevent salt water from reaching the farmland. The major concern with this proposal is; what are the optimum positions for any groynes, and can groynes be constructed in a manner which will not cause erosion of the down drift coastline?

An alternative suggestion for coastal protection is to increase the height of the barrier crest using material from the barrier backslope. This method would also prevent waves overtopping the barrier and would offer no obstruction to material moving alongshore. The provision of a reasonably stable barrier, by widening or increasing the crest elevation, could delay the need for moving the existing stopbank inland.

This report has been prepared for the Hawke's Bay Catchment Board to provide basic information on the coastal environment and past beach changes, to assist the Board to plan a successful shore protection scheme for the East Clive area. The report describes the physical conditions in Hawke Bay, recorded historical beach changes and discusses possible methods of coastal protection.

THE STUDY AREA

Geomorphology

The coastal foreshore between Clifton and Napier is the southernmost of two sand and shingle barrier beaches which link Cape Kidnappers Promontory, Scinde Island (Bluff Hill Napier), and Tangoio (Smith, 1968) (Fig. 1). The Heretaunga Plains are a roughly triangular, gently sloping alluvial deposit which reach the coast between Napier and Te Awanga. The barrier beach deposit is a separate feature to the plains lying on top of, rather than being part of, that formation (Hill, 1897). Behind the beach, between Clifton and Haumoana, are a series of beach ridges which extend inland to the base of a line of old sea cliffs. These beach ridges are truncated where the Tukituki River emerges from the hills on the southern side of the plains. Between Haumona and Awatoto, the beach barrier is a narrow structure, little more than 100 m wide with a beach crest elevation of 3-4 m above mean sea level. North of Awatoto, the barrier is wider, 200-300 m and higher, with a beach crest level of 5 m - 7 m above mean sea level.

The beach is exposed to the north-east and east. The Kidnappers promontory offers partial protection from the south-east and south. The Mahia Peninsula and the northern coast of Hawke Bay offer shelter from the north and north-west. Maximum fetch distances across the bay from the north are approximately 100 km.

Geology

On the eastern side the Cape Kidnappers promontory is comprised of Pliocene sediments characterised by fossiliferous calcareous siltstones (Kingma, 1962). On the western side, from just west of Black Reef, the promontory consists of weathered greywacke gravels and sands with beds of peat, silts and clays. The cliffs, which rise to 100 m - 140 m above sea level, are continually being eroded by streams which cut deeply incised valleys to sea level, by rills which erode the cliff face, and by wave action undercutting the toe during high seas.

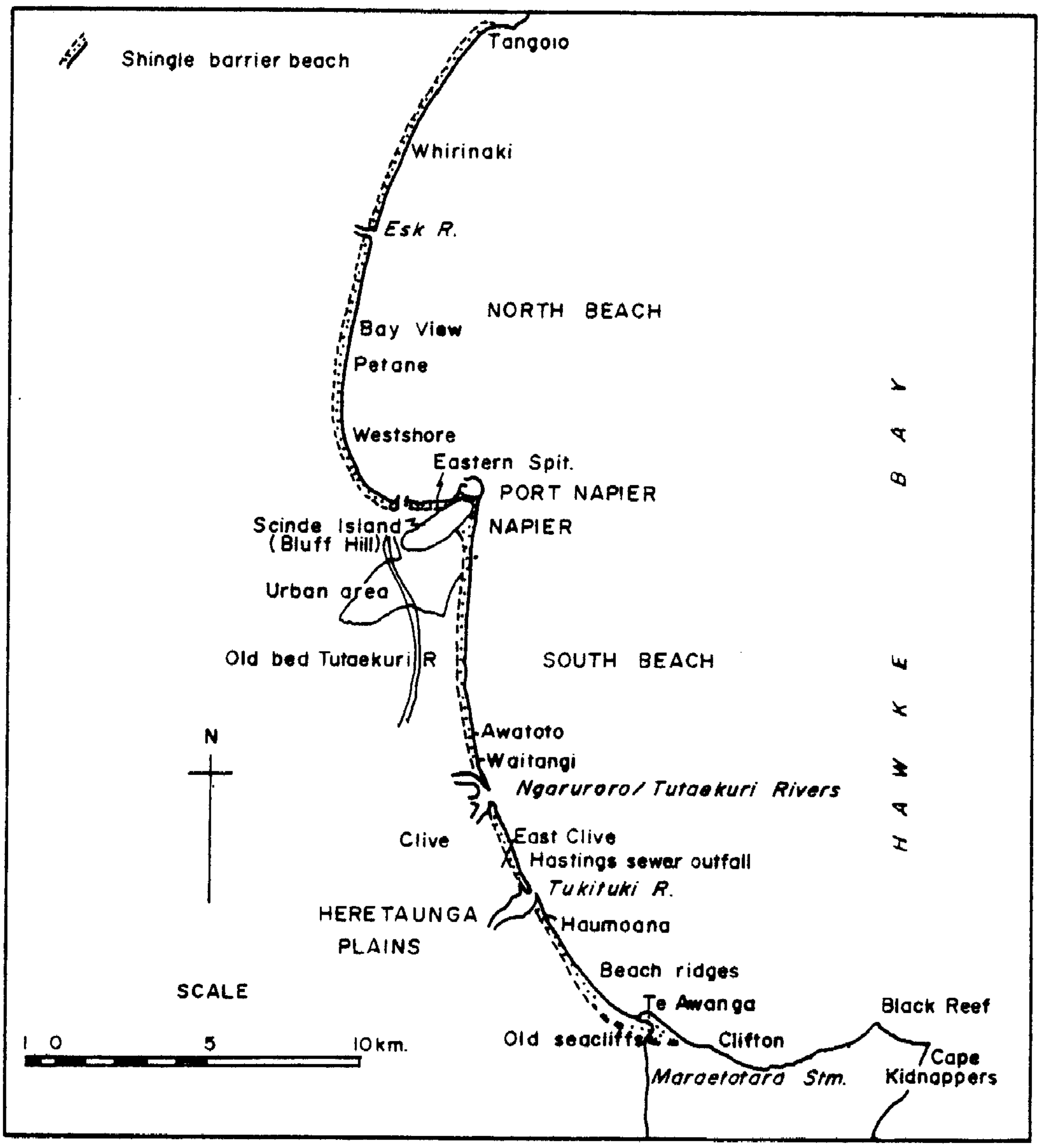

Figure 1 : Location map showing the main coastal features between Cape Kidnappers and Tangoio

Slips are also occasionally triggered by earthquakes. Cotton (1956) suggested that the erosion of these cliffs was one of the most significant coastal processes occurring in Hawke Bay.

To the north of the Kidnappers promontory, the Heretaunga Plains consist of marine and fluvial sands and gravels with some interbedded layers of silts and clays. The Tukituki, Ngaruroro and Tutaekuri Rivers which drain the Ruahine and Kaweka Ranges have gravel-lined braided channels and are a potential supply of beach material. Each river has at least one shingle extraction plant in its lower reaches.

Offshore

Offshore the bay slopes gently to the Lachlan Ridge (Fig. 2). The sea floor contours are approximately parallel to the coastline (NZ Hydrographic Office, 1952; Pantin, 1966). Pantin (1966) studied the offshore sediments which consist of a deposit of gravels off the mouth of the Maraetotara Stream, a sand belt parallel to the coast and an offshore mud belt. Pantin (1966) also described a sand salient which extends from the sand belt from just north of Napier in a southeasterly direction and ends about 5 km north of Cape Kidnappers. Further offshore, in the middle of the bay, are another series of sediments associated with earlier sea levels (Pantin, 1966). Most of the sand belt which lies adjacent to the beach, is comprised of muddy sand ranging from 2ϕ (0.25 mm) to 4ϕ (0.06 mm). Though some particles of up to -1ϕ (2.0 mm) occur in these sediments, they are rare. The proportion of mud in the sand belt varies between 7% and 50%. Only the sand and mud belt appear to be affected by present sedimentation processes (Pantin, 1966).

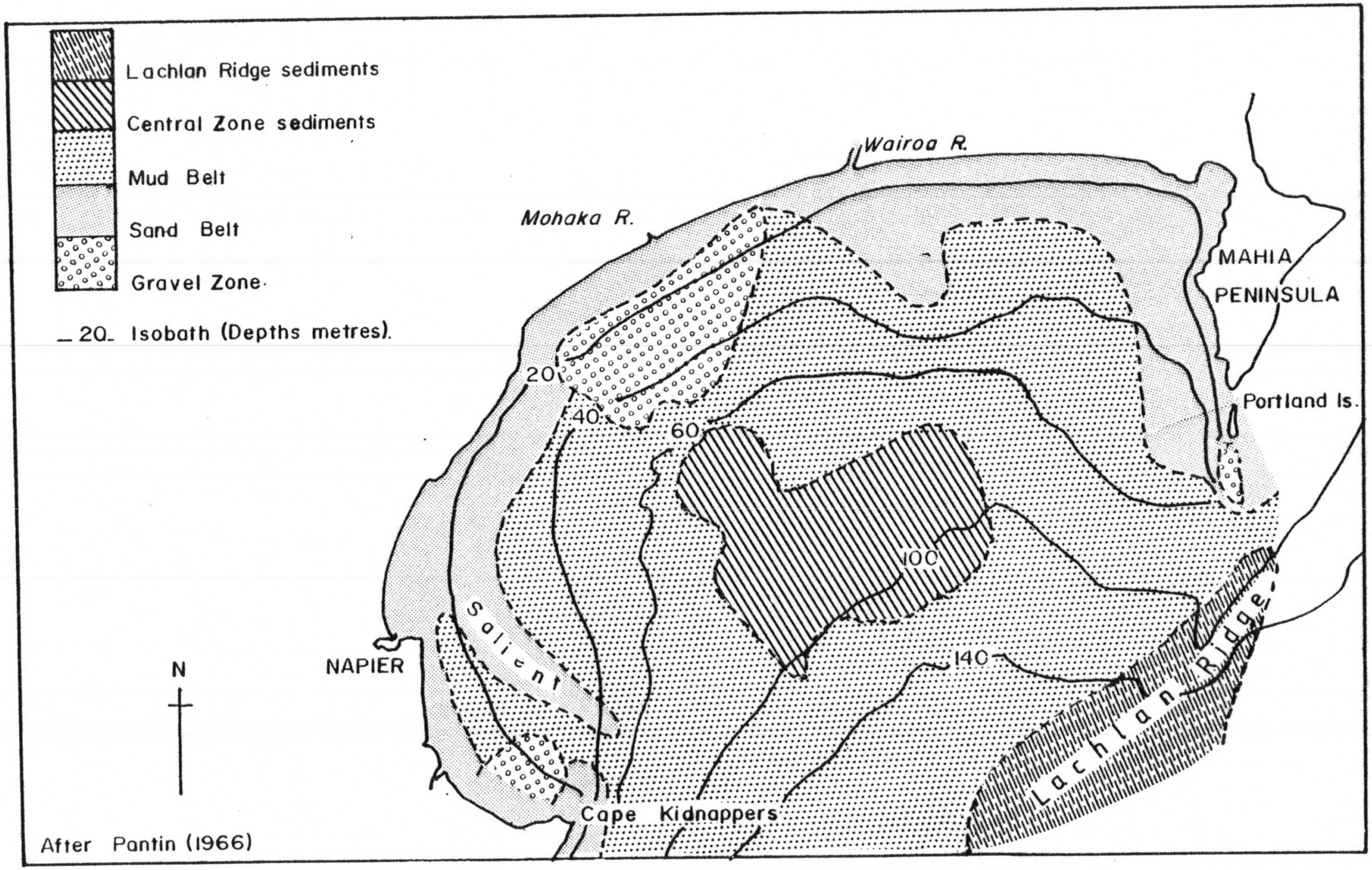

Figure 2 : Bathymetry and sediments of Hawke Bay, after Pantin 1966.

BEACH SEDIMENTS

Beach sediments consist of greywacke sands and gravels. The greatest variation in particle size was found at Te Awanga and in the vicinity of the river mouths (Smith, 1968) (Fig. 3). Beach sediments show a reduction in size northwards (Marshall, 1929; Lindup, 1948; Smith, 1968). Adjacent the river mouths, particularly around the Ngaruroro/Tutaekuri mouth, there was an increase in the proportion of sand in the deposit and also a slight increase in the size of the gravel particle size (Smith, 1968).

Two surveys of shingle particle shape have been made; the first by Smith (1968) and the second by the writer in February 1981. The latter survey was made shortly after a moderate flood and was an attempt to ascertain the contribution of the rivers to the beach deposit by a moderate flood event. Sediment samples were taken from the beds of each of the rivers using the method of Wolman (1954). Cliff derived material was sampled from a number of slips along the cliff toe and also from the cliff face. Beach sediments were sampled at three to five sites across the beach. Each sample consisted of 100 stones. The shape ratios that were used were those of Sneed and Folk (1958) while roundness was assessed using Powers (1953) and Cailleux (1948) methods. Statistical tests found the following significant results ($P = 0.05$).

(a) The shortest axis of the particles on the beach was shorter than those found in river or cliff deposits.

(b) The effective setting spherecity (Psi, Ψ) was higher in the river, cliff and lower beach face samples.

(c) Sediments on the upper beach face and backshore were more bladed than those on the lower beach face.

(d) Particle roundness was greatest on the beaches and increased northwards.

The natural similarity of greywacke particle form makes it impossible to establish the relative contribution of river and cliff sediments to the beach

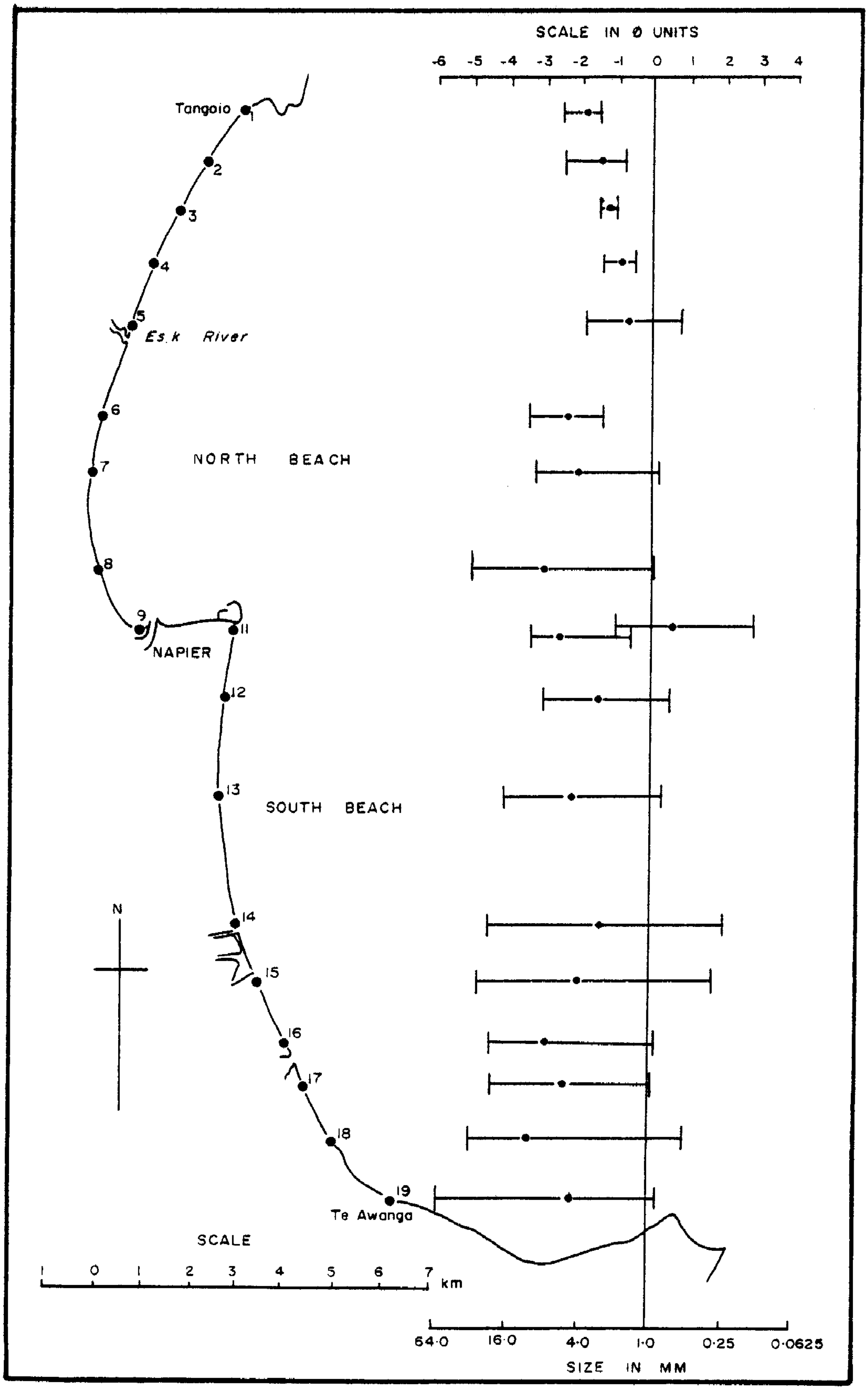

Figure 3 : Sediment distribution and sampling sites south Hawke Bay beaches.

