CONSERVATION
TE PAPA ATAWHAI

SCIENCE & RESEARCH SERIES NO. 55

A STANDARDISED COASTAL SENSITIVITY INDEX BASED ON AN INITIAL FRAMEWORK FOR PHYSICAL COASTAL HAZARDS INFORMATION

by

Jeremy Gibb, Angela Sheffield, and Gregory Foster

SCIENCE & RESEARCH SERIES N0.55

A STANDARDISED COASTAL SENSITIVITY INDEX BASED ON AN INITIAL FRAMEWORK FOR PHYSICAL COASTAL HAZARDS INFORMATION

by

Jeremy Gibb, Angela Sheffield, and Gregory Foster

Published by
Head Office,
Department of Conservation,
PO Box 10-420,
Wellington,
New Zealand

ISSN 0113-3713
ISBN 0-478-01453-8

Edited for publication by
Ian Mackenzie

National Library of New Cataloguing-in-Publication data

Gibb, Jeremy G. (Jeremy Galwey), 1939-
A standardised coastal sensitivity index based on an initial framework for physical
coastal hazards information / by Jeremy Gibb, Angela Sheffield, and Gregory Foster.
Wellington, N.Z. : Head Office,
Dept. of Conservation, c1992
1 v. (Science research series, 0113-3713 ; no. 55) Includes bibliographical references.
ISBN 0-478-01453-8
1. Coasts–New Zealand–Classification. 2. Coastal ecology–New Zealand–Classification. 3. Coastal zone
management–New Zealand
I. Sheffield, Angela Tania. II. Foster, Gregory Andrew. III. New Zealand
Dept. of Conservation. IV. Title. V. Series: Science
research series; no. 55.
333.917012 zbn92-115632

Keywords: coastal processes, erosion, planning, sea-levels, New Zealand

CONTENTS

A STANDARDISED COASTAL INDEX BASED ON AN INITIAL FRAMEWORK FOR PHYSICAL COASTAL HAZARDS INFORMATION

by
Jeremy Gibb, Angela Sheffield, and Gregory Foster
Coastal Resource Inventory Task Force, Department of Conservation, Wellington

ABSTRACT

A Coastal Sensitivity Index (CSI), based on an initial framework for physical coastal hazards information, is described including it's development and application. The CSI provides a standardised method for assessing the relative sensitivity of areas of the New Zealand coastline to selected physical processes that may become natural hazards. CSI’s are derived by numerically integrating 8 variables which include elevation, maximum storm wave run-up level, gradient, maximum tsunami wave height, lithology, natural landform, horizontal shoreline trend, and short-term shoreline fluctuations. Each variable representing the end effects of many interacting processes is ranked into 5 sensitivity classes (1 to 5) in a matrix and a specific CSI is derived by adding the class allocated to each of the 8 variables for a coastal site. CSI’s potentially range from a minimum of 8 (very low sensitivity) to a maximum of 40 (very high sensitivity), the classes ranging from very low (8-13), low (14-20), medium (21-27), high (28-34), to very high (35-40).

During the development and standardising of the technique 113 field sites were tested, representing the diversity of open-exposed to sheltered estuarine and harbour coastlines. For all these sites good quality data were available, demonstrating that the internally consistent CSI technique may be confidently applied to most coastlines provided reliable, professionally defensible information exists for each of the 8 variables.

Coastlines with very high CSI’s are typically low-lying coastal landforms of unconsolidated sediments with a history of shoreline retreat, high to very high shoreline fluctuations, and inundation from storm wave run-up and tsunami. Coastlines with very low CSI's are typically hard rock landforms of steep elevation, with a history of low to very low shoreline movements and inundation from the sea. The technique is rapid and cost effective, providing a mechanism for achieving national consistency whilst accommodating local and regional variations.

EXECUTIVE SUMMARY

The Resource Management Act 1991 establishes a partnership for coastal management between the Minister of Conservation as the Crown's representative and regional and district councils. Under the Act regional councils are responsible along with the Minister of Conservation for controlling any actual or potential effects of the use, development, or protection of the land within the coastal marine area including the avoidance and mitigation of natural hazards. Outside of Restricted Coastal Activities the Minister's main role is that of policy setting whilst Regional Councils are responsible for day-to-day licensing.

The shared responsibilities of both central and local government suggest a need for nationally consistent frameworks for information gathering. Equally important, there is a need to provide assessments rapidly especially of the sensitivity of the coastal environment to natural hazards.

In this study a Coastal Sensitivity Index (CSI) has been developed and rigorously tested to identify the relative sensitivity of coastal areas to existing physical processes which may become hazardous to human property and values. The framework of the CSI is the Coastal Hazards Database, comprising the eight variables of elevation, storm wave up level, gradient, tsunami, lithology, landform, horizontal shoreline trend and short-term shoreline fluctuations. These variables are ranked into 5 sensitivity classes from Very Low to Very High sensitivity, and integrated by a simple numerical method to generate the CSI. Projected sea-level rise from an enhanced Greenhouse Effect was also considered.

During the development, testing and standardising of the technique, a total of 113 field sites were investigated representing the range of open exposed coastal types to sheltered estuarine and harbour conditions. The internally consistent CSI technique may be confidently applied to all parts of the New Zealand coast provided each of the eight variables is based on a reliable, professionally defensible database.

Coastlines with Very High Sensitivity were characterised by being low-lying, unconsolidated sand, with a history of inundation from both tsunami and storm wave run-up, and instability from both short and long term erosion. Conversely, coastlines with Very Low Sensitivity were characterised by high elevation, consolidated hard rock, with a history of minimal inundation and erosion, including landslip.

The CSI is of practical use to coastal planners and managers because it provides an important first step by identifying sensitive coastal areas which may require more detailed monitoring, especially in areas of proposed development, or areas of conservation value. The techniques set out in this report provide a useful framework and guidelines for coastal management agencies to establish a comprehensive information network about the coast, and establish priorities for continued monitoring and further investigations.

1. INTRODUCTION

New Zealand coastal history records many instances of a loss of human property and values (both natural and commercial) as a result of coastal processes (Plate 1). Wise coastal management needs pertinent, accessible and understandable information, which is preferably collected in a nationally consistent framework.

The Resource Management Act 1991, establishes a partnership for coastal management between the Minister of Conservation as the Crown's representative and regional and district councils. Under Section 30 of the Act, regional councils shall, amongst other functions, "control the use of land for the purpose of… the avoidance and mitigation of natural hazards." For the coastal marine area seaward of mean high water springs (MHWS) that function is shared under Section 30 with the Minister of Conservation with respect to the control of… "any actual or potential effects of use, development, or protection of land, including the avoidance or mitigation of natural hazards…".

Under Section 35 of the Resource Management Act 1991 all local authorities are obliged to gather information and monitor… "the state of the whole or any part of the environment of it's region or district…". The Director-General of Conservation has a discretionary function toward the gathering of information under Section 53 of the Conservation Act 1987.

Plate 1 Erosion and loss of residential property at the southern end of Wainui Beach, Gisborne, 23 July 1992.

At present both local authorities and the Department of Conservation hold, gather and disseminate selected information on physical coastal processes. However, the information is collected to different standards in a variety of formats, and is often difficult to access. Further, no framework for physical coastal hazards information presently exists in New Zealand. There is clearly a need for rapid, cost effective assessments of natural coastal hazards (erosion, landslip, flooding), and at present no single method combines information in a simple yet comprehensive form.

To meet this need the Coastal Resource Inventory Taskforce of the Department of Conservation has developed and tested an initial framework to collect and store information about New Zealand coastal areas in a Coastal Hazards Database. The Taskforce have created a simple first-step technique to assess the sensitivity of those areas to change. The Coastal Sensitivity Index (CSI) described here integrates information from eight physical parameters ranked into five classes from very low to very high sensitivity. This provides an estimation of the sensitivity of the coast to physical change **regardless of the value placed on the resources** by property owners, Maori or conservation/ recreation groups.

As the technique is internally consistent it is possible to compare the relative sensitivity of coasts at local, regional or national scales to potentially hazardous processes. The technique also has the potential to rapidly assess which areas within a region are most sensitive to physical processes, thus providing an early warning mechanism to monitor highly sensitive areas.

A projected acceleration in sea-level rise from the enhanced greenhouse effect has the potential to increase the CSI for certain parts of the coast. Consideration was also given to this during the development of the technique.

Although specific areas of the coastline can be identified as being at risk to certain coastal hazards through coastal hazard zone mapping (Gibb 1981), there is no standardised method for estimating just which areas are at greater risk. The East Otago Coastal Hazard Mapping discussion document (Otago Regional Council 1991)states "…the desired information for this study does not fully exist or is patchy in its coverage. Further research would be necessary to build an adequate information base for determining existing risk areas and predicting future areas." Hume *et al.* (1992) in their review of New Zealand coastal oceanography and sedimentology have also stated that "Coastal research needs…. a quantitative approach to assessing storm surge and tsunami hazards into coastal hazard surveys and coastal management plans, (and) to set these hazards in a realistic perspective against coastal erosion which tends to have dominated coastal hazards assessments to date." The Coastal Hazards Database and Coastal Sensitivity Index described below contribute towards resolving these issues.

1.1 Study objectives

The prime objectives of this study were to:

- Develop a standardised method by which the relative sensitivity of coastal areas to a specified range of existing physical processes could be rapidly assessed

- Provide guidelines to use the technique with maximum consistency in order to obtain repeatable results

- Establish an initial framework for a "Coastal Hazards Database" in which the parameters are collected in a nationally and regionally consistent manner

- Assess whether an enhanced greenhouse induced sea-level rise may be incorporated into the Coastal Sensitivity Index technique.

1.2 Document outline

This report is divided into five main sections:

1. The introduction and objectives.
2. The development of the Coastal Sensitivity Index matrix.
3. The development of the Coastal Sensitivity Index.
4. Application of the technique, field procedures, and case studies.
5. Conclusions.

2. DEVELOPMENT OF THE COASTAL SENSITIVITY INDEX MATRIX

Outline of the concept by Gornitz and Kanciruk (1989)

The concept of a technique to combine coastal information arose from a scheme designed by Gornitz and Kanciruk (1989) and Gornitz (1991) to identify which areas of the United States coastline would be at risk from a rise in sea-level associated with enhanced greenhouse warming. The technique is set out in Table 1. The authors noted that the vulnerability of the coast to changing sea-level would be non-uniform, being dependent on a number of variables -relief, rock type, landform, vertical movement or local relative sea-level change, shoreline

Table 1 The risk classes defined by and Kanciruk (1989) and Gornitz (1991).

	Rank				
Variable	**Very low 1**	**Low 2**	**Moderate 3**	**High 4**	**Very high risk 5**
Relief (m)	>/= 30.1	20.1-30.0	10.1-20.0	5.1-10.0	0-5.0
Rock type (relative resistance to erosion)	Plutonic Volcanic (lava) High-medium grade metamorphics	Low-grade metamor. Sandstone and conglomerate (well cemented)	Most sedimentary rocks.	Coarse and/or poorly sorted unconsolidated sediments	Fine unconsolidated sediments Volcanic ash
Landform	Rocky, cliffed coasts Fiords Fiards	Medium cliffs Indented coasts	Low cliffs Glacial drift Salt marsh Coral reefs Mangrove	Beaches (pebbles) Estuary Lagoon Alluvial plains	Barrier beaches Beaches (sand) Mudflats Deltas
Vertical movement (RSL change) (mm/year)	</= -1.1	-1 to 0.99	1.0 to 2.0	2.1 to 4.0	>/= 4.1
Shoreline displacement (m/year)	>/= 2.1 Accretion	1.0 to 2.0	-1.0 to 1.0 Stable	-1.1 to -2.0	</= -2.0 Erosion
Tidal range (m) (mean)	</= 0.99 Microtidal	1.0 to 1.9	2.0 to 4.0 Mesotidal	4.1 to 6.0	>/= 6.1 Macrotidal
Wave height (m) (max.)	0 to 2.9	3.0 to 4.9	5.0 to 5.9	6.0 to 6.9	>/= 7.0

C.V.I. formula after Gornitz (1991) using the square root of the geometric mean.

$$CVI = \sqrt{\frac{1}{n}(a_1 \times a_2 \times \ldots \times a_n)}$$

where a_1 to a_n = the variables contained in the table above; n = the number of variables.

displacement, tidal range and maximum wave height. Measurements of the actual coastal conditions were assigned a rating ranging from very low (1)to very high (5) and were combined using an equation to generate a number termed the Coastal Vulnerability Index (CVI), where vulnerability is defined as the liability of the shore to respond adversely to a hazard. Theoretically, the higher the rating the more vulnerable the coast. Further hazard assessment terminology is contained in Appendix 1.

