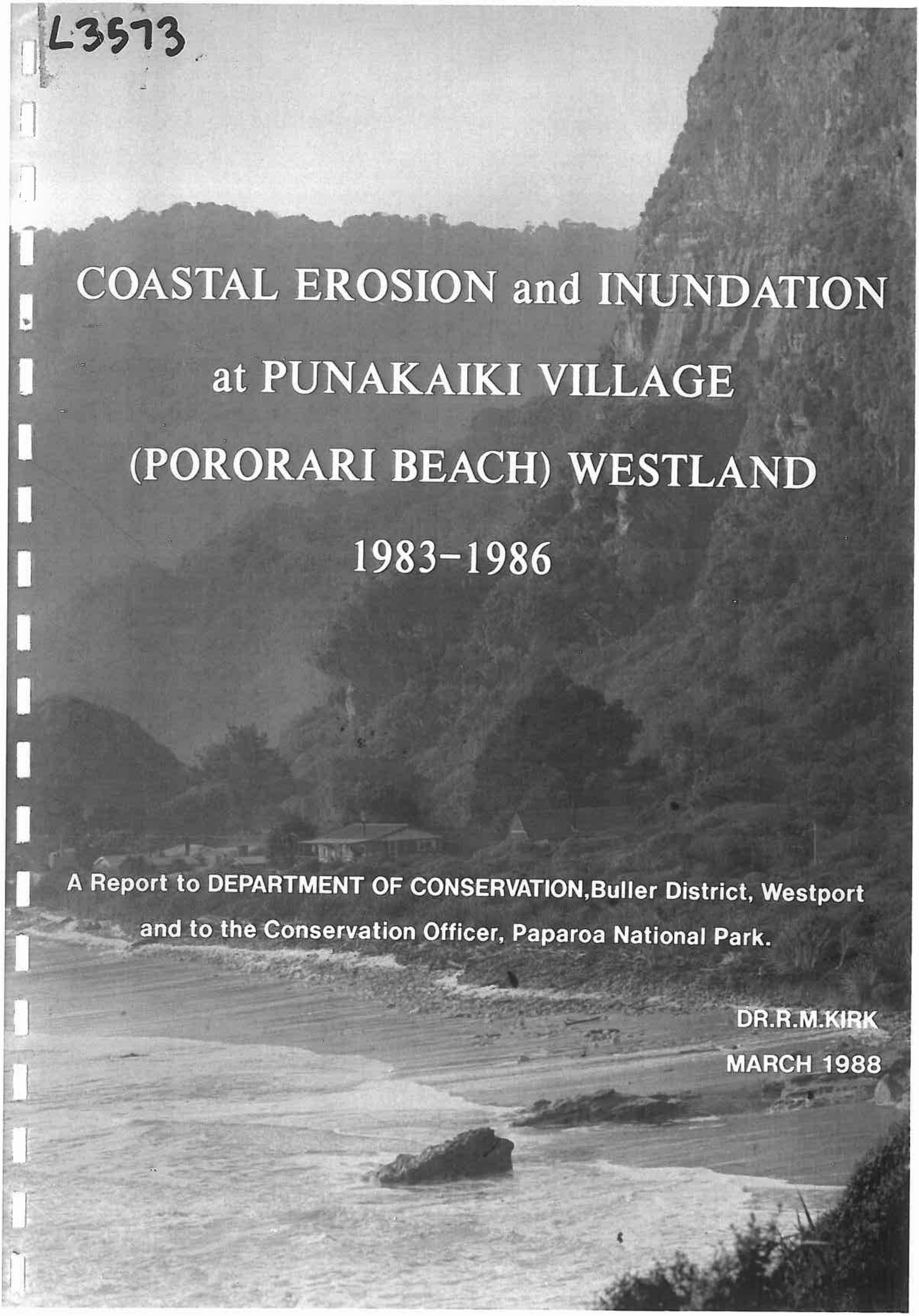

COASTAL EROSION and INUNDATION at PUNAKAIKI VILLAGE (PORORARI BEACH) WESTLAND

1983–1986

A Report to DEPARTMENT OF CONSERVATION, Buller District, Westport
and to the Conservation Officer, Paparoa National Park.

DR.R.M.KIRK
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1

INTRODUCTION

This report concerns the nature, present extent and likely future impacts of coastal erosion and saltwater inundation hazards at Punakaiki Village, (Pororari Beach), Paparoa National Park, Westland. The report arises because of ongoing concern about erosion and inundation and its effects on properties at the village since at least the early 1980's. On several occasions storm wave runup has penetrated properties and caused structural and other damage, most recently in September 1987. As a direct consequence of the hazard impacts, there has also been ongoing discussion of the possibilities for provision of protective works to ameliorate the hazards. Consideration has been given at various times to both formally planned and informal works, principally to construction of a rock revetment to protect the village.

The writer became involved in these concerns and discussions in November 1983 while participating as an instructor on a coastal erosion management course (dealing with a quite separate problem), held for Department of Lands and Survey Planning Officers in the Punakaiki area. Toward the end of this exercise, an inspection of Punakaiki Village and the adjacent beach was made and a series of discussions and exchanges of correspondence ensued. The present report and the work it reviews are thus out-growths of an ongoing involvement by the writer.

In particular, a feature of the 1983 discussions and subsequent correspondence was that while there were clear threats from the sea at the village, the precise causes, patterns and rates of development of these were unknown at that time. Certainly, the data necessary for designing and costing major capital works such as rock revetments were lacking.

A prime requirement for the village was thus a coastal monitoring programme, carried out to acceptable technical standards and of sufficient quality and duration to define the erosion and inundation hazards. Such a programme was begun in 1983 and the data derived from it, form the basis for the present report.

On advice from the writer, the monitoring programme amounted to a cautious approach to definition of the hazards, an interim "wait and see" stance before committment to the considerable capital and maintenance expenses of engineered sea-defence works. Such works also carry marked significance for aspects of environmental quality, matters now given added weight with the creation of Paparoa National Park.

In detail, the monitoring programme fell into two parts. The first necessitated direct, daily observation of wave, current and beach erosion processes at the village. Mr Grahame Champness, Conservation Officer, Punakaiki, organised and partly undertook this work. Robin Reid with other staff has arduously assembled almost a complete daily record of the beach over more than a four-year period. Data up to October 1987 are analysed here and only in part since a full analysis of the wealth of material assembled would go well beyond the requirements of the present report. In the experience of the writer, nowhere in New Zealand has such a complete or extensive record been acquired before.

The second part of the monitoring programme, again based on advice from the writer, as to the methods of data collection and analysis to be used, necessitated periodic re-surveying of a series of seven beach profiles established along the Pororari foreshore. A total of ten surveys up to July 1986 were available for analysis here. Seven of the surveys were made at monthly intervals from June 1983 to December 1983 by survey staff from Department of Lands and Survey, Hokitika. The remaining three were made in June 1984, September 1984 and July 1986 by staff of Westland Catchment Board; the data being furnished to Department of Conservation. The ten surveys thus provide for nine sequential inter-comparisons of beach behaviour at uneven time intervals and no data are available after July 1986.

In addition to examination of the erosion processes and provision of opinion on possible management strategies, it is therefore a function of this report to comment on the data gathering, specifically to offer further advice on how the survey should proceed in light of findings to date.

2

PORORARI BEACH

Before proceeding to analysis of the monitoring results, it is useful to consider the general physical context of the beach from which they were made. Punakaiki Village occupies the backshore areas of what is properly termed a pocket beach that has formed as a narrow series of prograded sandy beach ridges and dunes in the re-entrant between the high, steep limestone bluffs to landward and the outlet of the Pororari River to the north. The coastal flats are a product of both the river and the sea and are geologically very young since they have been formed during only the last 5,000-6,000 years for which sea-level has been at its present stand. Following the last glacial low stand of sea-level (ending perhaps 15,000-20,000 years ago) - perhaps as much as 130 metres below present level, sea-level rose rapidly to drown what is now the continental shelf. Present levels were achieved about 5,000-6,000 years ago, at which time the bluffs landward of the village would have been active sea cliffs. Sand and gravel drifting northward along the coast was added to material from the Pororari River to form beach and dune ridges that filled the embayment and displaced the sea from the cliffs. To the north, a lagoon enclosed by a sandy spit was formed at the river mouth. Such beaches and spits are notoriously changeable landforms under natural conditions and are readily de-stabilised by a range of land and river use practices, especially under the prevailing high wave energy conditions of the west coasts of New Zealand.

Long-term stability of such beaches depends crucially on an adequate and continuing supply of sediments to offset losses due to removal by wave action and that stem from ceaseless abrasional reduction of sand and gravel to silts in the ever-present surf. Backshore areas of Punakaiki Village have been heavily modified for roading and settlement and the Pororari River has been used as a source of aggregate from time to time. Both of these aspects of the history of the site make important but presently unquantifiable contributions to the hazards.

Two other factors are important to the context of long-term erosion and both concern the relationship between land and sea-levels. It is well documented (for example, see Gibb 1978) that coastal erosion is both regionally widespread and (historically) long-term in Westland. Apart from accumulation against harbour breakwaters, as at Westport, almost all beaches in central Westland are eroding at rates ranging from a few centimetres per year to several metres per year. Erosion at Pororari Beach must therefore be seen in a regional context in respect of its physical presence and character.

