

Shoreline Fluctuations and an Assessment of a Coastal Hazard Zone along Pauanui Beach, Eastern Coromandel Peninsula, New Zealand.



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Jeremy G. Gibb and John H. Aburn

Water and Soil Directorate
Ministry of Works and Development
P.O. Box 12-041
Wellington North

Ministry of Works and Development
Private Bag
Hamilton

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by Jeremy G. Gibb, Water and Soil Directorate, MWD, P.O. Box 12-041, Wellington North, and John H. Aburn, MWD, Private Bag, Hamilton.

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A 54 to 116 m wide Coastal Hazard Zone (CHZ) comprising Extreme, High and Moderate Risk Zones is assessed for Pauanui Beach based on extensive onshore-offshore investigations made in 1983-1984 by Ministry of Works and Development, Hauraki Catchment Board and the Royal New Zealand Navy. A change from a state of dynamic equilibrium to a long-term trend of erosion is forecast for the 2.65 km long ocean beach frontage during the next 100 years with erosion increasing in severity southwards. The erosion would be caused principally by an acceleration in global sea-level rise from about 1.5 mm/year to 7.0 ± 1.8 mm/year as a result of CO₂ build-up in the Earth's atmosphere. Within the CHZ, Extreme and High Risk Zones are subject to the coastal hazards of long and short-term sea erosion, wind-induced erosion and deposition of sand, and tsunami inundation. The Moderate Risk Zone is subject to sea erosion resulting from a predicted 700 to 880 mm rise in sea level between 1980 and 2080 AD. Landward of the CHZ risk is considered low to very low. It is recommended that the Thames-Coromandel District Council adopt this paper and its recommendations and use the CHZ as a management tool to control both residential subdivision and building within the CHZ.

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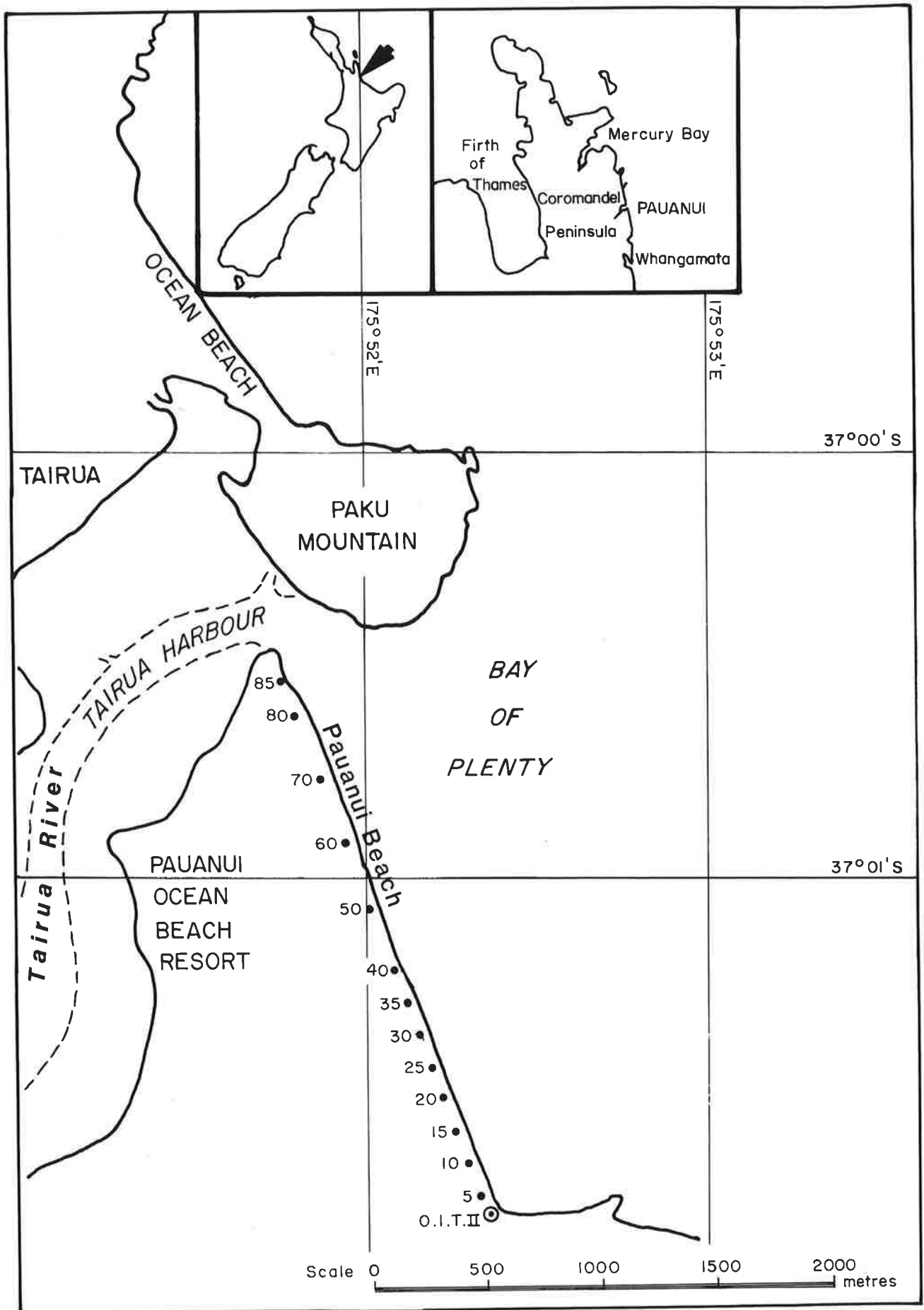


Figure 1: Sketch map showing the location of Pauanui Beach, Eastern Coromandel Peninsula, New Zealand, and 13 selected MWD beach survey cross-sections referred to in the text and in Tables 3, 5 and 6, and Appendix II.

INTRODUCTION

Comparing past positions of the shoreline in space and time provides a useful basis for assessing present, and predicting future shoreline movements along a particular stretch of coast. From such comparisons the pattern and rate of movement may be determined, the rate being calculated by dividing the amount of horizontal shoreline displacement by the time interval between successive surveys. In general however, the siting of many coastal settlements around New Zealand has not been based on such assessments so that houses have been placed too close to the beach. The consequences of such bad planning have been either the loss of housing and services to the sea or the construction of very expensive coastal protection works often resulting in the eventual destruction of the very asset the people chose to live next to, the beach.

Pauanui Ocean Beach Resort is a high-class development located about 100 km from both Auckland and Hamilton cities (Figure 1). Since the area was first subdivided in 1967 there are now 67 beachfront sections bordering the 2.65 km long Pauanui Beach. Beachfront sections are presently selling for \$100,000 or more and harbour-front sections for around \$50,000 (Mr Ian Hopper, developer, Pauanui, pers. comm. 1984). All the houses are architecturally designed and the present capital value of the first line of beachfront properties is estimated here to total about \$15,000,000. Between the seaward boundaries of these properties and the beach there is a foreshore reserve of mown grass which is presently 32 to 55 m from the top seaward edge of the foredune north of Pauanui Airfield and 26 to 47 m to the south. The reserve comprises sand dunes that have been extensively modified by bulldozing during development, followed by the spreading of topsoil and the planting of grass (Gibb 1973).

In 1982 a controversy arose concerning the long-term stability of Pauanui Beach. A trend of long-term slow erosion was argued by Hauraki Catchment Board with the eroded sand being lost into Tairua Harbour (Healy *et al.* 1981). Conversely, Pauanui Ocean Beach Resort Ltd, supported a long-term trend of accretion with the eroded sand being lost offshore and replaced by sand supplied from the harbour (Carrier 1980). In October 1982, the Director of Water and Soil Conservation, Ministry of Works and Development, requested Dr J. G. Gibb to resolve the controversy. As such an investigation was commenced in November 1982 and completed in December 1983, during which, data relevant to the long-term stability of Pauanui Beach were collected and analysed. In this paper, we report on our findings in relation to past shoreline fluctuations and predicted future trends along Pauanui Beach. Based on the data an assessment of a coastal hazard zone (CHZ) is made, combining techniques developed by Bruun (1962; 1983) and Gibb (1981; 1983a).

SHORELINE MOVEMENTS

Before the shoreline can be fixed it must first be defined. In New Zealand, the "official" shoreline, or seaward boundary of any land, is defined as mean high water mark (MHWM) (Kelly 1971). As MHWM is located on the beach it is subject to displacements of several tens of metres during one or a number of tidal cycles coupled with severe onshore storms. Therefore, as an indicator of real gains and losses of "dry" land, MHWM is an unreliable reference shoreline to adopt. For coastlines such as Pauanui Beach that are backed by sand dunes it is better to adopt the seaward toe of the foredune as the reference shoreline, an approach followed in this study.

Coastlines of the world that are composed of unconsolidated sand or gravel move in and out in response to changing atmospheric, sea and land conditions. Such coastlines are dynamically balanced between the forces of nature. For example, a coastline with a history of accretion may suddenly reverse to erosion if there is a reduction in sediment supply, rise in sea-level or a change in configuration of the adjacent headlands and nearshore seabed. Conversely, a coastline with a history of erosion may reverse to accretion if there is an increase in sediment supply or fall in sea-level. An apparent change in sea-level may occur if the coastline is raised or lowered by tectonic movements or compaction.

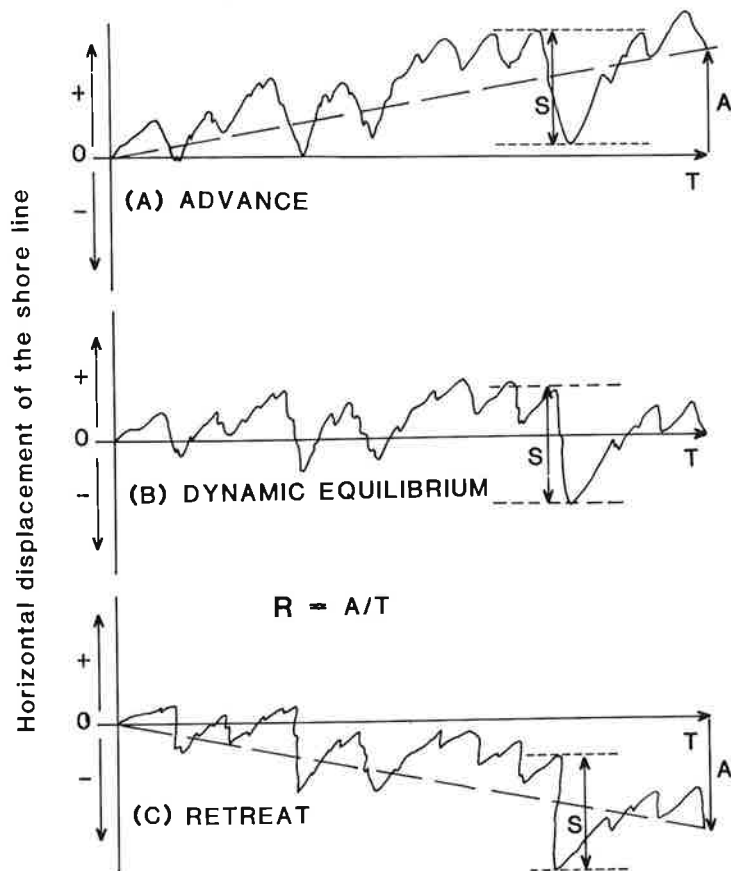


Figure 2: Diagrams showing short-term fluctuation S in the position of the shoreline (foredune seaward toe), and long-term trend, R , where R is the net rate of movement in m/year calculated by dividing the horizontal distance, A , by the survey time interval, T . (A) is advance seaward from net accretion. (B) is fluctuating about a mean position indicating dynamic equilibrium. (C) is retreat landward from net erosion.

Long-term trends of either shoreline advance, retreat or dynamic equilibrium may be discerned in most places from survey and geologic data spanning the last several millenia. The process though is not regular along unconsolidated sedimentary coasts but takes place in a series of episodic short-term movements (Figure 2) of the order of 15 to 350 m (Gibb 1978; 1983a). Such movements are mostly unpredictable and are likely to occur within a period as short as one year.

For each of the three trends shown in Figure 2, R is the net rate of accretion or erosion and S the *maximum* range of short-term fluctuations. Factor R varies according to such influences as fluctuations in sediment supply, changes in sea-level and modifications to the coastline and nearshore seabed. Factor S varies mostly according to the magnitude of either one or a cluster of severe onshore storms superimposed on the long-term trend. It is a well known fact that beaches erode by combinations of storm tides and storm waves and build up with normal or low tides and by swells (Bruun 1984).

Assessing the extent of any CHZ must take into account both R and S factors and whether the past trend is likely to continue into the future or reverse. Therefore, we first need to ascertain whether Pauanui Beach has a history of erosion, accretion or dynamic equilibrium. Second, we must judge whether the past trend is likely to continue into the future or change. Third, we must establish the magnitude of storm-induced erosion.

PREVIOUS WORK

For Pauanui Beach, cadastral surveys fixing the toe of the foredune were made in 1895 (Survey Office Plan, S.O. 6910D²) and 1967 (Deposited Plan, D.P. S11962), and vertical sequential black and white aerial photographs covering the beach and dunes were taken in 1944, 1963, 1971, 1975, January and September 1978 and 1982. From a selection of these surveys several reports have been produced since 1980 assessing the stability of Pauanui Beach.

Carryer (1980) compared the 1895, 1967 and 1977 MHW positions, finding 20 to 40 m accretion from 1895 to 1967 and that Pauanui was "in a phase of dynamic equilibrium" with sediment lost offshore during erosion being compensated by replenishment from Tairua Harbour. Healy *et al.* (1981) and Dell and Healy (1982) compared the 1944, 1963 and 1978 dune toe positions recording 5 to 25 m erosion from 1944 to 1963 and 4 to 7 m accretion from 1963 to 1978, noting 19 to 30 m short-term erosion during a severe storm in July 1978. Based on a net erosion of 5 to 18 m over the 34 year period, these authors concluded that long-term slow erosion was likely to continue with the eroded sand being lost into Tairua Harbour. Raudkivi (1982) compared the relative positions of the 1895, 1944, 1963, 1967, 1971 and 1975 "shorelines", concluding a "zero trend" along Pauanui Beach over the 80 year period and that "there is no evidence to suggest a long-term (century) erosional trend", nor "a significant accretional trend".

METHODS

For the study of shoreline fluctuations along Pauanui Beach the following data were collected between November 1982 and May 1984:

- Controlled aerial survey completed December 1982
- Controlled hydrographic survey completed June 1983
- Bore-holes completed July 1983
- Controlled ground surveys completed December 1983
- Volumetric analysis completed March 1984
- Radiocarbon dating completed May 1984

The aerial survey (SN 8143) was carried out by New Zealand Aerial Mapping Ltd (NZAM); the hydrographic survey (HI 122) by the Hydrographic Branch of the Royal New Zealand Navy (RNZN); the bore-holes by Thames Valley Well-drillers; the ground surveys and volumetric analysis by the survey section of Ministry of Works and Development (MWD), Hamilton District Office, and the radiocarbon dating by the New Zealand Radiocarbon Dating Laboratory of the Institute of Nuclear Sciences, DSIR. Mr J. Aburn, MWD, coordinated the aerial and ground surveys and supervised the volumetric analysis. Lieutenant I. F. P. Martin, RNZN, coordinated the hydrographic survey. Mr P. Dell, Hauraki Catchment Board, coordinated studies of the nearshore currents discussed elsewhere (Dell 1983) and assisted with aspects of the hydrographic and ground surveys. As Project Leader, Dr J. G. Gibb, MWD, coordinated and directed the entire study.

Aerial Survey

From the aerial survey conducted by NZAM, Photogrammetric Branch of the Department of Lands and Survey produced two planimetric rectified photomaps at 1:2000 scale (Aerial Plan No. 1469, Sheets 1 and 2). On the sheets, trained operators of the branch using sophisticated stereoplotting instruments plotted the foredune toe from the 1944, 1971 and January 1978 sequential black and white aerial photography. The shorelines were mapped with respect to both the New Zealand Map Grid and Mount Eden Meridional Circuit.

The stereoplotting instruments compensate or eliminate the effects of all inherent errors in the photographs and have the capacity to make accurate measurements to ± 0.1 mm or better (Gibb 1983b). Because of scale limitations and poor quality the aerial photography of 1963, 1975 and September 1978 was found by Photogrammetric Branch to be unsuitable for planimetric mapping. Most, if not all of these photographs were used by Healy *et al.* (1981), Dell and Healy (1982) and Raudkivi (1982) for their measurements.

Hydrographic Survey

During the period 9 May to 3 June 1983 a 5-strong party under the command of Lieutenant I. F. P. Martin (RNZN), carried out, amongst other tasks, a precise hydrographic survey of the study area from the sounding motor boat *Pandora*. Baselines for the control of the survey were established along the coastline by the MWD survey section including the establishment of 89 beach cross-

sections along Pauanui Beach, spaced at 30 m intervals. Every fifth cross-section was surveyed at low water to 0.8 m below mean sea level (MSL) to provide an adequate gradient overlap with the inshore sounding lines surveyed at high water by *Pandora*. All soundings and heights in this study are in terms of MSL Moturiki Datum.