deposit using textural characteristics. However, a rough estimate of the volume of river derived material supplied to the beach annually can be obtained from suspended sediment discharge data. Smith (1976) found that the volume of sediment contributed annually to the beaches in Poverty Bay was approximately one percent of the river suspended sediment discharge. On this basis, the average annual sediment load from the Tukituki, Ngaruroro and Tutakuri rivers, is estimated to total 7000 m^3 (σ = 5000 m^3). Because shingle supply is event dependent, the volume of material reaching the coast is highly variable from year to year. The other major sediment input is likely to be from the eroding Kidnappers section east of Clifton. The volume of material from the cliffs and nearby gullies cannot be easily determined. Rates of cliff retreat have not been documented but Davis (1949) and Haskell (1949) have noted active erosion of the cliff toe. Haskill notes that local residents claimed that the bluff immediately east of Clifton Domain had 'cut back several chains in living memory' (Haskell, 1949, p.1). A further, intermittent contribution of material may come from the offshore gravel deposits off the mouth of the Maraetotara stream during heavy sea conditions.

The sediment data, particularly the size and roundness, indicated net longshore transport to the north. The importance of each sediment source area could not be determined precisely but evidence suggests the primary source of raw material is from the cliffs east of Clifton, followed by the rivers, and supplemented intermittently by offshore gravels. Fluctuations in sediment supply and transport can be expected with variations in wave conditions and the river's regime.

WAVE CLIMATE

Wave conditions and refraction patterns have been described by Gibb (1962), Smith (1968) and Pickrill and Mitchell (1979). Wave data have been collected by MWD (1975-80). The Hawke Bay Harbour Board have collected maximum wave height data for ten years.

The majority of deep water waves in Hawke Bay approach from the southeast (Pickrill and Mitchell, 1979). On shore, these southeasterly swells appear as easterly to eastsoutheasterly approaching waves. Ministry of Works and Development records (1975-80) show some 55% of all waves approach the beach from the east to eastsoutheast, while 42% approach from the east to eastnortheast (Fig. 4). For most of the time wave induced drift is towards the north, however, Lindup (1948) noted that southerly drift occurs with prolonged periods of north and eastnortheast wave conditions.

The dominant wave periods are from 8-10 seconds followed by 11-13 seconds and wave periods tend to be shorter in summer and longer in winter (Smith, 1968). The variation in wave periods within one month is as great as the annual variation so no seasonal pattern is apparent.

Wave heights recorded by MWD 1975-80, ranged from 0.1 m to 3.5m. Dominant wave height was between 0.5 m and 1.0 m with the largest waves tending to come from the east to eastsoutheast direction. Waves tended to be larger in winter but the variation between seasons is similar to the monthly variation. The largest waves, that is waves over 2 m, do show a seasonal trend (Table 1); autumn and winter months have the highest frequency of waves over 2 m while the spring months are the most quiescent. On average, there are 27 days per year when waves are in excess of 2 m high.

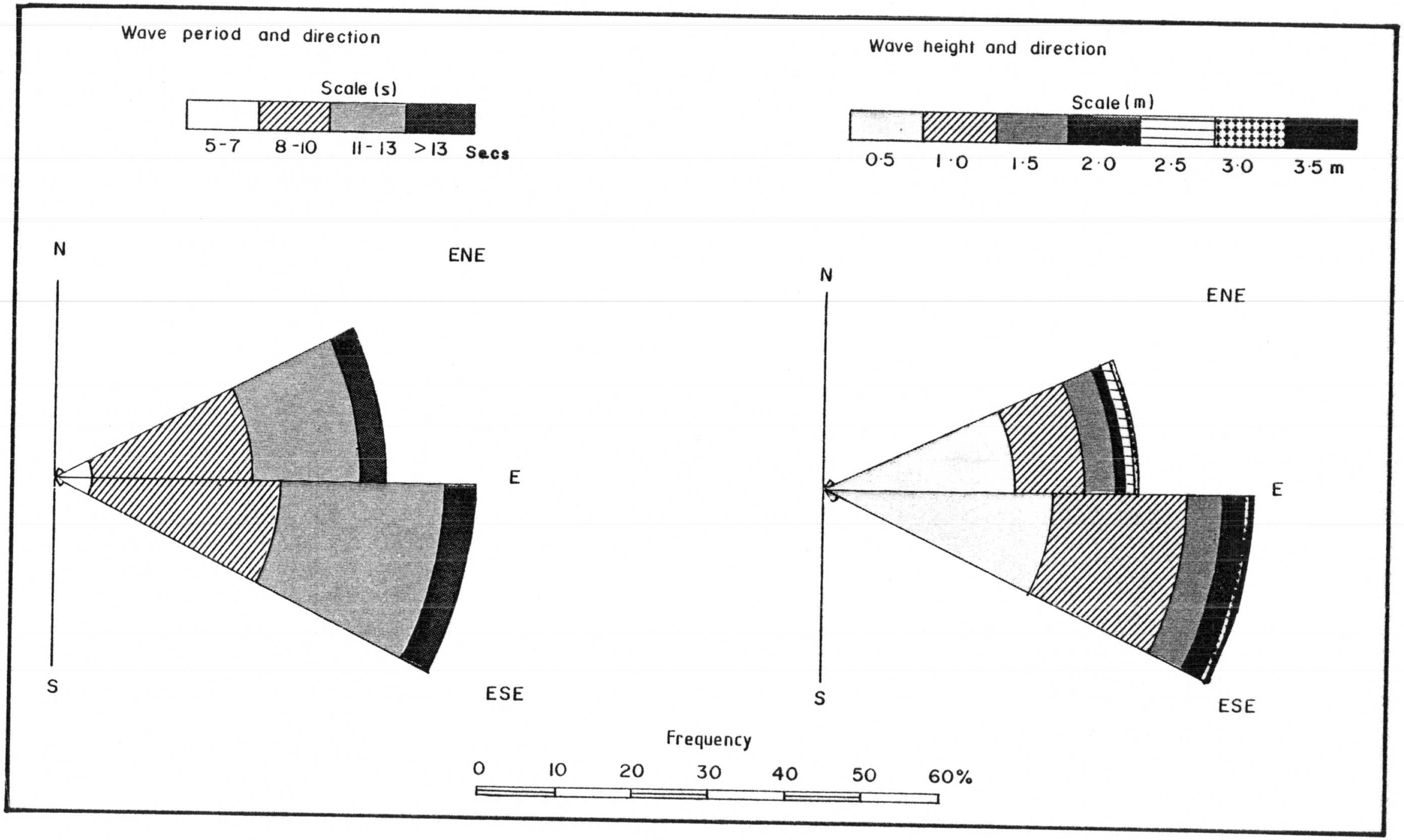

Figure 4 : Wave rose of wave height, period and direction : K7 site, Marine Parade, Napier.

Table 1 : Waves over 2 m, average occurrence, days per month (1975-80).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
1.7	2.7	0.0	3.2	2.0	6.1	6.3	3.3	1.6	0.0	0.7	0.0	27.6

Storm Conditions

There is little quantitative data on coastal storms in Hawke Bay. Appendix 1 lists reported storms and comments by observers. Few numerical values are given. However, the engineer's reports on sea conditions while the Napier Harbour breakwater was being built, do occasionally give some estimate of wave size for the more severe events. A northeasterly storm in April 1906 appears to have been the most severe on record. Though no wave heights are given the waves were reported to be large enough to wash over the beach barrier and onto the Petane road near Bay View; an event which has not been repeated in historical time. Storms of April 1894 and March 1895 are of similar size having waves of 30 feet (9 m). As far as can be ascertained the large waves of August 1974, which were measured by the Harbour Boards tug as being 20 feet (6 m) with a maximum of 23 feet (7 m) is the fourth largest storm to have occurred in Hawke Bay. Using the method of Grengorten (1963) these four storms are estimated to have return periods of 310, 88 and 48 years respectively. Because of the lack of quantitative data on waves below 6 m, the return periods for waves between 3 m and 6 m cannot be computed. The 1975-80 wave records indicate waves of 3 m have a return period of approximately one year.

Most storms occur in the autumn and winter months while the spring months are most quiescent (Table 2).

Table 2 : Monthly frequency of large waves, Hawke Bay.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
% frequency	5.3	7.9	13.1	14.9	11.4	12.3	13.1	7.9	6.1	2.6	1.7	3.7

Observations of waves at the Marine Parade site (K7) and at the Hastings City sewer outfall were made during December 1979 and January 1980. The range of wave heights observed was from 0.2 m to 2.5 m. The observations were correlated and are the basis for Table 3. Extrapolated values in the table, above 2.5 m, should be used with caution as they exceed the range of observations. Further caution should be exercised when using the table because it is based on a number of events which approached from the southeast. Wave heights from a northeasterly storm will probably be higher than shown in the table because of the increased exposure from this approach.

Table 3 : Probable wave heights at the Hastings City sewer outfall based on observations at K7 Marine Parade, Napier.

Marine Parade (K7) height metres	Hastings City sewer outfall
0.5	0.5
1.0	0.9
2.0	1.6
3.0	2.3
4.0	3.1
5.0	3.8
6.0	4.5

Corbett (1948) reported that the seas which caused the most damage at the Napier City abattoirs were usually associated with little or no wind, indicating the swell had come from a distant disturbance. Table 4 summarises the wind condition for the storm events listed in Appendix 1. Heavy seas associated with strong winds are mostly associated with events from the northeast although some southerlies have high winds too. Heavy swells and little wind are primarily associated with events approaching from the southeast and less frequently with events approaching from the northeast.

Table 4 : Storm seas and strong winds in Hawke Bay, 1810-1980.

	Large seas with gale force winds Direction		Large seas and no wind Direction		Unknown
	NE	SE	NE	SE	
% frequency	31.9	16.8	4.2	45.4	1.7

Beach erosion and damage to foreshore works can occur through two different circumstances. The most spectacular and best reported, are the infrequent, catastrophic events such as the storms of 1906, 1974 and the 'Wahine' storm of 1968. The less spectacular though often equally destructive process, is caused by two, or more, less severe events occuring in close succession. In these occasions the beach does not have time to recover from one event before the next arrives. For example, the partial destruction of the sheet piling groyne used for launching the Hastings sewer pipe was caused by two series of southerly waves which were generated by two depressions which developed on the east coast of the South Island over the Christmas/New Year period 1979-80. These two depressions caused waves in Hawke Bay of 1.0 m - 1.5 m from 30 December 1979 to 2 January 1980 and 1.5 m - 2.0 m from 5-8 January 1980. These two events eroded the lower beach face and undermined the sheet piling sufficiently for the longshore drift to push the structure out of alignment at the wave break point (Plate 1). Previous to this double event the structure had survived similar sized events with no damage. Any coastal protection scheme must consider the

Plate 1 : Wave damage to sheet piling tunnel at the Hastings City sewer outfall, December-January 1979-80.

effects of both infrequent large events and/or a succession of small events causing erosion to the works. Table 5 summarises the frequency distribution of the number of days between wave events in excess of 1 m for the period 1976 to 1980. The distribution is noticably skewed with the modal class of 11-15 days separating events, which reflects the cyclonic pattern of weather typical of this latitude. The average period between events was 19 days.

Table 5 : The number of days between wave events greater than 1.0 m.

No. days	No. events	% frequency
0 - 5	1	1.64
6 - 10	11	18.03
11 - 15	25	40.98
16 - 20	6	9.84
21 - 25	8	13.17
26 - 30	3	4.92
Over 30	7	11.48

Summary

The foreshore between Napier and Clifton is influenced by waves from both the north-east and south-east. Waves from the north-east are lower and usually of shorter period than those from the south-east. Net longshore drift, under these conditons, is to the north. Reversal of the drift direction does occur.

The wave climate in general does not display any distinctly seasonal trends, the variation within any month being similar to the annual variations. There is, however, a seasonal pattern to the occurrence of waves greater than 2 m. Storm waves occur most frequently during the autumn and winter months while spring is the most quiescent. Serious wave overtopping of the beach barrier will occur with waves of 6 m (measured at K7), and such storms have a return period of about 50 years. Erosion of the beach face can also take place when two or more moderate events occur in close succession.

THE 1931 EARTHQUAKE

Hawke's Bay has experienced a number of earthquakes. The earliest in historical times, August 1850, was reported by William Colenso (Wilson, 1939). An earthquake in February 1863 is reported as being of similar magnitude to that of 1931 (Wilson, 1939). Another severe earthquake was experienced in 1904 and was felt over a wide area of the North Island (Wilson, 1939). On 3 February 1931 an earthquake of force 7.5 on the Richter scale shook southern Hawke's Bay. The fault where the movement took place was situated east of Napier City. In general, the land to the east of the fault either remained at the same level or subsided, while the land to the west was raised. Where the landmass comprised unconsolidated gravels and sands, subsidence usually took place. This event has caused some long term changes to the beach system (Smith, 1968). Figure 5 illustrates the changes in land levels as they affected the coastline (Henderson, 1983; PWD Plans DO 140 and 185 1932; Bevin, 1981). As far as can be ascertained, the area near Clifton and Te Awanga probably suffered little or no change in elevation. Near the mouth of the Tukituki River the land subsided 0.76 m, while just north of the Ngaruroro River no change occurred. At Bluff Hill, Napier city, a rise of 1.8 m occurred.