In contrast to this the main aim of the New Zealand CSI was to assess the sensitivity of the coast to **existing** physical processes which can become hazards to human property and values. The potential hazard of sea-level rise was considered once the current processes were assessed (see section 5.2). In the process of adaptation to New Zealand coastal conditions the technique lost all similarity to the Gornitz and Kanciruk model. Departures from their work included the number and choice of variables, the equation used to integrate the data, and the scale of coastline under consideration.

Evolution of the matrix during the field phase

The technique evolved through being thoroughly tested on 113 sites, representing the diversity of open-exposed to sheltered estuarine and harbour coastlines (Figure 1). After each phase of field work, discussion and modification of the technique occurred. Consultation was sought from specialists from universities, government agencies and the Department of Conservation, detailed feedback from individuals within these organisations being acted upon. During the development stage the technique was presented to the Canterbury Coastal Research Group (27 May 1992) where valuable discussion raised many valid points.

As part of the development process, field work was undertaken to test the applicability of the data matrix to field conditions, and to make adjustments where necessary to matrix components. The table in Appendix 3 is a version composed of all 13 variables actually tested in the field, included to document the modification carried out during this developmental phase.

The Wairarapa coast was the first area in which the matrix was tested, and the following problems were identified and resolved:

- The datum for measuring elevation was selected as MHWS to enable measurement during all stages of the tide.

- Storm surge and maximum wave height were concluded to result in storm wave run-up.

- Tsunamis were initially considered impractical to include due to the lack of complete data coverage for New Zealand but were later reinstated owing to demand for tsunami information to be included.

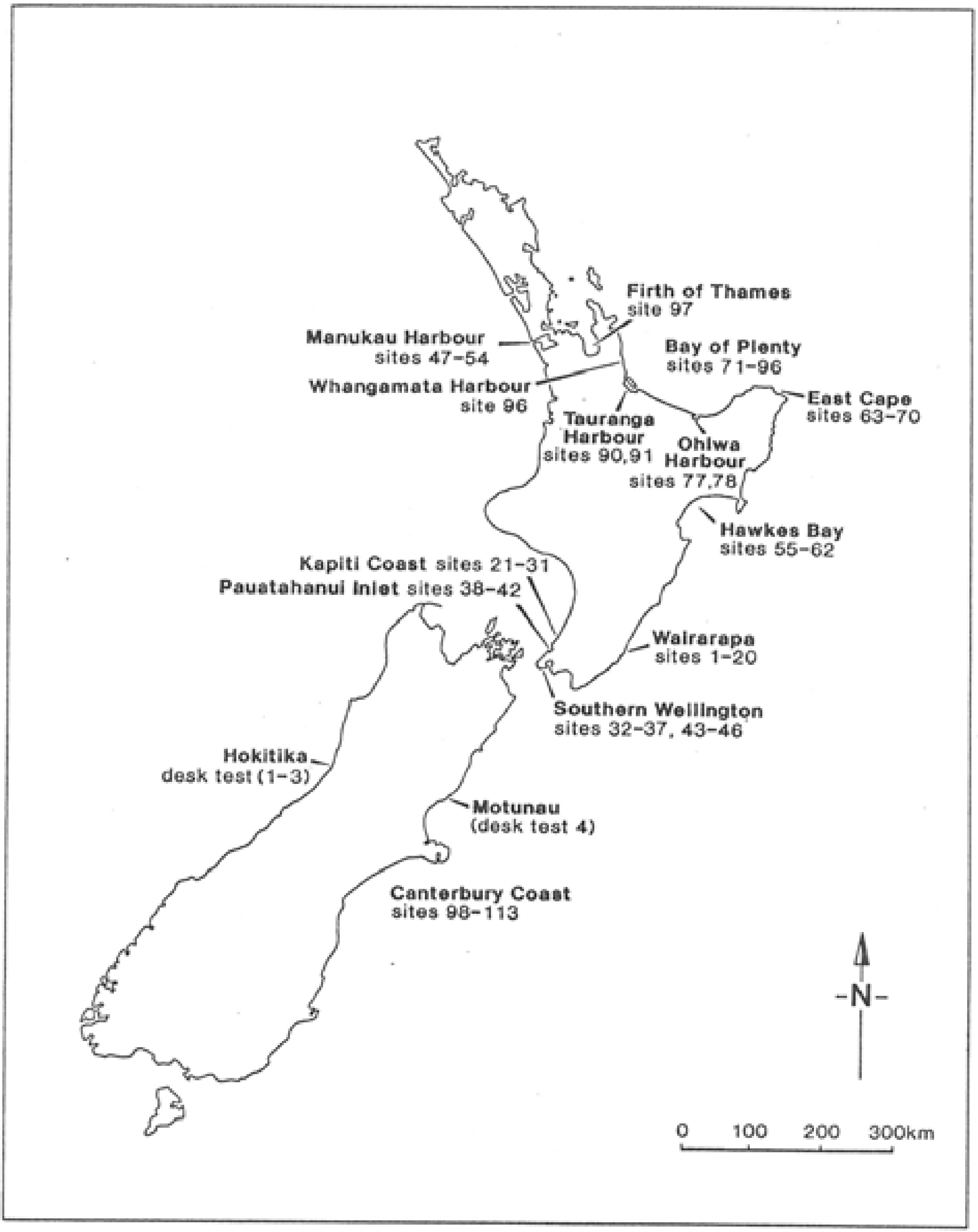


Figure 1 The site numbers and localities of both exposed and sheltered test area visited during the development and testing of the Coastal Sensitivity Index (CSI).

- It was confirmed that the lithology that controls the horizontal trend rather than underlying basement materials was assessed, (e.g., when gravels are overlying a shore platform it is the lithology of the platform which is assessed).

- Soft rock cliffs and platforms were adjusted from medium to high sensitivity owing to their relatively high erosion rates.
- Colluvium was added to the lithology variable to account for landslip debris.

- The position and horizontal trend of river mouths were concluded to reflect the horizontal trend of the adjoining coast.

- The problems of assessing short-term fluctuation of cliffs (taken as the maximum slump) and gradient (assessed after determining the effect of inundation) were overcome.

During field work around Wellington, the issue of engineering structures arose, and it was decided that the CSI technique applied only to natural coasts, and that it may be necessary to develop a separate system to assess areas with coastal protection works. Field testing of sheltered, estuarine conditions around the Manukau Harbour in Franklin District led to the inclusion of relict dunes and beach sands.

Hawkes Bay field testing led to concerns about how to treat landslide areas. It was decided to acknowledge these for further investigation after discussions with Dr D. Bell of the Geology Department, University of Canterbury.

East Cape and the Bay of Plenty enabled further testing on open coastlines which lead to further refinements including:

- Resolving the problem of assessing elevation on steep, gravel beaches such as at Torere
- Consideration of ignimbrites on the coast which was resolved after discussions with Dr R. Briggs (Earth Science Department, University of Waikato)

- Saltmarshes and mangroves were included to allow assessment of these landform types in harbours

- The use of beach cross-section data for assessing heights and gradients where these are available was reinforced

- Overtopping was removed after difficulties in making accurate assessments of water depth involved or using an area of inundation

- The vertical trend variable was also removed after difficulties of separating Late Quaternary uplift and downdrop rates with local relative rates of sea-level rise averaged over the last 90 years around New Zealand.

2.1 Selection of the Coastal Sensitivity Index variables

The field testing process enabled an assessment to be made of the many variables with potential to be included, and all are discussed below. It became clear during field testing that in the interests of developing a technique designed for rapid field assessment, it was the **end effects** which were of importance. For example, tidal range, wave height and storm surge were originally considered individually, yet it is the combination of these and other parameters which culminate in the maximum storm wave run-up level. Similarly, the horizontal trend is considered the resultant of such parameters as sediment budget, lithology, vegetation and landslip. Hence, maximum storm wave run-up level and horizontal trend are discussed below as **actual variables,** whereas tidal range, wave height and storm surge, sediment budget, vegetation and landslip are then discussed as **contributing** factors.

The theoretical background, and development and placement of the boundaries for each of the selected variables, followed by guidelines to users in the field are included in this section, so that all information relevant to each variable is contained within one place.

2.1.1 Elevation

Elevation is the height of the immediate coastline, or first line of defence in metres above Mean High Water Spring (MHWS), and expresses the sensitivity of the immediate area to inundation. Elevation is considered an important variable because sections of coastline which are at lower elevations, (i.e., a few metres above sea-level), are more sensitive to inundation effects than more elevated areas.

During initial field work in the Wairarapa, MHWS was selected as the survey datum as Mean Sea Level (MSL) could not be reached practically at most stages of the tide. MHWS is also used as a datum for worst case situations in storm run-up studies, and as the landward boundary to define the coastal marine area under the Resource Management Act 1991.

Boundaries in the matrix were derived from heights of features along the New Zealand coast, with lower areas (Onepoto 1.6 m, and Hicks Bay 0.8 m, East Cape) being more sensitive than higher cliffed areas (Wairarapa and Canterbury coasts have cliffs over 20 m above MHWS). The divisions between the values are not equal, decreasing with increasing sensitivity reflecting that areas at lower elevation are more susceptible to inundation.

Class	1	2	3	4	5
Elevation above MHWS (m)	>20.0	20.0 -10.1	10.0 -5.1	5.0 -2.0	<2.0

User guidelines

The lowest points along foredunes are the most sensitive to inundation, scour and wind blow-out if unprotected. These areas should be considered when assessing the elevation, therefore during the development of the technique a CSI was carried out on both the average dune height and these lower areas to observe the change in CSI and to compare the values obtained for lower and higher CSIs in other areas. The user is therefore encouraged to test both the average height, and other areas of possible concern. The height of the vegetated berm, crest of foredune, or top of the sea cliff is measured, and can be derived from:

1. Spot heights, contours or survey cross-sections (Figure 2). These are the most accurate forms of data obtainable to use. Normally survey heights are in terms of MSL so that the difference in height between MSL and MHWS derived from the New Zealand tide tables must be subtracted from such heights.

2. Field observation. MHWS can be visually estimated from flotsam lines known also as the "wetted line" (Gibb 1976b) where wave run-up is minimal (Figure 3). Estimations are more accurate during spring tidal periods. The sea horizon technique involving aligning the sea horizon with measurements on a survey staff, can also be used as an estimation of height during field work. It is the still water level of MHWS that field measurements are made from.

Very steep beaches

Elevation may be over-estimated on very steep beaches where waves run up to a higher level on the beach than the still water level of MHWS (Figure 4, Plate 2), when compared to lower gradient beaches where the wetted line provides a good estimate.

Plate 2 Photo taken 2 April 1992 looking north along the 6 m-high berm crest of the very steep gravel beach at Torere, eastern Bay of Plenty.