Soundings were controlled from ashore using theodolite transits plumbed over the established traverse pegs. An AGA Geodimeter 140 Total Station instrument, manned by both MWD and RNZN personnel, was used to rigorously control the sounding lines from ashore. The geodimeter was used for all distance measurements out to an offshore limit of 2500 m and fixes were made at approximately every 60 m along each sounding line. In total, about 185 km of lines were run at 60 m spacings normal to the coast to an accuracy of ± 1.5 m. Sounding lines were aborted whenever the boat diverged from the observed transit by ± 2.0 m. From a portable Atlas Deso 10 echo sounder consistent soundings were obtained to an accuracy of ± 0.2 m. A full report on the hydrographic survey is given in Appendix I.

Based on the soundings, a 1:6000 scale bathymetric chart of the area was produced by the Hydrographic Branch, RNZN (Figure 4). The chart accurately delineates the coastline and intertidal zone and shows depth contours at one metre intervals out to the 23 m depth contour. Nearshore topographic changes to the seabed were investigated by the Hydrographic Branch by comparing the 1983 bathymetry with a previous survey conducted by the RNZN in 1971. Results are given in Appendix I.

Bore-Holes and Radiocarbon Dating

Three shallow bore-holes (see Figure 5) were drilled across the base of Pauanui Spit using a truck-mounted rotary auger drill. For the bore-holes, heights above MSL and distances from the present shoreline were determined by the MWD survey team and logging of the stratigraphy and sampling was carried out by Dr T. M. Hume of the Water Quality Centre, MWD, Hamilton.

Bore-hole 1 was 375 m inland, 10.4 m deep and the ground surface was 6.28 m above MSL; bore-hole 2 was 740 m inland, 7.9 m deep and 5.18 m above MSL; and bore-hole 3 was 120 m inland, 14.9 m deep and 5.77 m above MSL. Broken shell from past shoreline deposits was collected from each bore-hole by catching washings flushed up from the bottom of the holes from the recirculating drilling fluids. Seven selected samples were then despatched to the New Zealand Radiocarbon Dating Laboratory for radiocarbon dating.

Ground Surveys and Volumetric Analysis

During the period November 1982 to December 1983 the MWD, Hamilton District Office Survey Section under the supervision of Mr J. H. Aburn, District Surveyor, carried out the following work in the study area:—

- (a) Survey control for photogrammetric mapping.
- (b) Establishment of baselines for the control of the hydrographic survey.
- (c) Establishment of control points around Paku headland.
- (d) Tairua Harbour channel control.
- (e) Plotting and calculations.

Details of these surveys (Appendix II) for Pauanui including a Coastal Hazard Zone are recorded on Sheets 1 to 9 of Ministry of Works and Development, Hamilton District Office Survey Plan Number 2/973/1/2204.

Six historical shoreline positions are shown on Sheets 7 and 8 at 1:2000 scale covering Pauanui Beach for the period 1895 to 1983. The 1895 and 1967 shorelines are plotted from cadastral surveys and the 1944, 1971 and 1978 shorelines are traced from Aerial Plan Number 1469 Sheets 1 and 2. The 1983 shoreline position was fixed in the field by the MWD survey team in December 1983. Also shown on Sheets 7 and 8 are property boundaries, the extent of the recreational reserve, the 1967 position of MHWL adopted from D.P. S11962, the top seaward edge of the foredune in 1983, the survey baselines, traverse lines and 89 beach cross-section positions.



Figure 3: Photographs taken May 1983 showing aspects of the Hydrographic Survey.
(A) RNZN and MWD survey personnel manning the AGA Geodimeter 140 Total Station and theodolite instruments.
(B) *Pandora* surveying a sounding line.
(C) *Pandora* hard aground after broaching on a breaking wave. The boat was later refloated to continue surveying.

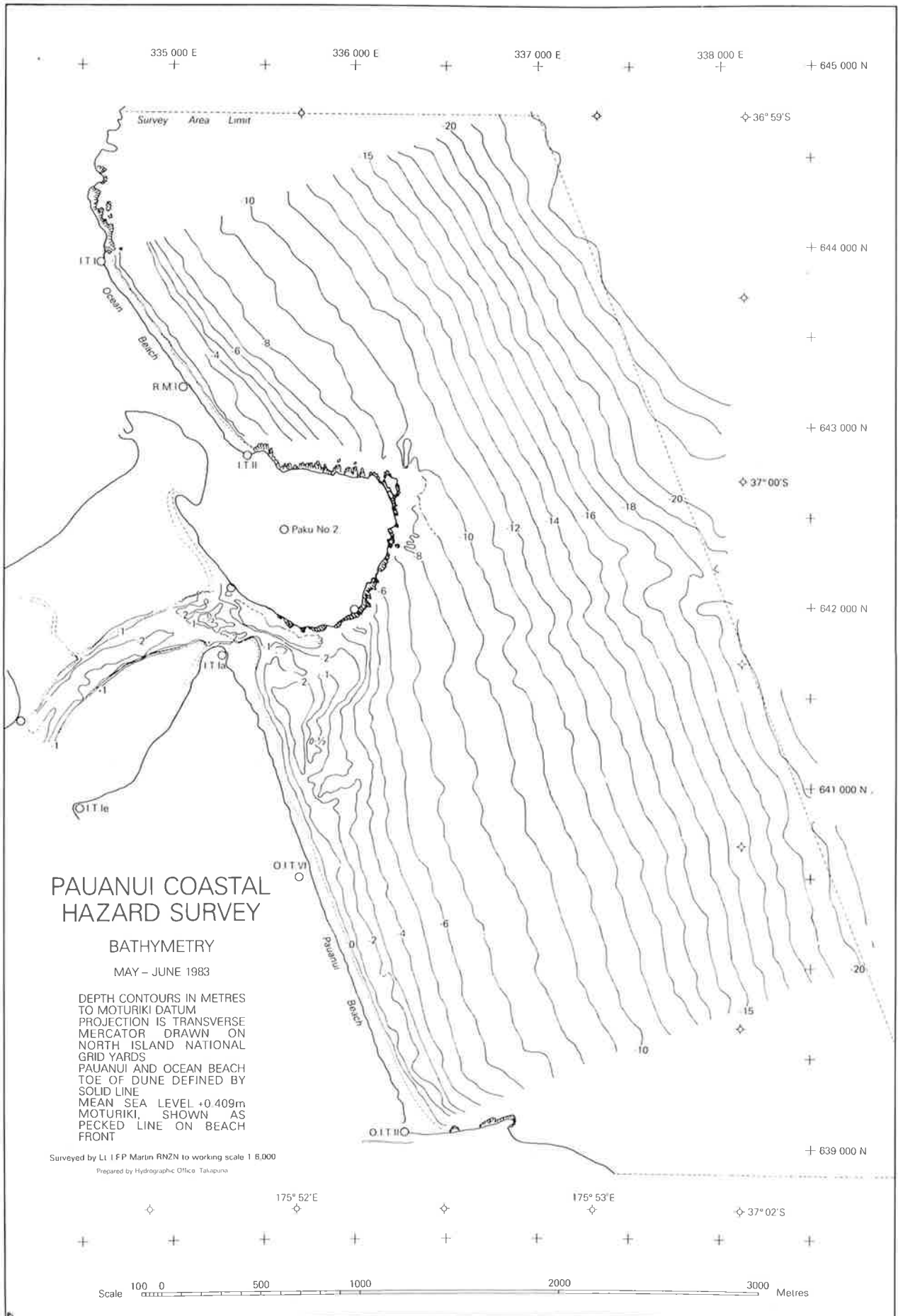


Figure 4: Bathymetric chart of the nearshore seabed between Pauanui and Ocean beaches.

The 1895 cadastral survey on S.O. 6910D² was the first along Pauanui Beach and is recorded on page 13 in Lands and Survey Department Field Book 961. Page 13 shows a straight traverse line with landward offsets along most of the traverse, up to 80 links (16 m), to an unidentified seaward boundary behind which the land is labelled "sand hills". In a memorandum dated 14 December 1967 from the Land Transfer Surveyor's Office, Department of Justice, Hamilton, to Mr D. F. McKay, Registered Surveyor, Takapuna, it is stated that the offsets along the beach were most likely "taken to the edge of sand hills or edge of vegetation and this was in effect their determination of HWM".

The only other cadastral survey of Pauanui Beach was made in 1967 by Mr D. F. McKay for the purposes of the present development and is recorded on D.P S11962 and in Lands and Survey Department's Field Book S133. The surveyors report notes that the height of MHWMM "was determined by tidal observations and obvious demarcation line on the foreshore". Both MHWMM and the "edge of vegetation" were fixed by the surveyor along offsets at the time of the survey. The width of the present recreation reserve between MHWMM and the seaward property boundaries were also determined.

Based on the relative positions of the 6 historical shorelines (seaward toe of foredune) and the survey cross-sections, volumes of sand either accreted to, or eroded from the foredune between the toe and the crest, were calculated for each of the 5 survey periods between 1895 and 1983. The gains and losses of sand thus calculated are recorded on Sheet 4 for the 2.65 km long Pauanui foreshore.

RESULTS

Geological Trends

Table 1 lists 7 radiocarbon dated beach and nearshore deposits, sampled from the 3 bore-holes across the base of Pauanui Spit. Of particular importance here are the 3 radiocarbon dated beach deposits which gave ages of 2020 ± 50 years B.P. (NZ6500B), 4120 ± 70 years B.P. (NZ6467B) and 5060 ± 60 years B.P. (NZ6522B) in terms of the new half life (5730 ± 40 years, after Godwin 1962). The dated beach deposits overly older dated (Table 1) and undated nearshore seabed deposits that have been progressively buried by the seaward advance of Pauanui Beach during the Holocene Epoch.

Although afforestation of Pauanui after about 1950 and residential development after 1967 have largely obliterated the pattern of Holocene dune ridge growth of the spit, the 1944 vertical aerial photography taken prior to these developments provides an excellent record of dune morphology. Based on the pattern of dune ridges recorded by the 1944 photography it is possible to reconstruct the original positions of the 3 radiocarbon dated shorelines (Figure 5). The early dated shorelines are inferred to lie where a particular dune ridge intersects one of the 3 bore-holes.

Table 1: Radiocarbon dated shell beds from three bore-holes across the base of Pauanui Spit, Eastern Coromandel Peninsula.

* — secular correction unreliable (Column K)

(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I) (J) (K)		
Locality	NZ ¹⁴ C	NZ Fossil Record No.	NZMS Grid Ref (Sheet N. 49)	Dist Inland From HWM (m)	Dated Sample	Depositional Environment	Height MSL Moturiki (m)	Radiocarbon Age (Years B.P.)		
								Old T $\frac{1}{2}$	New T $\frac{1}{2}$	Calibrated
Hole 3. Bonanza Place	6500	T11/f36	361395	120	Shell	Beach	-0.93	1960 \pm 40	2020 \pm 50	*
Hole 3. Bonanza Place	6501	T11/f37	361395	120	Shell	Nearshore	-4.63	2150 \pm 50	2220 \pm 50	*
Hole 3. Bonanza Place	6502	T11/f38	361395	120	Shell	Nearshore	-6.43	3410 \pm 40	3510 \pm 50	3760 \pm 70
Hole 3. Bonanza Place	6514	T11/f39	361395	120	Shell	Nearshore	-7.63	3500 \pm 80	3600 \pm 80	3910 \pm 120
Hole 1. Beaumont Green	6467	T12/f11	358393	375	Shell	Beach	-0.12	4010 \pm 70	4120 \pm 70	4620 \pm 150
Hole 1. Beaumont Green	6521	T12/f12	358393	375	Shell	Nearshore	-4.12	4220 \pm 70	4350 \pm 70	4900 \pm 14C
Hole 2. Traffic Island	6522	T12/f13	353392	740	Shell	Beach	-1.22	4920 \pm 50	5060 \pm 60	5600 \pm 60



Figure 5: Shoreline positions over the last 5000 years along Pauanui Spit as indicated by the seaward margin of dune ridges and locations of the 3 bore-holes, plotted on vertical aerial photograph Run 975, photo 32, flown 22 May 1944 (aerial photograph published by permission of Department of Lands and Survey).

Table 2: Geologic net rates of accretion along Pauanui Beach, based on data in Table 1.

¹⁴ C Years B.P. (New T _{1/2})	Period (years)	Accretion Amount (m)	Accretion (+) Rate (m/year)
5060–4120	940	365	+0.39
4120–2020	2100	255	+0.12
2020–Present	2020	120	+0.06
5060–Present	5060	740	+0.15

Figure 5 indicates that over the last 5000 years there has been a progressive eastward translation and clockwise rotation of the dune ridges forming Pauanui Spit with accretion of ridges over the last 2000 years remaining essentially parallel to the strike of the 1944 shoreline. The ridges have also progressively increased in length to constrict the entrance to Tairua Harbour against Paku Mountain.

Based on data in Table 1 and Figure 5, Table 2 sets out accretion rates for Pauanui Beach for the last 5000 years. Table 2 indicates a net accretion rate of 0.15 m/year over the last 5000 years, the rate decreasing progressively with time from 0.4 m/year (5000 to 4000 years B.P.) to 0.12 m/year (4000 to 2000 years B.P.) to 0.06 m/year for the last 2000 years B.P. The decrease of accretion rates with time indicates a shoreline steadily approaching a state of long-term dynamic equilibrium (see Figure 2B).

Historical Trends

Table 3 lists the magnitude of erosion-accretion along Pauanui Beach for the 5 survey periods between 1895 and 1983 and sets out net rates (Factor R) for the entire 88 year period. Figure 6 shows the pattern of shoreline fluctuations to the foredune for the same periods and Table 4 provides details on the volumetric fluctuations. As the foredune toe can only be fixed in the field to an accuracy of ± 1.5 m net erosion-accretion rates in Table 3 have an uncertainty of ± 0.03 m/year. For example, when comparing the 1895 and 1983 surveys to compute net rates, the combined error is ± 3 m (± 0.03 m/year over the last 88 years).

Two of the 5 survey periods are dominated by short-term erosion (1967-1971; 1971-1978) up to 12 m and the other 3 are dominated by short-term accretion (1895-1944; 1944-1967; 1978-1983) up to 48 m. Since 1895 the pattern of movement has been a northward trend from very slow net erosion at -0.03 to -0.11 m/year along the southern 0.64 km of the 2.65 km long Pauanui foredune to very slow net accretion at 0.08 to 0.36 m/year along the northern 2.01 km (Table 3). The pattern of progressive eastward translation and clockwise rotation of the dune ridges over the 88 year period is consistent with the pattern over the last 5000 years.

Table 4 indicates that over the last 88 years about 50 000 m³ of sand have accumulated to the Pauanui foredune at a very low net rate of 214 m³/km/year. Of this volume, 43 100 m³ (306 m³/km/year) have accumulated along the northern 1.60 km of foredune and only 6900 m³ (75 m³/km/year) along the southern 1.05 km. In fact without the accretion recorded between 1944 and 1967 the southern foredune would have shown a net loss of sand over the last 88 years.

The pattern of nearshore circulation and current velocities measured during this study (Dell 1983) helps to explain the very small accumulation of sand along the southern foredune. Although Dell found a general southerly flow in the nearshore, especially during ebb tides, the velocities dropped markedly from 0.5 m/s near the Tairua Harbour entrance to less than 0.1 m/s south of Pauanui Airfield. According to Dell the airfield represents the southern limit of sediment transport by tidal currents in association with northeast seas.

Volumes of sand up to +2226 m³/km/year (1978-1983) and -2170 m³/km/year (1967 to 1971) accreted to, and eroded from, the Pauanui Beach foredune respectively are recorded (Table 4). The short-term gains and losses of sand to and from the foredune balance each other, thus indicating that the present foredune is in dynamic equilibrium, confirming the long-term trend indicated by the geologic data.

Table 3: Historical net rates of coastal erosion and accretion at 13 selected MWD beach cross-sections along Pauanui Beach, measured from sheets 7 and 8 of MWD, Hamilton District Office Survey Plan Number 2/973/1/2204. Cross-sections are spaced at either 150 m (profiles 5–10 etc) or 300 m (profiles 40–50 etc). Net rates have an uncertainty of ± 0.03 m/year.

Cross-Section No.	5	10	15	20	25	30	35	40	50	60	70	80	85	
km North from O.I.T.II	0.09	0.24	0.39	0.54	0.69	0.84	0.99	1.14	1.44	1.74	2.04	2.34	2.49	
Survey Interval	Period (years)	Magnitude of Accretion (+) and Erosion (-) in Metres												
1895–1944	49	-2	-6	0	-4	+2	-2	+3	+10	+12	+7	+25	+17	+7
1944–1967	23	+13	+15	+17	+17	+16	+17	+16	+12	+12	+16	+9	+26	+48
1967–1971	4	+9	+5	-2	-3	-2	-4	-4	-5	-7	-5	-6	-4	-12
1971–1978	7	0	-7	-6	-4	-13	-8	-4	-12	-5	-15	-12	-11	-12
1978–1983	5	-18	-17	-15	-9	+6	+4	+7	+16	+12	+20	+16	+2	-3
1895–1983	88	+2	-10	-6	-3	+9	+7	+18	+21	+24	+23	+32	+30	+28
Net Rate metre/year		+0.02	-0.11	-0.07	-0.03	+0.10	+0.08	+0.21	+0.24	+0.27	+0.26	+0.36	+0.34	+0.32

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Table 4: Historical volumetric changes and rates along the 2.65 km long Pauanui Beach foredune and percentage of short-term coastal erosion and accretion for each survey period, based on Sheets 4R², 7 and 8 of MWD, Hamilton District Office Survey Plan Number 2/973/1/2204.