Because the beach is a narrow shingle barrier separate from the plains, changes in land level relative to sea level directly effect the barrier. The height of the original shingle beach was determined by wave conditions. Only extreme events could reach the crest of the barrier and any material transported to this point would be deposited there, building a feature in equilibrium with the wave climate. Subsidence of the landmass decreased the barrier height and allowed moderate seas to overtop the beach crest, carry material down the backslope and cause the barrier to retreat (Figure 6). Hill (1897) demonstrated that the Heretaunga Plains had the same general slope from the foothills to the Lachlan Ridge and that the barrier beach was the largest single topographic feature on

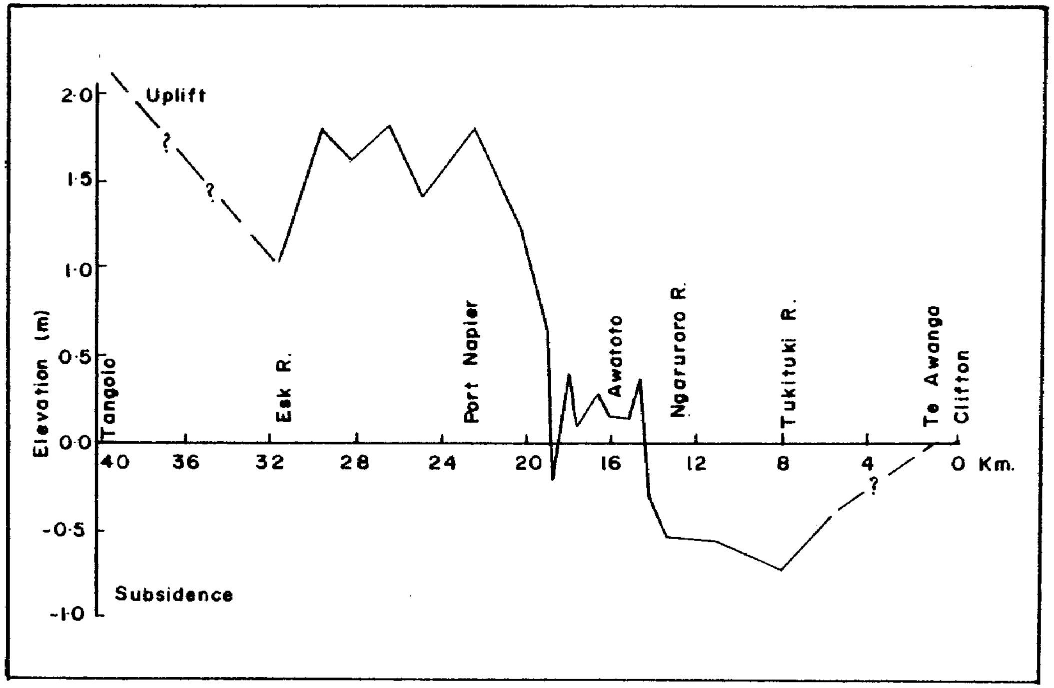

Figure 5 : Change in land levels caused by the 1931 earthquake.

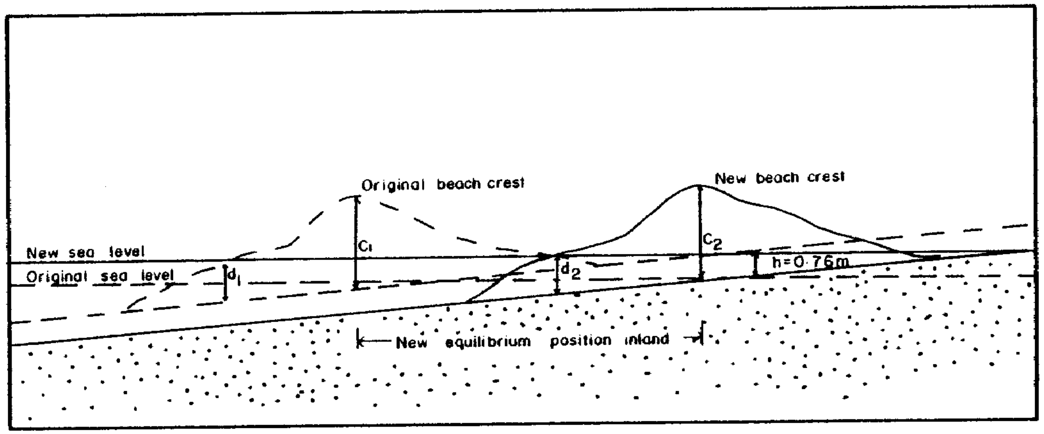

Figure 6 : Probable changes in beach position due to subsidence of the land.

these plains. The average gradient of the plains is 0.0025. Figure 6 demonstrates the changes that can be expected to take place along the barrier where the land has subsided. To reach equilibium, assuming there is no change in wave climate, the barrier will have to retreat inland until d2 = d1 and c2 = c1. This assumes the beach was in equilibrium with the wave climate and existing land level at the time of the earthquake. If it was in fact still adjusting to some earlier event, then the retreat could be greater or possibly less depending on the direction of previous movements. Because the subsidence varied along the coast, the plan shape of the beach will alter, retreating further inland between just north of the mouth of the Ngururoro to southeast of Haumoana settlement.

By contrast, where the landmass and seabed rose, the beach advanced and increased in volume. The sources of additional material are twofold; firstly offshore sediments are moved onshore and secondly sediment which would normally be moving alongshore is deposited because of insufficient wave energy for longshore transport due to the reduction in water depth. These processes initially formed a wide flat beach on which subsequent storms have heaped up the shingle forming an initial beach ridge. For example, measurements taken opposite the swimming pool on Marine Parade, Napier, show the combined effects of the earthquake and harbour construction have caused the beach to advance some 75 m since 1908.

BEACH CROSS SECTION SURVEYS

There have been three separate beach monitoring programmes along the coast between Napier and Clifton (Figure 7). The first in 1939, was initiated by the Public Works Department after the road was damaged at Waitangi (Batten, 1943). The second, commenced in late 1967 and finished in April 1968, was part of a study of the southern Hawke Bay coastline (Smith, 1968). The final study (K series) commenced in August 1974, was aimed at understanding the processes acting on the foreshore of Hawke Bay with a view to assessing the cost and feasibility of coastal protection (Borgesius, 1974).

Waitangi to Ellison Street Surveys 1939-1984

Initially there were seven cross sections between Ellison Street and the Waitangi Bridge. The origin of these profiles was the RST survey between Ellison Street (RST XXI) and Waitangi (RST XI). Batten (1943) found the seven profiles were inadequate for establishing the nature of changes along this section of foreshore and increased the number of cross sections to 40. These sections were surveyed at varying intervals up to 1961. In 1984 the baseline was resurveyed, and the profile sites located with the exception of lines 17 to 24 for which precise location data is missing.

Lindup (1948) described the beach changes between Ellison Street and Waitangi as showing erosion, particularly along the southern section, up to 1943 and a gradual recovery to 1948. He added however, that the beach profiles merely recorded the beach condition at the time of the survey and suggested that changes over a week could be as large as between surveys. White (1963) examined the profile data up to 1962, found the foreshore continuing to aggrade and decided further observations were not necessary. This initial study of beach changes south of Napier, provided some information on the size of natural changes and also the probable rate of beach recovery under both natural and man induced conditions.

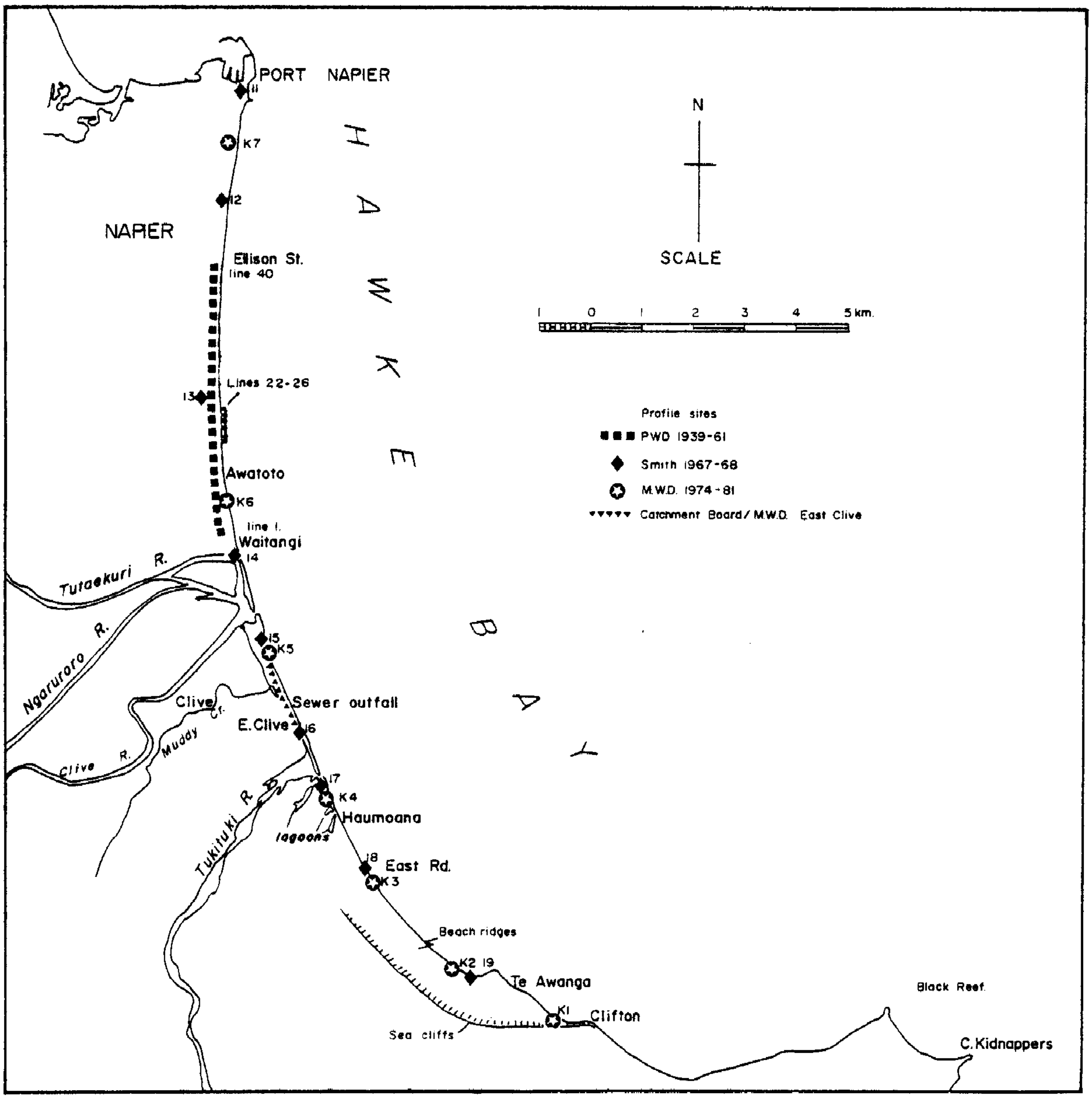

Figure 7 : Location of beach monitoring studies 1939–1984.

Profile data from the three surveys were obtained using a variety of methods. The following section describes the method used to assess the accuracy of the profile data to describe the position of the average excursion distance. For this study the method of profile analysis was by comparing average excursion distances to locate the position of the beach face. The average excursion distance was ascertained by finding the distance from the bench mark of each 0.5 m elevation between 10 m (mean sea level) and 12.5 m. The average of the six distances is the average position of the beach face or average excursion distance.

The elevation limit of 2.5 m above mean sea level was used because ballast pit development, reclamation and the often long distances between survey observations on the upper beach face and backshore, introduced unacceptable variability in the data at higher elevations.

The accuracy of the survey data to depict changes was examined. The beach profiles had been observed using a minimum of observation points (often only 2-5 down the beach face). To test if these observations provided adequate data to locate the beach face, a profile at line 13 (1968 series) was measured at 1.6 m horizontal intervals, (Fig. 8(1)) from the beach crest to the swash at low water. From these data the four most common methods of profile observation were examined (Figure 8):

(2) Observations at the beach crest and the swash

(3) Observations at the beach crest, storm berm and swash

(4) Observations at the beach crest, highwater berm and swash

(5) Observations at the beach crest and the base of the highwater berm with a line extrapolated to mean sea level.

Table 6 demonstrates methods (2) and (5) provide the least accurate results, underestimating the average extension distance by 5 m and 2.4 m respectively.

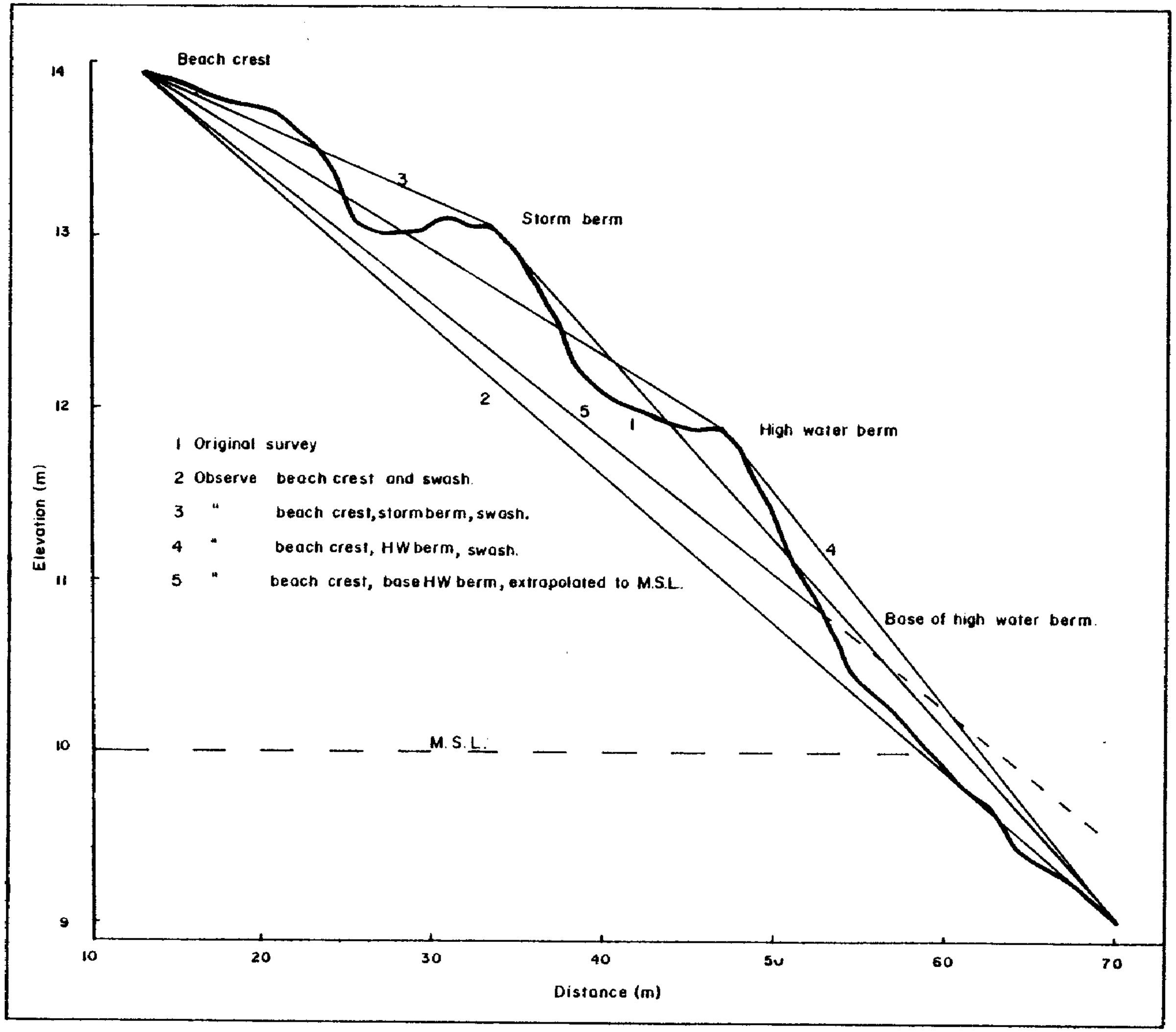

Figure 8 : Methods used for measuring beach profiles 1939-1961.

Method (3) provides the smallest error from the original but like method (4) overestimates the distance. Since most of the surveys between 1939 and 1961 included an observation on either the storm berm or high water berm, the method of average excursion distance analysis could probably overestimate the average beach face position by 1 m - 2 m.

Table 6 : Variation in average excursion distances caused by different survey methods.

Method	Average excursion distance (m)	Difference from original (m)
Original	42.48	
(2)	37.22	-5.06
(3)	42.94	0.64
(4)	43.67	1.39
(5)	39.83	-2.45

Another source of survey data variation is the surveying over a cusp horn on one survey and down a cusp bay in a subsequent survey. A test of the effect of beach cusps on the accuracy of average excursion distances was recently carried out on Hawai Beach in the eastern Bay of Plenty. The beach sediments and particle sizes at Hawai are similar to those at Awatoto. Beach profiles were surveyed over two cusp horns and through two cusp bays and the average excursion distance for each survey calculated and compared (Table 7). These results show that the effect of beach cusps on the average excursion distance would be an error factor of about ± 0.7 m which is smaller than the probable error associated with the method of profile observation.