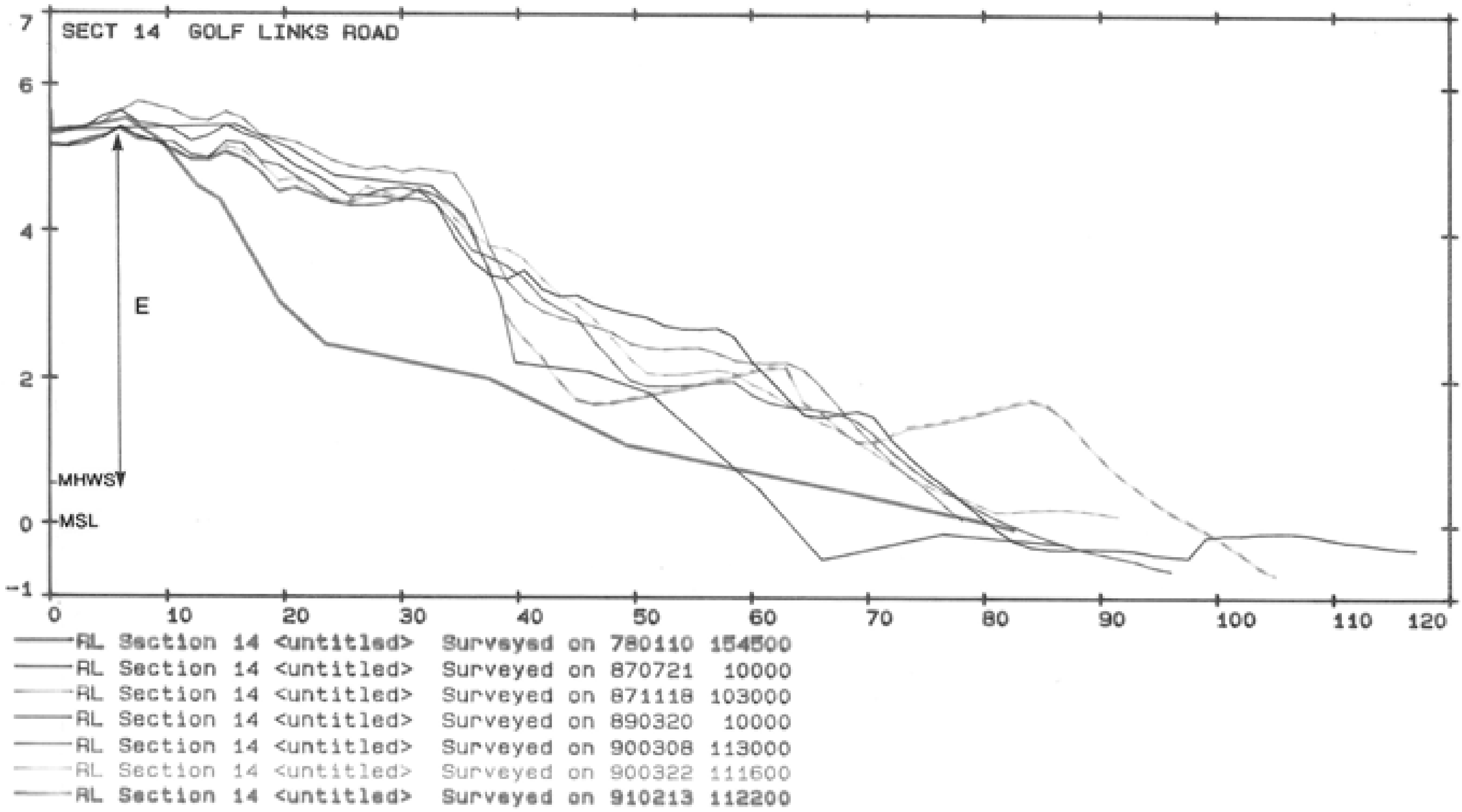


Figure 2 An example of a beach cross-section from Golf Links Road, Whakatane, supplied by the Bay of Plenty Regional Council, showing how elevation (E) is measured in relation to MHWS.

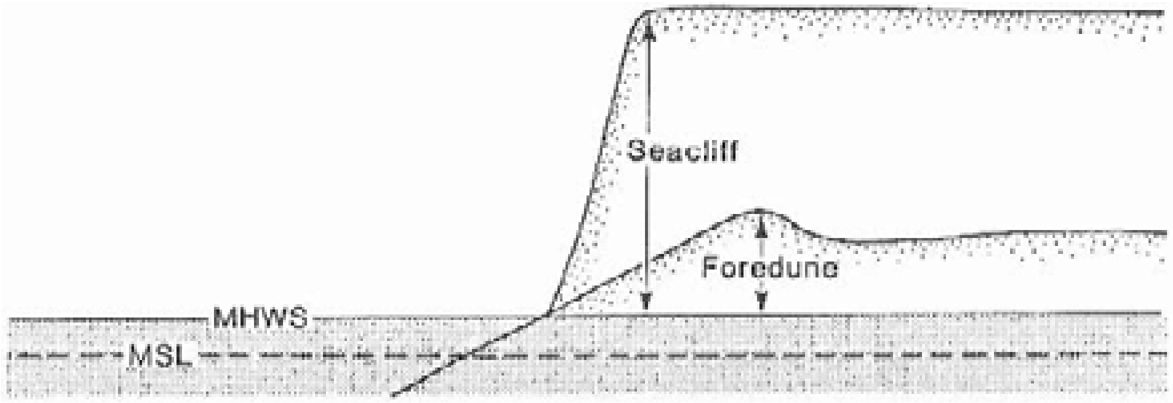


Figure 3 Diagram showing measurement of elevation in metres above MHWS

2.1.2 Maximum storm wave run-up level

In the absence of the need for the collection of expensive detailed wave records, and noting the current lack of precise wave and storm surge data on a nationwide basis (Hume *et* al. 1992), separate wave height and storm surge variables were not used. This does not imply that wave records should not be obtained because this information is required to provide a

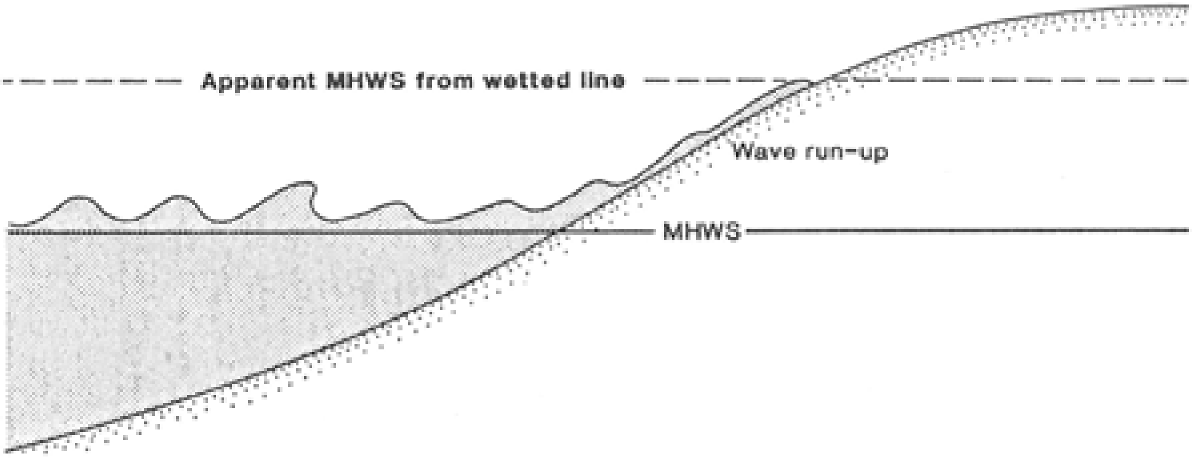


Figure 4 An estimation of mean high water spring level on steep beaches where the "wetted line" is higher than the actual (still water) level required.

basic understanding of coastal conditions. Instead it has been noted by Frisby and Goldberg (1981) that during storms a combination of barometric set-up, wind set-up, wave set-up, predicted astronomical tide level, and wave run-up contribute to a maximum level of storm wave run-up (Figure 5).

This variable has been included as it is a major contributor to coastal erosion and flooding. Inundation may result when the energy of the sea is greater than that absorbed by the beach profile, resulting in erosion and beach failure by the removal of sediment exposing the hinterland to attack, or when a beach is overtopped by storm wave run-up (Kirk and Todd 1992). For example, a swale behind sand dunes is more sensitive to overtopping from storm wave run-up than a cliff with an elevation greater than the storm wave run-up level.

Boundaries within the matrix were set between the maximum and minimum levels recorded in New Zealand. For example, Gibb (1978a) recorded a 2.6 m storm wave run-up level after a damaging onshore storm along the exposed Kapiti coast; 6 m storm wave run-up levels have been noted along the Canterbury coast (D. Todd, Canterbury Regional Council, pers. comm., 1992); and a storm surge and wave run-up of 0.75 m at the entrance of Pauatahanui Estuary were observed during field work on 20 March 1992, which rose to 1.2 m at the head of the estuary. Again the boundaries are not placed evenly between the two extremes, but are placed in favour of the higher levels of run-up with differences being 0.5, 1.0 and 2.5 m from low to high sensitivity.

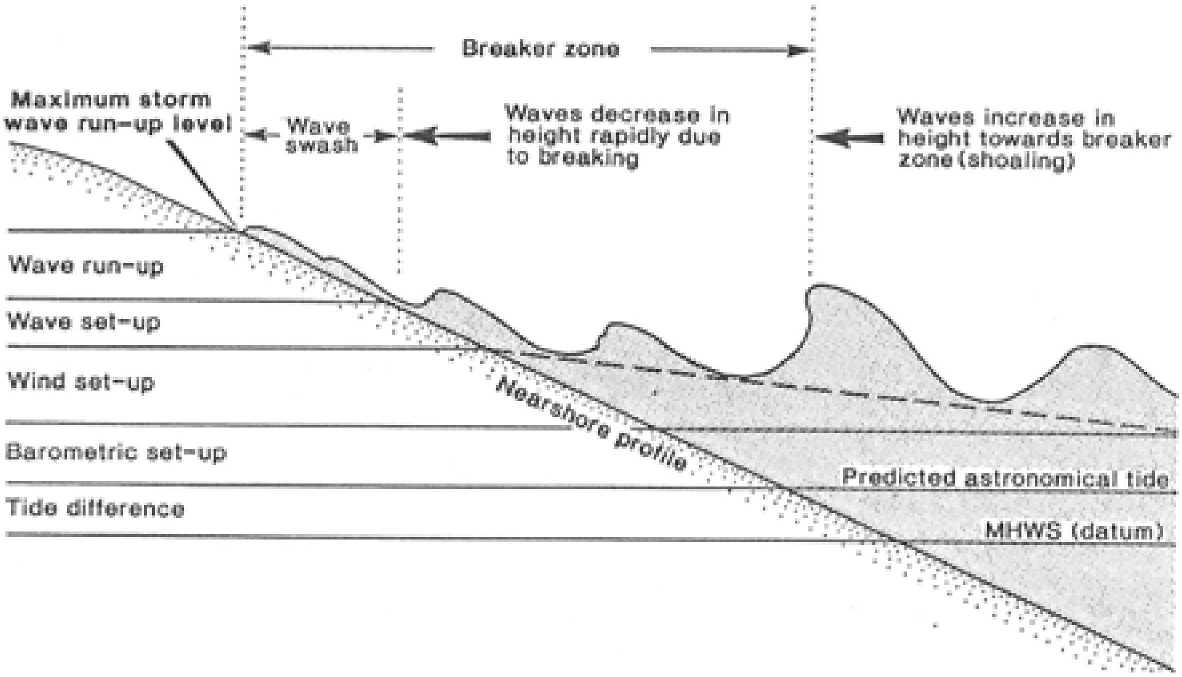


Figure 5 Schematic diagram showing the components determining maximum storm wave run-up level. (Detailed methodology is given in Frisby and Goldberg, in Gibb 1981).

Class	1	2	3	4	5
Max. Storm Wave Run-up Level above MHWS (m)	<1.0	1.0 -1.5	1.6 -2.5	2.6 -5.0	>5.0

User guidelines

1. Observations. The maximum storm wave run-up level can be estimated directly in the field by flotsam and driftwood lines (the height inland to where flotsam has been deposited by storms), anecdotal evidence, and the presence of storm berms, especially on gravel beaches (Figure 5, Plate 3**)**. On hard rocky coasts the run-up level can be observed as the lowest line of vegetation. The value for storm wave run-up level tends to be fairly uniform along tracts of coast. Along actively eroding, cliffed coasts the Wairarapa, where evidence is not visible, and for long tracts of comparable coast it is possible to extrapolate levels from adjacent coastal areas. For example Gibb (1978a) noted a uniform 2.6 m maximum level above Mean High Water Mark (approximately 3.1 m above MHWS) along Wellington's west coast as far north as Wanganui following the September 1976 storm.

2. Calculations. The storm wave run-up level can also be derived indirectly using the standard technique of Frisby and Goldberg (1981) contained in Appendix 3 of Gibb (1981). Figure 5 incorporates each of the five components that combine to cause storm wave run-up,

Plate 3 Looking east towards Te Araroa township, East Cape, 1 April 1992. The low gradient means this beach is at greater sensitivity to inundation from storm wave run-up.

and illustrates the contribution of each to the over-all level from a reference storm. This method uses Mean High Water Neap (MHWN) as datum but this can easily be modified to MHWS, the datum used throughout this technique. This method requires some specialist knowledge of coastal wave processes, and the examples given in Frisby and Goldberg provide a detailed outline of the calculations required. Where wave records and offshore data are unavailable then option 1 above is best used.

2.1.3 Gradient

The gradient is the average slope of the coastal hinterland behind the initial elevation. The variability of the coastline precludes defining a set area inland from which to take the gradient. The user needs to identify areas which have been inundated in the past, or are so low-lying as to have the potential to be in future. The extent of coastal hinterland sensitive to coastal hazards is inversely proportional to the gradient. A lower or negative gradient equates to a higher risk especially from flooding, e.g., Heretaunga Plains (Hawkes Bay), low-lying Canterbury Plains, and Hicks Bay, East Cape (Plate 4).