This situation notwithstanding, it is equally well known that much of the West Coast is tectonically active, there being abundant evidence of older beaches dating from past stands of sea-level (similar to those of the present) that are now many metres above sea-level. Uplift tends to rejuvenate beaches through falling ocean levels and by driving sea-bed sands ashore through intensified wave action in the nearshore.

Because uplift occurs in episodes rather than continuously, this is an occasional contribution to beach growth. It is certain that this type of event has influenced the Punakaiki area, but the precise part played in the growth of its beaches is unknown because of the reworking of the beach and dune ridges for settlement.

The second influence dominates the longer, variable time periods between episodes of uplift. In these intervals, waves work to a given still-stand of sea-level, distributing and re-working the available sediment supply. Where this is limited it is likely that beaches rejuvenated by earlier uplift will be overtaken by the sea and effectively 'recycled' into the coastal zone. It is very probable that this condition is a significant element of present erosion at Punakaiki, as it is at a great many other sites along the West Coast.

To this must be added the fact that sea-level has been rising for most of this century, a circumstance that engenders widespread coastal erosion. In the view of the Coastal and Marine Directorate, Department of Conservation, the prospects are for rates of sea-level rise to accelerate during the next century because of the 'Greenhouse Effect' of increasing quantities of Carbon-Dioxide and other gases in the atmosphere. In brief, it is anticipated in this scenario that regional climate will warm and that sea-level will rise to about 0.5 metres higher than now by 2030-2050 AD and to about 1.0 metre higher than now by 2080-2100 AD, mainly by thermal expansion of the oceans. This scenario carries with it prospects for greater frequencies and intensities of inundation, greater rates and wider extents of coastal erosion; and major implications for the planning of coastal land-uses including protective works.

Careful, ongoing monitoring of actual as distinct from modelled or theorised behaviour of coasts will clearly be even more important for the future than it is at present. It may also be argued that data presently to hand are inadequate to predict future coastal behaviour under 'Greenhouse' should it transpire in the manner now postulated.

It is within this overall context then that it is now possible to turn to evaluation of the data to hand for Pororari Beach. Figure 1 (Drawing 921/5 from Westland Catchment Board) sets out the disposition of the beach and settlement at Punakaiki. The diagram also shows the locations of the surveyed beach profiles. As can be determined from the figure, the beach is about 1 kilometre long and it has a gently curved outline in plan with a general MNE-SSW orientation - so that it faces somewhat north of west (approximately WNW). Beach profiles are spaced at intervals of 100 metres along the shore and the wave observation site is adjacent to the meteorological screen at the southern end.

The present shore comprises a mixture of sand and gravel with a predominance of sand and a broad beach is backed by eroding remnants of a sandy foredune. This dune is lowest and has least bulk in the south and becomes both higher and more substantial with distance to the north. In the south, the rear of the dune is occupied by a road (Dickenson Drive) and the area further landward is heavily modified. It is here that both erosion and inundation hazards are greatest.

As will be shown, the beach receives waves from a wide range of directions, a factor which in itself is responsible for substantial and sometimes abruptly dramatic beach changes. There is potential for longshore drift of beach sediments in both directions along the shore, but the net direction appears to be northward toward the Pororari River where beach drift contributes to the spit enclosing the river mouth. Such a net drift pattern also diminishes the prospects for significant nourishment of the beach adjacent to the village by natural longshore drift of river sediments. On the other hand, artificial nourishment from this source is quite possible, since the distance is short and the sediments would be recirculated back toward the river mouth.

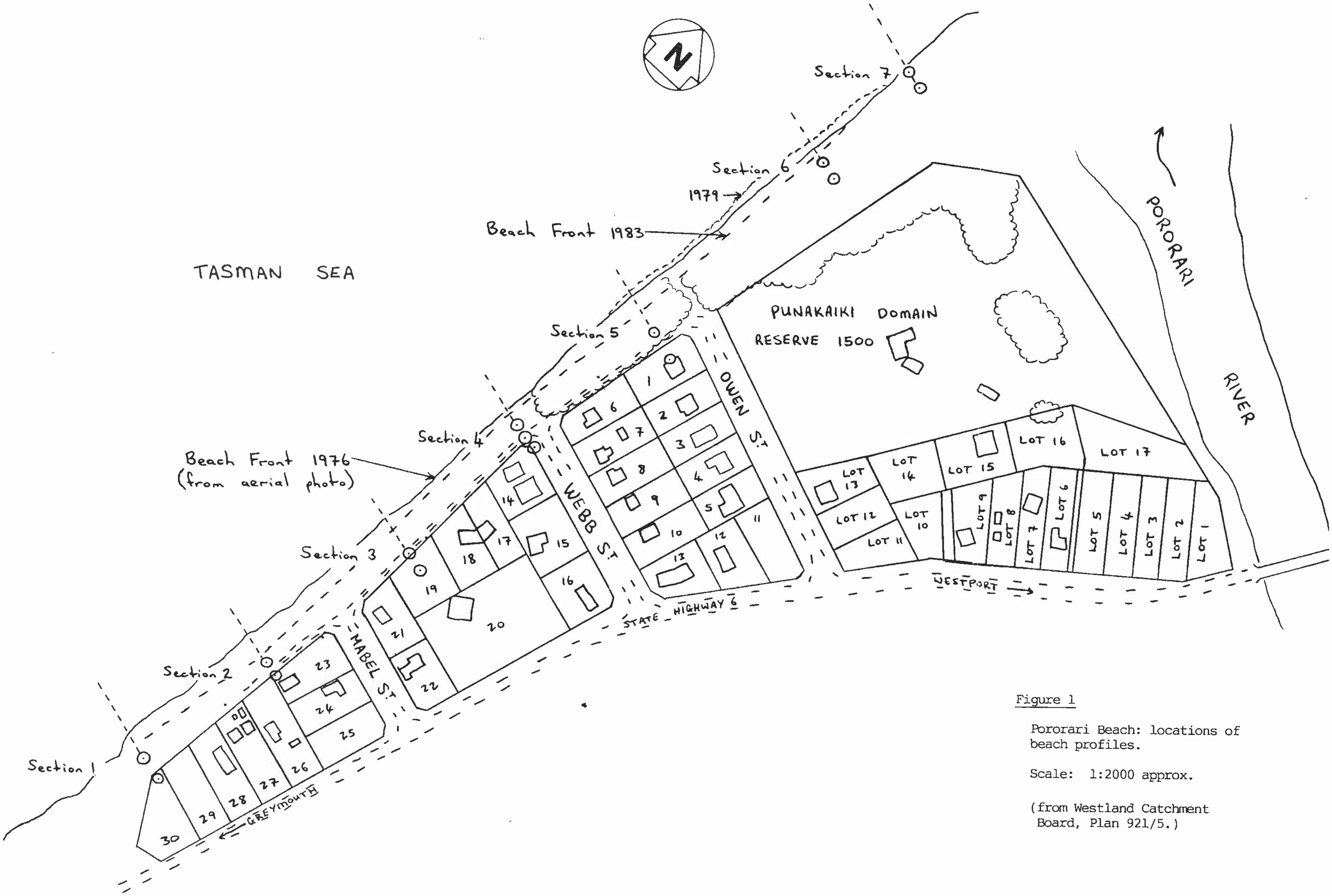

Figure 1

Pororari Beach: locations of beach profiles.

Scale: 1:2000 approx.

(from Westland Catchment Board, Plan 921/5.)

As can be seen from Figure 1, erosion and inundation hazards are most severe at the southern end of the beach where the beach ridge system is narrowest so that there is the least space in which to develop any form of protective work. In terms of the discussion just presented, this area is the (net) updrift end of the beach system and thus the least well nourished with sediment. Such an association of erosion and drift is common. The implications for protection strategies are that the area can be abandoned to nature, the sediment deficiency can be rectified by ongoing works (eg: beach nourishment or recycling of sediment), or the encroachment of the sea can be halted by appropriate works such as walls or revetments. Nourishment or recycling mean that sediment continues to move along and on/off the beach so that the whole system is benefitted. On the other hand, walls 'freeze' the beach position and do not rectify the fundamental cause of erosion (ie: a deficiency of sediment supply); indeed, they may contribute to under-supply. These matters are dealt with in detail later in the report.

3

UNDERSTANDING BEACH PROFILE BEHAVIOUR

The key to both the results and the advice to be presented lies in a clear understanding of the manner in which beaches function at a variety of time scales. It has already been mentioned that it was the purpose of the monitoring programme to provide data suitable for interpretation against such an understanding and several of the longer term natural and human influences at work in the area have already been discussed. The purpose of this section is to show how all these influences can be related to observed and measured beach behaviour.

Any beach may be thought of as a three-dimensional body of unconsolidated sediments resting on some basement, and through which a constant stream of particles is passing both along and across the shore. Such a definition focusses attention on the dynamic nature of beaches and suggests that the individual grains comprising them have some finite 'lifetime' within the system. Consideration of the various flows and storages of sediment across defined boundaries (eg. around headlands, away from river mouths), and within a beach leads to the classic notion of the sediment budget in which coastal stability is viewed as a reflection of the state of balance or imbalance among the various transfers (Kirk 1983).