Table 7 : Variation in average excursion distances caused by beach cusp development, Hawai Beach, eastern Bay of Plenty.

Position	Average excursion distance (m)	Difference from average distance (m)
Cusp bay	20.50	0.71
Cusp horn	19.29	-0.49
Cusp bay	19.29	-0.49
Cusp horn	20.07	0.28
Average distance	19.78	

The variability in results caused by the different methods of survey and the possibility of surveying over a cusp horn or through a cusp bay is ± 3.0 m. Any change in excursion distance of less than 3.0 m can therefore be regarded as insignificant for the Ellison Street to Waitangi beach surveys.

Excursion distances, for the located sites between Ellison Street and Waitangi, were calculated for the years 1948 and 1984 (Figure 9). The year 1948 was selected as these surveys were the most detailed of the early measurements. Figure 9 summarises the results showing that progradation has taken place throughout the length of the foreshore. However, the minimal (1.8 m) progradation in the vicinity of the Awatoto Shingle Company is significantly lower than at the other sections of the beach, and may indicate extraction of beach material exceeds natural supply. A comparison of excursion distances for lines 8 (Awatoto), 25 and 40, for all surveys indicate that both lines 25 and 40 have similar patterns. Minor fluctuations from 1939-1948, erosion in the early 1950s and accretion 1955 to 1984 (Figure 10). By contrast, line 8 shows accretion 1943-48, erosion 1950-1954 and accretion 1955 to 1961. Survey site K6 (1975 series) is located just south of line 8 and K6 data were related to the line 8 baseline to provide detail of changes from 1975 to 1980. This record suggests that accretion at line 8 was probably comparable to that at lines 25

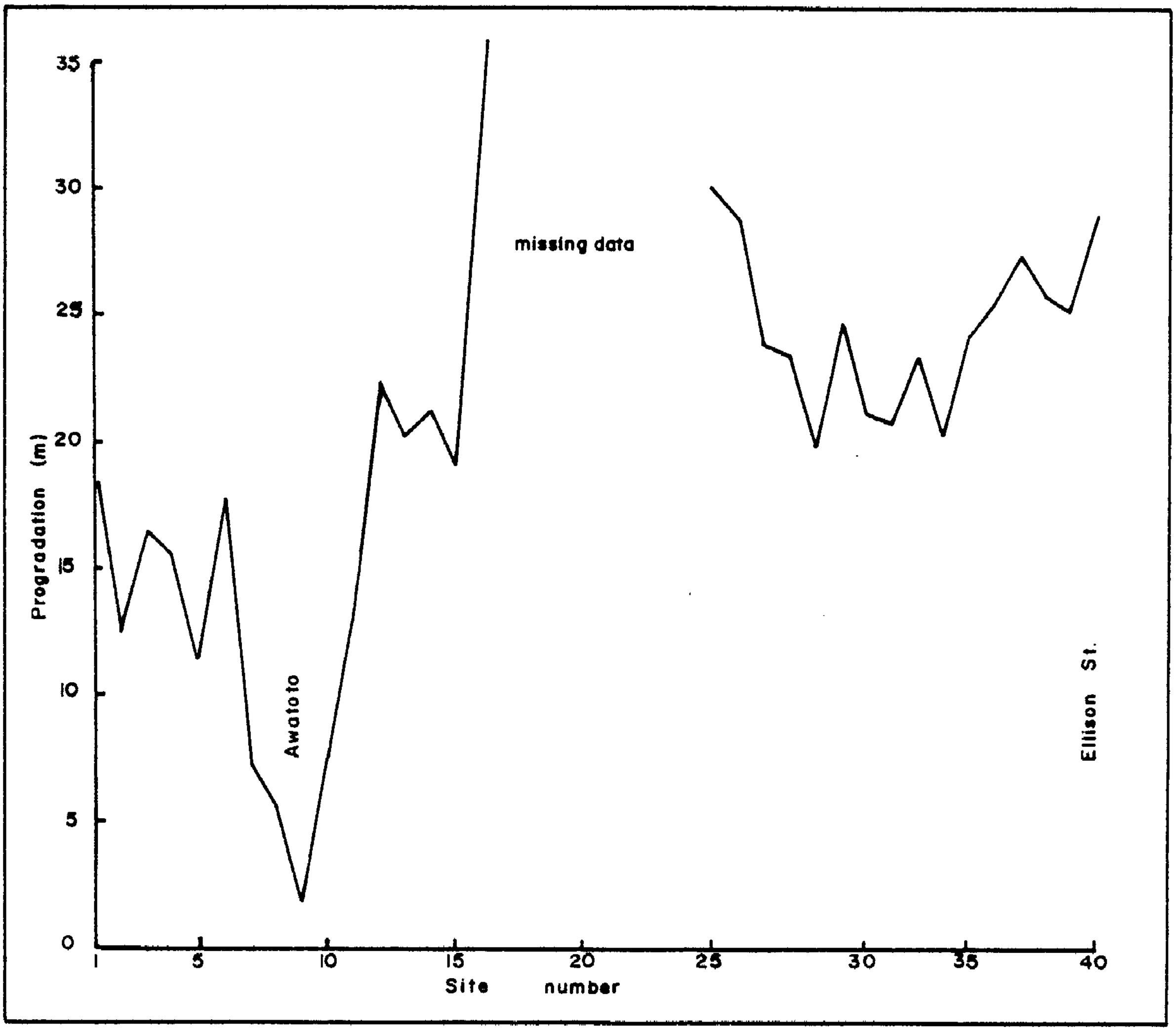

Figure 9 : Foreshore progradation Waitangi to Ellison Street 1948-1984.

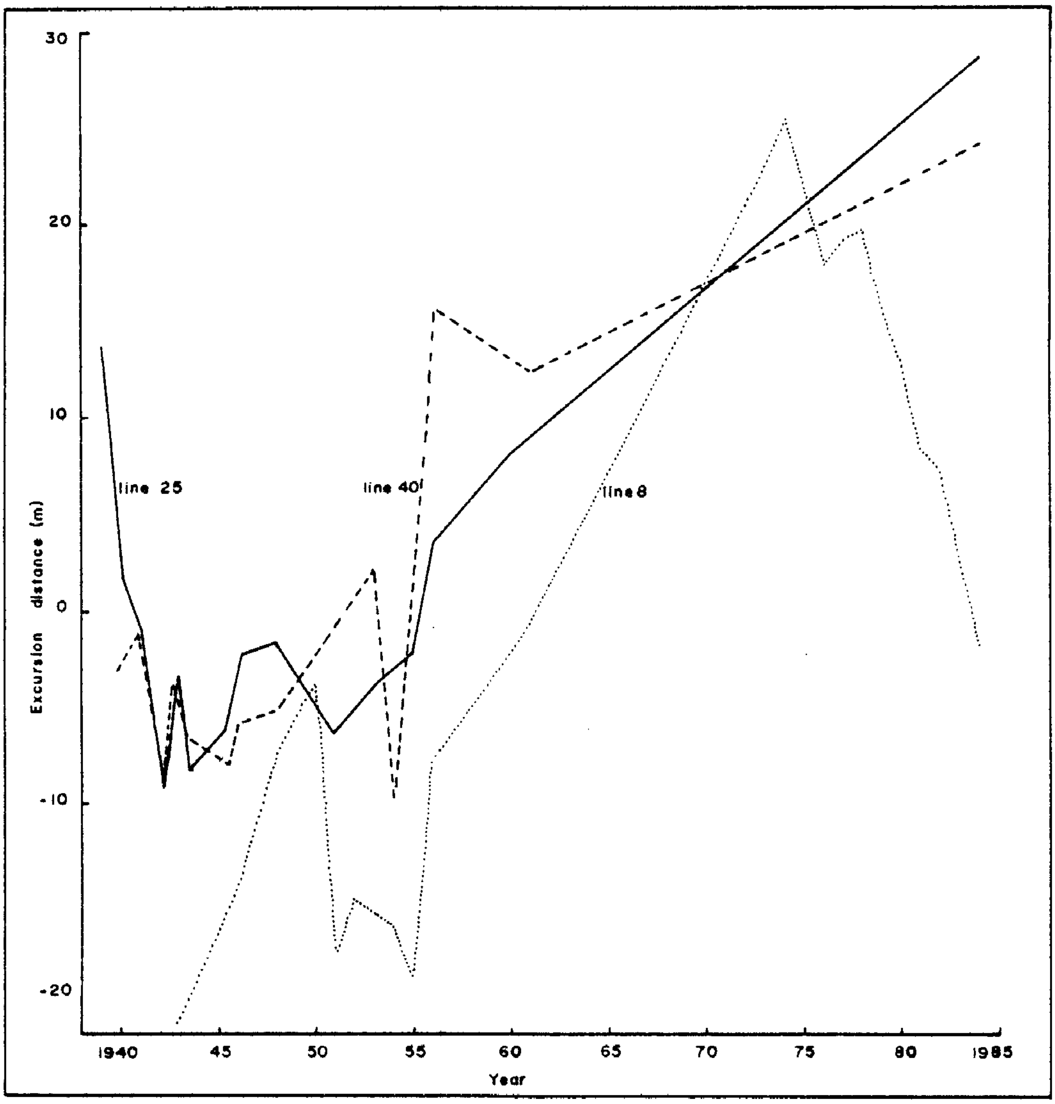

Figure 10 : Average excursion distances for lines 8, 25 and 40, Waitangi to Ellison Street surveys 1939-1984.

and 40 for a period after 1961. Since 1975 however, the beach has eroded steadily.

Lindup (1948, p.5) noted the accretion between 1943 and 1948 and concluded: "The most that I can read out of the data is that there is some evidence that the removal of around 19,000 cubic yards per annum was too great, and with a reduced consumption of 10,000 cubic yards in recent years, only partial recovery has been made."

The localised area affected by reduced progradation rates between 1948 and 1984, lines 6 to 10, is indicative a local process is causing the beach retreat. That lines 1-5, south of the extraction plant, do not show the effects of extraction may be explained by the periodic northwards migration of the river mouth which causes a slight bulge in the coastline (Plate 2).

An alternative hypothesis for the reduced progradation between lines 6 and 10 at Awatoto, is that it is the result of the Hastings City sewer outfall construction. As part of the construction a sheet piling tunnel was constructed to launch the pipe from the shore. This tunnel acted as a groyne, preventing the normal drift of material northwards and causing erosion of the beach from the construction site northwards to the southern side of the Ngaruroro/Tutakuri river's mouth. Continued northward migration of this undernourished beach form could possibly account for the undernourished conditions between lines 6 and 10. However, as the length of affected beach at Awatoto is only 500 m and the time lag is three years it is most likely that the Hastings City sewer construction is not the principle cause of the lack of progradation. Further, the rate of excursion distance retreat at line 8 (Figure 10) between 1980 and 1984 does not show a significant increase on that of 1975 to 1980. It is therefore unlikely that the construction work has had a significant effect on the beach conditions at Awatoto.

Plate 2 : Aerial view of the coastline from Awatoto to Te Awanga 1984
(Photo T M Hume).

Originally the beach cross sections between Waitangi and Ellison Street were established to monitor beach changes and also the effectiveness of highway protection works. Cross sections 22 and 26 were the location of the worst beach erosion during July 1946 when a storm surge and large waves overtopped the beach crest, flooding the highway and the railway line. To prevent further occurrences of this nature, the beach crest was artificially raised by constructing a barrier of limestone boulders and rubble to a height of 4.6 m to 4.8 m above mean sea level (Figure 11). At both sites the approach has been successful, with the upper half of the beach face prograding and similar, though not as extensive, deposition on the lower half of the beach face. The beach recovery in the vicinity of the artificial beach crest has been more rapid and more substantial than occurred under natural conditions at site 27 nearby (Figure 12). By creating the artificial beach crest, material that would have been washed over the beach crest was allowed to accumulate on the front of the barrier and form a backshore deposit, a reservoir of material to act as a buffer during storm periods.

Beach Surveys 1967-1968

Smith (1968) established nine profile sites (numbered 11-19), between the harbour breakwater and Te Awanga, in November 1967 and observed changes on an approximately monthly basis to April 1968 (Figure 7). In January 1984, sites 12, 13, 14, 16, 17 and 18 were resurveyed. The remaining sites could not be observed because the original benchmarks had been destroyed. The original profiles were measured using a tape and Abney level while the 1984 cross sections were measured using the technique of Emery (1961). Sites 12 and 13 show accretion with the beach crest moving 7 m and 13 m seawards respectively (Figure 13a). Site 14, on the northern side of the mouth of the Ngaruroro/Tutaekuri rivers, displays no discernable change in position but does illustrate the large changes which can occur when the river mouth migrates

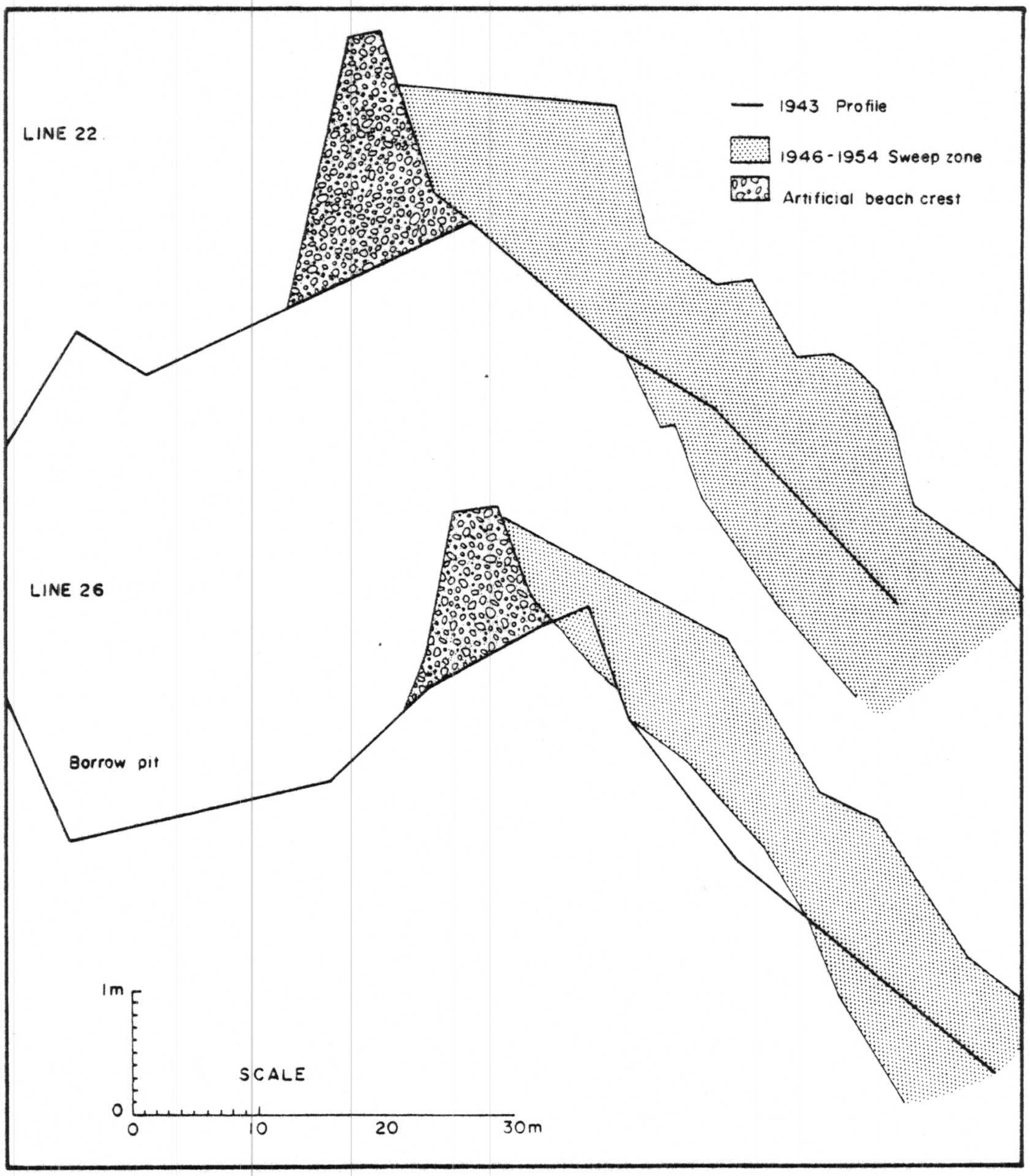

Figure 11 : Cross sections of beach at lines 22 and 26 showing the effect of raising the beach crest.