Classes were originally adapted from those used in the New Zealand Land Use Capability Survey Handbook (Water and Soil 1971). In this work however, the set boundaries were too large, that is, land with a gradient of up to 5° was considered to have very high sensitivity.

Plate 4 Looking west along Hicks Bay, East Cape, 1 April 1992. The very low gradient beach has been inundated in the past during storm events.

Class	1	2	3	4	5
Gradient *(°)*	>20°	20°-11°	10°-6°	5°-2°	<2° (including <0)

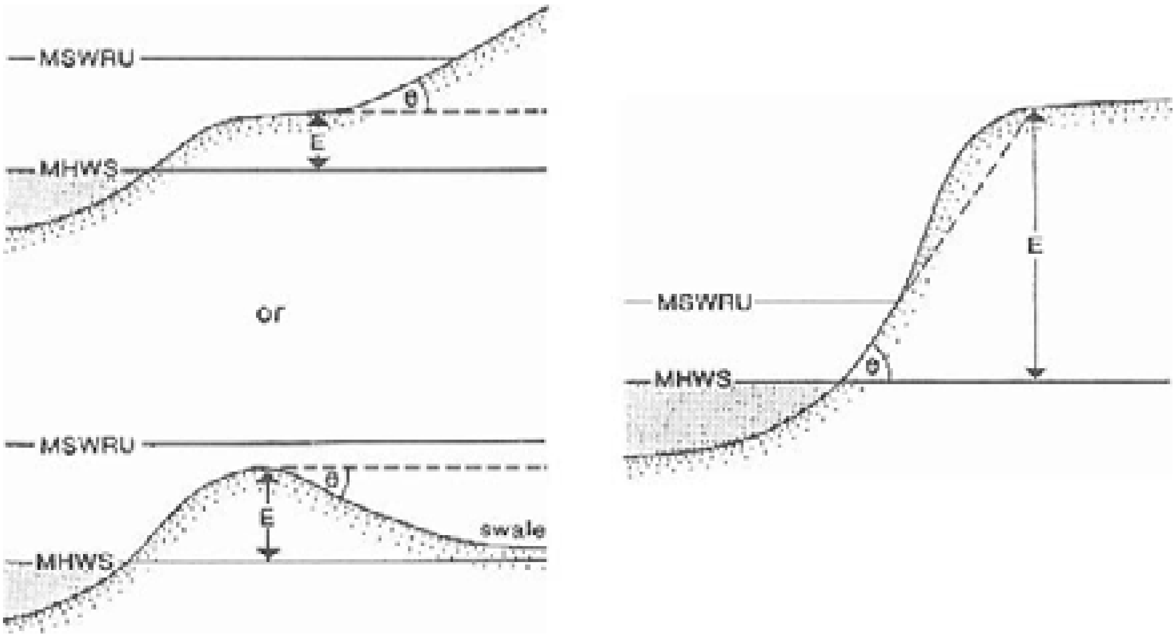
User guidelines

1. The gradient is determined **after** establishing whether or not storm wave run-up exceeds the initial elevation, as it is the gradient of the coastal hinterland which is **inundated** or has the potential to be inundated which is of interest.

2. If there **is** overtopping by storm wave run-up exceeding the elevation then the gradient is measured as the slope inland from the point of initial elevation at the coast, that is, from the backshore, top of the foredune, storm ridge or bank (Figure 6A**).** When there is a swale or negative slope then the gradient is <2° (at highest risk).

A. Overtopping (MSWRU>E) **B. No Overtopping (MSWRU<E)**

Ø = gradient angle, E = elevation, MSWRU = maximum storm wave run-up,
MHWS mean high water spring. When MSWRU>E = the hinterland is flooded by the sea.



Low lying dunes, ridges or beaches Cliff, high foredune

Figure 6 Estimation of gradient when the immediate to the sea is overtopped (A) and not overtopped (B).

3. If **no** overtopping from storm wave run-up occurs then the gradient is measured as the slope of the dune face, cliff, or bank (Figure 6B). The full range of gradient classes may be applied to areas which are not overtopped.

Gradients can be derived from beach cross-sections which extend inland (Figure 7). It should be noted that most profiles only measure the angle and position of the beach face (not inland), and therefore the user must ascertain just how far inland the profile extends, and use the correct part of the cross-section.

Gradients can also be measured from contour maps developed for subdivisions, which contain spot height information from which the inverse tan of the height over the distance equates to the gradient measured in degrees, in the equation below:

$$Gradient = \tan^{-1}\left(\frac{elevation}{distance\ inland}\right)$$

Steep gradients may contribute to the risk of landslide and slipping. These areas should be acknowledged as such, and are accounted for in the short-term fluctuation section, and under "Landslides" (section 3.1).

2.1.4 Tsunamis

Tsunamis are long-period waves (generally 20-30 minutes) generated by large short- duration disturbances of the sea-floor (Hume *et al.* 1992), and are recognised as significant natural hazards to the coast. Tsunamis may cause inundation, and/or a rapid acceleration of erosion

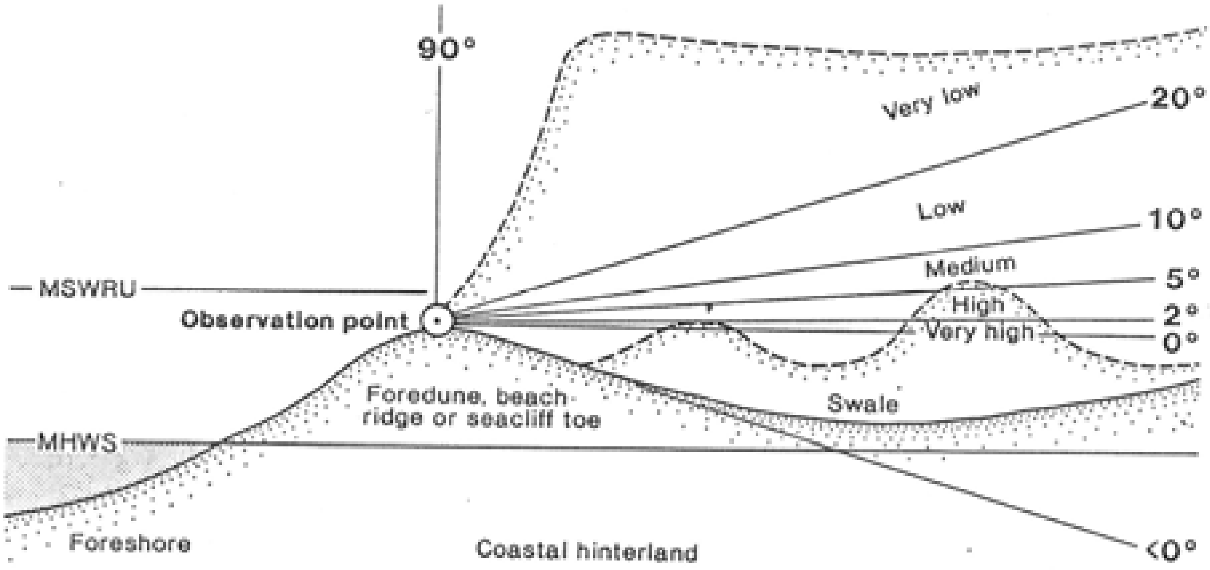


Figure 7 Gradient of the hinterland is measured in degrees and can be estimated by protractor and from surveyed cross-sections (see Figure 2).

in the short-term. The damage caused by tsunamis would be restricted to low-lying coastal areas, and may include loss of life and personal injury, structural damage, loss of floating objects, flooding and scouring (de Lange and Healy 1986a).

Tsunamis affecting NewZealand have been measured at ≤1.5m on the east coast with the exception of East Cape/ Gisbourne and Banks Peninsula where larger tsunamis, >3m, have been recorded, and on the west coast 0.2-1.0 m (de Lange and Healy, 1986a). It is possible that a locally derived tsunami such as from an earthquake of Magnitude 8 on the Richter Scale adjacent to the coast may reach a maximum height of 15 m, although the local population is likely to be more affected by the effects of the quake than the tsunami (W. de Lange, University of Waikato, pers. comm., February 1992).

The only detailed numerical analysis of potential tsunami hazards in New Zealand has been made for the Bay of Plenty region (de Lange (1983); de Lange and Healy (1986b)). Tsunamis in the Bay of Plenty have behaved like rapidly rising and falling tides, with an amplitude of <2m and with a period of 20-30 minutes. Results of the study suggest that locally sourced tsunamis represent the greatest hazard, with a volcanic eruption at Mayor Island presenting the greatest potential for damage. Hazardous effects of such an event with respect to lives and property include rapid water reversals, formation of bores in tidal estuaries and possibly the largest effect; the result of rapid recession of water following inundation of low-lying areas. This last effect has caused the most damage historically.

Tsunami data available in New Zealand are sparse and generally only for populated areas. Information has been summarised by de Lange and Healy (1986a) in their Appendix 1. The lack of detailed data has also prevented complete statistical analyses being undertaken to estimate the frequency and magnitude of tsunami re-occurrence, but this may be rectified in future (W. de Lange, pers. comm., February 1992). Other information relating to tsunami are available from the Tsunami Newsletter (NZOI), and warnings issued by the International Tsunami Warning Centre (Hawaii).

Class	1	2	3	4	5
Max. Tsunami Wave Height (m)	<0.5	0.5 -1.5	1.6 -4.0	4.1 -10.0	>10

Mitigation of such an irregular and unpredictable hazard is not easy, and most resources have concentrated on warning systems (International Tsunami Warning Centre, Hawaii), followed by mass evacuations (Carter 1988). An improvement to the New Warning System has been made with the establishment of a recorder on the Islands which gives information about the last hour of wave travel before reaching the New Zealand coast.

User guidelines
The value used is that of the maximum historical tsunami wave height recorded (in metres above MSL, therefore will need adjustment if relating to MHWS) above the expected tidal height. The height is **not** the excursion height, which is the maximum change in water level from the water being initially drawn out to sea then rising up to maximum height as it progresses ashore; nor are they noted as apparent "tidal" fluctuations. It may be necessary to extrapolate tsunami heights along large sections of coast unless detailed local records are available.

The tsunami is not measured as a maximum wave run-up. For example, the 1960 Chilean earthquake produced a tsunami whose excursion height in Lyttelton was 7.3 m, even though the maximum run-up level reached only reached 1 m above the mean high water mark.

2.1.5 Lithology

The type of bedrock lithology affects the erosional sensitivity of an area of coast to both shoreline retreat and landslip. Komar (1976) in a discussion of coastal landforms noted that solid and massive rocks (volcanic and metamorphic rocks) are very resistant to wave attack. In contrast sandstones, shales and rocks with bedding planes, closely spaced joints or faults (e.g., bentonites), are more easily eroded, and loose, unconsolidated sediments (sands, gravels) sustain the most rapid erosion rates.

Gornitz and Kanciruk (1989) used a simplified geologic classification to differentiate between different rock types as compiled on geologic maps; for example, resistant crystalline rocks differ from sedimentary rocks and from unconsolidated sediments. A similar approach was adopted for the Coastal Hazards Database, in addition to the investigation of other sources (bulletins, geological reports and consultation). Another source investigated was the New Zealand Land Resource Inventory (NZLRI) which includes a category on surface rock types and geological maps in its mapping classification. The NZLRI was limited for the purpose of this work however, because the surface rocks may in fact be overlying older or softer, less resistant ones at the actual coastal interface, and it is the substrate at the actual **shoreline** which is assessed.

User guidelines
Reports supported by field observations and geological maps are the primary source of lithology/rock type information. Although the geological maps of New Zealand use time stratigraphic units and have broad groupings of rock type, information is available from both the New Zealand Geological Survey 1:250 000 scale geologic maps and New Zealand Geological Survey Bulletins. Field observations are also required to confirm the accuracy of large scale geological maps as this detail is sometimes lost in their preparation.

Table 2 provides a basis from which to assess the erosional sensitivity of lithological units present at the coast. Although the divisions imply intact rock strength, the scope of the Coastal Hazards Database precludes the use of more detailed “rock mass strength” ratings (Selby 1982) which require detailed analyses of rock mass characteristics. Lithology classes were developed and modified after field tests and discussion with workers in the field

Table 2 Lithological deposits, as lithological classes based on varying erosional sensitivity, from very low (1) to very high (5).