Survey Interval	Period (years)	Erosion (% Coast)	Accretion (% Coast)	Volumetric Change (m ³)				Net Rate m ³ /km/year	
				Southern Rate 1.05 km		Northern Rate 1.60 km			Total 2.65 km
				m ³ /km/year	m ³ /km/year	m ³ /km/year	m ³ /km/year	m ³ /km/year	
1895–1944	49	23	88	- 2 500	- 49	+23 000	+ 293	+20 500	+ 158
1944–1967	23	0	100	+17 200	+712	+25 800	+ 701	+43 000	+ 705
1967–1971	4	85	15	- 300	- 71	-22 700	-3 547	-23 000	-2 170
1971–1978	7	95	5	- 4 000	-544	-16 000	-1 429	-20 000	-1 078
1978–1983	5	31	69	- 3 500	-667	+33 000	+4 125	+29 500	+2 226
1895–1983	88	12	88	+ 6 900	+ 75	+43 100	+ 306	+50 000	+ 214

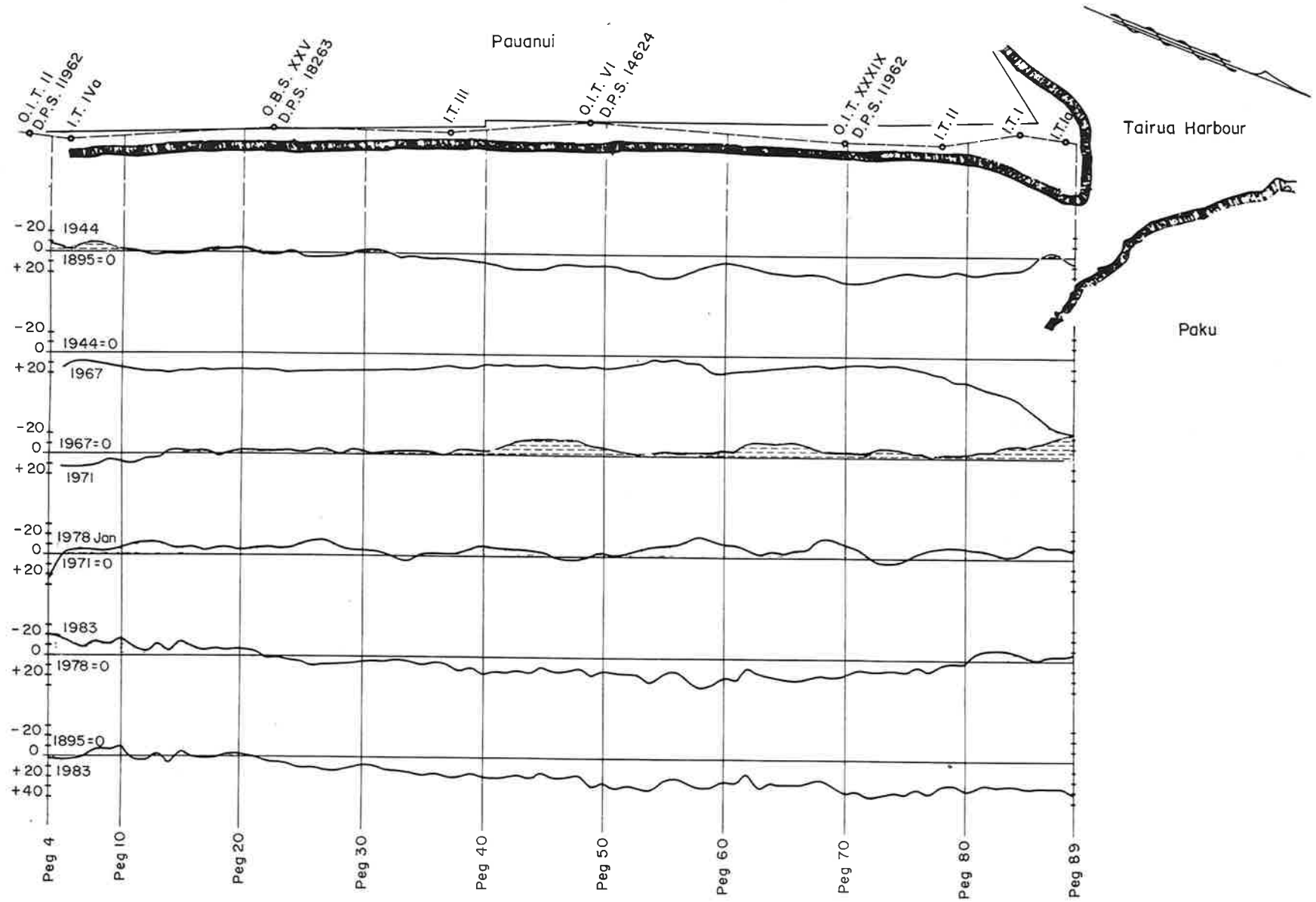


Figure 6: Horizontal fluctuations to the 2.65 km long Pauanui Beach foredune between 1895–1983 for 5 survey periods and for the entire 88 year period. Figure is adapted from Sheet 4R², MWD Hamilton District Office Survey Plan Number 2/973/1/2204, completed March 1983.



Figure 7: Photograph taken 15 August 1985 looking south showing a 4 m high erosion scarp cut into the Pauanui Beach foredune south of the airfield during the storms of 14 to 16 May, 1 to 2 June, 21 to 23 June and 27 to 28 July 1985.

A major limitation of comparative shoreline data is that they do not provide a true indication of the magnitude and extent of short-term shoreline fluctuations (Factor *S*) that may have occurred between surveys. According to local inhabitants, severe storms in the late 1960s and 1970s eroded the foredune toe back to the present top seaward edge (erosion scarp) shown on Sheets 7 and 8 of MWD Hamilton District Office Survey Plan Number 2/973/1/2204. During the 1980s, eroded sand stockpiled in both offshore bars and ebb-tide delta has migrated back to the beach, eventually building a 1.60 km long incipient foredune north of Pauanui Airfield. South of the airfield the foredune has not recovered, and during the winter of 1985, retreated several metres from storm-induced erosion, leaving a 4 m high erosion scarp (Figure 7).

To define the maximum extent of Factor *S* we scaled distances on Sheets 7 and 8 from the top seaward edge of the old erosion scarp to the most seaward historical position of the toe of the foredune. For all but the north end and central parts of Pauanui Beach we recorded distances up to 30 m which is in agreement with the findings of Healy *et al.* (1981) who observed up to 30 m short-term erosion during a severe storm in July 1978. For the north end of the beach we recorded a short-term fluctuation of 70 m which is thought to be associated with changes in the form and position of the entrance channel to Tairua Harbour and the ebb-tide delta. For central Pauanui Beach we recorded a very small movement of 10 m by the airfield which may possibly be associated with a nodal point along the beach between erosion-accretion.

Photographic Evidence

Along the northern half of Pauanui Beach there are several large Pohutukawa trees 11 to 16 m high with 0.4 to 0.6 m wide trunks at the base. The Pohutukawas grow along the seaward property boundaries and are presently 32 to 55 m from the top seaward edge of the foredune. Several of these trees are shown on historical photographs of Pauanui Beach taken from Paku Mountain in 1909 and from Tairua Township in 1904 and about 1880. These photographs are held at the Pauanui Information Centre, Pauanui, and at the Turnbull Library, Wellington.

The survival of the Pohutukawas indicates that short-term storm-induced erosion has not transgressed inland past the seaward property boundaries along northern Pauanui Beach during at least the last 100 years. Along southern Pauanui Beach there are also several Pohutukawas along the seaward property boundaries but they are 8 to 11 m high and much younger. Although

some are shown on the 1944 vertical aerial photograph they are not evident on the historical ground photographs. The age of these trees, therefore, is older than 40 years (1944 to 1984) and younger than 75 years (1909 to 1984). Like the trees to the north, their survival indicates that short-term erosion has not transgressed inland past the seaward property boundaries for, perhaps, the last 50 years.

Seabed Changes

According to Martin (Appendix I) direct comparison of the 1983 seabed topography with the 1971 survey was not possible owing to different datum sites being used for each survey. However, 5 profile depth comparisons of the 1971 and 1983 hydrographic surveys were made between Ocean (3 profiles) and Pauanui (2 profiles) beaches by the Hydrographic Branch, RNZN (Appendix I). For the 13 year period all 5 profiles show a net drop in elevation of the seabed up to -1.2 m with a mean variation of -0.5 ± 0.2 m, the Pauanui profiles showing -0.4 to -0.7 m change. Either a change in survey datum or degradation of the seabed has resulted in the change. The change in elevation is thought by Martin (Appendix I) to be due to the differences in datums between the 1971 and 1983 surveys, the former having a relatively higher datum. The similarity of the offset profiles (Appendix I) supports this contention.

If we accept this explanation, then a comparison of the depth contours off Pauanui Beach shows no significant variation in depth seaward of the 5 m contour since 1971. Between the 5 m depth contour and the beach, however, significant changes have occurred to the morphology of the ebb-tide delta along the northern half of the beach. In 1971 the delta was a regular shaped barrier running from Paku to mid Pauanui Beach but by 1983 it had contracted some 400 m in length. A "boomerang" shaped outer sand bar (see Figure 4) now extends further seaward than in 1971 with a foreshore channel cutting its way from south into a trough behind the longshore bar.

The data indicate a relatively static nearshore seabed seaward of the 5 m contour over the last 13 years. According to Dr T. W. Hume, however, (pers. comm. 1984) short-term fluctuations in seabed levels from storm events can be of the order of a few decimetres off Pauanui. For example, during a storm in October 1983, Hume observed 150 mm erosion of the seabed off Paku Mountain in 10 m water depth followed by aggradation of 80 mm over the next two weeks.

As one might expect the ebb-tide delta is anything but stable and is likely to change in shape and volume depending on such factors as the frequency of floods and storm-waves. Our studies have shown that sand is supplied to Pauanui Beach via the ebb-tide delta (Gibb 1983c).

DISCUSSION

Our findings suggest that the Pauanui Beach foredune and adjacent seabed have reached a state of dynamic equilibrium. The 2.65 km long foredune is now delicately poised between advance and retreat. Short-term fluctuations of the order of $2200 \text{ m}^3/\text{km}/\text{year}$ have and will continue to occur along the foredune with incursions up to 30 m along most of the beach and up to 70 m at the northern end.

Our findings agree in general with the deductions of Carryer (1980) and Raudkivi (1982) but we disagree in part with the findings and deductions of Healy *et al.* (1981) and Dell and Healy (1982). For Pauanui Beach, Healy *et al.* (1981) and Dell and Healy (1982) recorded erosion for the period 1944 to 1963 and accretion for the period 1963 to 1978 concluding that "in the long-term such beaches are likely to continue slow erosion". Had these authors taken into account the cadastral surveys of 1895 and 1967 their conclusions may well have been exactly the opposite. Their approach highlights the dangers of extrapolating long-term trends from short-term data. The determination of a long-term trend should always be based on a consideration of all available reliable historic and geologic data and any other relevant information.

We recorded accretion for the period 1944 to 1967 and erosion for the period 1967 to 1978 (Tables 3, 4) which is the opposite to the findings of Healy *et al.* (1981) and Dell and Healy (1982). For the periods concerned we used the 1967 cadastral survey and the January 1978 aerial survey rather than the aerial surveys of 1963 and September 1978 used by these authors. Based on an assessment by Photogrammetric Branch of the Department of Lands and Survey of all existing vertical aerial photographs of Pauanui, both the 1963 and September 1978 aerial surveys were considered by them to be unsuitable for the planimetric mapping carried out in this study. Inaccurate plotting of the 1963 dune toe position further landward than its true position by Healy *et al.* (1981) and Dell and Healy (1982) is a possible explanation for the differences in results.

The Future

Should the same conditions prevail in the Tairua-Pauanui area for the next 100 years as they have for the last 100 years then the state of dynamic equilibrium along the Pauanui foreshore should persist. The main factors that could upset the long-term state of balance are either a significant reduction in the amount of sediment supplied to the beach system, or a real or apparent rise in sea-level.

SEDIMENT SUPPLY FACTOR

According to Gibb (1983c) the Tairua River is the major supplier of sand to Pauanui Beach via the ebb-tide delta. A small amount of sand is also supplied from the nearshore seabed and from biogenic sources from within the harbour and along the adjacent coast. In all these source areas, there is presently an abundance of sand, particularly in the 13.5 km long tidal reach of the Tairua River bed between Hikuai and the sea. Each time there is a flood such as occurred in April 1981, the tidal reach sand banks migrate toward Tairua Harbour and most if not all of the flood-tide delta (Figure 8) is washed out to sea (Gibb 1983c).



Figure 8: Photograph taken 14 June 1983 at low tide looking southwest from Paku Mountain showing the flood-tide delta partially blocking the main navigation channel into Tairua Harbour.

Our investigations have revealed that sediment has accumulated at significant rates averaging 4 to 8 mm/year since about 1933 (± 11 years) over much of the Tairua and Pauanui central tidal flats. Accelerated sedimentation rates from local fluvial inputs have occurred near the mouths of Pepe Stream (8 to 12 mm/year) and Grahams Creek (16 to 22 mm/year) and just inside the harbour entrance (22 mm/year) from marine sediments transported into the harbour during flood tides (Hume and Gibb, in prep.). Accumulation of some 488 000 m³ of sand since about 1933 (± 11 years) at 10 000 \pm 2000 m³/year has occurred which is thought to be supplied in roughly equal proportions from the Tairua River, Pepe Stream, Grahams Creek, the ebb-tide delta, and from the natural attrition of shell beds (Gibb 1983c).

Much of the Tairua River contribution has probably resulted from accelerated catchment erosion following the milling of kauri trees and subsequent burning off between 1864 and 1909, and to a lesser extent from the construction of the Kopu-Hikuai Road across the Coromandel Ranges in 1967. Experience has shown that the weathered volcanic rocks of the Tairua River catchment are extremely susceptible to erosion and landslip once the ground is opened up and the hills lose their protective vegetative cover. Regeneration of vegetation since both deforestation and road construction is evident today, hence a reduction in catchment erosion and sedimentation rates is likely in the long-term.

How much Tairua River derived sand is transported out to sea is not known at present. Rates of accretion along Pauanui Beach of 0.08 to 0.36 m/year for the last 88 years show excellent agreement with the geologic rates of 0.06 to 0.39 m/year for the last 5000 years (Tables 2, 3). Therefore, man's impact on the Tairua River catchment has had comparatively little effect in accelerating the long-term supply of sand to Pauanui Beach. The present abundance of sand offshore and in the lower Tairua River bed suggests an ample stockpile of sand is available to supply the beach in the foreseeable future.

SEA-LEVEL FACTOR

A change in sea-level is *real* when the land is known to be stable, and *apparent* when sea-level is known to be fixed while the land is rising or falling. Bruun (1962; 1983) has shown that where the sea floor is in equilibrium with sea-level, a rise in sea-level promotes coastal erosion. Field and laboratory investigations (Schwartz 1965, 1967; Dubois 1975, 1976; Rosen 1978) have confirmed the theory that a rise in water level can cause such erosion.

For New Zealand tectonic downdrop of the coastline during major earthquakes coupled with differential compaction of underlying sediments are the factors most likely to cause an apparent local sea-level rise. However, for the Tairua-Pauanui area geologic evidence indicates tectonic stability for at least the last 125 000 years and certainly for the last 6500 years during which period Pauanui Spit was constructed (Gibb 1983c). A comparison of the bore-hole data (Table 1) with a New Zealand regional sea-level curve derived by Gibb (in press) shows no evidence for compaction of underlying sediments during spit formation either. Therefore, the lack of evidence for both tectonism and differential compaction rules out *apparent* sea-level rise from land lowering as a contributing factor to possible long-term erosion at Pauanui.

There is unequivocal evidence from many tide gauges throughout the world, however, for a *real* net global rise in sea-level during the past century of the order of 1.2 to 1.5 mm/year (Gutenberg 1941; Fairbridge and Krebs 1962; Gornitz *et al.* 1982; Barnett 1983). The most recent study by Barnett (1983) from tide gauge records around most of the world's continental margins and on a few islands, recorded an average rise in global sea-level of 1.51 \pm 0.15 mm/year since 1900.