Coastal erosion can have a variety of complex causes, arising either from processes which supply sediment to the shore, or in those which promote its removal, or in some combination of both. For this reason, the assessment of erosion is a difficult task since consideration must be given to a great many variables acting at several scales in time and space. These points can be clarified by a diagram of a transverse section of a beach which might be surveyed repeatedly to establish changes in the shore above some arbitrary datum, such as mean high water mark (MHWM), (Figure 2a). There will be frequent changes in the form, appearance and volume of the visible beach as waves change with the run of the weather. These short-term changes typically involve large quantities of sand and result in wide ranging displacements of the water line to and fro. Over many surveys, it is possible to define the envelope or sweep zone of forms which contains the beach. These events, together with their typical orders of magnitude and their causes, comprise the upper part of Table 1.

In addition to these short-term changes, there may also be displacement of the sweep zone as a whole in either a landward or seaward direction (Figure 2b). Such movements reflect longer term changes in the beach sediment bedget and are of major concern in coastal land use planning exercises. Their typical causes and magnitudes are detailed in the lower portion of Table 1. It can be a very difficult problem to separate longer term changes in the position of the sweep zone from shorter term variations in its form. Large sweep zone changes are characteristic of semi-stable and prograding shores while chronically eroding beaches have smaller envelopes.

Deciphering the presence and nature of longer term trends in envelope position amongst the shorter term 'noise' of variations within the envelope is the chief problem faced in making an erosion assessment. It should also be appreciated that the certainty with which this can be done is in part a function of the frequency with which the shore has been surveyed and of the reference lines which are chosen to represent the beach.

TABLE 1: TIME SCALES OF BEACH AND COASTAL CHANGES

TIME SCALE (years)	GEOLOGIC AND ENVIRONMENTAL FACTORS PRODUCING CHANGES	RESPONSE MAGNITUDE HORIZONTAL CHANGE (metres[1])
Short-term ($\leq 10^{-2}$)	Single storms, storm surges	± 0.1 to 15.0
Quasi-seasonal and Annual (10^{-2} to 10^{0})	Periods of storminess with higher than average sea levels; Possible coincidence of storms with spring tides; Annual cycle of sea level changes.	Dynamic Equilibrium ± 1.0 to 25
Historical (10^{1} to 10^{2})	Storm cycles of 2-20 years with sea level changes; Secular sea level changes of 10cm/century; Possible shore-normal sediment budget changes;	Trends of instability ± 10 to 50
Long-term (10^{2} to 10^{3})	Climatic changes (storminess, wind directions); Post-glacial sea level rise to near present ca. 6,000 BP and possible changes of ± 102m since; Sediment budget changes from terrigenous, marine and biogenic source areas.	Chronic Erosion, Deposition ± 50 to 100

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1. Note the overlap in range of responses.

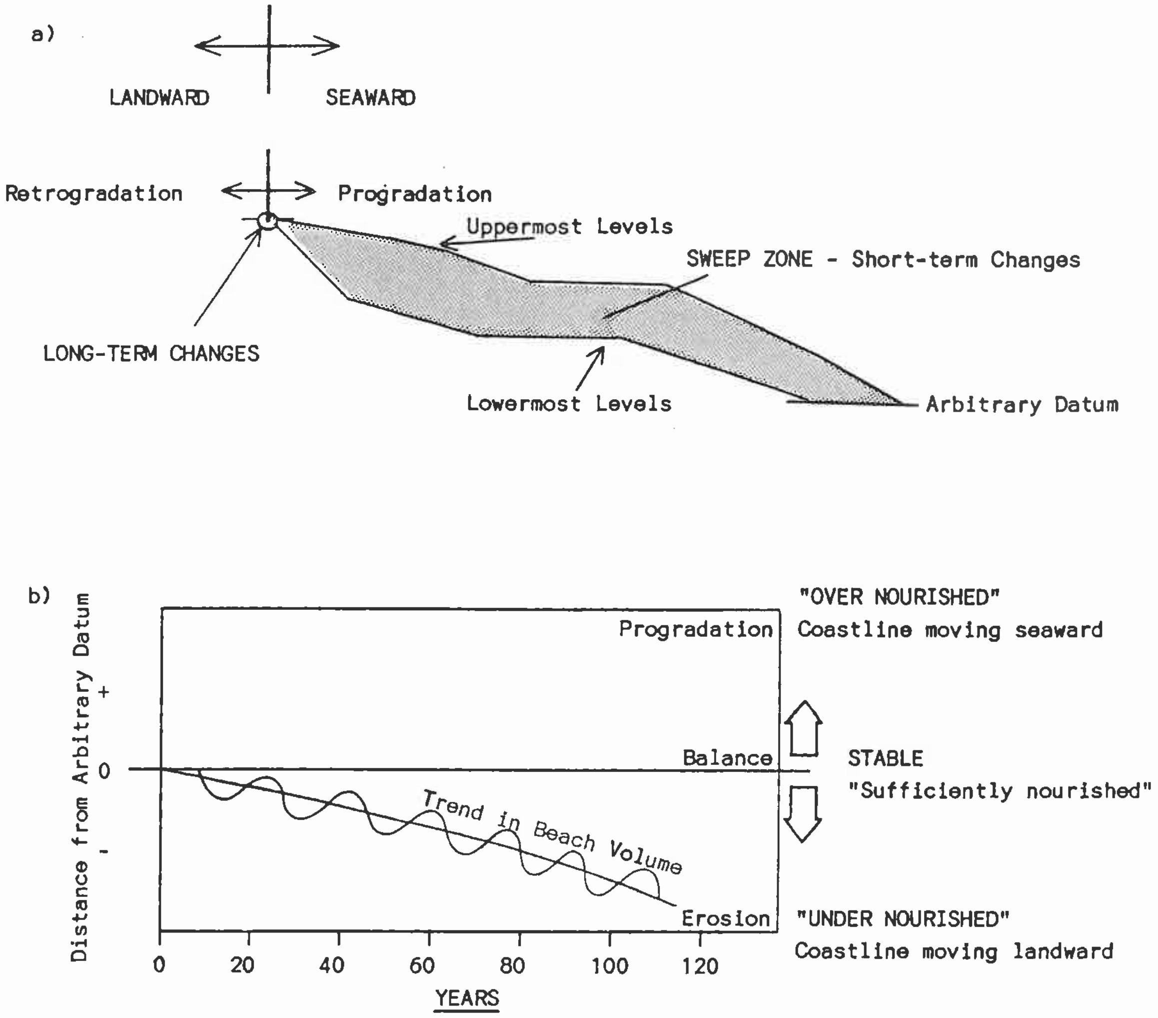


FIGURE 2: The dynamics of beach profile change.
a) Typical fluctuations in a sand beach profile
b) Long-term erosional trends in a sand beach sediment budget

In the context of land use planning the notion of a hazard implies some assessment of risk over a time horizon relevant to the planning exercise. Developments which were intended to have lifetimes measured in decades, such as buildings, have often intruded into the active zones of beaches where the shoreline is eroding. In other situations the coast has a stable long-term position, but displays periodic excursions within a wide zone in sequences of advance and retreat lasting for many years and characterised by abrupt reversals.

In the first case, where a shoreline is in persistent retreat, a genuine erosion problem exists, but planning has obviously been inadequate to identify and respond to its existence. In the second case, a long-term erosional state strictly does not exist because there is no net retreat. However, here there is risk to assets poorly sited with respect to the area within which changes to the beach system can occur (the 'envelope' of beach changes). This is especially the case when the shoreline is in a phase of retreat. Many of New Zealand's coastal erosion problems are of this second type, and their solution and/or avoidance are heavily dependent on foreknowledge and planning.

It is important to recognise that land development practices such as 'landscaping' and foredune removal can intensify significantly the incidence of erosion and/or inundation on any beach, and may even lead to persistent retreat where this did not occur previously. Similarly, neglect of foredunes, and the breakdown of their vegetation cover through intensive or incompatible uses, can lead to erosion and saltwater flooding hazards on beaches where they would not otherwise exist. This much is perhaps now quite widely appreciated, although there will always be debate about the extent to which erosion at hazardous sites on the New Zealand coast is either 'natural' or self-inflicted through various development practices.

For all the above reasons, it was advised in 1983 that the profiles set out on Pororari Beach should have sufficient landward extent and adequate frequency of survey to document the short-term envelope changes and to enable distinction of them from any net movement of the envelope positions which may be present. Analysis here is particularly directed to assessment of whether or not erosion at the village involves long-term retreat of the beach envelope and/or periodic backward excursions of the envelope occuring as a result of stormier than average years. This knowledge can then be carried into consideration of protective strategies.

4

WAVE AND BEACH OBSERVATIONS

As stated previously, the prime data resource here is a LEO (Littoral Environment Observations); type record assembled for the period October 1983 - October 1987 by Robin Reid and others at Punakaiki Village. The record is almost continuous over the 1,440 day period, and is invaluable. At 0900 hours, daily observations were made of the state of the tide, breaker height in the outer surf zone, breaker period, wave approach direction, wind direction and force, and the general physical state of the beach. Wave directions were recorded against an approach sector code.

In addition to these observations, more detailed records were made during some significant storms and a wealth of written and sketched information has been provided on the form of the beach at sites away from the observation point. Coastal management in New Zealand would be very well served by more observers of the thoroughness and persistence of Robin Reid, Grahame Champness and others at Punakaiki.