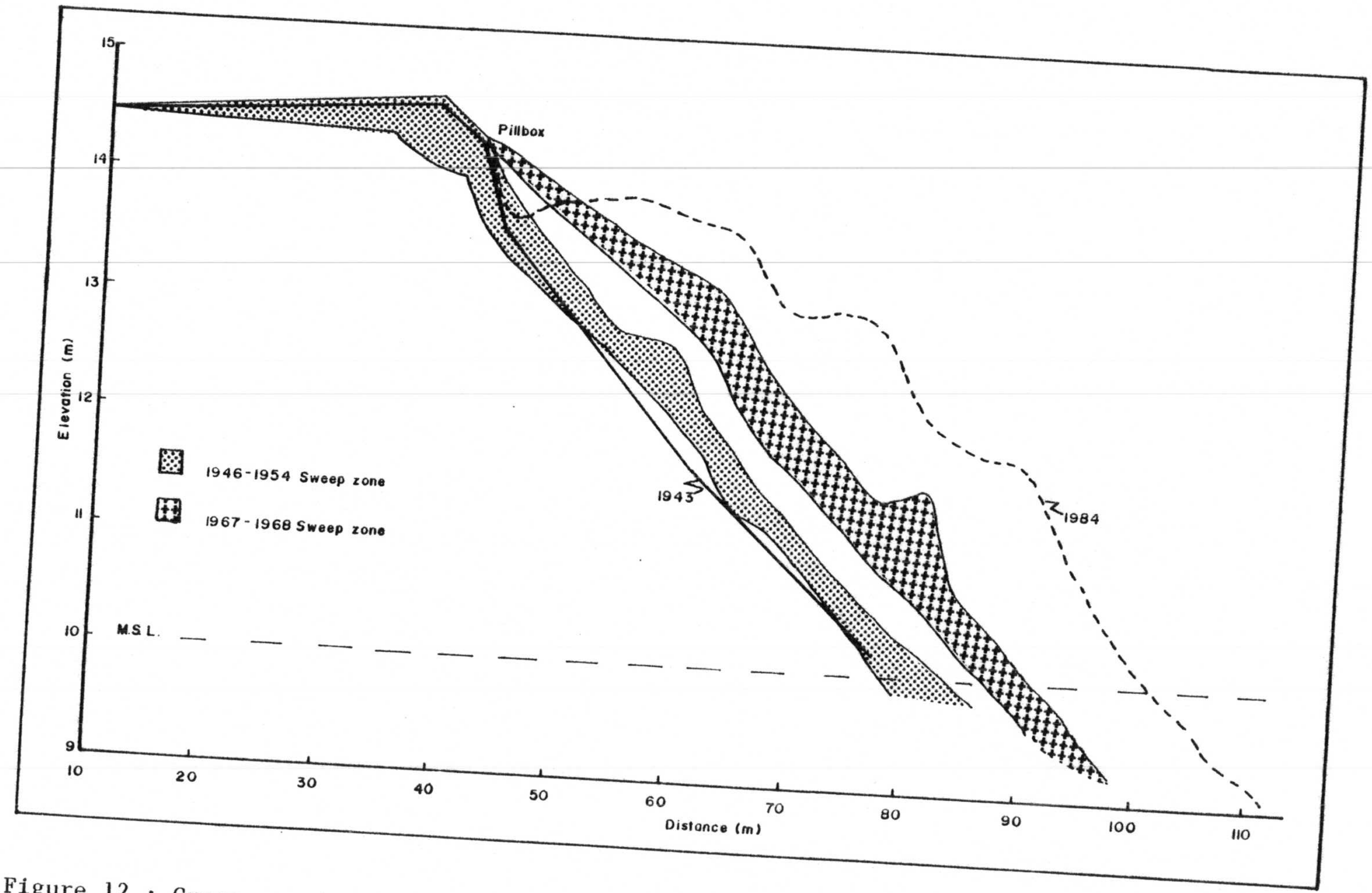

Figure 12 : Cross section 27 Waitangi to Ellison Street surveys 1943-1984.

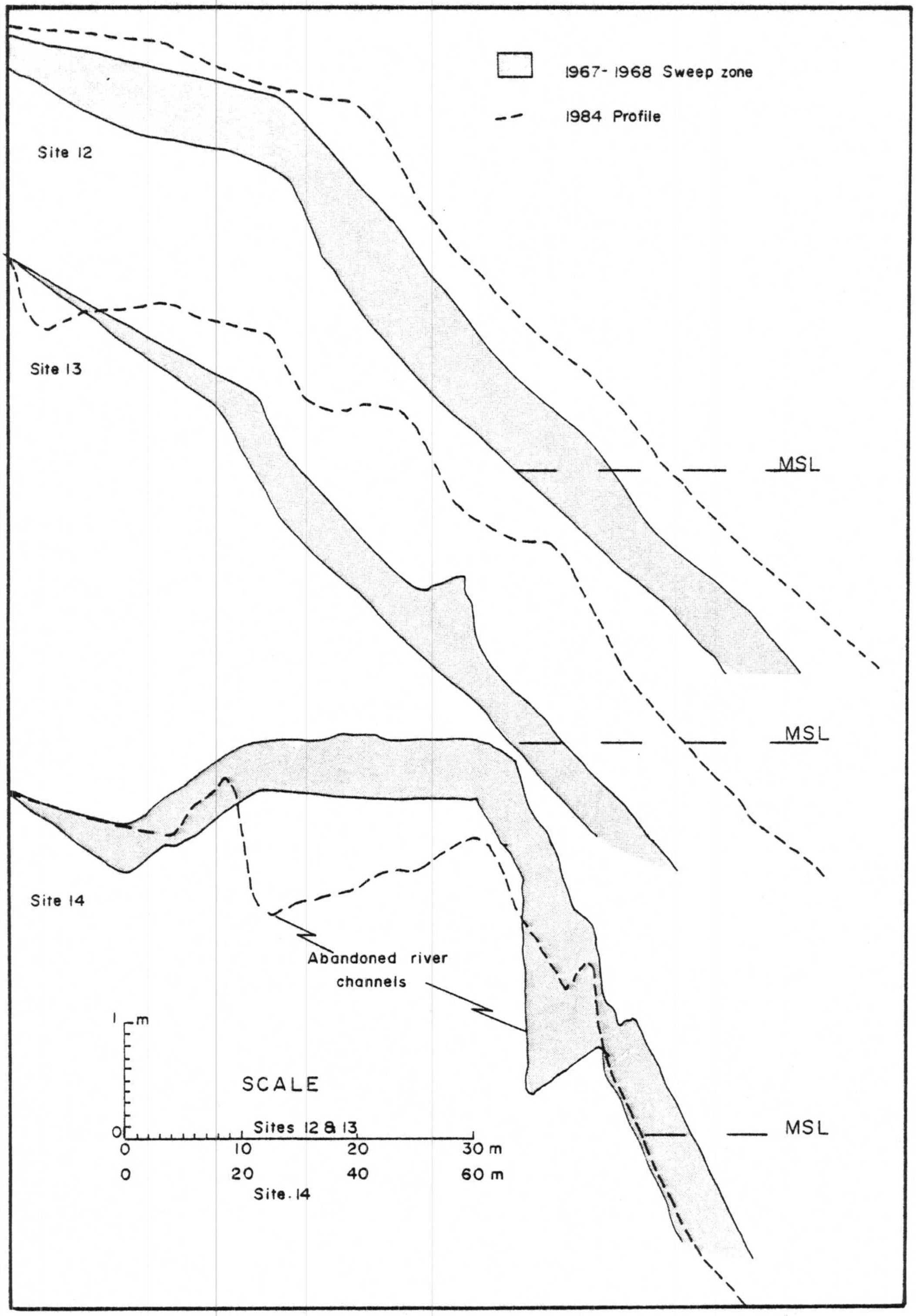

Figure 13(a) : Cross section sweep zones (1968 series) sites 12, 13, 14.

northwards. At site 16, on the northern side of the Tukituki River, the beach face is slightly seawards of the 1967-68 sweep zone (Figure 13b). Here the greatest changes have taken place behind the beach crest where there has been considerable deposition due to waves overtopping the beach barrier. Deposition on the backslope of the barrier was first observed after the 'Wahine' storm in April 1968 and the process appears to have continued through to 1984. Just south of the Tukituki River, site 17, the beach has suffered erosion followed by progradation. The 1968 beach crest has been eroded back nearly to the bench mark. This erosion phase, has been followed by accretion which has formed a wide gently undulating backshore with the beach face now about 26 m seawards of the 1968 position. The aggraded deposit is between 0.5 m and 1.0 m lower than the former beach crest. Site 18, at East Road, Haumoana, shows little or no change since 1968. However, it is probable that there has been a period of erosion followed by accretion as observed at site 17.

Beach Surveys 1974-1981

In 1974, a new series of profile observation sites were established along the coast between Clifton and Napier city (Figure 7). They consisted of seven key sites ('K' sites), and a number of temporary sites (T sites). The 'T' sites were initially used to compare observations made at the 'K' sites with adjacent sections of beach. Only the results from the 'K' sites are discussed in this report. In 1979, a further 16 sites were established between the mouth of the Tukituki River and K5. These are the East Clive sites and were installed to monitor the effects of Hastings City sewer outfall construction on the adjacent coastline.

The method of measurement for the 1974-1981 series was more detailed than that of previous surveys. Observations were taken at every change of slope on the beach face. Comparing a detailed cross section (measured at 1.6 m intervals)

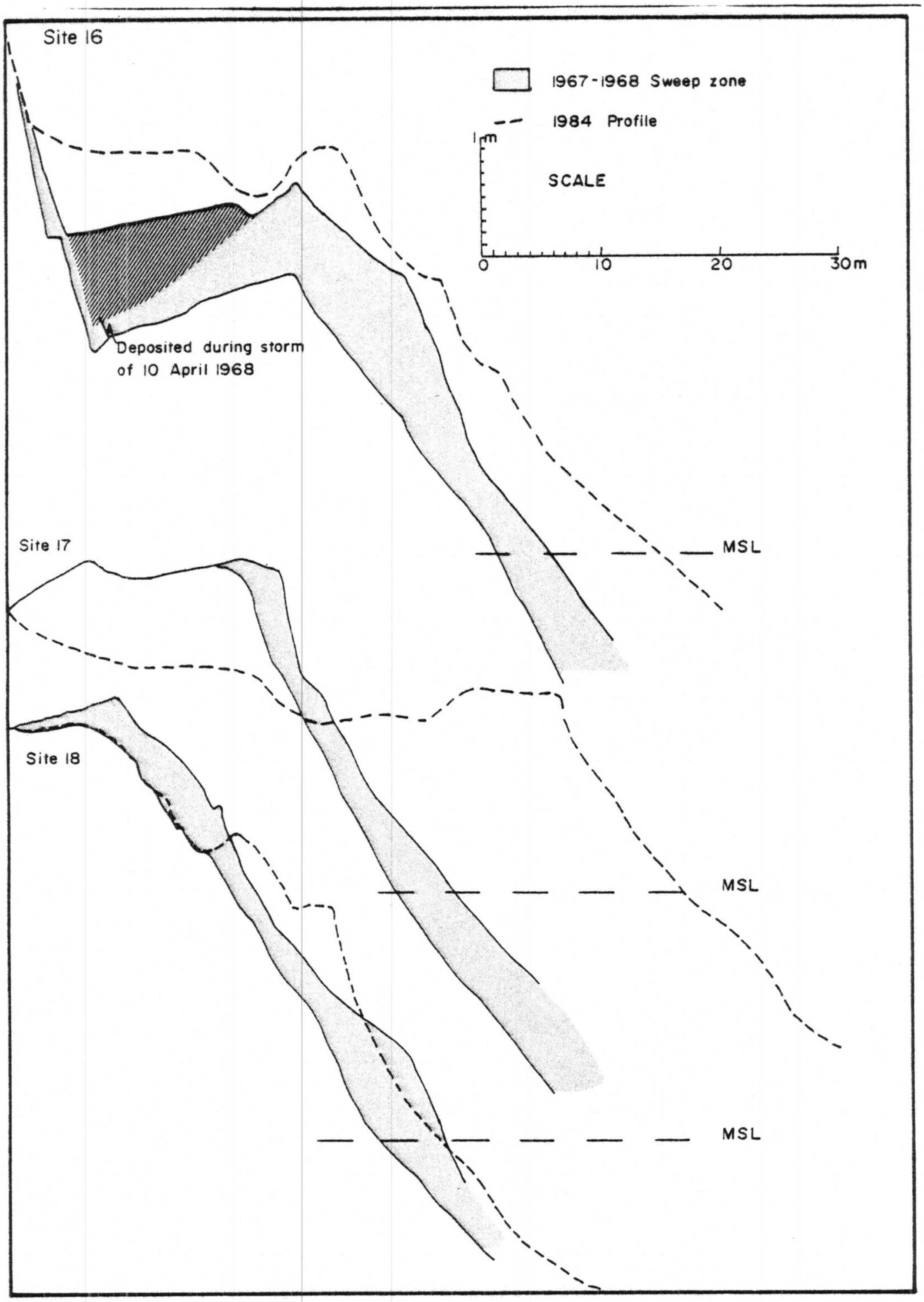

Figure 13(b) : Cross section sweep zones (1968 series) sites 16, 17, 18.

with a survey which observed each change in slope, and making allowances for surveying over cusp horns or through cusp bays, the probable error for the position of the average excursion distance was found to be ± 0.6 m.

The pattern of beach behaviour from 1974 to 1981 is illustrated in Figues 14a and 14b which show the average excursion distances at sites K2, K4, K5, K6 and K7. Sites K2 and K4 are south and updrift of the Hastings City Council sewer construction site. Site K2 shows small variations of up to ± 5 m. The small size of the fluctuations is probably indicative of the sheltered position of this site. Throughout the observation period, there is a weak trend towards recession of the beach face though this is not statistically significant. A longer record may confirm this apparent trend. Site K4 displays a significant trend towards erosion ($r = 0.7102$, $p = 0.01$) from 1974 to 1978, and a change to progradation from 1979 to 1980 ($r = 0.7808$, $p = 0.01$). By the winter of 1981 the average excursion distance indicated progradation of about 5 m from the average beach position for the whole period.

Sites K5 and K6 north, and downdrift of the Hastings City sewer construction, both have a significant trend towards erosion (K5, $r = 0.8703$, $p = 0.01$ and K6, $r = 0.8616$, $p = 0.01$). Site K7 has the greatest variation in excursion movements. The reason for this greater variation is twofold. The site is the most exposed on this section of coast and measurements were carried out more frequently here than at any other sites, particularly during 1977. The variation in average excursion distances over a three day period can be as much as 15 m which is large enough to conceal any long term trend.