Very low sensitivity		**Lithological Class**		*Very high sensitivity*
1	2	3	4	5
Igneous Plutonics. Intrusives.				
Metamorphic Metamorphics (high to medium grade).	Low grade metamorphics.	Sheared metamorphics.		
Volcanic Volcanic lava, dikes.	Very densely and densely welded ignimbrites.	Partially welded ignimbrite.	Non-welded ignimbrite. Consolidated volcanic ash.	Unconsolidated volcanic ash.
Sedimentary	Volcanic breccia. Densely indurated sedimentary rocks (greywacke, solid Well-cemented sedimentary rocks (limestones, quartzite).	Moderately indurated sedimentary rocks (sandstones, argillite, conglomorate)	Weakly indurated sedimentary rocks (mudstones, weak weak conglomerates). Relict sands. Lignite. Loess.	Unconsolidated sediments alluvium, gravels, sands, silts, muds). Peat. Swelling bentonites.

(B. Thompson, A. Hull, G. Gregory, Institute of Geological and Nuclear Sciences (DSIR GEO) pers. Comm..,1992; R. Briggs, University of Waikato, pers. comm., April 1992).

Where more than one lithological unit occurs at the shoreline, the lithology which controls the horizontal trend is selected. For example, where exposed peats underlie gravel, the variables are assessed for the peat; or where a cliff is composed of alluvium capped by loess (Canterbury coast), then it is the alluvium which is assessed (Plate *5).*

2.1.6 Natural landform

Coastal landforms result from the interaction of the sea with the edge of the land surface. Coastal landforms express the lithology at the coast, and are the resultant of horizontal (erosion/accretion) and vertical forces (relative emergence or submergence) interacting at the shoreline during the last 10,000 years.

Gornitz and Kanciruk (1989) interpreted landforms from topographic maps and classified them according to their relative resistance to erosion. These groupings were modified for New Zealand conditions (Table 3) corresponding to their relative resistance to erosion, their published erosion/accretion rates (Gibb 1978b, 1974) and their sensitivity to the effects of sea-level rise. Similar groupings have also been noted by Komar who described erosional and depositional landforms with respect to erosional resistance.

Plate 5 Loess overlying alluvium, looking north along retreating cliffs at Waitaki Boys High School, Oamaru, 14 May 1992. Lithology controls the retreat, hence the site is rated on the underlying alluvium.

Beaches and their associated landforms react rapidly to changes in sediment type, supply and wave energy, and are sensitive to any disturbances to the delicate balance in which they exist (Pethick 1984), hence the reason these features have a very high sensitivity rating. For example, the South Brighton Spit has fluctuated in length by 500 m since 1949 (R. Kirk, University of Canterbury). River mouths are highly variable features sensitive to change, and are dependent on the geomorphic and hydrologic controls on their form and location, and they too have a very high class rating. Examples of highly fluctuating river mouths include the Ashley River mouth which has moved north to south about 6 km during the last century (R. Kirk, University of Canterbury, pers. comm., 1992). The last two examples illustrate that these features can be affected by erratic, large scale movements.

Saltmarshes and mangroves are also highly sensitive to natural hazards and human influence, but are adaptable to change.

Soft rock platforms formed from mudstones and bentonites (Gibb 1981; Ballance and Williams 1982; Healy and Kirk 1982) are easily eroded and more sensitive to failures, slumps and landslides than their harder counterparts. The very hard, hard and moderately hard rock platforms and seacliffs reflect the decreasing sensitivity to physical change as a result of the more compact, indurated nature associated with their lithological make-up (from the previous variable). For example, the very hard rock platforms and sea cliffs occurring along Lottin Point (East Cape) are formed from the Matakaoa Volcanics (basalts); at Whitianga Bay (eastern Bay of Plenty) hard rock platforms of greywacke exist. The hard rock platforms and cliffs showed obvious signs of weathering and erosion (pitting, burrows, grooves and notches) when compared to their very hard counterparts at Lottin Point. It should be noted that platform features are always erosional and their sensitivity to change depends on their physical makeup and structure.

User guidelines

Landform data can be obtained from topographic maps, aerial photographs or databases in each region, supported by field observations. The Geopreservation Inventory (Geological Society of New Zealand) may also be useful, and Healy and Kirk (1982) provide the most up-to-date background information about New Zealand coastal landforms.

Table 3 Examples of coastal New Zealand landforms used in the Coastal Hazards Database and the Coastal Sensitivity Index matrix.

Landform	Example
Very Low: Very hard rock platforms and seacliffs.	Lottin Point (Matakaoa East Cape)
Low: Hard rock platforms and	Whanarua Bay, Whitianga Bay (East Cape -greywackes), Whangaroa Harbour, Curio Bay (quark sandstones, Catlins Coast).
Medium: Moderately hard platforms and seacliffs. Moraines.	Castlepoint (sandstones). Abut Head (Westland), Cascade Point (Westland), Gillespies Point (Westland).
High: Soft rock platforms and sea cliffs. Alluvial fan/ delta Saltmarsh/ mangroves	Waiapu (Tertiary siltstones and sandstones, East Cape), Whangaroa (Waitemata Group sandstones and siltstones). Waitaki River (Canterbury). Ohiwa Harbour; Southern Firth of Thames.
Very High: Sand barriers, beaches, dunes and spits. Gravel barriers, beach ridges, and spits. River mouths. Cuspate forelands.	Rabbit Is (Nelson), Papamoa (Bay of Plenty), Farewell Spit. Kaitorete Barrier (Canterbury), Nelson Boulder Bank, River Bar (Marlborough). Waimakariri River (Canterbury), Hokitika River (Westland), Manawatu River, Waipaoa River (East Cape). Kapiti Coast (Paraparaumu), Whangamata (Coromandel).

The landforms assessed for the CSI (section 3) are those that extend from and above. Littoral and sublittoral landforms (tidal deltas, tidal inlets, mudflats) were not included individually because of their nature as being "hazard" zones daily (M. Hicks, DSIR Marine and Freshwater, June 1992). It is the features at their margins (beaches, storm ridges, saltmarshes) which are assessed, and are thus incorporated into the matrix. Large scale land features such as (Mahia Peninsula, Banks Peninsula), fiords (Milford Sound), and rias (Marlborough Sounds) were also unnecessary to define as they are composed of smaller landforms such as platforms and beaches.

2.1.7 Horizontal trend

The horizontal trend is the long-term rate of erosion, accretion or dynamic equilibrium along the coast (Figure 8). Areas which are accumulating sediment and advancing (+5.91 m/year at Caroline Bay, Timaru), are inferred to be less sensitive to hazards than those which are retreating due to erosion (from -2.5 to -3.0 m/year at Washdyke Lagoon, Timaru), even though some areas that are rapidly accreting may adversely affect properties and assets such as high dunes at Brighton, Christchurch, and the Himatangi Beach, Manawatu, which are affected by encroaching dunes.

Class	1	2	3	4	5
Horizontal Trend (m/year)	>+0.50 Advance	+0.50 to -0.02	-0.03 to -0.49	-0.50 to -2.00	>-2.00 Retreat

Horizontal trend values are derived from a combination of erosion and accretion studies of the New Zealand coastline (Gibb 1978b, 1979, 1984; Healy *et al.* 1977; Kirk 1983; etc.), and are ideally inferred to span greater than 100 years in duration (Figure 8).

The accuracy of the rate depends on error in the aerial photograph measurements, measured field data, and calculations. As the photographic scale decreases, the errors increase and become more significant. Rate accuracy is also limited by the frequency of surveys with the greater number of surveys providing more realistic rates of long-term movement.

Evans (1992) noted that any map or photograph only provides a single historical record of the coastline on a particular date and that caution should be made in placing too much reliance on a time series of maps to calculate rates of shoreline erosion or accretion. Kirk (1983) noted “McLean (1978) has suggested that in order to distinguish a realistic net trend (direction) of shoreline change it would be desirable to have a minimum of 10 equi-spaced time frames for comparison (at decadal intervals) over the total length of the historic record. However, we generally have a smaller number of quite variably spaced time-frames and the starting and terminal dates are likely to be unique to one locality. Discerning the trend for that locality is therefore necessarily a matter for caution. Correlation with other localities can be extremely difficult”.

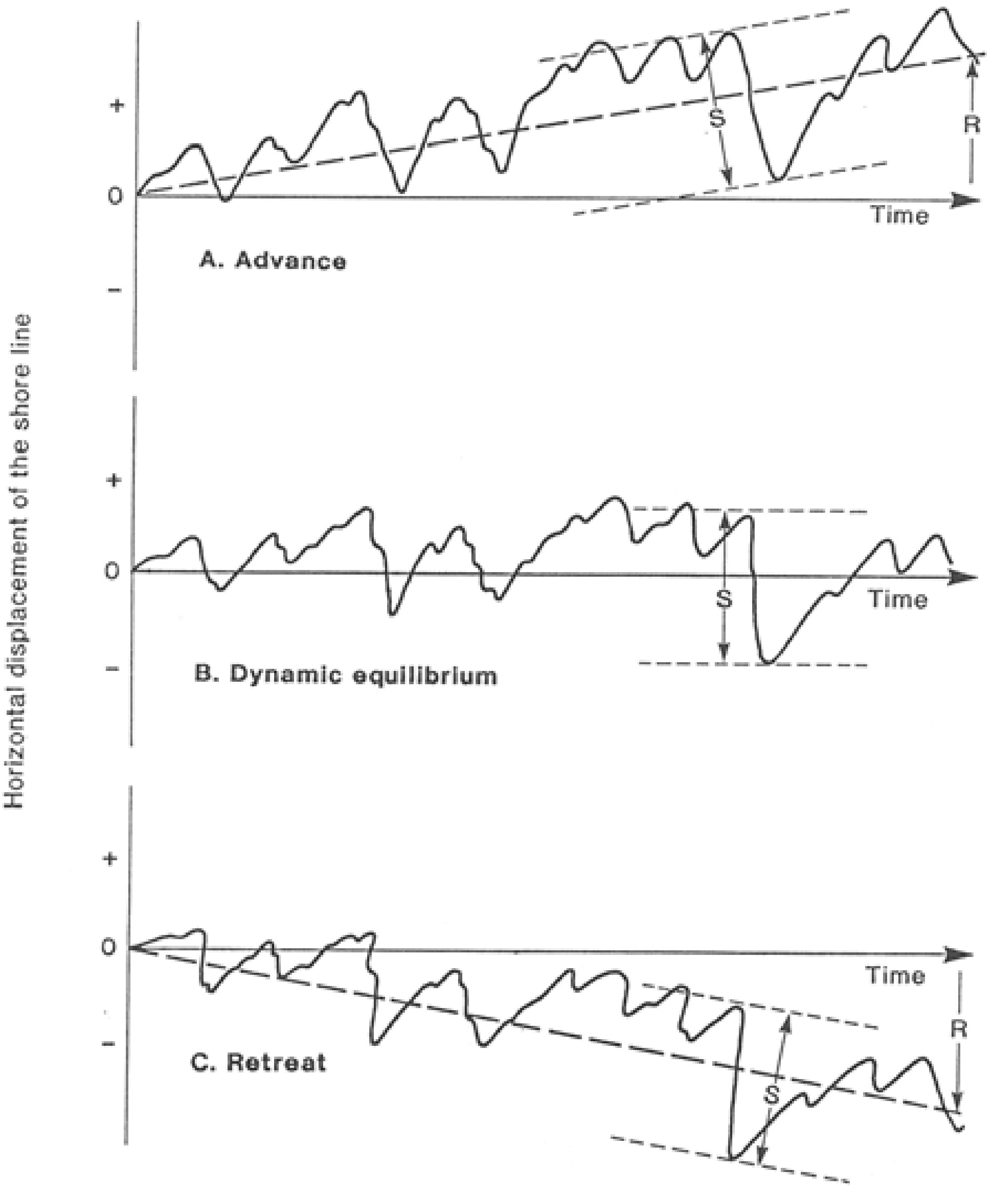


Figure 8 Conceptual diagram (after Gibb and Aburn 1986) illustrating the horizontal trend, where (R) is the net rate of movement in m/year calculated by dividing the horizontal distance (A), by the survey time interval (T). The short-term fluctuation (S), represents the maximum fluctuation in the position of the foredune or cliff edge. (A) is the advance seawards from net accretion, (B) is fluctuating about a mean position (dynamic equilibrium), and (C) is landward retreat from net erosion. Both (R) and (S) may vary in both frequency and magnitude from place to place around the New Zealand coast.

User guidelines

(This information is a minimum requirement for the assessment of a CSI.)