For purposes of the present report, analysis has focused on waves as the principal agents of coastal change, and episodes of large waves as the main agents of erosion and inundation. Average maximum wave heights in the outer surf zone were reported to the nearest 20 centimetres of elevation and it is well established that visual estimates of wave height tend to focus on the larger, more definite waves in a group, so that it is felt that reasonable estimates of the inshore wave climate have been obtained for the investigation period.

4.1

The Distribution of Maximum Wave Height (H_{max})

Detailed examination of the records and the accompanying notes and surveys reveals that waves of a wide variety of sizes, periods and approach directions are received at Pororari Beach. It is also evident that appreciable overtopping and erosion can and do occur for sea states having maximum wave heights as low as an estimated 1.5 metres. Here, it should be noted, that the observation system does not enable documentation of storm-surge water levels (due to onshore winds, low air pressure and/or the 'set-up' due to breaking wave action - often 10-20% of breaking wave height on sandy beaches), so that important components of inundation are beyond the scope of the analysis. Such storm water levels require instrumented recording or must be calculated by complex hindcast techniques.

Table 2 reveals that there were a total of 156 daily observations of wave conditions having heights greater than 1.5 metres in the outer surf zone, about 11% of the total conditions recorded.

The largest sea recorded may have exceeded 4.0 metres and only two events exceeded 3.0 metres. Below 3.0 metres the frequency of storm events increases markedly, there being 65 events having wave heights between 2.0 and 3.0 metres. These results may seem puzzling in that much larger seas are well known off the West Coast. The paradox is an apparent one since the observations reported here are made inshore where the primary determinant of wave height is water depth. As a rule of thumb, the ratio of water depth

TABLE 2: DISTRIBUTION OF MAXIMUM WAVE HEIGHTS (H_{max}) - metres October 1983 to October 1987 at PORORARI BEACH

Height Class (m)	No. of Observations
$4.0 \leq H_{max} \leq 3.5$	1
$3.5 \leq H_{max} \leq 3.0$	1
$3.0 \leq H_{max} \leq 2.5$	11
$2.5 \leq H_{max} \leq 2.0$	54
$2.0 \leq H_{max} \leq 1.5$	89
TOTAL:	156 Events

TABLE 3: DISTRIBUTION OF MAXIMUM WAVE HEIGHTS (H_{max}) - metres BY MONTH OF THE YEAR, October 1983 to October 1987 at PORORARI BEACH

Month	No. of Observations	Notes
January	16	
February	8	
March	5	Autumn Equinox
April	19	
May	10	
June	12	
July	6	
August	14	
September	21	Spring Equinox
October	16	
November	17	
December	12	
TOTAL:	156 Events	

SOURCE: Punakaiki Village LEO data set, G Champness, D.O.C.

to breaker height is taken as: $d_o / Hb = 1.28$, so that the observations in Table 2 suggest water depths of 2.5 to 5.0 metres in the outer surf zone during storms. Observations made during storms also reveal the presence of offshore bars on which the waves break.

Table 3 presents a monthly analysis of the occurrence of waves higher than 1.5 metres. From this it can be seen that no month is storm-free and that the incidence of large waves is highly variable from month to month. Examination of the data set shows a similar level of variability from year to year for a given month; the summer months being devoid of large waves in some years, though no two consecutive months at any time of year were storm-free. Table 3 also demonstrates that there was no particular seasonality to the arrival of large waves, though the periods of the autumn and spring equinoxes (especially the spring equinox) were times of greater storm wave incidence.

Analysis of the full observation sets for the 11 largest events shows that they occurred in January, April, May and June (one incident each), and in August, September (two incidences each) and November (three events). Breaker heights were 2.0 metres or more at the peaks of the storms and wave periods were in the range 9-12 seconds. The storms were thus fully developed seas that degenerated into very powerful swell that was commonly as damaging or more damaging than the seas occurring at the storm peaks. Significant overtopping is recorded for at least three of these events, but the largest (occurring on 19/20 November 1983), having breakers up to 4.0 metres has no accompanying notes of erosion or inundation. This may reflect the occurrence of the event very early in the observation period.

Because of the duration of the record and the uncertainties of the visual observation methods, it is not possible to calculate extreme-value distributions for the storm events and thus to derive estimates of design wave conditions or typical return periods for given storms. A further reason for caution against using the data in these ways is that the record makes it clear that storm seas at Pororari Beach have highly variable anatomies. Directions of approach, wave height distribution in time, persistence of wave heights and the relationships between wave heights and storm water levels are all highly variable over the largest events in the data set.

These points are underscored by consideration of Table 4 which presents an analysis of approach directions for the 156 events having heights greater than 1.5 metres. Because of the difficulties of accurately observing wave approach directions from the beach, a direction reporting code has been employed. As can be seen from the Table, this distinguishes waves approaching parallel to the shore (within ± 5° of angle - Code 3) from those approaching obliquely (left = Code 2; right = Code 4) and from those with a very high degree of obliquity (Codes 1 and 5). On open ocean sandy beaches, high degrees of obliquity in wave approach are rare, owing to significant refraction of waves (especially of long period swells) as they approach the shore.

Wave approach angle is an important property because it governs both the directions and rates of longshore sand transport. It is also a significant factor in the incidence of erosion and inundation since wave energy may be concentrated at some points on the coast and dispersed at others (leading to zones of higher and lower waves and to coast-wise hydraulic gradients). Also, shorelines are very sensitive to the angle of wave approach so that a beach adjusted to strong wave action from a particular direction will respond rapidly by relocating large volumes of sand when subject to strong waves from a different direction.

TABLE 4: DISTRIBUTION OF MAXIMUM WAVE HEIGHTS (H_{max}) - metres BY DIRECTION OF APPROACH, October 1983 to October 1987 at PORORARI BEACH

Direction Code	Arc of Shore (°)	Approx. Aspect	No. of Observations
1	60	+SW	0
2	25	W to SW	74
3	±5 (shore normal)	WNW	43
4	25	NW	32
5	60	NNW+	7
		TOTAL:	156 Events

SOURCE: Punakaiki Village LEO data set, G Champness, D.O.C.

Given that the orientation of Pororari Beach is generally from NNE-SSW, the pattern of directions for storm waves becomes evident in Table 4 , as one that has two strong but unequal modes. Some 74 occurrences (47%) of waves greater than 1.5 metres arrived at the beach from the west to southwest quarter. These waves would promote erosion of the southern (updrift) end of the beach and generate a northward and generally offshore transport of sediment. Some 43 occurrences (27.5%) of storm waves arrived more or less parallel to the shore and would have caused erosion over the full length of the shore. In contrast to these events, there were 32 occurrences of north-westerly approaches and 7 recorded from the NNW - making for 25.5% of the extreme events acting in the reverse direction along the shore. In these types of seas the southern end of the beach becomes the downdrift end while it remains exposed to overtopping.

Overall the ratio of northward to southward transport in high energy conditions can be seen to be about 2:1 in a northward direction, a finding that is consistent with the generally better nourished condition of the beach toward the river mouth (where the beach receives not only sediments transported from further south - including those eroded from around the settlement - but where this is added to river-derived material).

The conclusions to be drawn from the limited analysis presented here are that high energy events occur with considerable frequency (about 11%) of the time at Pororari Beach. While their incidence is certain, their timing and character are highly unpredictable as are their consequence for longshore drift, beach erosion and inundation in any given month or year. In such a situation, design of protection works is best based on the largest event known (+4.0 metres , in November 1983), with appropriate allowances for beach scour and for unknown factors such as attendant storm water levels and long-term sea-level rise. At Pororari Beach, storm-surge water levels will be not less than 1.0 metres above High Water Ordinary Spring Tide (and possibly as much as +1.5 metres HWOST), and long-term sea-level rise has been stated by D.O.C. as +0.5 metres by 2030-2050 AD and +1.0 metres by 2080-2100 AD.

As stated previously, there is a great deal more analysis that could be accomplished from the Punakaiki LEO data set, particularly in respect of lower energy events that cause short-term accretion of the beach. However, the time required for such an analysis is not justified in respect of the present exercise which is particularly concerned with defining erosion and inundation hazards.

It is recommended that the LEO observation programme be continued, and in addition, a full documentation of extreme events be recorded as and when they occur. A useful addition to the programme would be sketch maps and/or photographs of the maximum storm runup limits. Neither the elevations of these, nor their spatial limits are presently well documented, though they are undoubtedly known.

5

BEACH PROFILE SURVEYS

As noted earlier, a total of 11 of these have been made at various times since June 1983 for the 7 profile sites shown in Figure 1. Only 10 of these were available for the present report since a survey made on 31 March 1988 was not to hand. A theoretical maximum of 9 inter-comparisons is possible, both along and across the shore, to define the envelope changes and net movements in them. However, it has already been noted that the inter-survey time intervals are of unequal duration and that no survey has been made since July 1986.

The utility of the survey data is further decreased by two additional occurrences. First, the July 1986 (Westland Catchment Board) survey included only profiles 1, 3 and 6, so that the behaviour of a majority (4) of the profiles is assessable only from records over a 1.25 year period to September 1984. All seven profiles were surveyed on 31 March 1988.