The accretion observed at K4 from 1979 to 1980 appears to be related to the construction of the Hastings City sewer outfall at East Clive. The sheet piling launching tunnel acted like a groyne, prevented the northward drift of material, causing deposition to the south. Beach changes measured at East Clive from

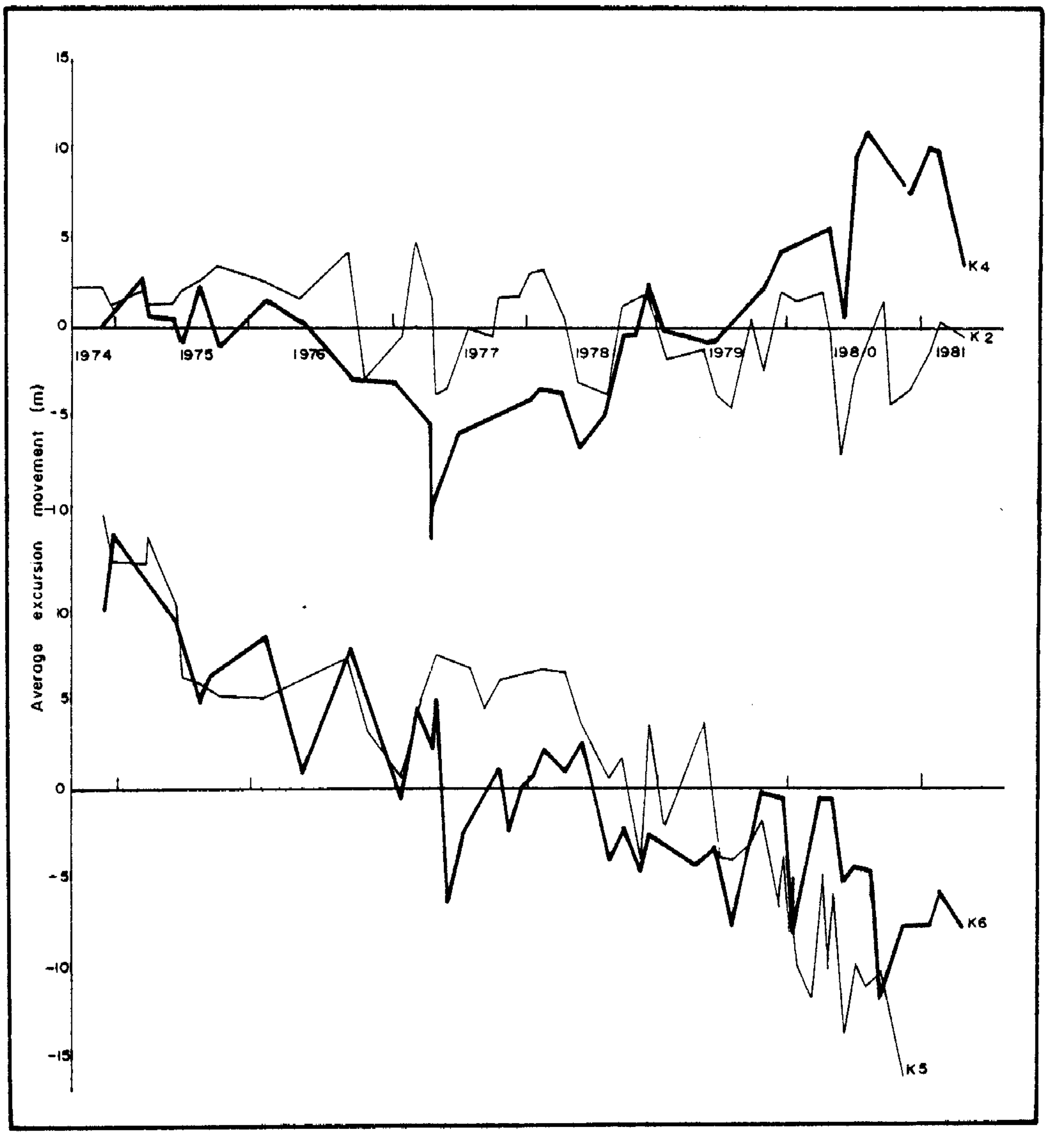

Figure 14(a) : Average excursion lines for sites K2, K4, K5 and K6 1974-1981.

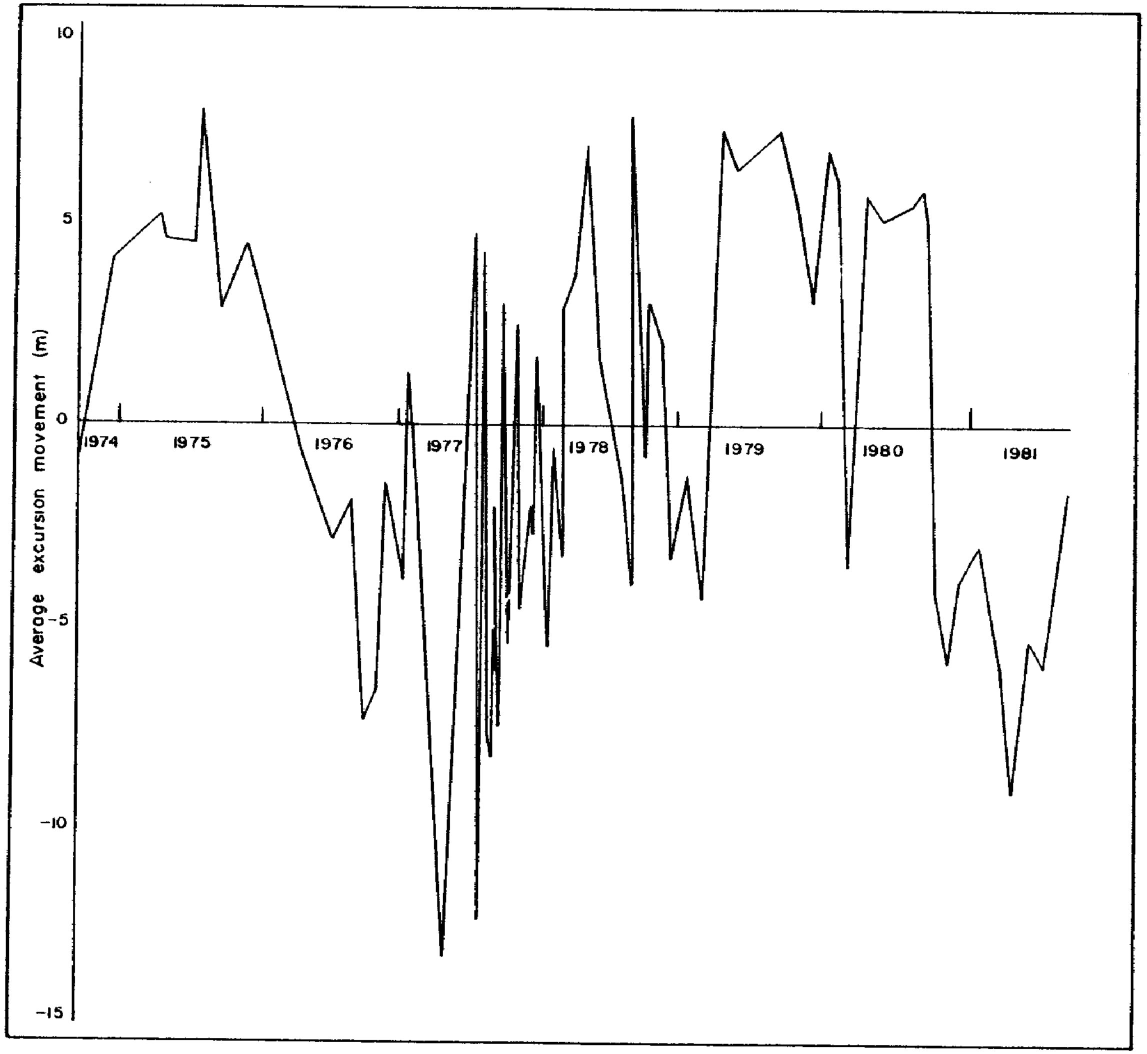

Figure 14(b) : Average excursion line for site K7 1974-1981.

September 1979 to July 1982 support this hypothesis. Figure 15 shows the location of the bench marks along the stopbank at East Clive. Profiles from these stopbank positions included the backslope of the barrier and the beach face. Four sites, K5, 200 m N, 1000 m N and 1600 m N are described to demonstrate the beach changes which took place during the sewer construction.

Cross Section K5

Observations commenced in August 1974 when there was one beach ridge in front of the barrier crest (Figure 16a). From 1974 to 1978, the beach face slowly retreated and the barrier crest increased in height. From 1979, the barrier crest was lowered and the beach face eroded. A significant proportion of material was washed over the beach crest and deposited on the backslope of the barrier (Figure 16b). The original survey of this cross section did not measure the barrier backslope profile and it is impossible to assess the amount of material, if any, that was washed down the backslope between 1974 and 1978. Powell, Fenwick and Johnson (1974) reported a considerable volume of material had been washed over the barrier during the 1974 storm.

Cross Section 200 m N

Figure 17 illustrates the successive retreat of the sweep zones from September 1979 to July 1982. As at profile K5, beach crest lowering was accompanied by deposition on the barrier backslope. From 1979 to 1982 the beach crest retreated 20 m and was lowered by 1.5 m, while the toe of the barrier backslope moved inland some 10 m. Not all the material eroded from the beach face was deposited on the backslope. The retreat of the beach face from the spring of 1979 through to the winter of 1980 is a response to the loss of material to the barrier deposit. After the winter of 1980, the retreat of the beach face was partly compensated for by deposition on the barrier backslope.

Cross Section 1000 m N

Initially, (1979-1980) movement here was the same as at K5 and 200 m N with the

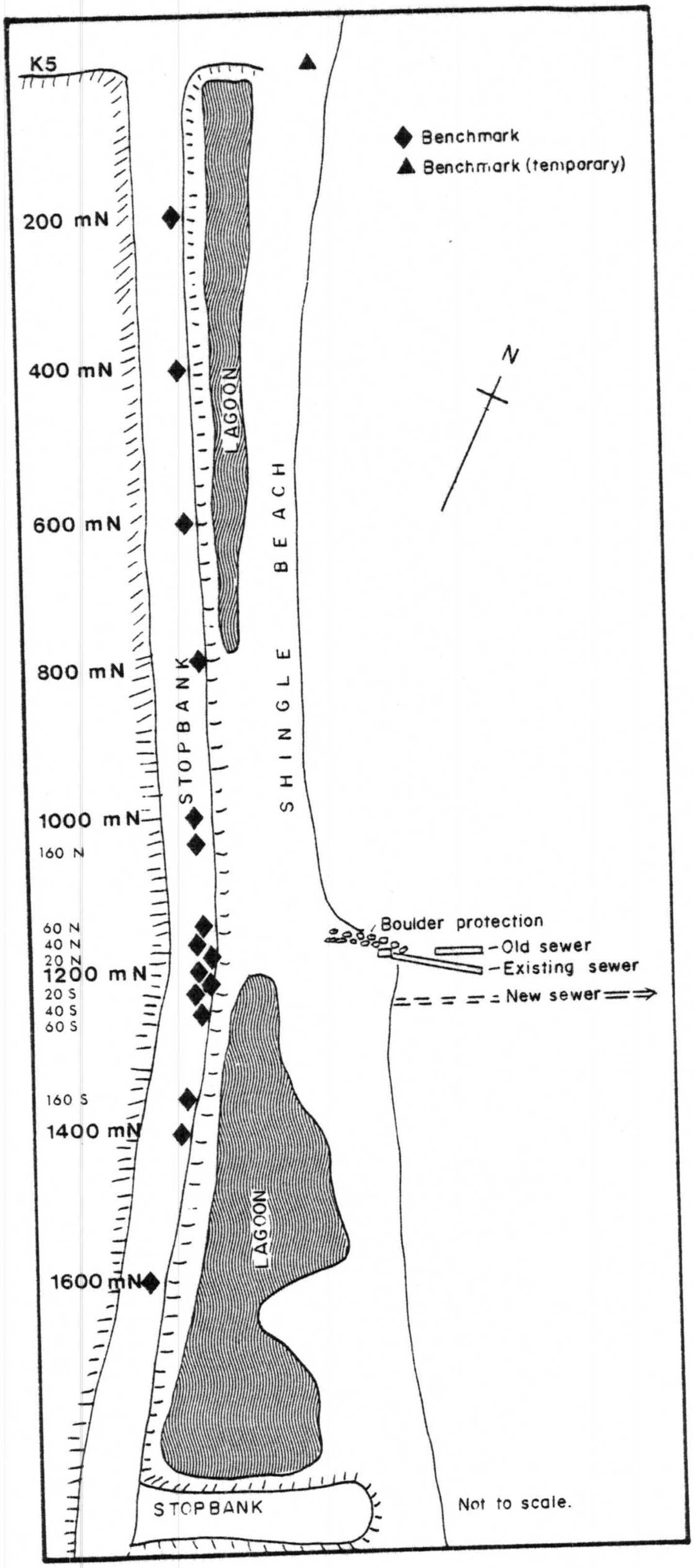

Figure 15 : Location of profile sites at East Clive.

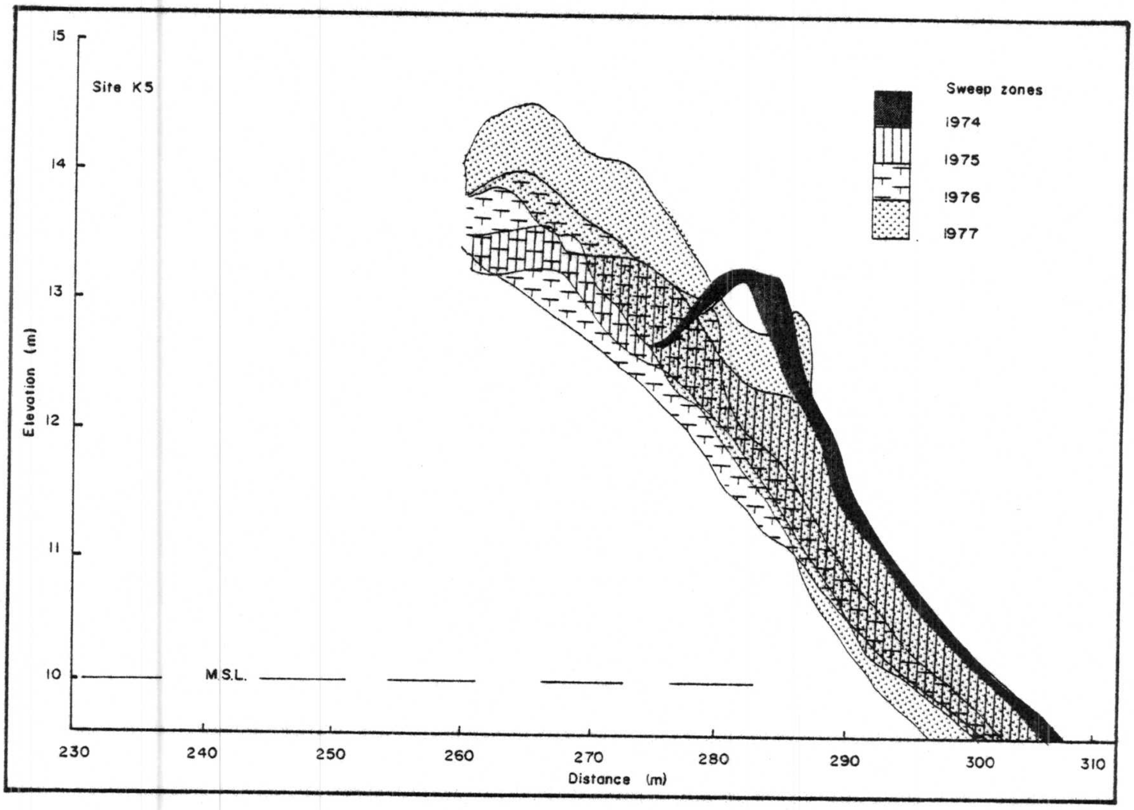

Figure 16(a) : Sweep zones for site K5 1974-1977.