Since 1903, an automatic tide gauge at Auckland Harbour Board has continuously recorded tidal levels providing a valuable record of long-term trends in MSL. Lee (1953) analysed these records for the period 1909 to 1946 finding no significant change for the 37 year period. Gibb (1979) analysed mean tide levels from Auckland for the period 1903 to 1977 (Figure 9) recording a net sea-level rise of 1.6 mm/year, for the 75 year period, the rate of rise increasing sharply after 1944 to 2.5 mm/year. The differences in results may possibly be explained by the fact that most of the sea-level rise recorded by Gibb (1979) occurred after 1944 which followed the period analysed by Lee (1953).

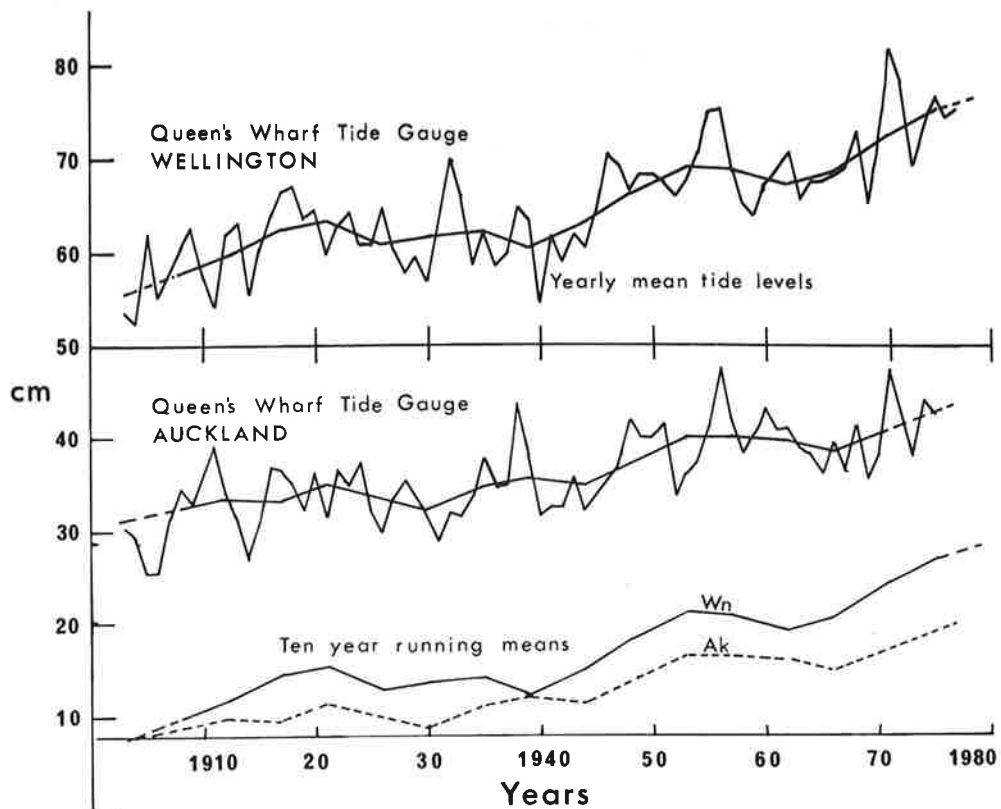


Figure 9: Diagram showing fluctuations in mean tide levels (1903–1977), with respect to the adjacent land, for tidal stations at Auckland and Wellington. Yearly values were smoothed by calculating 10 year running means (from Gibb 1979, Figure 6.7).

Recent tidal harmonic analysis of the Auckland Harbour Board tide gauge records by the Hydrographic Office, RNZN (Lieutenant Commander N. A. F. Young RNZN, Tidal Officer, pers. comm. 1985) supports the contention of an accelerated rise of sea-level in the Auckland region after 1944. Based on monthly MSL levels, MSL averaged 1.854 m above the zero of the automatic tide gauge for the period August 1984 to July 1985 compared to 1.753 m averaged by the Department of Lands and Survey for the period 1909 to 1946 (Mr G Linnell, pers. comm. 1985). That is, for the period 1946 to 1985 MSL has risen 101 mm at 2.59 mm/year.

If we accept a real net rise in global sea level of 1.5 mm/year during the past century then our findings show that the long-term erosion likely to be caused by such a factor at Pauanui has been offset by an adequate supply of sand to the beach from the Tairua River. The resultant effect has been a beach in dynamic equilibrium. Should sea-level rise continue at the historical net rate then we believe that the state of dynamic equilibrium will most likely persist. Should the rate of sea-level rise increase, however, as seems to be occurring at present, then the state of dynamic equilibrium will more than likely reverse to a long-term trend of erosion.

Atmospheric Carbon Dioxide and Sea-Level

It is thought in some quarters that the earth's climate is likely to become warmer because of a build-up of carbon dioxide (CO₂) in the atmosphere that will continue well into the next century. The build-up is likely to produce a "greenhouse effect" that traps re-radiated heat in the atmosphere. Uncertainty characterises many aspects of this global problem and has given rise to considerable speculation that varies all the way from fears of impending disaster to the belief that there is no problem (World Meteorological Organisation 1981).

Recently the White House Office of Science and Technology Policy requested the National Research Council (USA), the research arm of the National Academy of Sciences (NAS), to study both the rate at which atmospheric CO₂ could be expected to increase and the likely effects of such increases on global climate, agricultural productivity, sea-level, and other parameters. A

report entitled *Changing Climate*, compiled by the Carbon Dioxide Assessment Committee (National Academy of Sciences 1983) was released on 21 October 1983 (Ryan 1984).

Although the current level of atmospheric CO₂ concentration is about 340 parts per million by volume (ppmv), the NAS report predicts that atmospheric CO₂ could pass 600 ppmv in the third quarter of next century and that there is about a 1-in-20 chance that doubling could occur before 2035 A.D. (National Academy of Sciences 1983). In another report the dates on which CO₂ content is predicted to double range from 2035 to 2085 A.D. (MacDonald 1982). Both reports agree that a doubling of atmospheric CO₂ would cause a global surface air warming of between 1.5°C and 4.5°C although the Carbon Dioxide Assessment Committee suggest that values in the lower half (1.5° to 3.0°C) are more probable (National Academy of Sciences 1983). Warming is inferred to be 2 to 3 times as great over the polar regions as over the tropics and to be significantly greater over the Arctic than over the Antarctic (National Research Council USA 1982). However, the occurrence of temperature changes attributable directly to increasing atmospheric CO₂ concentration remains as yet undetected (National Academy of Sciences 1983; Hansen *et al.* 1983) although the only statistically significant, calibrated, and verified* proxy record of annual New Zealand temperature shows a (summer) temperature increase since the mid 1940s (Gellatly and Norton 1984, Figure 2).

Because of melting of glacial ice and the expansion of upper ocean waters as they heat up from global warming, sea-level rise is predicted to increase sharply. A rise of 0.3°C in sea surface temperature should increase sea-level by approximately 27 mm due to thermal expansion and a change of only 0.1% in the global land ice cover will produce a sea-level change of over 50 mm (Clark 1982).

The NAS report warns that if global warming of about 3° or 4°C were to occur over the next 100 years, a global sea-level rise of about 700 ± 180 mm is likely to occur between 1980 and 2080, compared to the rise of 150 mm between 1880 and 1980. The predicted 700 mm rise is made up of 400 mm from melting continental and alpine glaciers and 300 mm from thermal expansion of the upper ocean waters (National Academy of Sciences 1983). For the thermal expansion factor Gornitz *et al.* (1982) estimated a rise of 200 to 300 mm during the next 70 years in response to global warming. Further, progressive global warming could eventually result in the disintegration of the marine-based part of the West Antarctic ice sheet, causing a 5 to 7 m rise in global sea-level in the next several hundred years (Clark 1983; National Academy of Sciences 1983). For the occurrence of this event minimum estimates of between 200 and 500 years have been made by Bentley (1983) and Hughes (1983).

According to the NAS report the large uncertainty of ± 180 mm for the predicted 700 mm rise in sea-level is due to uncertainty over the causes of the current rise in sea-level, an inability to predict whether changes in atmospheric circulation will cause more or less snow to fall on the ice caps, an ignorance of the conditions for advance or retreat of alpine glaciers, and a lack of understanding of the physical processes associated with the flux of heat to the ocean (National Academy of Sciences 1983).

Although the reaction to the NRC report has been that it is "conservative" in nature (Ryan 1984), the fact remains that an accelerated rise in sea-level averaging about 7 mm/year would have a major impact on the long-term stability of the unconsolidated sedimentary coastlines of New Zealand including the Pauanui-Tairua area.

COASTAL HAZARD ZONE ASSESSMENT

The potential hazards most likely to damage or destroy beachfront property and assets along Pauanui Beach are:

- (a) Burial of property and assets by wind-blown sand.
- (b) Inundation of property by tsunamis.
- (c) Retreat of foredune from sea erosion.

Wind Erosion-Deposition Hazard

Wind erosion poses a minor threat at present and is easily controlled by maintaining a dense protective vegetative cover over the sand dunes in the foreshore recreation reserve. Should the present foredune be breached, however, by concentrated pedestrian usage or point discharges of stormwater for example, then blow-outs will quickly develop leading to differential retreat of the foredune. Encroachment of wind-blown sand on to properties and assets occurs during onshore gales but this is mostly confined to the recreation reserve (Figure 10), the sand seldom exceeding a decimetre in thickness.

Tsunami Hazard

Tsunamis are waves with an extremely long wave length that originate from submarine disturbances such as faulting, landslides, volcanic eruptions, or possibly from earthquake vibrations. They have a small wave height in the open ocean which increases dramatically on reaching shallow water. A review of historical New Zealand tsunamis by de Lange and Healy (1982) showed that those locally generated are potentially larger than distantly generated tsunamis and therefore, more dangerous to life and property (Ridgway 1984).

According to de Lange and Healy (1982) insufficient detailed data exist to allow the definition of potential tsunami hazard zones for most parts of the New Zealand coast. However, they recognise the following four major volcanic sources within the Bay of Plenty which could generate large local tsunamis, suggesting the use of numerical models for hazard assessment to overcome the lack of historical data:

- (a) White Island, an active andesitic volcano.
- (b) Mayor Island, a dormant rhyolite volcano which last erupted less than 1000 years ago.
- (c) The Okataina Volcanic Centre from which ignimbrites flowed over the land and into the sea about 150 000 to 200 000 years ago.
- (d) The Rumble group of submarine volcanoes seaward from Whakatane of which Rumble III is intermittently active.



Figure 10: Photograph taken 14 June 1983 looking south along the foreshore reserve south of Pauanui Airfield, showing encroachment of wind blown sand onto the reserve deposited during a south-easterly gale in June 1983. The sand was subsequently scraped off the mown grass and deposited back on the beach

Of these, White Island is potentially the most dangerous and Weir and White (1982) have mathematically modelled likely volcanic tsunamis generated by a range of volcanic eruptions. They found the height of widespread tsunami runup about the Bay of Plenty to be insignificant in all cases considered, with breaking wave heights typically less than 1.5 m. Only the most catastrophic Krakatoa-type eruption produced significantly large tsunamis with breaking wave heights of 3 to 6 m. Weir and White (1982), however, believe such catastrophic eruptive events at White Island are unlikely to occur.

Similar predictions were obtained by de Lange and Healy (1982) who produced a numerical model to evaluate tsunamis generated by a pyroclastic flow from Mayor Island, the closest volcanic centre to Pauanui. Their results showed a maximum wave-height of less than 1 m.

Neither Weir and White (1982) nor de Lange and Healy (1982) were able to assess the probability of the *causative* mechanism, a volcanic eruption, occurring. Indeed, this would be very difficult without an intensive study of the volcanic histories of each source area. Nevertheless, their models predict that for all but the most catastrophic event, most tsunami breaking wave heights in the Bay of Plenty are not likely to exceed 1.5 m. It is of interest to note that Harris *et al.* (1983) have calculated an average significant wave height of 1.55 m for the Bay of Plenty for *wind*-generated waves.

Our surveys show that the present-day heights of the foredunes along Pauanui Beach average about 7 m above MSL, ranging from 3.4 to 8.9 m. According to local inhabitants the foredune is not overtopped by 1.5 m high waves, hence it is unlikely that tsunamis of that height will do so. However, it is possible that minor overtopping could occur if a 1.5 m tsunami coincided with a high spring tide and a severe onshore storm but such an event would mostly be confined to the present recreation reserve. It is not possible for us to assess the probability of such a combination of events occurring. Predictions to date, however, suggest that the risk to beachfront properties from tsunami overtopping along Pauanui Beach is likely to be negligible.

Sea Erosion Hazard

Provided the same coastal processes occur at Pauanui over the *next* 100 years as have occurred during the *past* century, the state of dynamic equilibrium punctuated by short-term fluctuations up to 30 m should continue. If, however, the predicted acceleration of global sea-level rise from 1.5 mm/year to 7.0 ± 1.8 mm/year occurs then the past trend of dynamic equilibrium may well reverse to long-term retreat from erosion. Both the Auckland and Wellington automatic tide gauges have registered a marked acceleration in the rise of sea-level since the 1940s (Figure 9) hence, we believe the Carbon Dioxide Assessment Committee's predictions (National Academy of Sciences 1983) must not be ignored. To assess the extent of a CHZ along Pauanui Beach, therefore, we must take into account the rate of erosion predicted to be caused by the accelerated global sea-level rise X , the long-term erosion-accretion rate R , an assessment period T , and the maximum short-term erosion-accretion S . Based on a technique derived by Gibb (1981; 1983a) and taking the above factors into account, the width of a CHZ (in metres) may be calculated as follows:

$$\text{CHZ} = (X + R)T + S \quad (1)$$

For our assessment we first need to test whether the past trend of dynamic equilibrium is going to continue or change to long-term erosion or accretion. If $(X + R)T$ is zero the long-term prediction is dynamic equilibrium; if positive the prediction is accretion, and if negative it is erosion. Should the prediction be either a continuation of dynamic equilibrium or accretion [$(X + R)T$: positive or zero], then a minimum CHZ width of S should be adopted. The reason for this is that the short-term fluctuations S are independent of the long-term trend R and will occur irrespective of whether the shoreline is advancing, retreating or in dynamic equilibrium.

CHZ CALCULATION

As the global sea-level rise of 1.5 mm/year has not caused any appreciable erosion at Pauanui over the last century we must compute the impact of an increase to 7 mm/year, a difference of 5.5 mm/year. Table 5 provides values for X along Pauanui Beach for an acceleration in global

Table 5: Predicted net rates of erosion X at 13 selected MWD beach cross-sections along Pauanui Beach for a sea-level rise of 5.5 mm/year using the Bruun (1983) formula:

$$X = \frac{la}{h}$$

Where; l and h are in metres and a and X are in m/year.

Cross-section No.	5	10	15	20	25	30	35	40	50	60	70	80	85
a	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055
l	690	685	705	680	685	700	700	720	730	820	815	865	950
h	12.5	12.6	12.9	12.7	13.4	13.7	14.7	14.2	14.0	14.3	13.4	13.4	11.7
la	3.795	3.768	3.878	3.74	3.768	3.85	3.85	3.96	4.015	4.51	4.483	4.758	5.225
X	-0.30	-0.30	-0.30	-0.29	-0.28	-0.28	-0.26	-0.28	-0.29	-0.32	-0.33	-0.36	-0.45

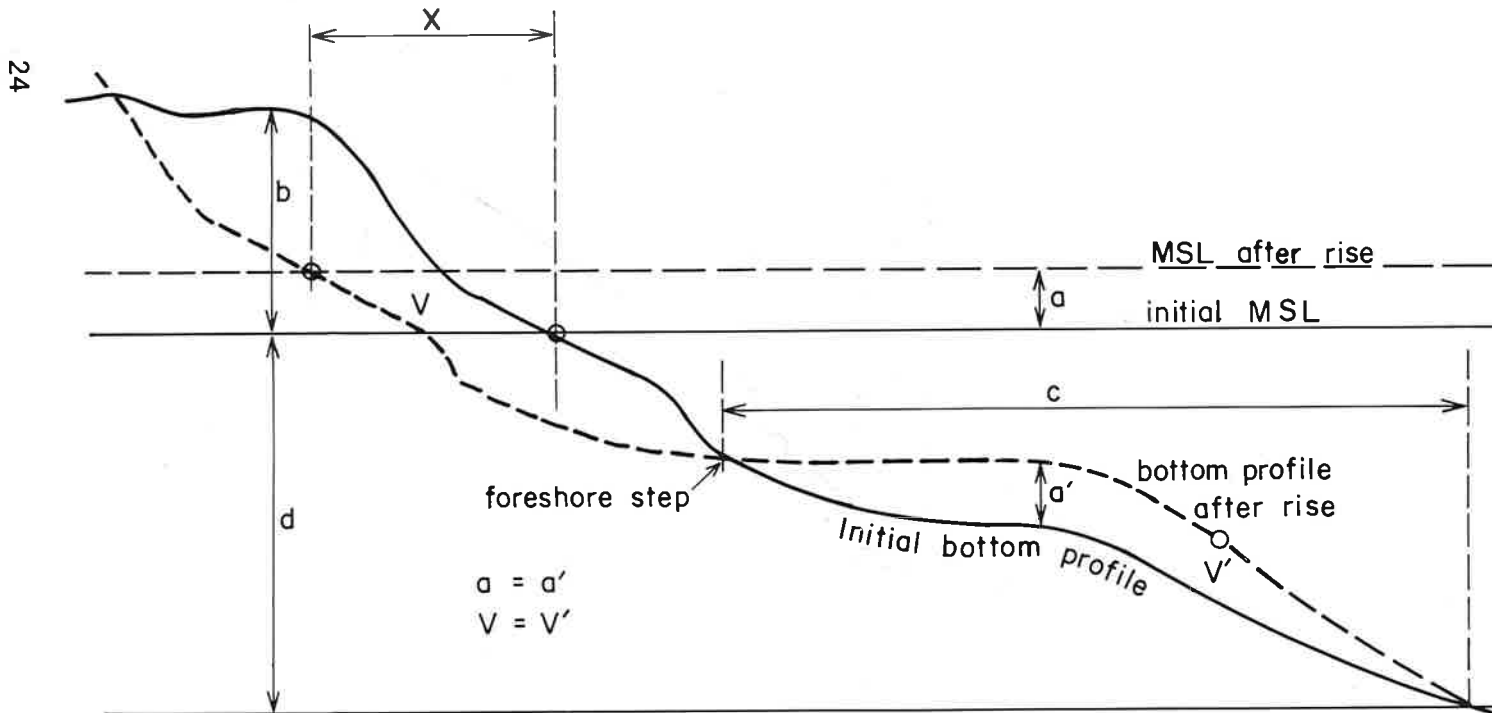


Figure 11: Diagram showing the response of the beach and nearshore zone to rising sea-level according to Bruun (1962) and Hands (1983). V =volume; a =sea-level rise; X =erosion amount; b =height of foredune; d =limiting (closure) depth of beach sediment; c =distance to closure depth from foredune step.