Secondly, the early (Lands and Survey) results were plotted on the advice of the writer to a vertical exaggeration of 2.5 times. Such scaling of the height is necessary to reveal important morphological features of beaches and to facilitate calculation of sediment volume changes over a number of (overlaid) survey lines. The Westland Catchment Board surveys (up to 3 since June 1984) have been plotted at natural (no vertical exaggeration) scales. This has necessitated time-consuming re-plotting of the data to render it both comparable with the earlier (Lands and Survey) data and comprehensible in its own right. It is therefore recommended that the WCB data be re-plotted at V.E. = 2.5 times and overlaid on the Lands and Survey information. It is also strongly recommended that the earliest possible attention be given to a full evaluation of data from re-survey of all 7 profile sites on 31 March 1988. Most of the sites have not been re-measured since September 1984.

5.1

Profile Envelope Changes

Bearing in mind the uncertainties and limitations introduced by the problems outlined above, it has been possible to make preliminary estimates of the sweep zone volumes and behaviours for Pororari Beach. This has been done by measuring the areas between the uppermost (most accreted) positions of the profiles and the lowermost (most eroded) surveys. The areas thus obtained have then been converted to volumes of sand and gravel by regarding each profile as representative of half the shoreline distance to the next adjacent profile site.

The results of this procedure reveal that the foreshore along all parts of Pororari Beach undergoes vertical changes of more than 2 metres in the short-term, primarily through berm growth during low energy, swell-dominated periods and by removal of berms in storms when the foreshore is cut down and reduced to a broad, planar surface with a prominent erosion scarp to landward.

The 1983 monthly surveys by Lands and Survey reveal a pattern of increasing berm heights and foreshore sand volumes to the north; a feature consistent with strong net northward transport of sand at that time. In contrast, the latter, less frequent surveys by Westland Catchment Board, display a reverse pattern with smaller short-term envelope changes in the north and larger ones in the south. This pattern is consistent with net southward transport. Both of these findings are consistent with the observations of the LEO data set since high energy events emanating from NW and NNW have been more common among the storms of the 1984-86 period.

Taking the data as a whole, the average short-term envelope change is close to 200 square metres, or 200 cubic metres of sand per metre of beach length. Over the 771 metres of shore represented by the profiles, this converts to a total short-term sand demand (by the procedure outlined earlier) of 154,200 cubic metres of sand involved in onshore-offshore and longshore re-distributions in response to variations in sea-state.

This estimate is an average because of the variable time periods for the surveys used and because some profiles exhibit extreme vertical fluctuations in the short-term of up to 2.75 metres.

Short-term fluctuations of this order are entirely in character for high energy, open ocean sandy shores. On the east coast of the South Island short-term variations are typically of the order of 100,000 cubic metres of sand per kilometre of beach over time periods ranging from as short as 12 hours to several months.

It is important to note that these envelope changes are much larger than could be supplied from the Pororari River or from net erosion of the beaches. Clearly, they involve significant exchanges of sand and gravel with the nearshore sea-bed adjacent to the coast. Also, it is necessary to acknowledge that these fluctuations play a large part in buffering the energies of storm waves because removal and relocation of up to 154,000 cubic metres of sediment dissipates considerable energies. For this reason, any protective work contemplated must at least permit and desirably enhance the short-term sand exchange system.

5.2

Movements of the Profile Envelope

An important objective of the monitoring effort at Punakaiki has been to determine whether or not and by how much there is underlying net movement of the beach as a whole. As argued earlier, this can be assessed by defining the locus of the short-term envelope and plotting any shifts in it.

For the present investigation, this has been done by a method known as Excursion Distance Analysis that involves plotting of the changing distances between survey markers and significant features of the beach morphology. For Pororari Beach, repeated measurements were made of the distances from 'Peg 1' on each survey line to the eroding crest of the foredune on the beach (the scarp top at the southern end), or to the crest of the dune where it is better nourished by sand (as in the north toward the river mouth).

Plots of these distances as functions of time have several useful features. Horizontal lines indicate either stability of the envelope or no change between surveys. Positive (up-sloping lines) indicate accretion of the beach and net seaward movements of the envelope. Negative (down-sloping lines) indicate erosion or net landward movement of the envelope. Significantly, the gradients of the lines are direct measures of average erosion (or accretion) rates betwwen surveys. The more surveys included in such a plot, the better the definition of trends in shoreline change, not only because the plot contains more data points, but also because a greater range of wave conditions (especially extreme conditions) is represented by the pattern that emerges. It is for this reason that updating and common-plotting of the Pororari Beach surveys are matters of urgency.

Figure 3 presents the Excursion Distance plots for each of the 7 profiles from south to north along the beach. The uncertainties and problems introduced by the unequal survey intervals and the partial re-survey of 1986 should be readily apparent from the diagram. The figure also presents a mean erosion rate for each site for the available data. The high value of -3.08 metres per year for profile 2 is a matter of clear concern and one that should be resolved by re-survey at the earliest opportunity.

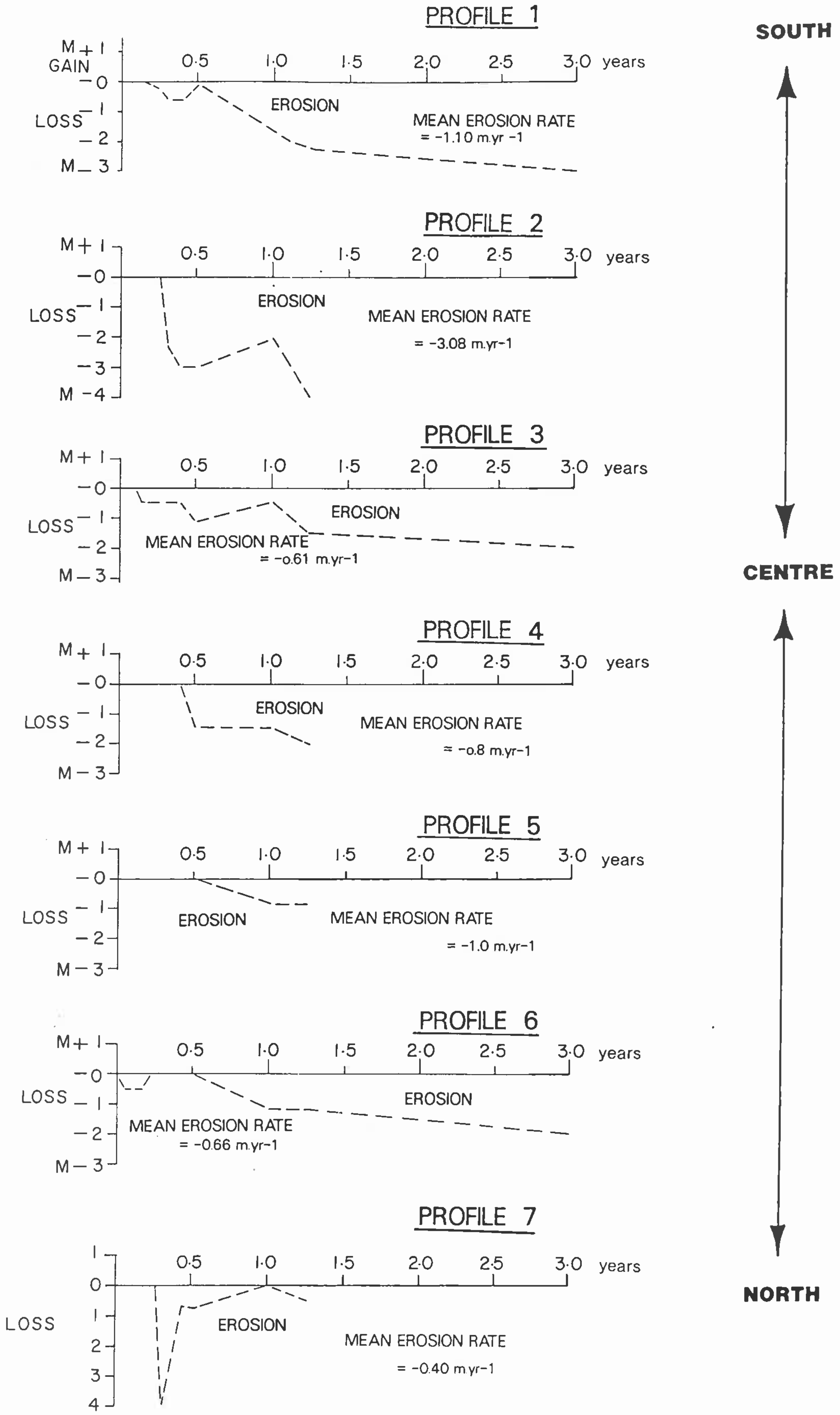
With the exception of profile 2, it can be seen that overall rates of erosion characterise the full beach length. It is thus certain even on the short record available here, that a long-term erosion problem exists at Pororari Beach. Inclusive of profile 2, the average erosion rate calculated from envelope movements is -0.93 metres per year. Exclusive of profile 2, the average reduces to -0.76 metres per year.

Several of the profiles show both positive and negative movements of the landward edge of the profile envelope, as is to be expected where a foredune is periodically eroded and then partially restored in times of beach accretion, but it is clear that such changes are second order variations on a strong underlying trend toward erosion (negative slopes of the lines). Because the plots have been presented cumulatively, the final point on each line is the net distance of retreat at the latest survey relative to the initial survey of 20-21 June 1983.