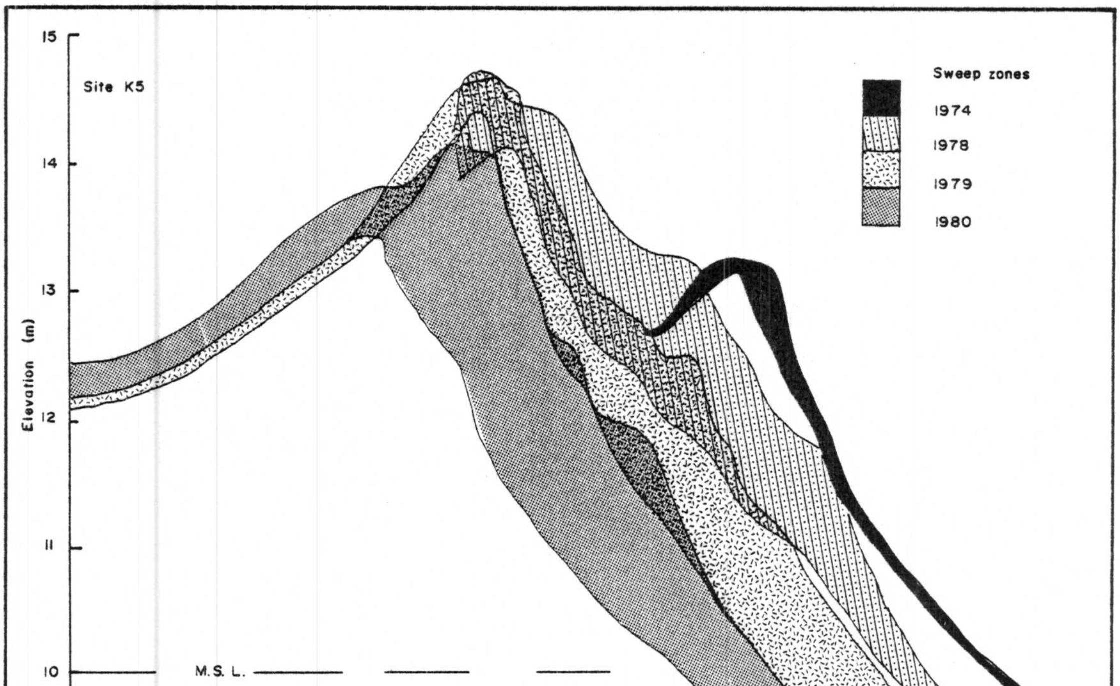

Figure 16(b) : Sweep zones for site K5 1974, 1978-1981.

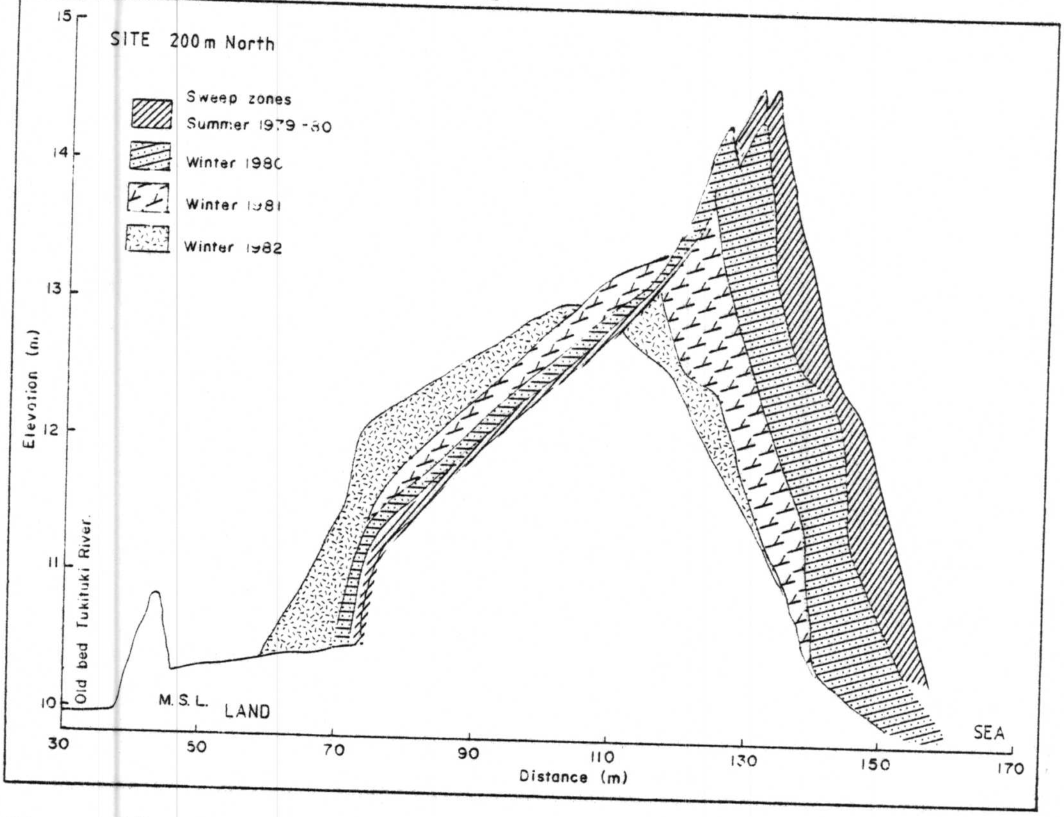

Figure 17 : Sweep zones, site 200 m N 1979-1982.

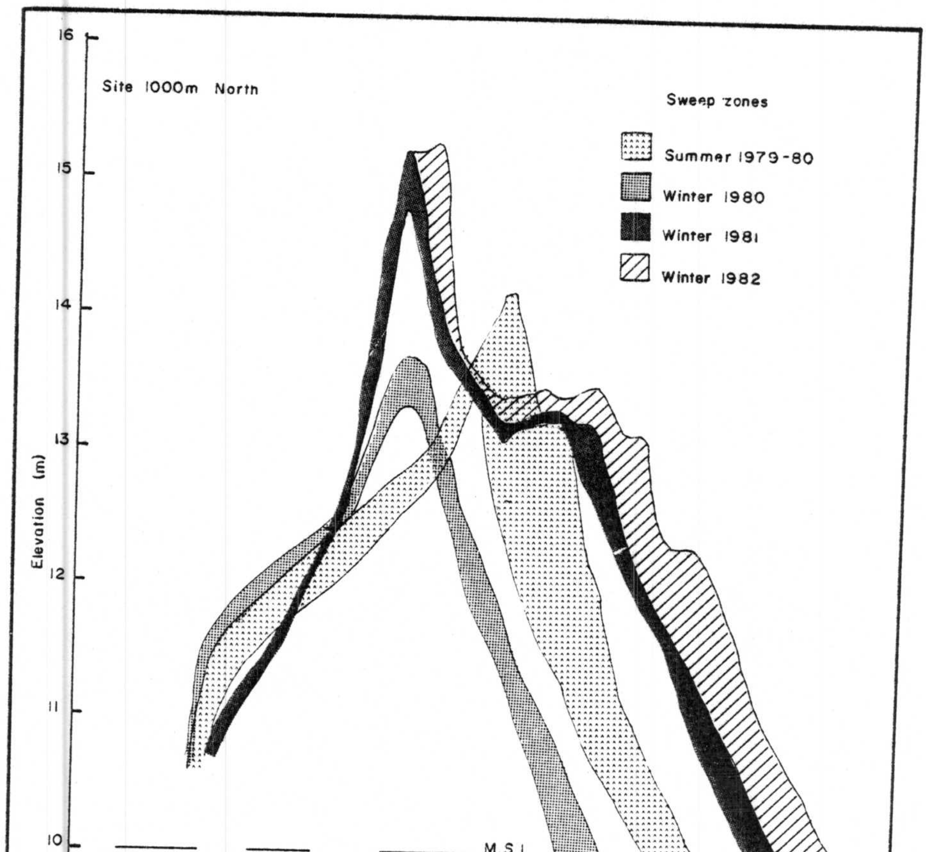

Figure 18 : Sweep zones site 1000 m N 1979-1982.

beach crest being lowered, the beach face retreating and deposition on the barrier backslope (Figure 18). This trend reversed during the summer of 1980-81 after a shingle ridge was built along the barrier to stop waves overtopping the beach crest. This bulldozed ridge of shingle, by preventing the waves overtopping the barrier, caused shingle to be deposited at the base of the shingle ridge and allowed an apparently stable beach to form. By the winter of 1982 this beach deposit had prograded some 30 m from its position during the winter of 1980.

Cross Section 1600 m N

This site is south and updrift of the Hasting City sewer construction site. Beach changes here (Figure 19) are opposite to those north and downdrift of the construction site. From the summer 1979-1980 through the winter 1980, the beach prograded 40 m and the material deposited on the front of the barrier was approximately 0.2 m to 0.6 m lower than the barrier crest. The elevation of the prograded deposit, compared to the elevation of the barrier crest, was similar to that found at cross section 17 (1968 series). The lower elevation suggests that progradation took place quite rapidly and the deposit was not formed into higher beach ridges because of insufficient storms. The period 1981-1982, after the construction tunnel was removed, was a period of erosion at this site. As the beach face retreated some deposition on the backshore did occur, forming a seaward beach ridge in front of the barrier crest.

Hastings City Council Sewer Outfall 1914-1978

Five surveys of the beach in the vicinity of the Hastings City sewer outfall, have been carried out from 1936 to 1978, which, together with a small section of a survey in 1914, provide a record of what has happened at East Clive over a longer period (Figure 20). From 1914 to 1936 a small amount of accretion occurred. Since 1936 the site has eroded, depositing a proportion of the beach

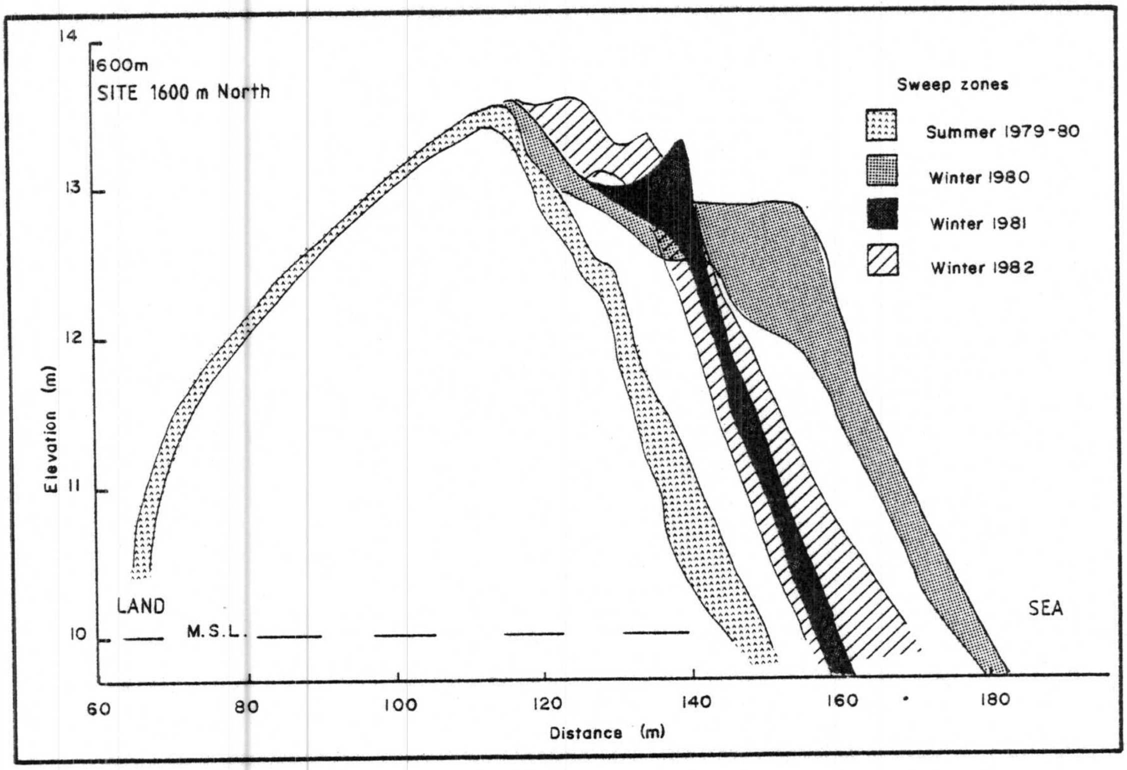

Figure 19 : Sweep zones, site 1600 m N 1979-1982.

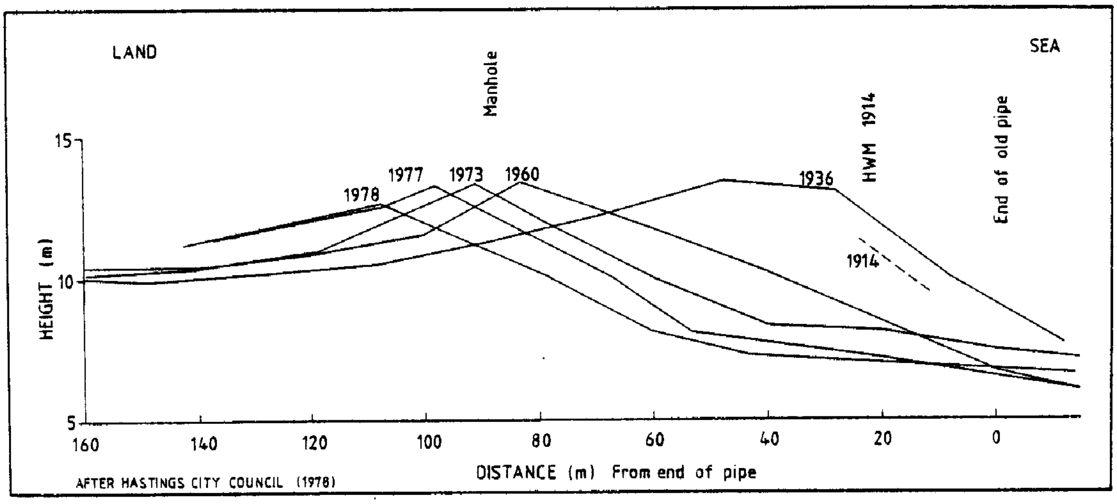

Figure 20 : Hastings City Council sewer outfall cross section 1914-1978.

face material on the barrier backslope. The initial response to the relative changes in land and sea levels was, as could be expected, rapid averaging 1.1 m per year from 1936 to 1960. From 1960 to 1973, the rate reduced and averaged 0.6 m/year. Since 1973 the rate of retreat has again increased attaining 10 m/year for the 1977-1978 period. This latest increase in erosion rate suggests that some factor(s), other than the change in land levels associated with the earthquake, are stimulating erosion of the barrier in this area.

DISCUSSION

Historical evidence, aerial photographs, land title surveys and profile data indicate that the beach south of Awatoto has been subject to recession, and the beach north of Awatoto has tended to accrete (Dinnie, 1946; Lindup, 1948; Smith, 1968; Gibb, 1973). The highest rates of erosion occur between the Tukituki and Ngaruroro rivers, and southeast of Clifton along the Kidnappers promontory. Erosion occurences have apparently been spasmodic (Clifton 1939-41, Haumoana 1938, 1974-1978, Waitangi 1939-1946). Other periods of erosion or accretion may have occurred but have not been documented.

Probable causes of shoreline retreat are:

(a) Changes in sea level

(b) Fluctuations in the supply of material to the beach

(c) Change in wind and wave climate

(d) Excessive extraction of beach materials.