sea-level rise of 5.5 mm/year. To quantify the amount of erosion likely to occur from such an increase we have used the Bruun Rule (Bruun 1962) which states that “for a shore profile in equilibrium, as sea-level rises, beach erosion takes place in order to provide sediments to the nearshore so that the nearshore seabed can be elevated in direct proportion to the rise in sea-level”. The Bruun Rule (Figure 11) relating shoreline erosion to sea-level rise is based on the relationship:

$$X(b + D) = ac \tag{2}$$

where: X = rate of shore retreat (m/year)

b = shore elevation (m) above MSL

d = maximum depth (m) of exchange (closure depth) below MSL between nearshore and offshore sediments

a = rate of sea-level rise (m/year)

c = distance (m) to closure depth from shore

To calculate the rate of coastal erosion X caused by a rise in sea-level Bruun (1983) has developed the following simple equation:

$$X = \frac{la}{h} \tag{3}$$

where: X = rate of shore retreat (m/year)

l = length (m) of the profile of exchange

a = rate of sea-level rise (m/year)

h = maximum depth (m) of exchange of material between the nearshore and offshore.

The Bruun Rule is two-dimensional, assuming a closed material balance system between firstly the beach and nearshore, and secondly the offshore bottom profile as illustrated in Figure 12. That is, for a given length of shoreline the rule assumes that the volume of longshore drift moving in is equal to the volume moving out. At Pauanui, however, there is a longshore disequilibrium caused by most if not all sediment being supplied to the north end of the beach via the Tairua River. The longshore disequilibrium, which has resulted in differential rates of coastal erosion—accretion along the beach (see Table 3), is the third-dimension not allowed for in equations (2) and (3). All three dimensions are taken into account however, in equation (1) for the assessment of the extent of a CHZ, with R taking account of the third-dimension.

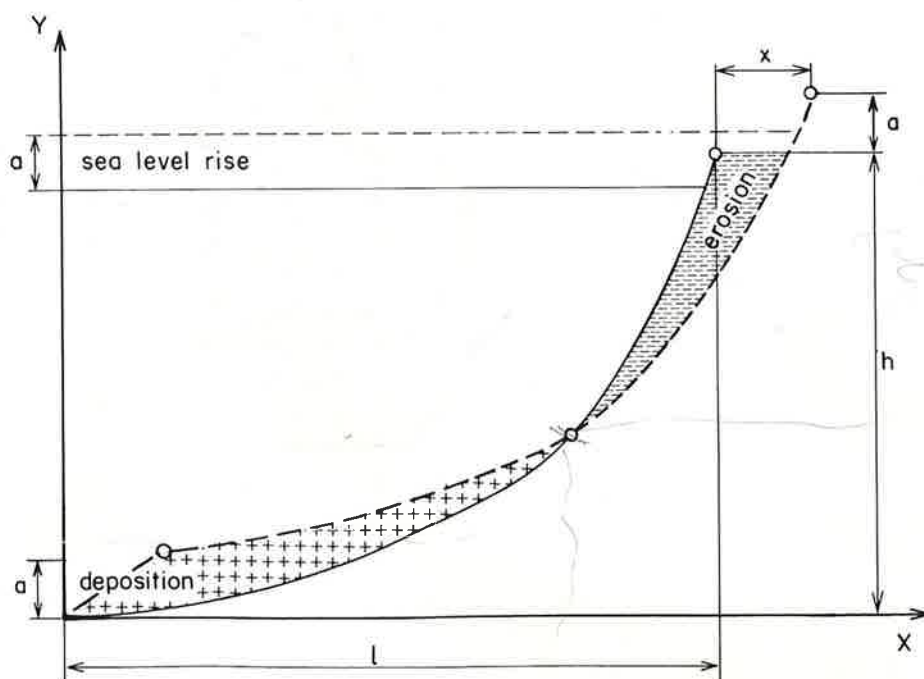


Figure 12: Diagram showing the Bruun's effect—translation of the beach profile, resulting in shore erosion and deposition of sediments (adapted from Bruun 1983, figure 1; and Hands 1983, Figure 10). a =sea-level rise; h =limiting depth of beach sediment; l =distance to limiting depth; X =erosion amount.

Based on equation (3), Table 5 gives values for X where the distance l was measured from the crest of the foredune to the limiting depth h . Horizontal distances range from 0.69 to 0.95 km generally increasing in width northwards. The limiting depth h is the crest height of the foredune above MSL plus 7 m, the maximum depth of exchange below MSL based on observations made at Pauanui during the study following a prolonged period of beach accretion. Although SCUBA diver observations supported by sedimentologic evidence (Gibb 1983c) indicated the 6 m depth contour to be the limiting depth, the bathymetry (Figure 4) shows a subtle change in offshore gradient at about the 7 m depth contour. If our observations had been made after storm-induced beach erosion during which beach sediments would have been transported further offshore then the limiting depth would most likely be nearer 7 m. For the Gold Coast, Chapman and Smith (1983) found from repetitive surveys since 1974, that the "active beach" extended 0.5 km offshore to 6.2 m water depth. Under stormy conditions they found that the active zone extended temporarily into deeper water. Because of likely variation with time, an uncertainty of ± 0.5 m is ascribed here to h , thus giving rise to an uncertainty of ± 200 m for l .

Values in Table 5 show that net rates of coastal erosion from a rise in sea-level of 5.5 mm/year are predicted to range from -0.26 to -0.45 m/year, averaging -0.31 m/year. As one might expect from the Bruun model (Figure 12), higher erosion rates are predicted where the foredune elevation is low and the active beach zone wide (cross-section 85), compared to lower rates where the foredune is high and the active beach zone narrow (cross-section 35).

CHZ ASSESSMENT

Having calculated X in Table 5 we can now test whether the past trend at Pauanui is going to continue into the future or change and assess the width of a CHZ for erosion (Table 6) and upper and lower limits of uncertainty (Table 7). For S a uniform value of 30 m is assumed for cross-sections 5 to 80, and 70 m for cross-section 85 (Table 6). For R we assume that the historical net erosion-accretion rates (Table 3) are principally a function of sediment supply and that this supply will continue at roughly the same rate for the next 100 years. For T , a 100 year assessment period is adopted here to accommodate the *minimum* useful life of new buildings and services and to allow for the occurrence of damaging coastal storms with return periods up to 100 years. Such a storm has a 63% probability of occurring within the 100 year planning period compared with, say, a 50 year event which has an 87% probability (Gibb 1983a).

Values of $(X + R)T$ in Table 6 indicate the onset of a long-term trend of coastal erosion along the 2.65 km long Pauanui Beach over the next 100 years, the amount increasing significantly south of Pauanui Airfield. Irrespective of the differential rates of long-term erosion the entire 2.65 km long foredune will be subject to short-term storm-induced episodic erosion of the order of 30 m but up to 70 m at the north end of Pauanui Beach in the foreshore reserve.

Extreme, High and Moderate Risk Zones

Figure 13 shows the 54 to 116 m wide CHZ which has been subdivided into zones of Extreme, High and Moderate Risk. Each zone comprising the CHZ has been measured inland from the top seaward edge of the present (1983) foredune and is shown in relation to beachfront properties and the foreshore reserve. The Extreme Risk Zone (Line A-B, Figure 13) is confined to the present 2.65 km long foreshore reserve. The High Risk Zone (Line B-C, Figure 13) is confined to the foreshore reserve north of Pauanui Airfield but widens to the south to cover part or all of 26 beachfront properties. The Moderate Risk Zone (Line C-D, Figure 13) covers part or all of 67 beachfront properties along the entire foreshore, widening south of the airfield to include a further 16 second-line beachfront properties. The differential width of the CHZ (Figure 13) indicates that the beachfront properties south of Pauanui Airfield are subject to greater risk from coastal hazards than the properties to the north.

The Extreme Risk Zone is extremely susceptible to the coastal hazards of short-term storm-induced episodic sea erosion, long-term sea-level induced sea erosion, wind-induced erosion and deposition of sand, and tsunami inundation. The zone ranges in width from 30 m between cross-sections 5 to 80, up to 70 m at cross-section 85 (Table 6).

Table 6: Assessment of Coastal Hazard Zone (CHZ) widths for coastal erosion along Pauanui Beach at 13 selected MWD beach cross-sections. Where $(X + R)T$ is positive, CHZ width is S . Where $(X + R)T$ is negative, $CHZ = (X + R)T + S$. Factor R is from Table 3 and a uniform value of 30 m is adopted for Factor S for cross-sections 5–80, and 70 m for cross-section 85. Factor T is 100 years. Recommended CHZ widths are rounded to the nearest 5 m. Positive (+ve) and negative (–ve) CHZ uncertainty values are from Table 7.

Cross-Section No.	5	10	15	20	25	30	35	40	50	60	70	80	85
S	30	30	30	30	30	30	30	30	30	30	30	30	70
X	-0.30	-0.30	-0.30	-0.29	-0.28	-0.28	-0.26	-0.28	-0.29	-0.32	-0.33	-0.36	-0.45
R	+0.02	-0.11	-0.07	-0.03	+0.10	+0.08	+0.21	+0.24	+0.27	+0.26	+0.36	+0.34	+0.32
T	100	100	100	100	100	100	100	100	100	100	100	100	100
$(X + R)T$	-28	-41	-37	-31	-18	-20	-5	-4	-2	-6	+3	-2	-13
CHZ	58	71	67	61	48	50	35	34	32	36	30	32	83
Recommended CHZ Width (in metres)	+25 60	+27 70	+23 70	+29 60	+24 50	+25 50	+23 35	+23 35	+26 30	+26 35	+24 30	+29 30	+31 85
	-21	-18	-23	-16	-20	-18	-5	-5	-0	-5	-0	-0	-15

Table 7: Upper and lower limits of uncertainty for Coastal Hazard Zone (CHZ) widths for predicted erosion along Pauanui Beach at 13 selected MWD cross-sections. For each factor, uncertainties have been added or subtracted from values in Tables 5 and 6 to obtain upper and lower limits respectively. Uncertainties are: sea-level rise $a = \pm 0.0018$ m/year; profile length $l = \pm 200$ m; profile depth $h = \pm 0.5$ m; erosion rate $R = \pm 0.03$ m/year. Factor T in $(X + R)T$, is 100 years, and $CHZ = (X + R)T + S$.

Cross Section No.	5	10	15	20	25	30	35	40	50	60	70	80	85
a_1	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073	0.0073
l_1	890	885	905	880	885	900	900	920	930	1020	1015	1065	1150
h_1	12	12.1	12.4	12.2	12.9	13.2	14.2	13.7	13.5	13.8	12.9	12.9	11.2
X_1	-0.54	-0.53	-0.53	-0.53	-0.50	-0.50	-0.46	-0.49	-0.50	-0.54	-0.57	-0.60	-0.75
R_1	-0.01	-0.14	-0.10	-0.06	+0.06	+0.05	+0.18	+0.21	+0.24	+0.23	+0.33	+0.31	+0.29
$(X_1 + R_1)T$	-55	-67	-63	-59	-44	-45	-28	-28	-26	-31	-24	-29	-46
S	30	30	30	30	30	30	30	30	30	30	30	30	70
CHZ_1	85	97	93	89	74	75	58	58	56	61	54	59	116
a_2	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037	0.0037
l_2	490	485	480	485	485	500	500	520	530	620	615	615	750
h_2	13	13.1	13.4	13.2	13.9	14.2	15.2	14.7	14.5	14.8	13.9	13.9	12.2
X_2	-0.14	-0.14	-0.13	-0.14	-0.13	-0.13	-0.12	-0.13	-0.14	-0.16	-0.16	-0.16	-0.23
R_2	+0.05	-0.08	-0.04	0.0	+0.13	+0.11	+0.24	+0.27	+0.30	+0.29	+0.39	+0.37	+0.35
$(X_2 + R_2)T$	-9	-22	-17	-14	0	-2	+2	+14	+16	+13	+23	+21	+12
S	30	30	30	30	30	30	30	30	30	30	30	30	70
CHZ_2	39	52	47	44	30	32	30	30	30	30	30	30	70

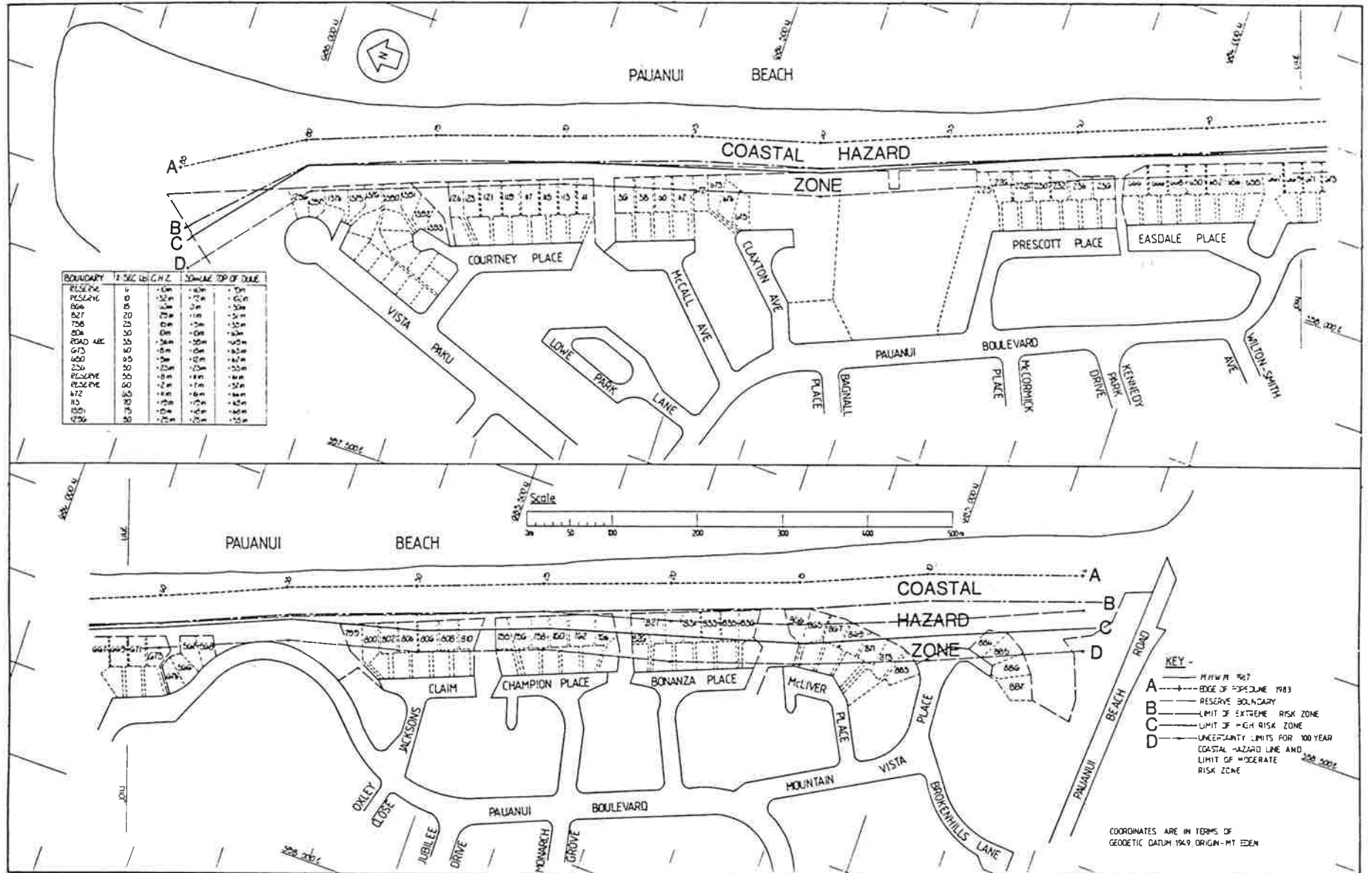


Figure 13: Reduced MWD Plan 2/973/1/2204 Sheet 9 showing the Pauanui Beach CHZ in relation to the top seaward edge of foredune (1983), property and reserve boundaries. The CHZ comprises Extreme (Line A-B), High (Line B-C) and Moderate (Line C-D) Risk Zones. Beyond Line D risk from coastal hazard is considered low to very low.