Figure 3 also reveals a weakly developed longshore pattern in erosion rates since profile 7 displays an atypical pattern of Excursion Distances. At that site, both seaward and landward displacements of the envelope are greatest and the net change is smallest. Such a pattern is to be expected adjacent to a river mouth and at the (net) downdrift end of the system. In contrast, variability of Excursion Distances is small at the (updrift) southern end of the beach and the trend toward net erosion is best defined (present in many individual surveys).

In order to further elaborate this pattern, Figure 4 has been prepared showing the longshore distribution of cumulative envelope movement at three time planes (October 1983, June 1984 and July 1986). Even mindful of the few data points available for July 1986, the figure displays clear evidence of the concentration of erosion at the southern (updrift) end of the beach and of progressive spread in chronic erosion to the remainder of the shore.

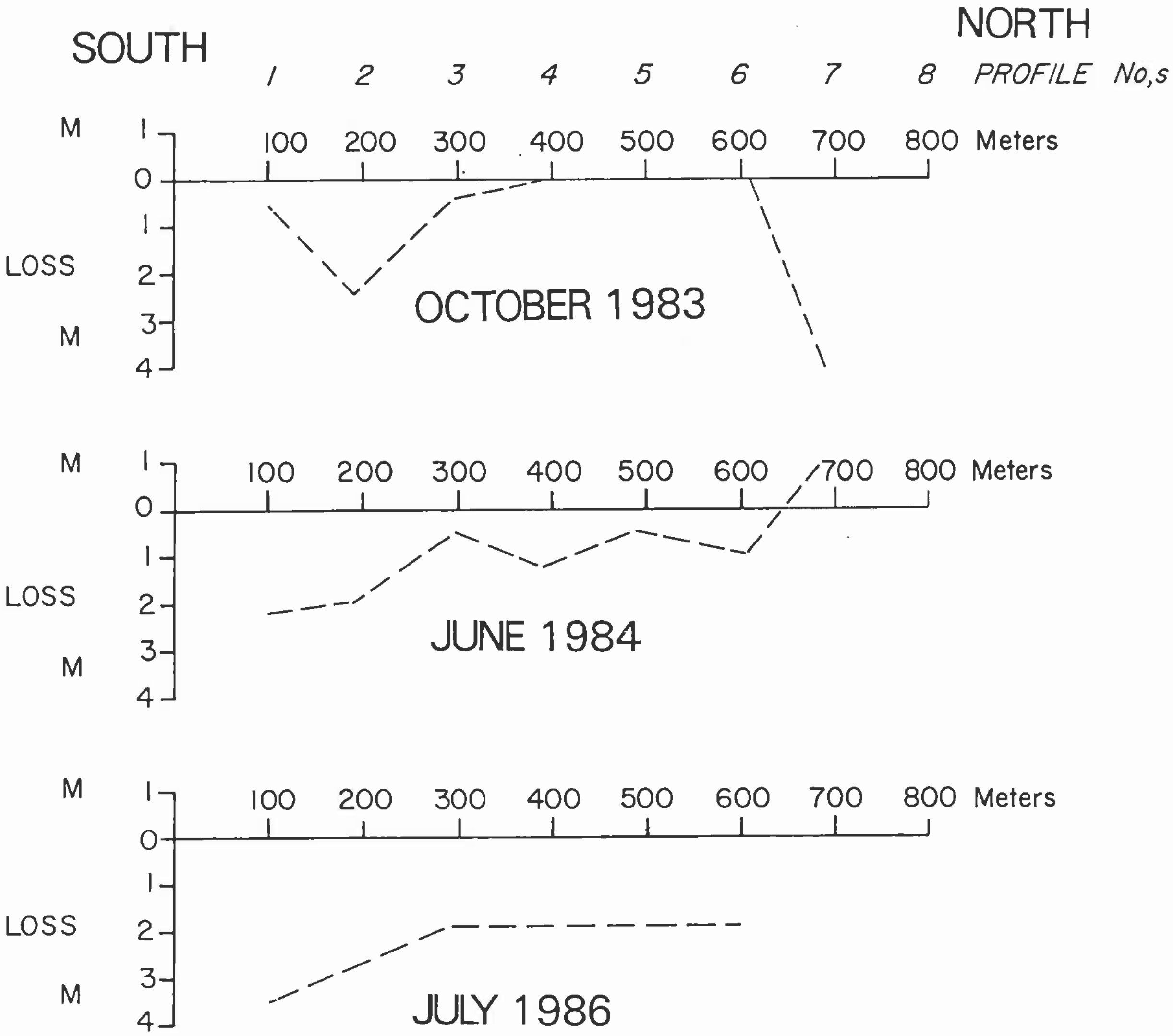
By regarding the foredune scarp/crest as being 1.5 metres high at full development and by again treating each profile as representative of half the distance to the next adjacent site, it has been possible to calculate estimates of the net sediment loss from the backshore along Punakaiki Beach. As with the short-term envelope changes, similar cautions apply to the resulting values, and the apparently anomalous nature of net erosion at profile 2 must be acknowledged.



N.B.Zero represent the dune crest or
scarp as at 20/21 June 1983

Figure 3

Cumulative excursion distances; scarp/ dune crest.



N.B. The zero line is the scarp or dune crest at 20/21 June 1983

Figure 4

Longshore cumulative excursion distances; scarp/ dune crest.

At the average annual erosion rates shown in Figure 3, the backshore losses sum a total of -1,230 cubic metres per year over the period from June 1983 to July 1986.

These net losses are, on average, some: 1,230/154,000 m3 = 0.8% of the short-term envelope change.

This confirms the view reached earlier in the report that short-term changes are much greater than can be accounted for by river sediment supply or by net erosion from the land. An alternative way in which to view the net losses calculated here is that the coastal sediment drift and the river provide enough material to satisfy 99.2% of the annual sediment demand needed to offset the energy of the Tasman Sea at Punakaiki.

From the standpoint of controlling erosion, the average erosion rate is classified as moderate when measured as horizontal retreat of the dune. In respect of the sediment budget, the annual deficit of sediment represented by loss of the foredune is not great. It therefore seems possible to consider protection techniques such as beach re-nourishment or dune reconstruction and maintenance that would both recify the deficiency of sediment supply and provide a physical, water-absorbant barrier to overtopping.

In conclusion to this section of the report, it can be seen, the certain deficiencies of the survey section of the monitoring programme have been identified. Nevertheless it has proven possible from the available data to derive estimates for both the envelope changes and positional shifts of the beach as a whole. The situation revealed is one in which Pororari Beach undergoes short-term fluctuations quite typical of open ocean sandy beaches and these have a longshore expression, the sand transport being sometimes southward and at other times northward. The net transport is northward, leaving the southern end of the beach and the adjacent sections of the settlement that are built on strongly modified and narrow beach ridges exposed to chronic erosion and to inundation. Underlying these short-term changes is a trend toward persistent landward retreat of the coast as a whole at rates determined thus far to be in the range 0.5 to 1.0 metre per year. By themselves, such rates and their associated sand volume losses are by no means insuperable problems to overcome by a range of coastal management techniques. Urgency attaches to updating and improving knowledge of these rates and their patterns along the Pororari foreshore, but an equally important matter concerns the 'Greenhouse Effect' and the scenario for rising sea-level and coastal erosion that attends it. The significance attached by D.O.C. to this matter in the context of the erosion mechanism demonstrated here may well prove to be the determining consideration in respect of coastal protection at Punakaiki. In order to facilitate discussion of this and other matters, the next section of the report reviews the options for protection strategies against what is presently known of erosion and inundation at Punakaiki.

6

COASTAL PROTECTION STRATEGIES

Table 5 presents a general model of the full range of coastal responses to hazards such as erosion and inundation. As can be seen, four main types of response are available as set out in the left hand column of the Table. The techniques available are then classified loosely into engineering and social categories for each type of adjustment.

It is evident that the first class of adjustment - adapting to the losses - is already in effect at Punakaiki since residents have sustained property damage through storm wave runup. It is not known to the writer what reliance or coverage is available from insurance sources, but whatever the case, this is clearly a limited source of redress. Clearly, loss bearing does not alter a hazard, particularly one steadily increasing in frequency and intensity as a coast erodes.

In respect of the second class of adjustments - modification of the loss potential, the obvious engineering response is relocation of those assets at risk within specified time planes and eventual abandonment of those incapable of relocation. Such a strategy may be deemed safest in the long-term, particularly in light of the 'Greenhouse' scenario, but it should be understood that this option is expensive not only in terms of the relocation itself, but in terms of loss of services and infra-structure at one site, provision of them at the other and restoration of the abandoned site to acceptable environmental standards in the context of a National Park. Also, it is possible that this option may entail problems of financial compensation.

Planning techniques are an important part of loss modification strategies. In New Zealand, building line restrictions, re-zoning and hazard zones have all been used to considerable effect to restrict the assets at risk from coastal erosion and inundation. The planning instruments and Ordinances in force at Punakaiki should be examined to determine whether or not they adequately reflect the character and extent of the hazards in the light of this report.