Historic rates (m/year) are determined by measuring the horizontal distance in a direction perpendicular to the shoreline, at various intervals of time over as long a survey period as possible. The rate is calculated by dividing the horizontal displacement by the time interval between successive surveys. To determine a long-term rate with confidence, at least two short-term cycles (Figure 8) must be spanned. For New Zealand this would suggest a minimum survey record of from 30 to 50 years and ideally, 100 years or more.

$$\text{Rate (m/yr)} = \frac{\text{horizontal displacement}}{\text{time}}$$

Reference shoreline positions (MHWM, toe of foredune, toe of cliff) derived from vertical aerial photos, cadastral maps and field surveys can be measured and compared, with at least 3 to 4 photo fixes and 1 cadastral fix being ideal. Figures 9 and 10 illustrate different ways of presenting accurate survey information.

The Department of Survey and Land Information (DOSLI, LandInfo N.Z.) have the most complete aerial photographic coverage of New Zealand from which consecutive coastline positions at as many intervals as they possess records of, can be overlain onto one photographic image and purchased (Appendix 4). An accurate assessment is however, difficult to give without first sighting the available photography. DOSLI tries to avoid using contact photo scales smaller than 1:250 000 as measurement errors from this scale of photography are approximately ± 1-3m.

River mouths

Landforms at river mouths fluctuate greatly over short time periods as the mouth migrates updrift and downdrift. As the river mouth advances and retreats with the adjacent coast, the long-term rate is similar to that for the adjacent coast, but the short-term fluctuation rate may be >100m owing to the instability of the river itself.

Wind erosion

Wind erosion on the coast may exacerbate long-term erosional trends. For example, Omaha Beach (Northland) has had on-going problems with this (Healy 1981). Important dune protection measures such as dune stabilisation, by marram, spinifex of pingao, plus sand trapping fences all contribute to help reduce the effects of wind erosion and maintain a healthy sediment budget for the foredune (T. Healy, University of Waikato, pers. comm., June 1992).

This factor has also been considered by the New Land Resource Inventory (Ministry of Works and Development) and Land Use Capability studies (NWASCA) with respect to land-use and development. Wind erosion is difficult to measure, and in part contributes to the long-term trend and short-term fluctuation variables.

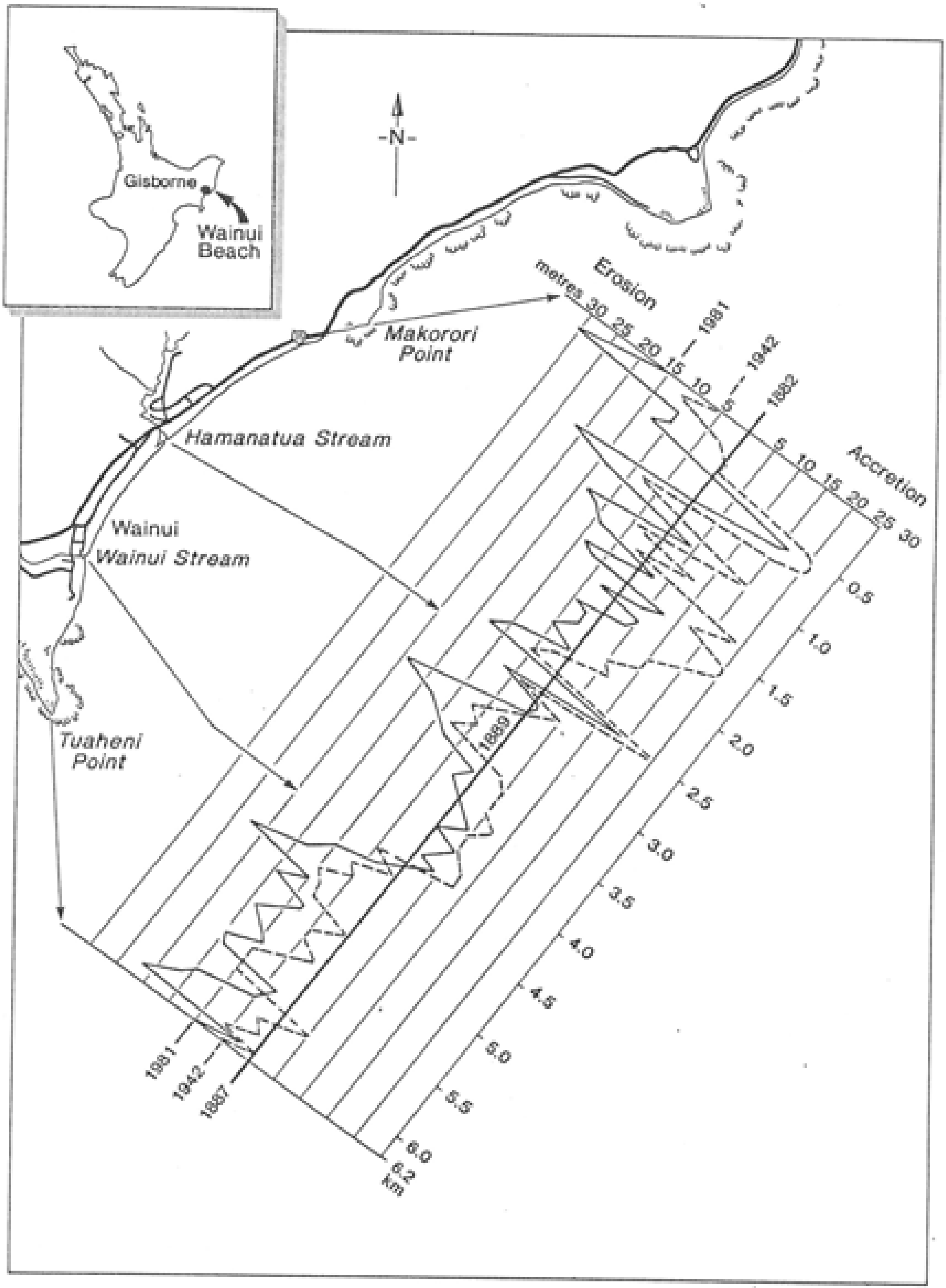


Figure 9 Sketch map of Wainui Beach, Gisborne, showing an example of detailed horizontal trend data that can be collected for a single beach (after Gibb 1981).

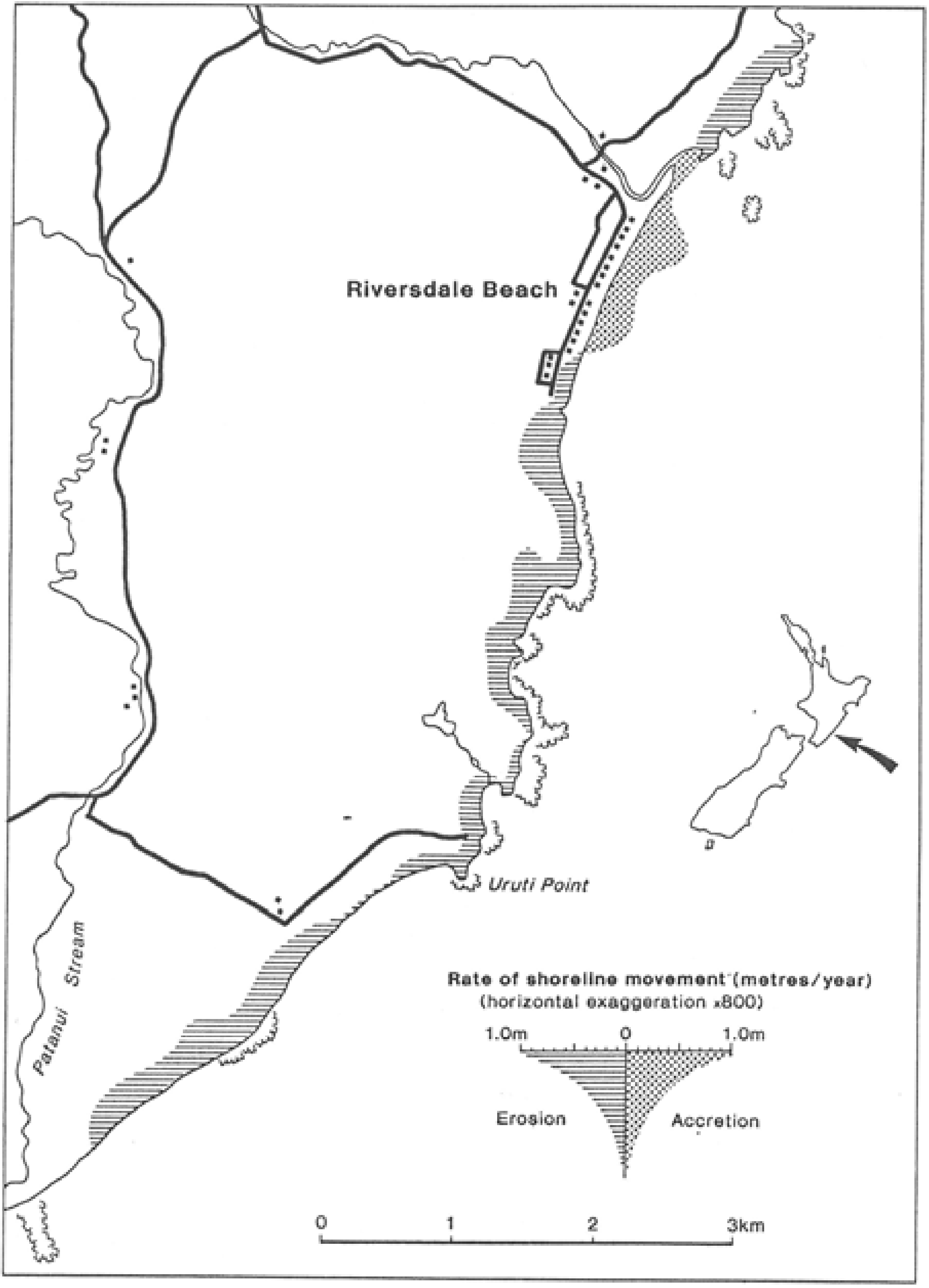


Figure 10 Sketch map of the east Wairarapa coast showing an example of long-term rates of shoreline erosion/accretion over the last century.

2.1.8 Short-term fluctuations

Variations in the long-term trends of shoreline advance and retreat are mostly episodic (irregular occurrences). These variations or S factors defined by Gibb (1983), occur as the maximum short-term fluctuation or fluxes of both accretion and erosion, in the long-term shoreline trend (Figures 8 and 11). Variations may occur as a result of one or a cluster of severe onshore storms, and may range from 2 m to greater than 30 m around New Zealand depending on the width of the beach and the nature of the hinterland behind. The short-term fluctuation may also be inferred to be the minimum width of a coastal hazard zone (Gibb and Aburn 1986). For cliffed areas the short-term fluctuation is the largest slump or failure that can be identified (Figure 11). It is the maximum landward fluctuation that is measured.

Large fluctuations represent greater sensitivity to natural hazards. The highest measured during field surveys was >100m at Hicks Bay (see Plate 4) where a subdivision was demolished by the sea and a migrating river mouth in the early 1970s. Lowest fluctuations are associated with very hard rock cliffs and platforms. For example, the cliffs in the Lottin Point region (East Cape) formed by the Matakaoa Volcanics experience little or no short-term movements associated with either landslides or normal cliff erosion processes.

Class	1	2	3	4	5
Short-term fluctuation (m)	<2	2 -5	6 -10	11-30	>30

User guidelines

The short-term fluctuation can be derived from comparing historic and cadastral coastal surveys, repetitive surveying of beach profiles, anecdotal evidence or estimated in the field (Gibb and Aburn 1986).

Historic shoreline positions

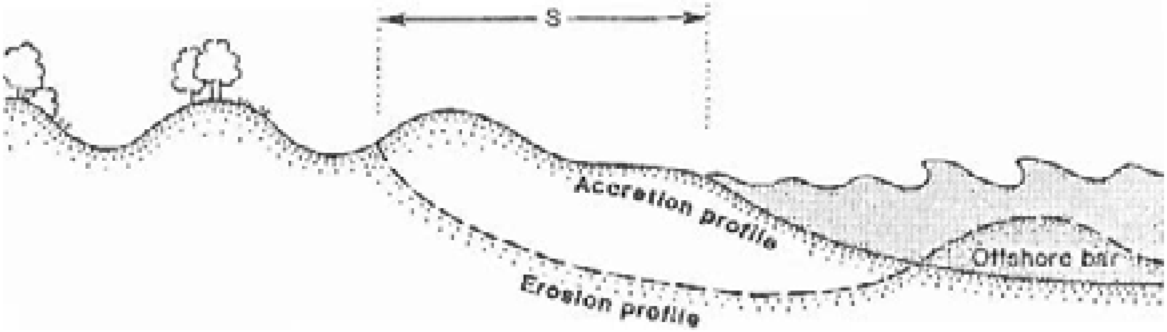
Comparison of shoreline positions between aerial photographic and historical surveys which note MHWM can provide information regarding fluctuations. Horizontal measurements of scarps (if identifiable), and pulses of shoreline accretion and erosion can be made, with the maximum distance of change being used.