The High Risk Zone is highly susceptible to both long-term sea-level induced sea erosion from a predicted 520 to 700 mm rise in sea level and to minor wind-induced deposition of sand. The zone ranges in width from 20 to 40 m south of Pauanui Airfield to 0 to 15 m to the north (Table 6).

The Moderate Risk Zone is moderately susceptible to long-term sea-level induced sea erosion from a predicted 700 to 880 mm rise in sea level. The zone ranges in width from 23 to 31 m along the entire 2.65 km long foreshore (Table 6). Landward of the Moderate Risk Zone the risk from coastal hazards to property and assets, within the period of their useful life, is considered low to very low.

It is important to realise that the coastal erosion predicted here from an accelerated sea-level rise of 5.5 mm/year is based on the latest research into the long-term impacts of increasing atmospheric CO₂ on global sea-level. Should the rise in global sea-level exceed the 700 mm predicted by the NAS report for the next 100 years, then coastal erosion will accelerate proportionately. Equally, if the predicted rise is less than 700 mm then the extent and rate of coastal erosion will also be proportionately less at Pauanui.

Published reports to date, however, consistently predict a rise in global surface temperatures of $3^{\circ} \pm 1.5^{\circ}\text{C}$ over the next 100 years which will certainly accelerate the present rise of global sea-level. The predictions may well be realised as both the rate of sea-level rise and the mean summer temperature for New Zealand have increased sharply since the mid 1940s.

If the West Antarctic ice sheet disintegrates as a result of the global warming then a 5 to 7 m rise in sea-level will occur which will devastate low lying coastlines, harbours and estuaries around New Zealand. For example, using values for l and h in Table 5, a 5 m rise in sea-level (0.05 m/year) would cause net erosion rates along Pauanui Beach of -2.38 to -4.05 m/year, generally averaging -2.8 m/year. For a 7 m rise (0.07 m/year) net rates would increase to -3.33 to -5.68 m/year, averaging -3.9 m/year. Such rates could erode more than 50% of Pauanui Ocean Beach Resort during the next 100 years. However, minimum estimates of between 200 and 500 years have been made for such an event.

Should all or part of the 2.65 km long Pauanui foredune retreat from the predicted, long-term sea-level induced erosion then the 54 to 116 m wide 100 year CHZ should be adjusted landward. Such an adjustment would result in those properties presently in the zones of High and Moderate Risk being included in the Extreme and High Risk Zones, respectively. Because the problem is potentially serious and of national importance, we strongly recommend further research including both the monitoring of Pauanui Beach and sea-level trends in the eastern Bay of Plenty.

CONCLUSIONS

1. Over the last 5000 years Pauanui Beach has advanced from accretion at 0.15 m/year, the rate decreasing progressively with time from 0.4 m/year (5000 to 4000 years B.P.) to 0.12 m/year (4000 to 2000 years B.P.) to 0.06 m/year for the last 2000 years B.P. indicating a shoreline steadily approaching a state of long-term dynamic equilibrium.
2. Since 1895 there has been a northward trend from very slow net erosion at -0.03 to -0.11 m/year along the southern 0.64 km of the 2.65 km long foredune, to very slow net accretion at 0.08 to 0.36 m/year along the northern 2.01 km. The historical trend has been punctuated by short-term fluctuations up to 30 m in the position of the dune toe with volumetric gains and losses of dune sand up to about ± 2200 m³/km/year.
3. Provided long-term factors affecting Pauanui Beach, such as sediment supply from the Tairua River and global sea-level rise remain the same over the *next* 100 years as they have for the *past* 100 years then the state of dynamic equilibrium, punctuated by short-term movements up to 30 m, should persist.

4. The predicted increase in the rate of global sea-level rise from 1.5 mm/year to 7.0 ± 1.8 mm/year would result in a change from a state of dynamic equilibrium to one of long-term erosion along the entire 2.65 km long Pauanui Beach with erosion increasing in both rate and extent southwards. The prediction should be taken seriously as sea-level rise at Auckland has accelerated to 2.59 mm/year since 1946.
5. A 54 to 116 m wide Coastal Hazard Zone (CHZ) is assessed for Pauanui Beach comprising three zones of risk. The Extreme and High Risk Zones are subject to the coastal hazards of long and short-term sea erosion, wind erosion and deposition of sand, and tsunami inundation. The Moderate Risk Zone is subject to sea-erosion resulting from a 700 to 880 mm predicted rise in global sea-level.

RECOMMENDATIONS

The following recommendations made to the Thames-Coromandel District Council (TCDC) are that:

1. TCDC adopt this paper.
2. The Pauanui Beach Coastal Hazard Zone should be incorporated into the TCDC District Planning Scheme to alert the public to the presence and extent of identified hazards. **Note:** Only Line D (Figure 13) would need to be shown on the appropriate planning map of Pauanui. Both the provisions of the Second Schedule, clause 8a of the Town and Country Planning Act 1977 and the July 1981 policy on Natural Hazards of the National Water and Soil Conservation Authority would be satisfied by this action.
3. In the long-term public interest TCDC develop a policy to effectively apply the requirements of sections 274, 641 and 641A of the Local Government Act 1974 for the control of further subdivision; residential, commercial and industrial development; and additions and alterations to existing development, of property and assets lying within the CHZ.
4. The new policy developed by TCDC ensure for the continued preservation of the essential elements of the natural beach system such as the protective vegetation, dunes and beach profile along Pauanui Ocean Beach. Under no account would individual property owners be permitted to construct private protection works that adversely affect the natural beach system.
5. The Hauraki Catchment Board and Thames-Coromandel District Council continue to monitor Pauanui Beach and use the techniques developed here to reassess the Pauanui Beach CHZ every 5 to 10 years.
6. Should sea erosion directly threaten beachfront property and assets then the assets will either need to be relocated inland or a coastal engineering solution found. An engineering solution such as a seawall could destroy Pauanui Beach, a priceless national asset. Beach replenishment from Tairua Harbour sand, however, could maintain beach volumes whilst protecting property and should seriously be considered as a possible long-term solution, particularly along southern Pauanui Beach.

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APPENDIX I

28 July 1983

The Hydrographer RNZN,
Hydrographic Office,
P.O. Box 33-341,
TAKAPUNA

Report of Survey—HI 122—Pauanui Coastal Hazard Survey 1:6000

Introduction

1. The Pauanui Coastal Hazard Survey was undertaken by a detached party over the period 9 May to 3 June 1983. A five strong party, under the charge of Lieutenant I. F. P. Martin, Royal New Zealand Navy, were supported and enhanced by personnel from Her Majesty's Ship *Tarapunga*, *Philomel* and *Tamaki* as well as two draughtswomen from the Hydrographic Office. The party were accommodated in rented quarters at Tairua and for sounding purposes used the sounding motor boat *Pandora*; transported by road from Auckland on a specialised boat trailer.

The precise hydrographic survey was part of a joint venture involving the National Water and Soil Conservation Organisation, the Ministry of Works and Development (Hamilton Survey Office) and the Hauraki Catchment Board. The objectives of this detailed survey being to primarily provide an extremely accurate bathymetric data base of the area loosely bounded by the 20 m contour to seaward, Ocean and Pauanui Beaches and the harbour basin. Secondly to ascertain the total sediment distribution within the same area and indicate the direction and quantity of sediment transportation. Finally to provide an accurate coastline and inter-tidal zone delineation, using the one vertical datum.

Weather

2. Fine drizzle and numerous showers proved to be the major limiting factor since the resulting poor EDM signal return, reduced the workable range by half. A total of five days were lost due to adverse weather conditions; all of these whilst working outside the harbour entrance. The predominant winds throughout the survey were westerlies, however a localised morning effect tended to produce a north-easterly breeze. The required accuracy of the survey meant that otherwise normal sea conditions were on the fringe of being unworkable.

Control

3. The survey is referred to the New Zealand Geodetic Datum (1949) and is plotted on the North Island National Grid, scale 1:6000. The greater majority of control work was observed by the Ministry of Works and Development using Mount Eden Meridional Circuit Grid with NING coordinates derived from these values using the Ministry of Works and Development Grid Conversion Program. An adjustment of +26' 32" was required when working from NING bearings to Mount Eden bearings. This was accepted as being the difference of true north at the initial station of each circuit and since all observations were based on Mount Eden no further investigation was undertaken.

The hydrographic survey control was designed around the use of the AGA Geodimeter 140, a total station instrument (see Appendix 1), using its associated electronic fieldbook to store the large volume of data. To this end shore control was rigorous and work intensive.

Existing cadastral control was linked by traverse along both beaches. A baseline established the length of the beach and the traverse was utilised to subdivide the base into the required 30 m bays. The orientation of the sounding lines was then set at right angles to the base from each bay. The same orientation was extended along Ocean Beach. Considerable time and effort was required to recover, mark, observe, compute and set out the ground control.

Without this accurate service being provided by the Ministry of Works and Development the hydrographic survey would not have achieved its aim within the time-frame.

Sounding was controlled from ashore using theodolite transits plumbed over the established traverse bay pegs. The initial concept for control was to deploy the total station on the rear transit and the theodolite on the front transit. By use of portable radios the sounding boat was coned along the theodolite bearing while the geodimeter would fix the vessel's position every 30 seconds. However, failure of the electronic fieldbook necessitated a compromise, since instantaneous recording of horizontal angle, vertical angle and distance were not possible. The working solution was still controlled transits, however the geodimeter tracking facility was only used. This meant that the theodolite now occupied the rear transit and the geodimeter was offset to one side (see Figure 3 in main text). Large visual marks were also used to enhance the transit for use by the boat's coxswain.

Lines of sounding were only run inshore since greater control of the boat was obtained especially inside the 5 m contour line. Although considerable time was spent moving the instrument station, no problems were encountered setting either instrument up on the sand base.

The absence of the full capability of the geodimeter meant that the prescribed positional accuracy of ± 0.5 m was abandoned and the fall-back accuracy of ± 1.5 m achieved. Sounding lines were aborted whenever the boat diverged from the observed transit by a boat width; this being ± 2 m.

For the secondary tasks, namely current metering and sediment stations, the prescribed accuracy of ± 3 m was obtained using either horizontal sextant resections from selected shore marks or theodolite/geodimeter intersections and/or trilateration.

The control required to provide an adequate gradient overlap between sounding boat and shore profile work was available, however the attainment of consistent overlap was not met. This was due to unfavourable sea conditions inshore (particularly at Ocean Beach) which prevented the sounding boat from entering into the shallows. At the same time the shore profile teams, despite wet suits, were at the mercy of the dumping waves as they stood with their backs to the sea, clutching the extended tachstaff. In order to obtain a regular coverage of the shore/sea profile every fifth line was chosen for particular attention. While shore teams observed these lines at low water the sounding boat would be used at the opposing high water. Despite this procedure the unfavourable inshore sea conditions prevented a consistent overlap. The results obtained at Pauanui were 80% successful while no results were obtained at Ocean Beach between the 1 m and 3 m contour, on Moturiki Datum.

The sounding motor boat spent six working hours stranded high and dry after being caught at the end of one line, inside the breaking surf (see Figure 3 in main text).

Distance Measurements

4. The AGA Geodimeter 140 Total Station was used for all distance measurements to sea. The infrared GaAs Diode light source was effectively used to a vertical cluster of eight prisms (positioned over the echo sounder transducer) and out to a working limit of 2500 m in stable weather conditions. The fast tracking mode, enabling a 0.4 second update and the audio tone emitter which indicated an aligned target, proved extremely reliable and beneficial.

A scale factor of 1.000014337 for the chosen mean true easting of 337313.13 yards was programmed for use in the computer/plotter option, however the failure of the electronic fieldbook, negated this. The manual correction was not applied to the booked ranges prior to hand plotting since at 2500 m an error of only 0.04 m resulted.

Tides

5. A 3 m tide pole and an automatic tide gauge were erected at Tairua Jetty. The automatic tide gauge was a Foxboro Water Pressure Recorder working on the 0 m to 7 m range.

The existing Hauraki Catchment Board's Foxboro gauge situated on the Tairua Wharf was used to conduct a transfer of sounding datum from both Auckland and Tauranga, using direct comparison of 16 days low water heights (see NP 122(2) paragraph 8). This datum was in turn transferred to the new gauge and tide pole following a 13 hour pole/gauge correlation. Sounding datum was established at 0 m on the jetty pole, with the gauge's "floppy bag" sensor 0.3 m below this datum. Automatic tide gauge readings were obtained for reduction of soundings daily. The subsequent tidal analysis was based on 37 days data covering the period 15 May to 23 June 1983. The resultant chart datum (from the Hydrographic Tidal Analysis Program) being -0.06 m off the jetty pole, with mean sea-level at 1.109 m on the pole (Moturiki values being -0.76 m and $+0.409$ m respectively).

Chart datum is 3.336 m below an RNZN brass benchmark set in concrete on the northern side of the seawall on Paku Jetty and 4.319 m below a similar benchmark set in concrete on the south-east corner of the concrete toilet block, 125 m north of the Paku Jetty.

No direct comparison of the 1971 tidal data was possible since the Slipper Island benchmarks had been destroyed prior to this survey and no data exists for comparison between the Tairua and Slipper Island gauges.

A direct comparison of 31 days low water established chart datum on the Tairua Wharf at 0.12 m on the pole (Moturiki -0.61 m).

Current Meters

6. A total of 10 current meter stations were deployed during the survey using two each of the following current meters: Aanderaa, InterOcean 135 and Ono meters. The Aanderaa and Inter Ocean meters were deployed at a fixed location over the period and formed a base framework to obtain the maximum coverage of current within the survey limits. The InterOcean 135 meters functioned for 22 days at 10 m water depth and on recovery, significant marine slime was found on the metal body.

The Ono meters were deployed on a three day cycle around the harbour mouth and Pauanui Beach in order to cover the tidal cycles and weather generated flows. The Onos like all the meters were rigged to read the current 1 m above the sea floor. The subsequent analysis of the InterOcean meters showed no tidal cycle, instead two dominant flows; north (360) and east-south-east (110) at irregular intervals. A mean flow rate of 7.2 cm/sec (0.14 kt) in the north and 10.4 cm/sec (0.20 kt) in the south were recorded. Such flow rates would not sustain mass sediment transportation.

Echo Sounder

7. A portable Atlas Deso 10 echo sounder was used throughout the survey and was motor speed checked when fitted to the boat, thereafter calibrated daily by bar check. Lead line checks were also conducted daily for depth confirmation. Good, consistent results were obtained throughout the survey. The required accuracy in vertical measurement of ± 0.1 m was not achieved over the complete survey area, however the fall-back accuracy of 0.2 m was met using the present practise of swell compensation during reading-off.

The 10° cone coverage of the Atlas Deso 10 high frequency transducer (210 KHz) provided a seabed radius of 1.8 m at 20 m depth.

Sonar

8. EG&G Side Scan Sonar type 272 mark 1B was deployed in an attempt to obtain seabed texture and sediment zones. Very limited success was achieved due to equipment defects, particularly broken circuits inside the 50 m portable cable, believed to be caused by incorrect handling prior to the survey. Despite successful continuity checks in Auckland before the deployment, anomalies became evident once the cable was under tension in the field. These anomalies were responsible for the loss of three very valuable days. However, a successful sonar passage through the area using the Inshore Survey Craft was completed several months later.

Sounding

9. The primary hydrographic objective of the survey, that of providing an extremely accurate data base, was achieved in all areas completed. One hundred and fifteen miles of sounding lines were run at 60 m intervals, double line spacing, in order to obtain complete coverage of the area within the available timeframe. A boat speed of 4 kt provided an advance of 2.06 m/sec. Every thirty-second fix recorded an advance of 61.67 m and equated to 10.28 mm when plotted to scale. The 0.5 cm ordered coverage on the survey scale was only completed along the length of the critical entrance bar. Starring was used to extend the basic bathymetric information around Paku Hill, while two wedges at the north and south extremities of the survey area were omitted altogether.