A further aspect of planning matters deserves particular mention. In New Zealand it is possible under a 1981 Amendment to the Local Government Act for an Authority to grant permission for construction of so-called 're-locatable' dwellings in areas known to be hazardous. Such a practice can hardly be a 'wise use' of resources under the Town and Country Planning Act and must conflict with the powers and duties charged to D.O.C. Use of this procedure could only increase the assets at risk so that it is argued here that its use be strongly disavowed at Punakaiki.

The third class of adjustments - modification of the hazard itself - is perhaps of most interest for Punakaiki Village, given the will to commit to retaining the development and the acceptance of ongoing needs for maintenance of protective works in the face of future storms and/or higher sea-levels. Solutions to erosion and inundation problems under this type of response include the full battery of coastal engineering responses (the so-called 'technological fix') as well as less well known techniques of beach renourishment and dune creation/stabilisation. The last mentioned amount to manipulation of a deficit sediment budget to offset erosion and the use of dunes to hold runup. Such techniques directly address the causes of erosion and overtopping and are generally environmentally acceptable because they result in beach or dune landscapes similar to those that occur naturally at a site. Such works also benefit adjacent areas in that as they wear down under use, their 'waste product' is sand fed to the system and that is transported to adjacent areas of beach.

Detailed consideration of design for sea-walls suitable for Punakaiki Village is neither possible here nor appropriate to the expertise of the writer. However, some requirements have been suggested here from study of the erosion processes. Since erosion is general along the beach and is ongoing, there seems little prospect for walls or revetments that protect only part of the beach. Such a structure could be readily outflanked by erosion. Similarly, an estimate has been presented here of the vertical changes in beach sand level that a revetment or wall would require to withstand (up to 2.75 metres). In addition, a structure would require to extend deeper into the beach to withstand the additional scour that occurs on the toes of walls during times of storm wave runup. At its crest, a wall or revetment would require to stop all but spray from the runup of breakers up to 4 metres high having periods of 10-12 seconds. The storm ocean water levels attending this runup may be as high as HWOST +1.5 metres, and if the structure had a design life of 100 years, it may be a requirement to allow further for up to +1.0 metre sea-level rise. Viewed in these terms, the requirements for walls or revetments assume large proportions as engineering works and as financial committments (ignoring as well the inevitable committments to ongoing maintenance). In the alternative to full, formal protection works as discussed in general terms here, it is possible to design and construct less comprehensive works with appropriate reductions in the protection gained, the duration of protection and increases in the consequences of failure.

As well as competently designed and constructed protection works, it is also necessary to consider informal and individual attempts at protection that are inevitably made by property owners in notional defence of their homes. Such works are most often incompetently designed, poorly constructed, badly integrated with the coast (if at all), and they - not infrequently - fail. New Zealanders have been no less inventive in their uses of any materials to hand (eg: trees, cuttings, car tyres, poles, rails, car bodies, concrete or other rubble) to combat coastal erosion than they have in other fields. At best, such works are ineffective in controlling erosion and/or inundation and they contribute to a loss of aesthetic quality in the beach (often polluting it with a variety of exotic and unsavoury materials).

At worst, such structures actually intensify erosion by increasing turbulence and scour during storm wave runup. Quite commonly, because such works extend along individual property boundaries and work varies from lot to lot, the effect of a home-grown work can be to greatly magnify erosion and/or inundation in neighbouring properties. In such cases, grounds for action in law may be found to exist.

For all these reasons, informal attempts at protection should be strongly discouraged and preferably prevented at Punakaiki Village. Whatever work is carried out should satisfy well-established principles of coastal protection and must be unified over the property frontages concerned.

In view of the erosion rates documented here, and, setting aside for the moment, concerns about 'Greenhouse' and their expression in D.O.C. policy, beach renourishment and associated dune reconstruction are techniques that offer the prospect of significant relief, particularly from overtopping at Punakaiki. However, their use, especially in the southern part of the settlement where the hazards are most severe, would require the creation of space within which to develop a scheme. Presently, the eroding remanant dune has almost retreated as far as the road and the road space would be

TABLE 5: THEORETICAL RANGE OF ADJUSTMENTS TO COASTAL EROSION

CLASS OF ADJUSTMENTS	ENGINEERING	SOCIAL
Adjustments that allow adaptation to the losses		Loss bearing Insurance Relief and Rehabilitation
Adjustments that Modify Loss Potential	Move endangered structures	Storm warning Evacuation Coastal zoning Building restrictions Public purchase of endangered areas
Adjustments that Modify the Hazard	Seawalls/bulkheads/ revetments Beach nourishment Private protective structures eg: rubble filled drums/car tyres	Dune stabilisation
Adjustments that affect the cause	Sand by passing Removal of obstacles to the passage of river silt (Example: dams)	Prevent beach excavation and harbour dredging

SOURCE: Sinnathamby (1981)

required as the base for a dune. Should such a scheme be comtemplated it would again require to be comprehensive in its coverage of properties, it would necessitate location of a suitable source of sediment (such as the Pororari River) and associated planting and fencing plans. It would be intended that such a dune would progressively erode so that it would require periodic maintenance 'topping up' and planting. It is also quite feasible to utilise such a scheme as shorter term protection within a longer term plan for relocation of the settlement.

The final class of adjustment shown in Table 4 concerns modification of the hazard causes, particularly in cases affected by man-made obstacles to the longshore flow of sediments. Its application at Punakaiki is limited to the prospects for relocation of sand from the downdrift northern end of the beach to the updrift southern end as a means of ensuring an adequate sediment budget within the short-term envelope. Such a 'beach grooming' operation would be expensive and may be objectionable on environmental as well as cost grounds. Insufficient data exist in the present survey results to fully consider this option. Under social or management techniques it should clearly be an aim at Punakaiki to prevent any and all removal of sand from the beach system or the associated foredune. A similar prohibition should apply to willful disturbance of the foredune vegetation for any purpose other than planned construction of a protection scheme.

Finally in this section of the report, it should be evident from the above that it is possible to consider a mixed approach to hazard solution at Punakaiki, ie: a comprehensive mix of planning and engineering controls. An approach combining restrictions on further development and controls on activities known to reduce beach stability with remedial dune and beach restoration works for short and medium-term protection could be adopted as measures preparatory to eventual planned, orderly relocation. Whether relocation would occur in whole or in part for the settlement is a matter that can be decided in the light of ongoing monitoring and experience at the site. This type of solution is the preference of the writer.

Decisions as to strategy that omit any committment to structural works or to dune restoration/beach nourishment will require early relocation or abandonment for buildings presently subject to inundation because the ongoing nature of erosion ensures that wave impact damage and water damage will increase in both frequency and severity. The risk to life escalates similarly.

7

CONCLUSIONS

This report has demonstrated the value of initiating and maintaining an ongoing shoreline monitoring programme at Punakaiki Village. It has also demonstrated some areas in which the data base in notably deficient, particularly in response to the frequency and coverage of the profile re-surveys and to compiling the information obtained.

Some important aspects of the storms that cause erosion and inundation have been identified from a limited analysis of the larege available body of LEO data. Similarly, some first estimates of short-term beach envelope change have been derived, and the existence of underlying, persistent erosional retreat of the beach has been demonstrated and quantified in a manner that can be soundly related to discussion of a range of possible responses. A full range of potential responses has been reviewed in the context of experience at Punakaiki and several matters have been detailed for early action as well as those that must be resolved by wider discussion.

That net long-term erosion exists at Punakaiki is clear so that the outlook is for steady intensification of the frequency and severity of inundation hazards, regarless of consideration of the 'Greenhouse Effect' and its associated anticipated shoreline and sea-level effects.

8

RECOMMENDATIONS

The following matters arise from the report and are offered as lines of early action by Department of Conservation:-

1. Following finalisation of this report, it should be circulated widely with ample opportunity for discussion among the interested and affected parties at Punakaiki Village.

2. At the earliest convenience, there should be evaluation of the re-survey of all seven beach profiles on 31 March 1988 to update and further refine the erosion rates and patterns.

3. Profile data held by Westland Catchment Board should be re-plotted at 2.5 times vertical exaggeration and overlaid on the earlier Lands and Survey information. The survey of 31 March 1988 and all future surveys should be so plotted. For each profile site an Excursion Distance Analysis plot of the type presented here should be maintained and updated.

4. Future profile surveys should be carried out as soon as is practicable after major erosion and/or inundation events.

5. The LEO observation programme should be continued and extended to full documentation during major storms using the same format and variables supplemented by sketches, notes and photographs.

6. Information to hand on the heights and spatial distributions of past overtopping and runup inundation, events should be co-ordinated and documented as a file separate from the LEO data.

7. Planning controls and Ordinances relating to land-use at Punakaiki should be reviewed in the light of this report, including existing hazard zoning.

8. As an aid to co-ordinated discussion, each of the interested parties at Punakaiki might be asked to prepare a summary of its responsibilities and views according to the classification set out here in Table 5. Cross-tabulation of the results would readily identify possibilities for co-operative activity as well as identify areas of conflict and difference of preferred approach.

9. Early consideration should be given to policy and action in relation to individual, informal attempts at coastal protection works along the sea frontage of the village.