Beach profiles

Fluctuations can be estimated by comparing various beach profile records over the longest period that they are available for. Successive erosion and accretion events (be they seasonal or episodic) can be measured and fluctuations determined as the maximum gain or loss of the shoreline.

Field observations

Field estimations of short-term fluctuation can be made where scarps are preserved marking past episodes of erosion when it is possible to measure the horizontal distance between the scarps. Gibb (1979), for example, identified a major erosion scarp at Needles Point, South Island east coast, cut during the winter of 1974. From 1974-77 accretion extended approximately 128 m during which two further phases of erosion also marked by scarps occurred.



Unconsolidated sedimentary coasts

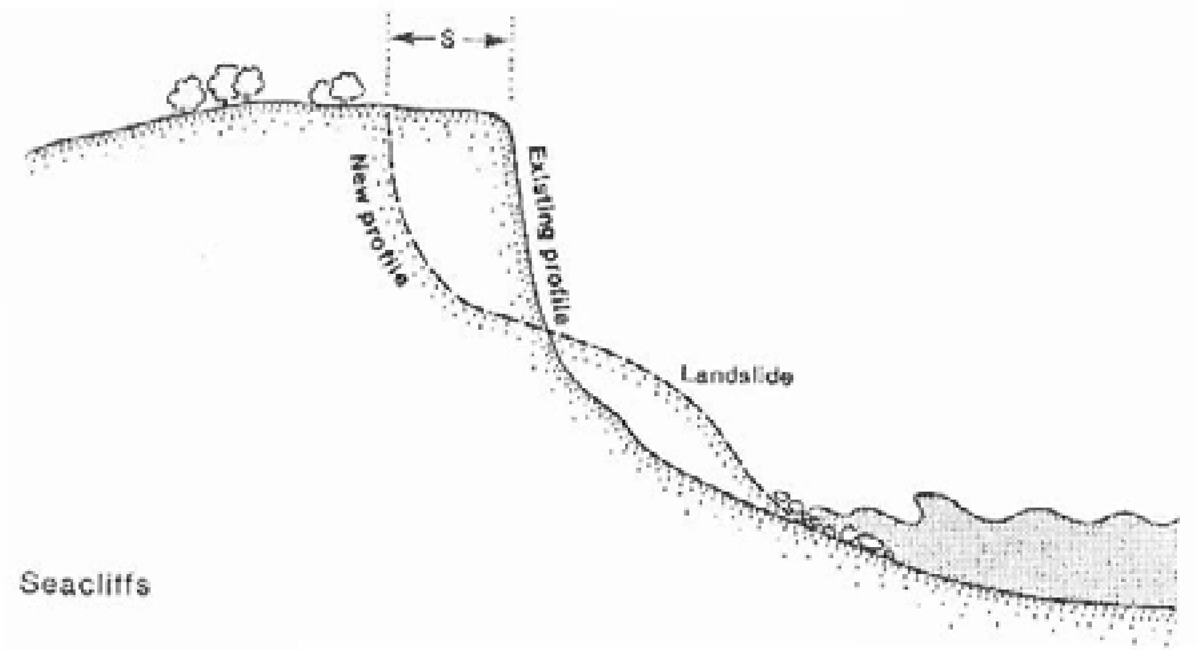


Figure 11 Diagrams illustrating determination of maximum short-term horizontal shoreline (S), for unconsolidated sedimentary coasts and seacliffs.

Seacliffs

The short-term fluctuation for seacliffs can be defined as the largest slump or failure that can be measured in the field, from aerial photographs, long-term trend maps, or minimal (<2m) if no obvious erosion/slumping occurs (very hard rock cliffs and platforms).

Fluctuations usually vary significantly along a short section of coast, so careful consideration must be given to decide whether to use an average value, or to re-calculate the CSI for specific areas depending upon the scale of interest. It is incorrect to apply an average value along a length of coast with changing short-term fluctuations from such factors as changing drainage characteristics, as in Canterbury where slumping of the coastal cliffs is affected by agricultural irrigation and drainage, lithology, gradient and height.

2.2 Parameters contributing to the selection of the actual variables

Other variables considered during development which were either not used on the basis of a lack of data, were impractical to measure in the field, or were incorporated into another variable, and are discussed below. These discussions are provided to clarify the reasoning behind not including them separately into the CSI at this stage, and to provide food for thought regarding future direction that a New Zealand Coastal Hazards Database and CSI could take.

2.2.1 Wave height and storm surge

Wave height and storm surge were originally considered separately, however in reality these actually contribute to the maximum storm wave run-up on the coast.

The maximum significant wave height was considered as a separate variable for application along open, exposed and sheltered coasts because of the ability of waves to rapidly transform the shoreline. This very useful information could be collected from wave records, however the lack of these, and the patchy coverage of New Zealand (Hume *et al.* 1992) meant that incorporation of a separate wave height variable could only be considered if and when more complete regional information becomes available in the future. Pickrill and Mitchell (1979) provide a summary of wave conditions which remains the main source of summarised wave data for New Zealand. A further point associated with this factor includes converting a deep water wave height to a shallow water wave height and allowing for shoaling.

Storm surge levels were also considered but not retained as an independent variable owing to the lack of nationally available data from tide gauge analysis, although some records are given in Heath (1979). The Institute of Water and Atmospheric Research (formerly DSIR Marine and Freshwater) has begun to analyse some regionally held tide records for the purpose of determining the magnitude of these levels from storm events (R. Bell, DSIR, pers. comm., February 1992).

2.2.2 Spring tidal range

Spring tidal range was considered as a separate variable because of the association that larger spring ranges with stronger tidal currents are capable of eroding and transporting sediments (Gornitz and Kanciruk 1989). Spring tides can also produce proportionately high equinoctial and astronomical tides which can exacerbate coastal hazards. For example, the highest astronomical tide (HAT) occurs at some stage during the 18 year lunar tidal cycle (Gibb 1991) and is commonly used as a component in storm wave run-up studies.

Coastal landforms are however generally in equilibrium with the local tidal range, and it is not necessarily true that areas with larger tidal ranges experience greater erosion and inundation during storms, than areas with smaller tidal ranges. Spring tidal range is therefore considered to contribute to the storm wave run-up variable rather than occur as a separate variable.

2.2.3 Landslides

Acknowledged as one of the three major hazards in the coastal zone (erosion, inundation and landslip), landslides are incorporated in the calculation of a CSI in both the short-term fluctuation as mass movements, slumps and failures, and in the long-term horizontal trend as erosion of the coastline. While this variable is not separate within the matrix, it is recommended that as part of the field testing, evidence for landslides be sought from anecdotal and historic records, aerial photographic records and field observation. Should landslip be considered as a potential hazard, then this should be included as a qualifier for the CSI and attached as notes on the site record form, serving as an alert that these areas may merit further detailed geological and geotechnical studies.

2.2.4 Vegetation

While being an important physical feature on the coast, the occurrence of vegetation has not been included for the purposes of the CSI which encompasses measurable physical landform factors. It is noted, however, that vegetation such as marram, pingao and spinifex, play an important role in stabilising loose coastal sediments. Many dune stabilisation schemes exist around New Zealand and these contribute to the long-term horizontal trend by helping to minimise erosion and prevent dune blow-outs, and to the short-term fluctuation by minimising the effects of short period erosive events.

It is not intended to incorporate this as a variable, but this information can be recorded on site record forms if available. This type of information has been compiled by Johnson (1992) and Partridge (1992) as a part of the New Zealand coastal and dune vegetation inventory.

2.2.5 Overtopping

This variable was considered to indicate the effects of inundation when storm wave run-up level exceeded the elevation of the first immediate feature. "Overtopping" as a separate variable became redundant as it had been accounted for in the storm wave run-up level and elevation variables and in effect had placed a double emphasis on inundation.

Another difficulty was the use of a height or depth to assess the amount of overtopping as this can not be easily measured from field response data (R. Kirk, University of Canterbury, pers. comm., June 1992) and is also dependent on sediment size and water table effects.

2.2.6 Sediment budget

On a nationwide basis sediment transport and budget data is very localised and subject to inherent calculation errors. While sediment transport information would add to the accuracy of the CSI, it is noted that the sediment budget is an integral part of the horizontal trend variable used here. Positive sediment budgets result in accretionary horizontal trends while negative sediment budgets contribute to erosion. Sediment budgets may also be represented by the state of the foredune as growing dunes have positive budgets and eroding dunes have negative ones.

If these rates or volumes are known then these can be noted on site record forms. Beach nourishment schemes which also contribute to positive beach budgets could also be noted, for example, Mt Maunganui beach underwent renourishment in December 1990 (Foster 1991).

2.2.7 Vertical trend

This variable was initially considered to assess the sensitivity of the coast to vertical movement of the land associated with tectonics (uplift/ downdrop), and to superimpose on this the eustatic sea-level rise at the current average rate of 1.7 mm/year (Hannah 1990; Gibb 1991) around New Zealand since about 1900. The combination of a rising sea-level and subsiding shoreline will increase the sensitivity of the coast to erosion and inundation.

Rates of tectonic movement were primarily derived from uplift/ subsidence maps of New Zealand by Wellman (1979) and Pillans (1986, 1990) which assess trends during the Late Quaternary (approximately the last 200 000 years). The trends are average values that include many rapid earthquake-induced movements from discrete episodic catastrophic events (e.g., Wairarapa Earthquake, 1855; Napier Earthquake, 1931). They do not necessarily reflect a constant rate of uplift or subsidence over shorter periods (decades, centuries). It was considered inappropriate to superimpose the historic rate of sea-level rise of 1.7 mm/year on to the known tectonic trends because of the hugely differing time scales and the likelihood of either land stability or even reversals in emergence or submergence between discrete earthquake events. For example, there is clear evidence along the North Island east coast of coastal retreat in areas with a geologic history of tectonic uplift (Gibb 1981). Theoretically, the coast should be advancing in such areas. Similarly, along the Rangitiki Plains coastline, Bay of Plenty, the area is subsiding at 0.4- 2m/1000 years and yet the coast has a history of advance.

Use of this variable by Gornitz and Kanciruk (1989) was justified however, in that the North American land mass is still adjusting at a steady rate from post-glacial rebound, or in places is sinking at a steady rate as a result of the removal of groundwater in deltaic deposits such as the Mississippi River Delta. The relevance of such long-term trends to the time scales used by planners who consider the future of developments with regards to the next 20-100 years was further justification against including vertical trend information as a major variable.

2.2.8 Storm frequency

Significant stormy periods appear to occur episodically in New Zealand every 20 ± 10 years (Gibb 1978a, 1987), but damage to the coast does not necessarily happen during one storm. Far more serious may be a cluster of storms which individually cause minor damage, but collectively culminate in massive damage, overtopping, breaching and inundation as the beach system is progressively weakened allowing the hinterland to come under attack.

It is impractical to incorporate storm frequency at this stage as a discrete variable owing to a lack of data and the difficulty of assigning a probability. The effects of storms as individuals and in clusters are nevertheless accounted for by the maximum storm wave run-up level, horizontal trend and short-term fluctuation variables used here.

2.2.9 Engineering structures

Seawalls and groynes have been built in response to property and assets being threatened, or as a legacy to the engineering priorities and values of the time. Seawalls have been constructed to differing standards, from car bodies to concrete walls to rock revetments, and may actually increase erosion further along the beach. Failure during storm events may increase local erosion because the beach in front of the seawall is generally depleted of sediment by constant wave reflection entraining sediment (Plate 6) and scouring the seabed.

Plate 6 Southeasterly swells reflecting off a rock seawall at Wainui Beach, Gisborne, 1992. Breaking wave heights effectively doubled, exacerbating the erosion problem.

Seawalls also prevent the foredune from acting as a supply of sand during storm events. For example, at Raumati sand reservoirs at the end of the seawall are being depleted and the dunes are being eroded to compensate (Plate 7). Even though the seawall appears to be functioning, erosion of the foreshore is still continuing and may even be exacerbated by the presence of the seawall. Since construction of seawalls in the 1950s and 1970s the long-term rate of retreat has increased from -0.2 m/year to more than -2.0 m/year.