Direct comparison of the seabed topography with the 1971 survey was not possible due to different datum sites, viz Tairua for 1983 and Slipper Island for 1971. However, a series of profile depth comparisons were graphed and appear as Appendix 3, numbers 1 to 5. These profiles were run from Ocean Beach control pegs RM II, RM I, and IT II, and Pauanui Beach pegs IT II and OBS XXV. A mean variation of +0.5 m (\pm 0.1 m) is evident on all graphed profiles and indicates a difference in datum between the 1971 and 1983 surveys. With this difference of datum applied comparison of contours show no marked variation in depth from the previous survey except for that area forming the flood delta. For all areas seaward of the 10 m contour no measurable change has occurred. This also applies to Pauanui Beach between the 5 and 10 m contours while Ocean Beach shows a 0.5 m seabed erosion, about the 9 and 10 m contour, at the northern end of the beach.

The significant change within the survey area occurs around the northern half of Pauanui Beach, between pegs OIT VI, IT 1a and the 5 m contour. The flood-tide delta charted in 1971 as a regular barrier running from Paku to mid-Pauanui Beach has contracted some 400 m in length. A "boomerang" shaped bar now extends further seaward than in 1971 with a foreshore channel cutting its way from the south into a small lagoon behind the bar.

The massive quantity of sand forming the bar is subjected to continual wave action, hence the shape, orientation and size are only as charted during the month of May. Bar conditions prevented any conclusive check lines being run at the end of the survey period. The conclusion drawn from the area bathymetry is neither in terms of net erosion nor accretion. The seabed appears stable and any variation in foreshore (toe of dune to high water springs) being the result of seasonal weather conditions, causing the supply and resupply of sediment between the foreshore and the nearshore depths.

Bottom Samples and Photography

10. The Operational Diving Team under the direction of Warrant Officer P. Kneebone conducted extensive underwater photography of the seabed features. At each dive station a 10 m orbital search, based on the drop line, was carried out and the following features recorded:
 - (a) Sediment Definition
A bagged sample collected and annotated with dive station number, date and depth.
 - (b) Sand Wave Amplitude
A base board overlaid with a 2 cm grid was worked into the seabed enabling a scale of length and amplitude of the seabed feature to be recorded on film and measured.

(c) Sand Wave Orientation

An indicator arrow was aligned to magnetic north, $\pm 5^\circ$, by hand compass and recorded on film and measured. Four exposures at each station consumed the ODT's yearly allowance of imported flash lamps.

Transition zones and sand boundaries were also delineated by profile swimming into the beach. The professional conduct of the ODT on task was a credit to themselves and the RNZN.

All retained seabed samples are held by Dr J. Gibb of NWASCO.

Leading Beacons

11. A set of leading beacons, situated on the northern end of Pauanui Beach, provides safe directional passage over the seaward bar on a bearing of 225° true. The beacons are inverted triangles and are not illuminated. No navigational lights exist within the survey area although lamp posts are located on or near both the Tairua Wharf and jetty. Passage into the harbour is best at high water and even then should be carried out with caution due to the extensive ebb-tide delta inside the harbour basin.

Coastline

12. Both Pauanui and Ocean Beach were walked and fixed in the field. All remaining areas were accepted from aerial photographs and checked on site. No discrepancies were found.

The beach foreshore was profiled every 30 m and the required accuracies met in full. Consideration should be given to amending accuracies seaward of the toe of the dune in future surveys as the beach gradient was observed to vary daily by decimetres.

General

13. The survey, although not meeting the 100% bathymetric coverage, was overall very successful and a credit to the contributing departments, namely the National Water and Soil Conservation Organisation (Dr J. Gibb), the Ministry of Works and Development (Mr J. Aburn), and the Hauraki Catchment Board (Mr P. Dell). The interaction of equipment, transport, personnel and expertise, between all concerned, enabled the detailed data from both ashore and at sea to be obtained, despite the many problems encountered.

If the Royal New Zealand Navy and in particular the Hydrographic Specialisation is to extend its professional operations into the field of joint venture projects, and is to be seen as a viable unit, then funding for reliable vehicles, equipment modernisation (seabed mapping systems), alternative sounding platforms and shore logistics must be urgently investigated.

(I. F. P. Martin)
Lieutenant RNZN
OIC Detached Survey

- Appendices: 1. AGA Geodimeter 140 Total Station.
2. Geodetic Data.
3. Profile Depth Graphs (Numbers 1 to 5).

Appendix 1 to HI 122 Report of Survey Dated 28 July 1983

AGA Geodimeter 140 Total Station

The Geodimeter 140 Total Station is a distance and angle measuring instrument designed to reduce the repetitive functions in the field and by doing so increase productivity. This is achieved by a new angle technique and powerful microprocessor.

Angle Measurement

This second generation total station compensates for all the errors and inaccuracies of conventional optical and electro-optical theodolites and tachymeters with a unique, totally electronic angle measuring system.

As distinct from conventional optical systems, Geodimeter 140 uses a signal integrated over a surface and the angle information is collected as a mean value of the total circle. Any disc imperfection is then compensated without changing the circle setting and full angle accuracy is obtained in a single face measurement. This advanced capability is achieved by the use of a powerful microprocessor which monitors the flow of information from the surface averaging circles and dual axis plumb line sensor.

Distance Measurement

The distance measuring part of the Geodimeter 140 is based on the well proven electronic system providing an excellent range, broad beam for easy target location, automatic horizontal distance and fast tracking measurement; the latter being the primary reason for its selection for the survey.

Data Recording

The Geodimeter 140 comes complete with data outlet for connection to the Geodat automatic field data recorder otherwise referred to as the electronic fieldbook. Horizontal angle, vertical angle and distance are automatically recorded at the touch of a button. Full coding information can be entered manually when required and standardised field procedures established. A prompt facility assists correct format, which minimises booking mistakes. Geodat has a memory capacity of 32 K, sufficient for 500 to 1000 points of detail depending on the amount of coding required.

For Pauanui the simplified coding was utilised on Program 2 and the following data retained:

1. Line number.
2. Fix number.
3. Horizontal angle.
4. Vertical angle.
5. Slope distance.

At the completion of a day's work the Geodat can be interfaced directly into a desk-top calculator, micro or mini-computer. For Pauanui a micro-computer was used and initially designed to operate a small plotter. However, problems with equipment compatability prevented a total package being available. To further complicate matters the Geodat developed a fault on the keyboard which prevented the automatic recording of data, and the system deployed in the field was limited to hand recorded data from the fast tracking measurement facility.

Despite the plotter and acquisition problems the Geodimeter 140 proved to be a compact, robust and comfortable instrument to operate (see separate sheet for Technical Specification details).

Geodimeter® 140

Technical data



TECHNICAL SPECIFICATION

Range 1 prism 2500 m (1,5 miles)
3 prisms 3600 m (2,2 miles)
8 prisms 5500 m (3,4 miles)

Ambiguity Short range 1 km
Long range 10 km

Distance accuracy $\pm (5 \text{ mm} + 5 \text{ ppm})$ M.S.E. (0.02 ft + 5 ppm)
 $\bar{D} \pm (5 \text{ mm} + 3 \text{ ppm})$ M.S.E. (0.02 ft + 3 ppm)
Super Tracking $\pm (20 \text{ mm} + 5 \text{ ppm})$
M.S.E. (0.07 ft + 5 ppm)

Resolution \triangleright 1 mm (0.01 ft)
 \triangleright 10 mm (0.1 ft)

Measuring time Short range 5 s
Long range 10 s
Super Tracking 0.4 s

Tracking speed Max. 4 m/s

Light source Infrared Ga As diode

Beam divergence 2,5 mrad (250 mm/100 m)
(2,5 ft/1000 ft)

Angle accuracy $\pm 0.6 \text{ mgon}$ ($\pm 2''$) M.S.E.

Angle resolution 0,5 mgon ($2''$)

Transit angel + 44 gon (+40°)
- 55 gon (-50°)

Operating temperature range -20° C to +50° C
(-4° F to +122° F)

Atmospheric correction $\pm 50 \text{ ppm}$ continuously
(or 0-100 ppm switchable)

Telescope Magnification 30X
Focussing 1.3 m to ∞
Objective aperture 40 mm
Objective length 170 mm
Field of view at 100 m 2.6 m
(100 ft 2.6 ft)
Illuminated cross hairs

Levelling Circular level on tribrach 180 mgon/2 mm
(10'/2 mm)
Plate level on alidade 6 mgon/2 mm
(20"/2 mm)
Automatic level compensation $\pm 100 \text{ mgon}$

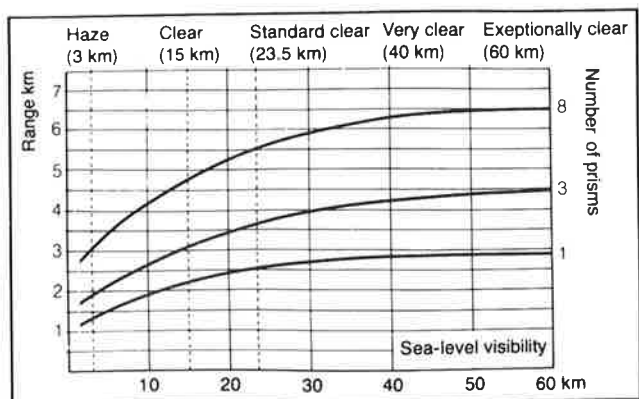
Centering Optical plumb on tribrach

Power consumption Approx. 12 W

Battery 12 V, 2 Ah NiCd
Operating cycle 2.0 hours at 20° C

Dimensions
Instrument 230 mm \times 280 mm \times 350
Carrying case 350 mm \times 290 mm \times 450 mm

Weight Instrument only approx. 7.5 kg (16.5 lb)
Total with accessories 14.5 kg (32 lb)
(including carrying case)



Maximum range with AGA prisms (Part. No. 571 125 021).
The range is also dependent on atmospheric conditions and background radiation.

Geodat 122

Technical Data



AGA Geodat 122 is a portable data memory for field data collecting and recording. It is intended for use with the various Geodimeter instruments, for automatic and/or manual input. The unit is programmed for recording measured data, station number, instrument and signal height, point type and number, and additional coded information.

STANDARD EQUIPMENT

Part No.	Description	Weight kg	Lbs
571125620	Geodat 122 The equipment consists of:		
571125600	Registration unit	0.6	1.3
* 571125644	Battery charger 220V	0.2	0.4
or 571125646	Battery charger 115V	(0,2)	(0,4)
571125625	Operating Manual	0.1	0.2
	* (to be specified when ordering)	1.1	2.3

SPECIFICATIONS

- Memory:** CMOS-memory, 32K characters.
Display: 16 characters LCD display.
Data storage: 2000 hours on memory back-up battery.
Operation: 80–100 hours on internal battery.
Instrument connections: • Direct data transfer from the following Geodimeter instruments:

Geodimeter	Horizontal angle	Vertical angle	Slope distance
112			X
120, 122		X	X
140 (710)	X	X	X

(For Geodimeter 710 an optional interface is available.)

- Output:**
- RS-232C (V24) interface with optional cable, transfer rate 300 or 1200 baud.
 - ASCII character specification: one start bit, two stop bits, even parity.
 - Connection to optional external data memory and tape recorder.
- Power:** Rechargeable NiCd battery. Separate memory back-up battery.
- Temperature:** –20°C to +50°C
Dimensions: 88 mm × 172 mm × 39 mm
Weight: 0.6 kg

- Manual input of additional data. Also manual input from other instruments than those mentioned above.
- Data can be transmitted from Geodat 122 to Geodimeter 140. (Two-way communication.)
- Ten different input sequences can be designed by the user for special applications.

**Appendix 2 to
HI 122 Report of Survey
Dated 28 July 1983**

Geodetic Data

Field observations were accurately undertaken by the Ministry of Works and Development (Hamilton Survey Office) on the Mount Eden Meridional Circuit Grid. North Island National Grid coordinates were derived from these values using the MWD Grid Conversion Program. A list of traverse control pegs and major geodetic control stations follow in both NING (yards) and Mount Eden (metres).

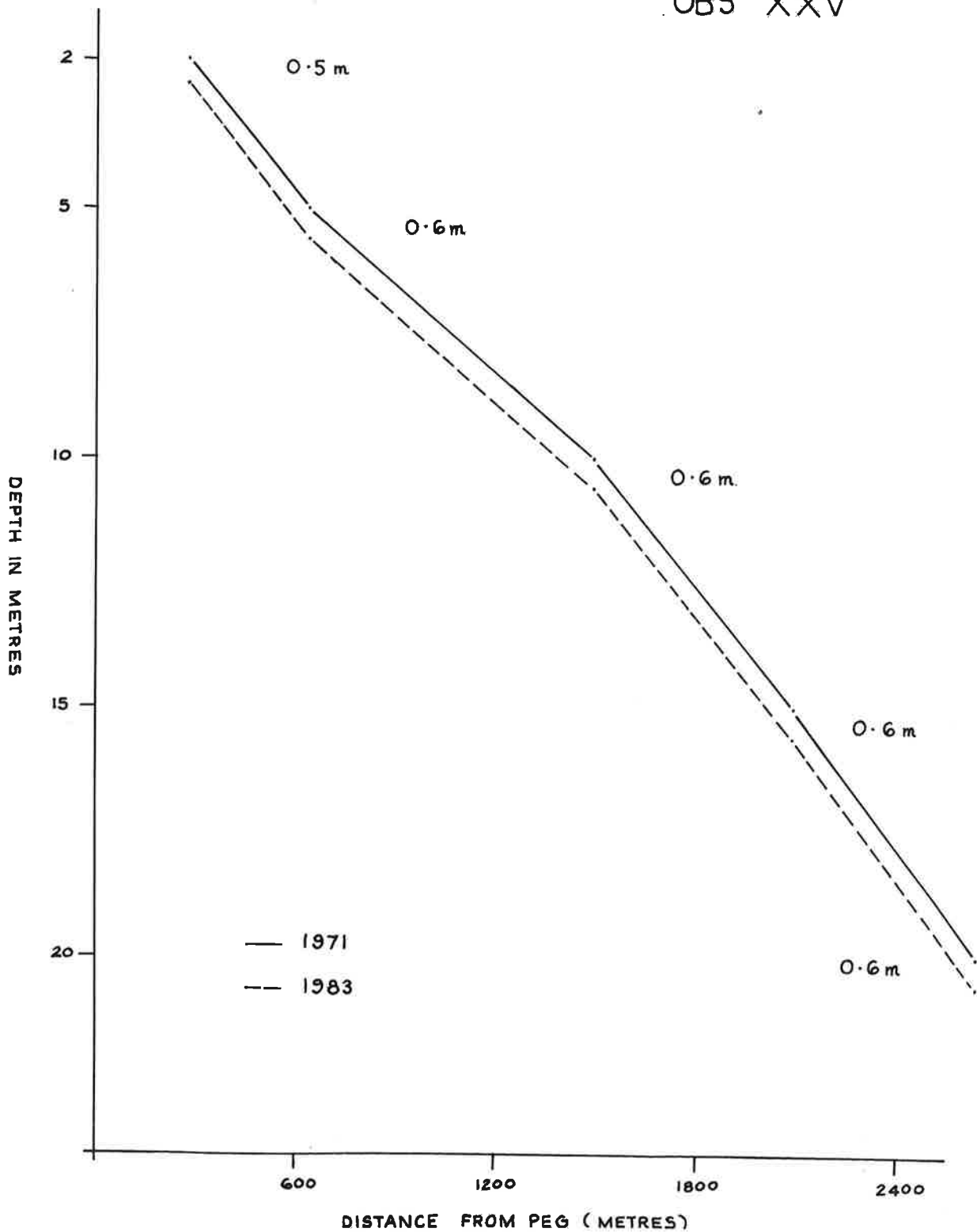
	NING (yards)		MOUNT EDEN (metres)	
Ocean Beach				
IT I (Pit)	643915.70N	334601.85E	687208.44N	397125.64E
RM II	643740.99	334673.65	687048.19	397190.04
RM I (House)	643219.71	335053.47	686568.86	397533.68
IT III	642890.93	335330.37	686266.28	397784.58
IT II (Tree)	642845.58	335408.21	686224.26	397855.43
Paku				
IT (Chimney)	642696.55N	336132.90E	686082.86N	398517.02E
Paku No. 2	642434.29	335610.78	685846.75	398037.75
IT R (Dazzle)	641991.78	335997.18	685439.39	398387.94
Beacon	641858.72	335714.74	685319.72	398128.74
Nail	642112.78	335318.04	685554.83	397767.80
OIT (Wharf)	641379.35	334164.44	684892.36	396707.80
Pauanui Beach				
IT 1a	641740.85N	335269.72E	685215.09N	397721.00E
IT 1b	641749.74	335218.78	685223.58	397674.48
IS 1c	641690.84	335188.06	685169.94	397645.97
IT 1d	641271.35	334923.40	684788.24	397401.01
IT 1e	640895.08	334487.66	684447.27	396999.92
IT I	641618.13	335302.67	685102.65	397750.25
IT II	641428.96	335408.00	684928.93	397845.23
OIT XXXIX	641180.88	335497.52	684701.46	397925.33
OIT VI	640514.55	335693.74	684090.79	398100.04
IT III	640169.13	335855.42	683773.81	398245.43
OBS XXV	639716.45	336017.08	683358.74	398390.05
IT IV	639370.29	336156.05	—	—
IT IVa	639210.78	336243.30	682894.77	398593.33
OIT II	639100.06	336272.33	682793.32	398619.09
Leads				
Fwd BN	641646.21	335293.85	685128.38	397742.39
Rear BN	641629.16	335230.40	685113.24	397684.25