9

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POST SCRIPT

Evaluation of Pororari Beach profile resurveys of 1988 and 1989

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Summary Analysis of additional Pororari Beach profile data from 1988 and 1989 gives rates of erosion lower than those calculated from earlier data by Dr R M Kirk, averaging -0.64m/yr (or $-647m^3$/yr of backshore sediment) over the whole beach.

In accordance with Recommendation No 2 in the report on coastal erosion and inundation at Pororari Beach, by Dr R M Kirk, the following report evaluates subsequent beach profile surveys.

In the survey of 31 March 1988, profiles measured at sites 5 and 7 could not be accurately related back to previous surveys. Four of the profiles (Nos 2-5) were again resurveyed on 4 April 1989. The results of these surveys are shown with previous data from Dr Kirk's report in Figures PS1 and PS2.

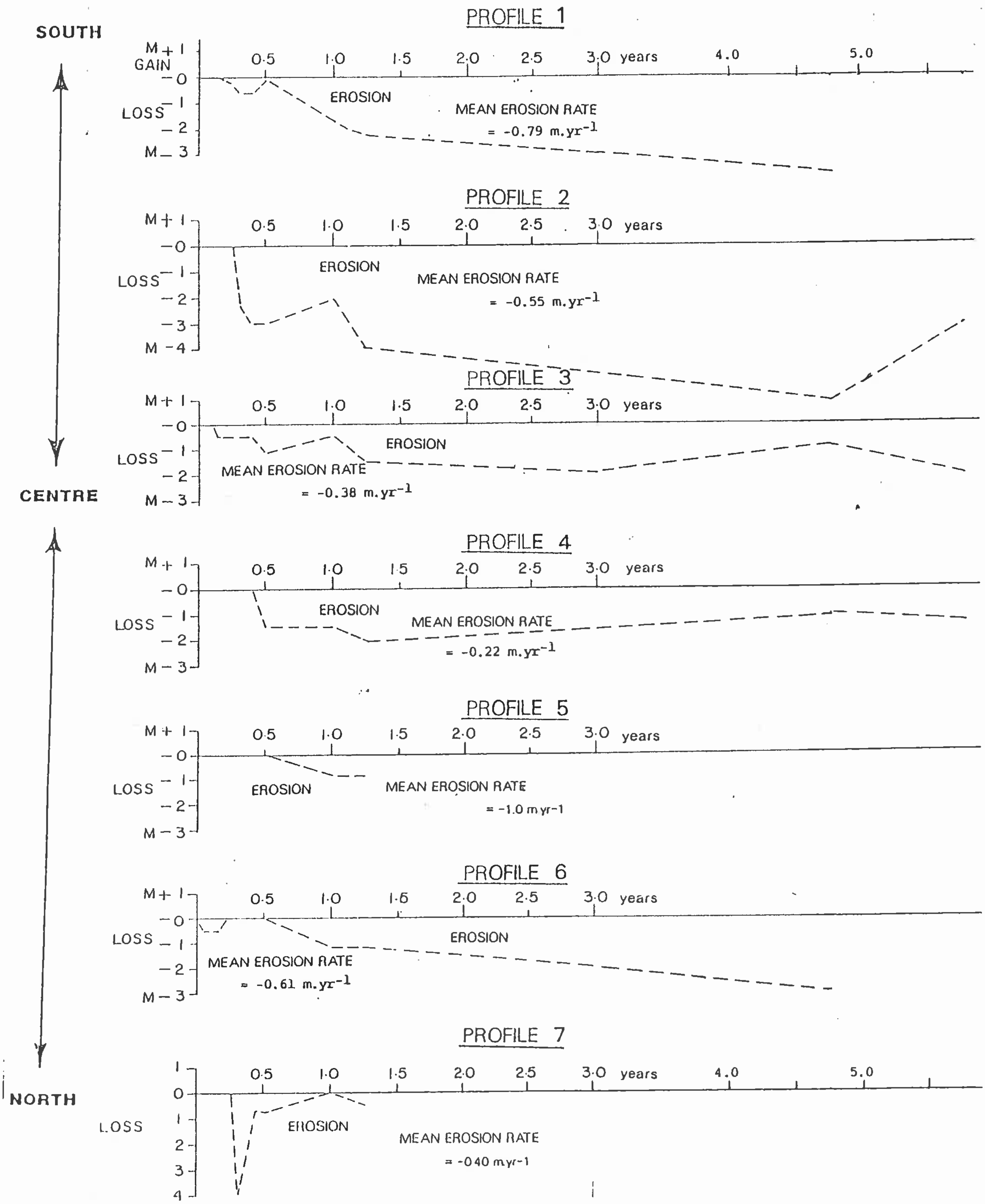
New mean erosion rates have been calculated for each profile and are also included in the diagram.

Again, interpretation of the results is hindered by the relatively long periods between surveys. However, from the data available, it appears that the erosion trend is not as severe as the earlier measurements suggested. It can also be seen that the apparent anomaly at profile 2 that was of concern to Dr Kirk may indeed indicate that an extraordinary level of erosion occurred there in late 1983. However, the site appears to have since recovered, and has in fact shown considerable accretion (build-up of sediment) over the past year.

It also appears from the two figures that the middle of the beach (near profiles 3 and 4) is in a less erosive state than the southern and northern ends. The smaller fluctuations and flatter trends of these two profiles in Figure PS1 suggest that the middle section of the beach is more stable in both the short term (Over storm events) and longer term (over years).

By the same methods of analysis used by Dr Kirk, an average erosion rate for the whole beach and an estimate of the net sediment loss from the backshore can be obtained using these new results.

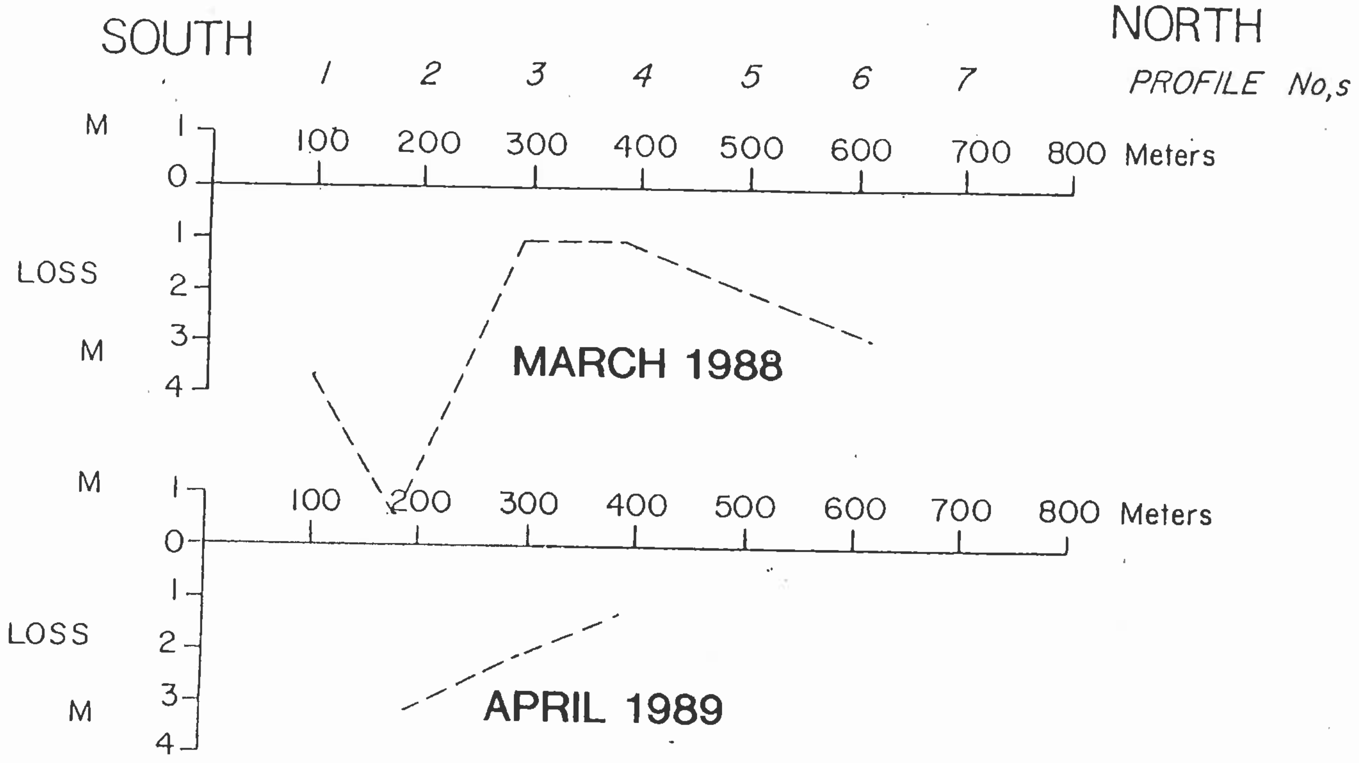
Mean erosion rate at Pororari Beach = $-0.64m\ yr^{-1}$
Net loss of backshore sediment = $-647m^3\ yr^{-1}$



N.B.Zero represent the dune crest or
scarp as at 20/21 June 1983

Figure PS1

Cumulative excursion distances;
scarp/ dune crest.



N.B. The zero line is the scarp or dune crest at 20/21 June 1983

Figure PS2

Longshore cumulative excursion distances; scarp/ dune crest.