The change in sea level relative to land level erosion or accretion depends on the direction of change (Brunn, 1962, 1983). A rise in sea level will cause erosion, while a fall in sea level will cause accretion. Smith (1978) applied this principle to the coast between Napier and Clifton. The average slope of the Heretaunga Plains is 0.0025 and the maximum known subsidence was 0.76 m. If the barrier beach was in an equilibrium position at the time of the earthquake in 1931, the barrier could be expected to retreat some 300 m to regain equilibrium in the area of greatest subsidence. This estimate of the extent of beach retreat was compared using the method of Weggel (1979) which indicates the probable retreat would be 320 m where subsidence was greatest. Repositioning the barrier can be expected to occur from just north of the Ngauroro-Tutaekuri river's mouth, south to at least Haumoana. The lack of data on changing land levels south of the Tukituki River makes it impossible to determine the southern limit of probable barrier retreat.

Besides the land subsidence caused by the 1931 earthquake, there is a world wide increase in sea level taking place (Schofield, 1967; Heath, 1976) which, though small, (about 10 cm/century), will also have a long term effect on the barrier.

The fluctuations in the supply of material are a result of climatic conditions which change the pattern of wave approach or the conformation of the river mouth (Dinnie, 1946; Lindup, 1948). Dinnie (1946) proposed that the delta formation at the river mouths caused a diversion of shingle offshore to form a bar and consequently, starved the beach downdrift of sediment, causing erosion. Lindup (1948) after examining survey plans, found that the occasional migration of the Ngaruroro/Tutaekuri river's mouth caused the deposition of approximately 690,000 m^3 of material on the south side of the rivers' mouth, between 1918 and 1947. Lindup (1948) also found that there had been 260,000 m^3 of material deposited on the south side of the river's mouth between 1943 and 1947. This latter accumulation of material suggests an average annual longshore drift volume of 65,000 m^3. The temporary detention of material by river action was thought to be the cause of the short period of erosion at Waitangi between 1939 and 1946. Further evidence of river mouth obstruction to longshore sediment movement was observed at the mouth of the Tukituki River between 1978 and 1984. Initially, accretion found to the south of the river mouth was attributed to the groyne construction at the Hastings City sewer outfall. However, a flood in December 1980 built a large delta and offshore bar at the river mouth. This bar caused continuing accretion to the south of the river mouth even after removal of the groyne at the sewer outfall. By January 1984, the offshore bar had been destroyed by wave action leaving the coast at an unusual alignment, approximately 4° east of the original orientation. The volume of material deposited between 1978 and January 1984 was approximately 300,000 m^3 suggesting an average annual longshore drift rate of 60,000 m^3, a figure which closely agrees with the estimate of Lindup (1948).

A change in wind and wave climate will effect the supply of material to the foreshore and the rate of longshore transport. Barnett (1938) and Reid (1978) have described severe storms on the northeast coast of the North Island while Trenberth (1977) and Grant (1981) have discussed climatic change in the New Zealand region.

Evidence does suggest that there has been a change to more frequent storm events, causing damage to the coast and hinterland (Grant, 1981). The increased frequency of storms, particularly tropical cyclones is causing an increase in sediment yields from catchments and the associated river mouth changes could cause more frequent fluctuations in sediment supply to the beaches. The cross section data from Waitangi to Ellison Street do show erosion associated with storms in the early 1950s, but on the whole, with the exception of the area adjacent to the Awatoto Shingle Company, the foreshore has not shown a significant erosion trend.

Only the beach at East Clive and along the foreshore adjacent to Clifton is there evidence of continuing erosion. The Hastings City Council cross sections at the sewer outfall do indicate an increase in the rate of coastline retreat since 1973 which may be attributed to increasing frequency of storm waves overtopping the barrier. The increased frequency of storms does not appear to have caused a change in longshore transport rate. Lindup's (1948) observations and the investigation at the mouth of the Tukituki River (1978-84) show no difference in sediment transport rates since the 1940s.

Excessive shingle extraction has caused damage to the beach backshore in the past. Harbour Board reports indicate that shingle removal from the beach near Napier, during breakwater construction, allowed waves to attack the backshore and threaten the root of the breakwater during storm events. The damage at Awatoto during the July 1946 storm, was attributed to excessive shingle removal (the Napier Borough Engineer) but this was refuted by the Public Works Engineer (Dinnie, 1946).

Since the extraction point offers no obstruction to longshore drift, sediments will continue to pass by and be deposited further north. Damage to the foreshore is likely to be at or updrift of the extraction site. Finch (1919) and Fisher (1976) both have estimated the annual accumulation of material on the south side of the Napier harbour breakwater as 6000 m^3. The accumulations observed around the river mouths suggest a longshore drift rate of 60,000 m^3 per year. If cross section 1600 m N, between the mouth of the Tukituki and the Hastings City sewer construction, is assumed to be representative of the rate of accumulation on this 700 m of foreshore, the volume of accretion 1979-80 was 66,000 m^3 and the loss for the 12 months after the groyne was removed was 39,000 m^3. These differences at site 1600 m N highlight the fact that longshore transport is not a regular occurrence but is dependent on wave conditions. To obtain an approximate sediment budget, averages have to be used. The average of all estimates of longshore drift is 57,000 m^3 per year at East Clive and reduces to 6000 m^3 per year at the breakwater. Abrasion of the particles will account for some loss in volume together with a further loss attributed to material washed down the backslope of the barrier. Table 8 presents the information at present available on longshore sediment movement and suggests that the current extraction rates at Awatoto are probably excessive, and therefore may be contributing to erosion at East Clive.

Table 8 : Probable sediment volumes for the beach between Clifton and Napier.

	Input m^3	Loss m^3	Residual m^3
Rivers	7,000		
Longshore transport	57,000		
Abrasion		?	
Washed over deposits		?	
Extraction			75,000 (up to)
Accumulation of breakwater			6,000

Figures 9 and 10 illustrate the undernourished state of the beach in the vinity of Awatoto and show that erosion in this area is continuing, suggesting an excessive rate of removal.

The beach retreat at East Clive appears to be the result of a combination of factors : increased storm frequency, mining downdrift and subsidence caused by the earthquake. Besides these factors are the effects of the rock groyne recently constructed by Hastings City Council to protect the existing shoreline outfall and the 4° change in beach orientation in the foreshore fronting Haumoana. The form of shore protection designed for East Clive will have to consider all these factors.

In the past, two methods of shore protection have been attempted, both successfully, on the coast between Clifton and Napier; namely, groynes and artificial barrier crests. Groynes were used successfully at Clifton (Dinnie, 1939) and during the Hastings City sewer construction. In both cases the beach updrift of the groyne accreted rapidly. However, the disadvantage of this method is the inevitable downdrift starvation of the beach, albeit, temporary. Material lost from the downdrift beach causes a serious weakness, for the undernourished beach is unable to withstand storm events, is easily overtopped, and has a tendency to migrate more rapidly inland. The second method of shore protection using an artificial barrier crest, has also been successful at East Clive (1000 m N site) and at Waitangi (lines 22 and 26). In contrast to the groyne method, the construction of an artificial barrier crest does not deplete the supply of material but does create an environment which promotes deposition on the upper beach face, improving the barrier's abiity to withstand storms.

At East Clive, the construction of an artificial beach crest appears to offer the best method of beach protection. While groynes have proven capable of widening the barrier updrift, probable downdrift erosion could decrease the barrier stability. The construction work for the Hastings City sewer demonstrated the rapidity at which downdrift erosion can take place in Hawke Bay. Any sites selected for groyne construction would have to be chosen carefully. For instance, a groyne south of the Ngaruroro/Tutaekuri river's mouth could promote instability of the river mouth, allowing wave action into the estuary which may have a detrimental effect on both road and rail bridges. If construction was north of the river mouth, shingle deposition may obstruct flood flows, increase the possibility of flooding adjacent lowlying farm land and promote erosion in the vicinity of the Awatoto Shingle Company, the wool scourers and abattoirs. The Hawke Bay Catchment Board (1982) report that the erosion scarp which developed at East Clive moved northwards even after construction had finished and shingle was again moving northwards. Thus, the effects of groyne construction could be long term and far reaching. In contrast, the use of an artificial beach crest would not impede the longshore movement of material and the downdrift effects should be minimal.

The construction of an artificial barrier crest should prevent waves overtopping the barrier and create at least temporary stability of the shoreline position. Fluctuations in sediment supply from the south through wave action and river mouth behaviour will possibly induce short term instability (for example

Waitangi 1939-46), which cannot be avoided. An immediate problem may be caused by the new orientation of the foreshore at Haumoana. The recent 4° change in beach alignment may change the rate of longshore transport here and cause continued erosion of the beach immediately north at East Clive.

Long term beach changes south of the Tukituki River in response to changing levels associated with the earthquake, cannot be ascertained because of the absence of before and after level data. Early maps of the area (Wilson, 1984; Rockfort, 1896; Hawkes Bay Rivers Board, 1911) show an old channel of the Tukituki River between the barrier and the township of Haumoana. All that remains of this channel are two lagoons. The remaining area has been infilled with washed over gravel. This evidence suggests that protective work will be required at Haumoana if the flooding and sedimentation problems experienced in 1938 and 1974-1978 are to be avoided, and any protective work at East Clive will need to be safeguarded against being outflanked.

If an artificial beach crest was to be constructed, the structure would need to be large enough to withstand occasional wave attacks and high enough to prevent overtopping. To achieve this, the barrier would have to be slightly higher than RL 15 m (5 m above mean sea level). The cross section data at both Waitangi and East Clive indicate that wave action is not capable of moving material above RL 15 m. The storm of August 1974 produced 6 m waves which were probably 4.5 m - 5.0 m at East Clive (Table 3) and have a return period of about 50 years. Therefore a beach crest elevation of 15.0 m to 15.5 m should provide adequate protection for most storm events. The grade of the material used in the crest construction would probably best be local gravel. This material is on site and has been demonstrated to have adequate stability at line 1000 m N. Alternatively, limestone rubble, as used at Waitangi, would probably prove satisfactory.

CONCLUSIONS

The gravel beach linking the Kidnappers promontory with Napier city is a narrow shingle barrier beach breached at two points by river mouths. Periodic migration of river mouths, in a northerly or southerly direction, may cause short term fluctuations in the volume of sediment available for transport along the beach. The rate of sediment transport along the beach is about 57,000 m^3 annually, but may fluctuate considerably depending on wave conditions. Approximately 7,000 m^3 of sediment is supplied annually from the rivers but this supply is also likely to fluctuate considerably from year to year. The balance of material transported along the beaches is probably derived from the cliffs east of Clifton. The textural characteristics of the greywacke gravels making up the beach, river and cliff deposits are very similar and indirect methods are required for assessing the probable contribution of each source to the beach sediments.

Wave climate and sediment data indicate a net drift of material northwards, though periods of northeasterly weather do cause a reversal of drift. Dominant waves are between 8 and 10 seconds and are between 0.5 m and 1.0 m high. Waves of 3.5 m have approximately a one year return period. Waves in excess of 9 m have been observed but are very infrequent. Waves of 6.0 m have a 48 year return period and will produce conditions similar to those experienced in 1974.

Historical records indicate the beach north of Awatoto has had a predominantly accretionary history associated with breakwater construction at Napier and uplift caused by the 1931 earthquake. South of Awatoto, much of the coast has tended to recede, most probably in response to subsidence which occurred in this area during the 1931 earthquake.

Profile data indicate that recession of the barrier deposit is achieved primarily by waves overtopping the barrier crest and depositing material on the barrier backslope. Erosion of the beach appears to occur only when there is an interruption to the supply of material along shore. The interruption of shingle supply can be natural, associated with river regimes (as at Waitangi 1943-1946), or man induced by excessive shingle extraction, or as a result of construction of coastal facilities.

Two forms of beach protection have been used in the past and both have proven successful. The use of groynes and the erection of an artificial beach crest to stop waves overtopping the barrier have successfully protected the Hastings City sewer outfall, Clifton Domain and State Highway 2. Of the two methods, the construction of an artificial beach crest has the least downdrift effect. Beach crest protection creates an environment where sedimentation can take place on the upper beach face and backshore, naturally strengthening the barrier deposit and providing a sediment buffer deposit for protection during stormy periods.

Any protective work at East Clive will have to be associated with work at Haumoana to ensure the protection at East Clive is not outflanked by erosion to the south.

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APPENDIX I

A LIST OF COASTAL STORMS IN HAWKE BAY : 1810-1980

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Date	Comment	Date	Comment
1810 Feb	NE gale	1852 Jan	SE gale
1816 March	NE gale	1852 April	SE gale
1832 ?	NE-SE gale	1853 ?	NE gale
1836 July	NE gale	1854 Oct	S gale
1836 July	NE gale	1856 May	E gales
1840 April	NE gale?	1859 ?	SE gale
1841 Aug	S gale	1860 Aug	NE gale
1843 Aug	E gale	1863 June	SE gale
1845 July	NE gale	1863 Sept	NE gale
1846 June	S gale	1866 June	E gale
1846 Sept	S gale	1867 March	NE gale
1847 July	NE gale	1867 Oct	E gale
1847 Sept	S-SE gale	1868 Feb	NE gale
1849 June	S gale	1869 Feb	NE gale
1850 Feb	SE gale	1875 Jan	SE swells
1850 July	NE gale	1876 April	S gale
1850 Sept	SE gale	1876 Nov	Heavy S swell
1851 June	S gale	1879 June	S gale
1851 July	S gale	1880 March	SE swell

1882	June	S swell
1883	March	NE gale
1883	June	Heavy seas S?
1884	April	SE Heavy seas
1885	March	SE heavy seas
1886	Aug	SE heavy seas
1886	Sept	NE heavy seas
1887	May	NE gale
1888	March	SE gale
		Extraordinary HW
		Continual heavy seas
		May to August.
1889	May	Shingle buried crane
		NE heavy seas.
1890	Feb	SE heavy swell
	March	NE seas
	April	Waves 14 ft SE?
	Nov	12 foot swell SE?
1891	Feb	14 foot waves S?
	March	Heavy sea S
1892	May	Heavy S
	June	S waves 8-10 feet
1893	July	Heaviest seas yet
1894	Feb	Heaviest storm yet S
	April	30 foot waves
	May	Severe storm 30'+
1895	Mar	Most severe NE yet
1896	?	Heavy storm S
1897	Feb	Hurricane
	April	E gale
1900	April	SE gale
	June	Heavy seas SE
	August	Heavy seas NE
1901	April	NE sea
	Sept	NE gale
1902	?	SE gale worst known
1903	March	Heavy sea
1904	Jan	ESE tremendous storm
1905	March	SE heavy seas
1906	April	ENE Heaviest storm
		yet. Crossed Petane
		Road.
1908	April	Heavy seas
	May	Damaged W Spit Road
1909	?	SE gale
1910	April	SE huge seas
1911	July	Heavy seas S

1912	July	Heavy seas S
	August	Heavy swell S
1913	April	SE sea
	August	SE sea
1914	June	Heavy S sea
	Dec	E gale
1915	June	Heavy seas
1916	June	Damage to Westshore
1916	Aug	Damage to breakwater
1917	May	Large waves
	July	High tides
		Strong winds E
1918	March	Very high seas S
1919	Oct	Heavy seas
1920	July	Heavy seas
1921	July	Heavy seas
1923	May	Heavy seas.
1924	May	S gale
1927	March	E gale
1932	March	Heavy SE swell
1937	?	WSW gale S seas
1946	June	S gale
1947	July	S gale severe
1951	May	Heavy seas
1952	July	NE gale
1961	Jan	E storm
1962	Jan	E storm
	Dec	NE gale
	Dec	E gale
1967	March	E sea
1968	April	E 12' waves
	April	E 9' waves
	May	S 9' waves
	July	SE gales
1969	Sept	E storm
1971	May	Heavy S swell
1973	May	E gale
1974	August	20' E swell
1977	April	3.5 m waves
1979	Feb	3 m waves
	Dec	3 m waves
1980	Jan	3 m waves