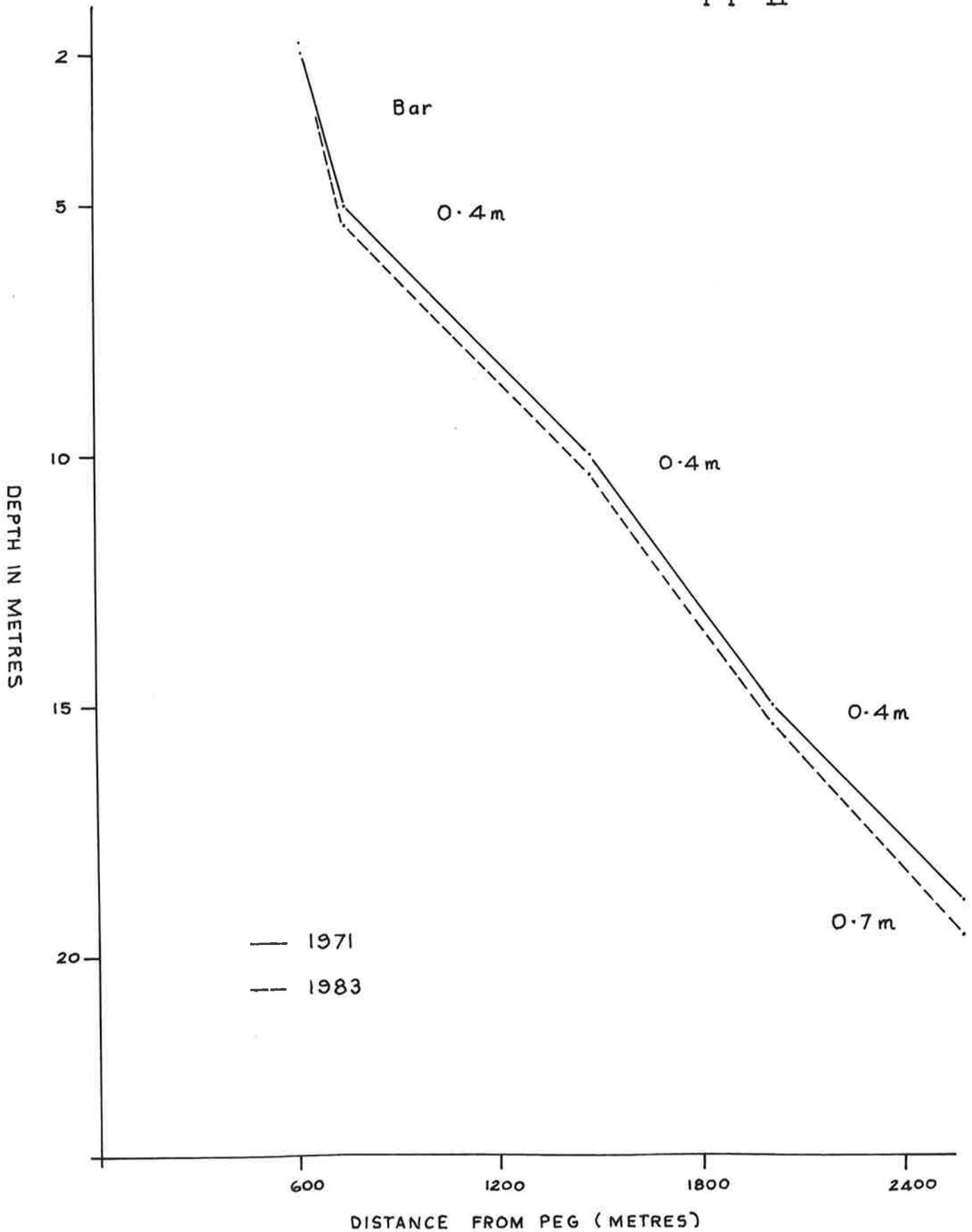
Appendix 3 to
HI 122 Report of Survey
Dated 28 July 1983

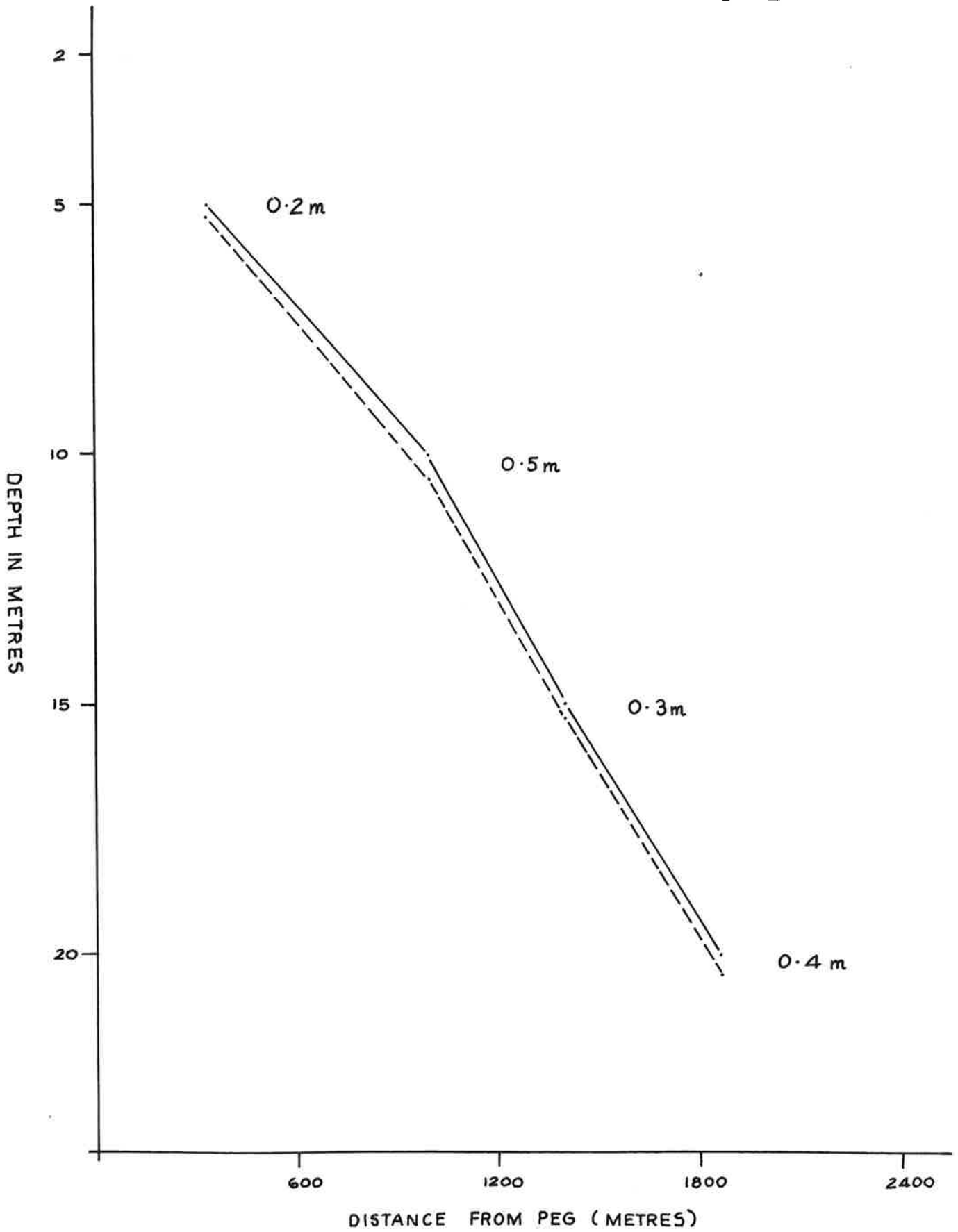
Comparison of 1971 and 1983 Seabed Profiles

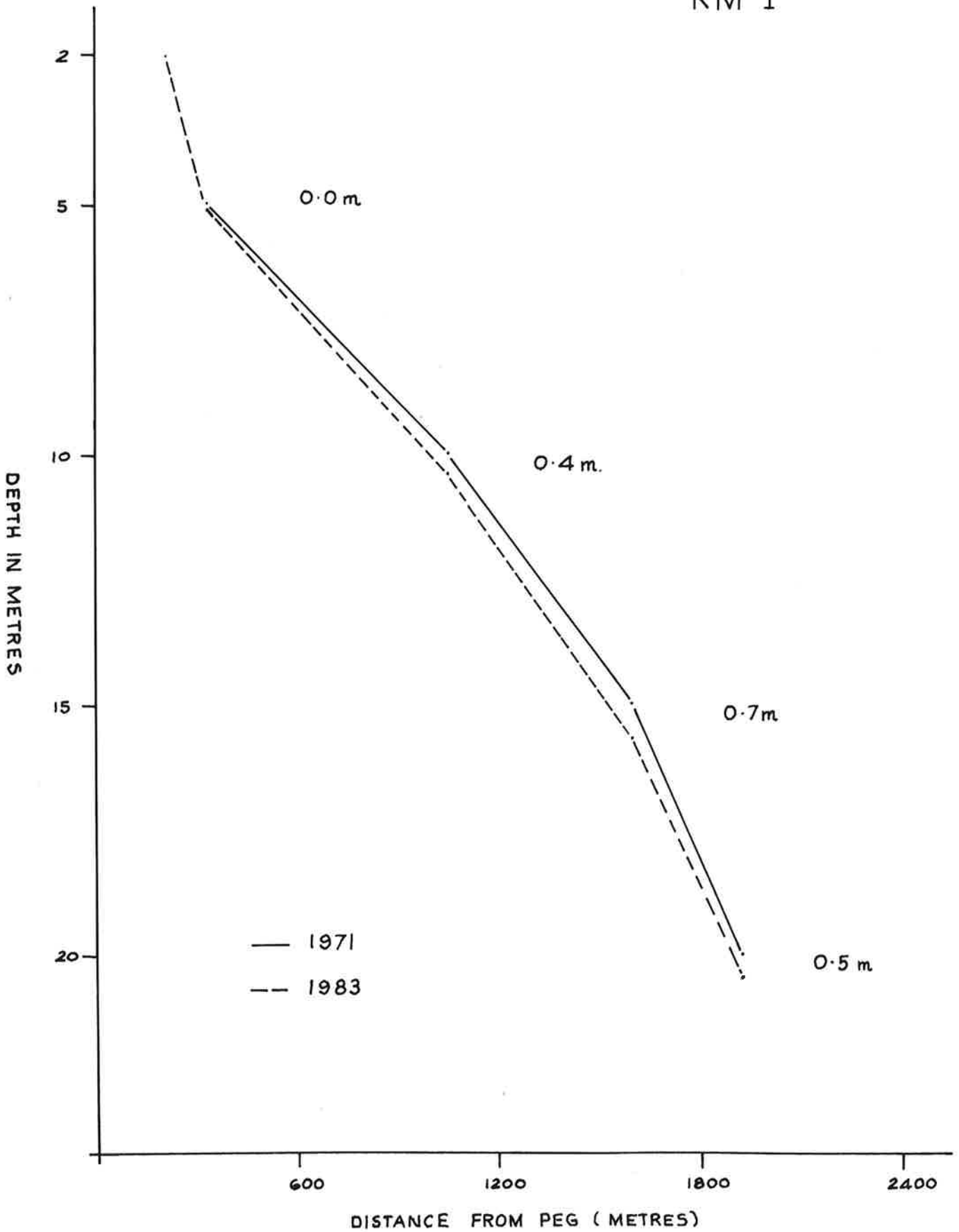
Pauanui Coastal Hazard Survey
Graph N° 1

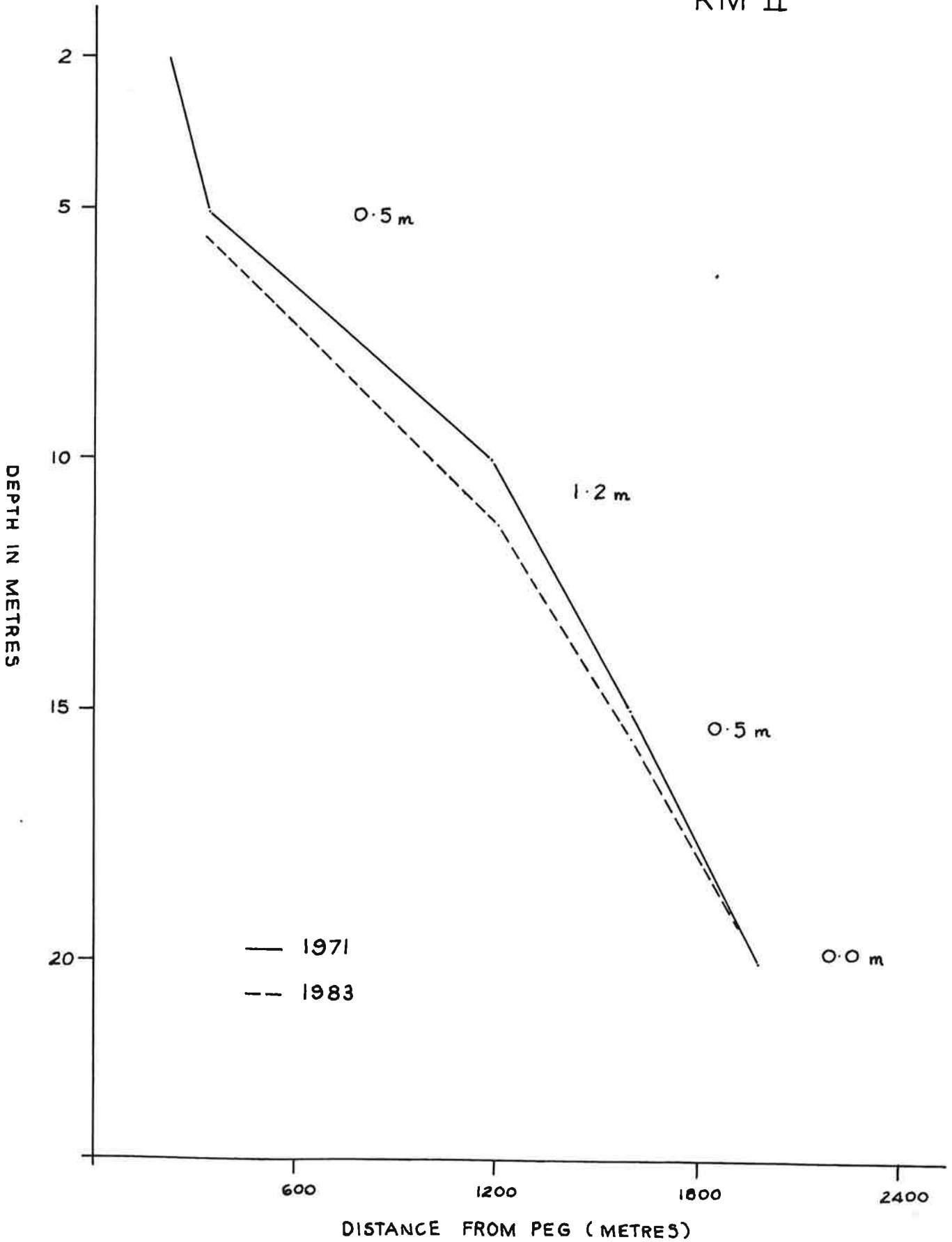
PAUANUI BEACH
OBS XXV











APPENDIX II

Annotated list of Sheets 1 to 9 of Ministry of Works and Development Hamilton District Office Survey Plan Number 2/973/1/2204. Each sheet covers part or all of Pauanui Beach and are held by the District Surveyor, MWD, Private Bag, Hamilton.

- (a) Sheets 1 and 2. Compiled plans showing the HWM from S.O. 6910D² (1895), MHWM from D.P. S11962 (1967) and vegetation line as from the field notes held in Chief Surveyor's office, Department of Lands and Survey, Hamilton, of the 1967 survey DPS 11962.
- (b) Sheet 3. The survey control for cross-sectioning of Pauanui Beach showing the baseline adopted for the survey and the 89 pegged intercepts on the survey traverse line.
- (c) Sheet 4R². A plan showing the periodic movements of the toe of the foredune 1895–1983 based on 4 aerial surveys and ground survey of May 1983, checked in the field December 1983, and the volume of sand movement over those years.
- (d) Sheets 5 and 6. The photogrammetric plot by the Department of Lands and Survey Photogrammetric Branch of the foredunes of Pauanui Beach based on the 1944, 1971, 1978 photos and related to the 1895 and 1967 surveys as compiled on Sheets 1 and 2.
- (e) Sheets 7 and 8. A composite plan of the toe of dune as on Sheets 5 and 6, the baseline and traverse pegging, reserve boundary and subdivisional survey fronting Pauanui Beach used in conjunction with cross-sections of the beach to arrive at the volume calculations on Sheet 4.
- (f) Sheet 9. A plan showing the Pauanui Beach Coastal Hazard Zone in relation to beachfront property boundaries, foreshore reserve and the top seaward edge of the foredune.