It may be possible to assess the performance of structures (seawalls, groynes, breakwaters) by investigating six rules which structures should have met when they were designed; adequacy of protection, adequacy of protection against end effects and outflanking, adequacy of foundation conditions, stone weights or piece fastenings, void space control, and adequacy against overtopping by green water (U.S. Army Corps of Engineers (n.d.).). Additional considerations may be how safe the wall is and whether it is being maintained. Modern seawalls are designed to give the area behind protection from overtopping to an acknowledged low return-period event, therefore it is possible by contacting the designers or local body engineers to obtain the level of wave run-up which they calculated to apply.

Seawalls had been constructed on seven of the test sites visited in this study. However, normal coastal processes such as wave run-up and erosion have been affected in these areas and therefore the CSI technique was not strictly applicable. Data on the rate of horizontal movement for example, would be inapplicable if the seawall had halted the

Plate 7 Looking south from the Raumati seawall, Kapiti Coast, 13 March 1992. Since 1974 the foredunes have retreated about 45m because of the seawall, coupled with a long- trend of retreat.

SR55

PAGE 36 MISSING FROM ARCHIVES

Table 4 The combined matrix for the Coastal Information Database from which a Coastal Sensitivity Index can be derived. To calculate a CSI refer to section 3.0.

CLASS VARIABLE	***1 Very low***	***2 Low***	***3 Medium***	***4 High***	***5 Very High***
Elevation above MHWS (m)	>20.0	20.0 -10.1	10.0 -5.1	5.0 -2.0	<2.0
Max. Storm Wave Run-up Level above MHWS (m)	<1.0	1.0 -1.5	1.6 -2.5	2.6 -5.0	>5.0
Gradient	>20	20 -11	10 -6	5 -2	<2
Max. Tsunami Wave Height (m)	<0.5	0.5 -1.5	1.6 -4.0	4.1 -10.0	>10
Lithology ***Igneous***	Plutonics. Intrusives.				
Metamorphic	Metamorphics (high to medium grade).	Low grade metamorphics.	Sheared metamorphics.		
Volcanic	Volcanics (lava, dikes)	Very densely and densely welded ignimbrites. Volcanic breccia.	Partially welded ignimbrite.	Non-welded ignimbrite. Consolidated volcanic ash.	Unconsolidated volcanic ash.
Sedimentary		Densely indurated sedimentary rocks (greywacke, solid argillite) Well cemented, sedimentary rocks (limestones, quartzite).	Moderately indurated sedimentary rocks (sandstones, argillite, conglomerate).	Weakly indurated sedimentary rocks (mudstones, weak weak conglomerates). Relict sands. Lignite. Loess.	Unconsolidated sediments luvium, alluvium, gravels, sands, silts, muds). Peat. Swelling bentonites.
Natural Landform	Very hard rock platforms and sea cliffs.	Hard rock platforms and sea cliffs.	Moderately hard rock platforms and sea cliffs. Moraines.	Soft rock platforms and sea cliffs. Alluvial deltas. Saltmarsh/ mangroves.	Sand beaches, dunes, and spits. Gravel barriers, beach ridges and spits. River mouths. Cuspate forelands.
Horizontal Trend (m/year)	>+ 0.50 Advance	+0.50 to -0.02	-0.03 to -0.49	-0.50 to -2.00	>-2.00 Retreat
Short-term fluctuation (m)	<2	2-5	6-10	11-30	>30

3. DEVELOPMENT OF THE COASTAL SENSITIVITY INDEX

Methods investigated

In the course of developing any classification scheme, the question arises as to how to treat the data once it has been collected. When attempting to describe an area of complex interacting processes such as the coastline, perhaps the minimum numerical description would be the mean and standard deviation. This is more applicable when the database is large, but in most regions fairly thorough coverage may be found in sites. The standard deviation tends to complicate the CSI, it being simpler and more realistic to actually look at the range of ratings assigned to an area than to interpret a mean and standard deviation.

Many methods of combining the data were considered in this study including the Gornitz (1991) original equation (Equation 1), the geometric and harmonic means (Equations 2 and 3), and the root mean square (Equation 4) set out below. The Gornitz equation, stated as the square root of the geometric mean, was initially used. This equation was sensitive to small changes in individual rankings and tended to grossly distort the original data of the matrix by expanding the range of sensitivity values (see Table 5). The geometric and harmonic means tended to weight towards the lower extreme values, while the root mean square equation was more sensitive to both the high and low extreme values. Table 5 presents a theoretical range of variable conditions that may be present on the coast, and the manipulation of the data by each method.

Table 5 Worked example using 5 methods of combining variable values (average to extreme). Comparisons across the lower portion show the effects of different equations on the raw data.

	Average			**Extreme**
Variable Values	**3 3 3 3 3 3 3 3**	**2 2 2 2 4 4 4 4**	**1 1 3 3 3 3 5 5**	**1 1 1 1 5 5 5 5**
Average	**3.00**	**3.00**	**3.00**	**3.00**
Equation 1) Gornitz (1991)	**76.80**	**57.20**	**42.70**	**17.70**
Equation 2) Geometric mean	**3.00**	**2.83**	**2.67**	**2.24**
Equation 3) Harmonic mean	**3.00**	**2.67**	**2.38**	**1.67**
Equation 4) Root mean square	**3.00**	**3.16**	**3.26**	**3.60**

Where according to Gornitz (1991) the equation is stated as the square root of the geometric mean;

$$CSI = [\frac{1}{n}(x_1 * x_2 * \ldots x_n)]^{\frac{1}{2}} \qquad \textit{Equation 1}$$

the geometric mean =
the nth root of the product;

$$CSI = (x_1 * x_2 * \ldots * x_n)^n \qquad \textit{Equation 2}$$

the harmonic mean = number divided by the sum of the reciprocals;

$$CSI = \frac{n}{\sum \frac{1}{x}} \qquad \textit{Equation 3}$$

and the root mean square = the square root of the mean of the squares.

$$CSI = \sqrt{\sum \frac{x^2}{n}} \qquad \textit{Equation 4}$$

Where x_i= each variable, and
n= the total number of variables present.

After discussion of these methods with university specialists (Prof. A. Sutherland, University of Canterbury, Christchurch, pers. comm., June 1992; Dr W. de Lange, University of Waikato, pers. comm., June 1992) and the presentation of a seminar to the Canterbury Coastal Research Group it was decided that the above equations had a tendency to give "false credibility" to what in effect is a value based judgement. To overcome this a straight-forward addition (Equation 5) was finally selected because it can be rapidly calculated and does not distort the data.

CSI = elevation + storm wave run-up + gradient tsunami + lithology

+ horizontal trend + short-term fluctuation

Equation 5

After all 8 variables have been assessed for each site, and assigned a class value from 1 to 5, the CSI can be calculated by simply adding up the class values.

Defining the CSI boundaries
If every variable rated either the minimum of 1 or the maximum of 5, the minimum and maximum CSI's would be 8 and 40 respectively. In this study the boundaries adopted between each sensitivity class are listed below and are based on an approximate even division of the total with the very low and very high classes being slightly less than the remaining three. . .

Very low	*Low*	*Medium*	*High*	*Very high*
8-13	14-20	21-27	28-34	34-40

Even though CSI'shave been categorised in this manner, it is the relative sensitivity of the areas whether on a national or regional scale which is important. An alternative to defining such boundaries is to note **any** area which rates a 5 for a particular variable to be in the very high sensitivity class.

The 5 classes of CSI so obtained can be used as a basis to classify the coast according to its sensitivity to natural processes which may prove hazardous to human property and values. From this classification a policy, planning and management framework can be developed to meet the requirements of the Resource Management Act 1991, for "sustainable management" and "preservation of the natural character" of the coastal environment. Such a classification of a stretch of coast would provide early warning of areas likely to pose future problems to potential developments and values.

4. APPLICATION OF THE COASTAL SENSITIVITY INDEX TECHNIQUE

4.1 Preparatory work for field assessments

There are three steps to ensure that field time and costs are kept to a minimum, while attaining maximum areal coverage.

4.1.1 Variability of the coastline and selection of sites

It is in the users' best interest to carry out a thorough survey. The number of field sites to assess should be dictated by the amount of shoreline variability there is along the coast. There is no point in repeating a field test on an area which is so similar to its neighbour that none of the boundaries on the matrix are crossed. The important point to note is whether an adjacent site varies enough in data to warrant re-assessment of the CSI. Also included for assessment should be areas of concern and interest to the user, areas with the potential to be developed, and currently threatened areas. Ease or lack of access should also be considered during field work planning.

4.1.2 Time and personnel

Along a "uniform" coast rapid progress is limited only by travelling time. In this study each site took from 15 to 30 minutes to assess where good background data were available, but these times should be flexible to enable the maximum information to be gleaned during the field phase. It is possible to assess up to 10 sites per day, or less if the user is restricted to the normal 8-hour working day. This depends on the size of the region, travel time between sites, and access.

For one region, and depending on the number of sites and availability of reliable data it would take two people 1-2 weeks to complete the field phase, and 1-2 weeks to write up and present a report. Broadly it is estimated that it would take less than one month to complete the field work and write-up for a region, providing the personnel are working full time on the project. Lack of data required for the assessment (e.g., horizontal change) would result in a proportional increase in the amount of time to complete the project.

4.1.3 Cost

It is necessary to obtain a value for all the variables in order to calculate a comparable CSI. Achievable through a combination of field work and existing information, one variable which may require a financial outlay if the data doesn't already exist is the long-term trend. The 1992 cost is outlined in Appendix 4. Other costs include photography, computing and publication.

4.2 Field procedure

The following checklist includes the equipment and data required in the field:

pens, pencils, erasers
metric scale ruler
field book for observations
protractor

long-term horizontal trend maps and data
5 m survey staff
cross-sectional profile data (if available)
calculator
geological and topographic maps
aerial photographs
camera and film, preferably one camera with **slides** Kodak Ektachrome 100 Plus) and one with **prints** as backup for presentation purposes and permanent records.

At each site a fairly rapid assessment of the field conditions can be made. For each of the following steps, the measurement or confirmation is made and the rank of sensitivity noted from the matrix. An example for each step is given for a field site used during this study at Te Araroa (Appendix 9).

1. Record the date, time, location.
2. Become familiar with the test site, looking for a) evidence of landslip, and b) the presence of dune control or restoration works, and recording this.
3. Measure the elevation of the first immediate feature.
4. *Assess the level of storm wave run-up from field and anecdotal evidence and reports.
5. Is the first immediate feature exceeded by the storm wave run-up level? **Yes:** the gradient is determined as that behind the first feature. **No:** overtopping = zero so the gradient is determined as the slope face of the first feature.
6. *From de Lange and Healy (1986a) determine the largest tsunami on record, or utilise any local additional information.
7. Confirm the lithology and landform by field observation and checks with the geology literature.
8. *From the long-term horizontal trend data assess the rate of erosion or accretion for each field site. This can be done while travelling between sites.
9. *From the long-term trend data and from field inspection make an assessment of the short-term fluctuation variable.
10. Take a photograph.
11. *Calculate an initial CSI using Table 4.

* As a time saving measure these steps can be completed prior to or after field work.

4.2.1 Data treatment and computer information storage

An important tool used for the storage of field information is the computer database-known as the Coastal Hazards Database established by the CRI Taskforce, Department of Conservation using dBase IV V1.1. A further explanation of how to use this is given in Appendix 5.

An alternative to using a computer database for storage is to manually record and store the information onto a copy of the data sheet provided in Appendix 6. Copies can be made and stored in clip-binders or in filing systems.

4.3 Applying the technique

4.3.1 Case studies

As part of the field work to establish, test and modify the method to derive a standardised Coastal Sensitivity Index, nine regions around New Zealand were visited. In order of testing the regions were Wairarapa, the Kapiti Coast, Wellington Coast, Pauatahanui Inlet, Manukau Harbour, Hawkes Bay Region, East Cape Region, Bay of Plenty, and the Canterbury Region (see Figure 1). These were visited because of the availability of good quality horizontal trend data and differences in lithology and landform types. The following case studies summarise the data and CSI results collected.

1. Wairarapa Coast

This section of coast was the first visited for field testing and provided a good initial indication of the scope of the method, changes to and of variables that could be made, and how to make practical measurements of elevation in the field.

Approximately 32 km of coast from Whareama River to Flat Point was visited and 20 sites tested over a 3.5 day period (9-12 March 1992). This region possesses a wide variety of coastal landforms ranging from river mouths to soft and hard rock cliffs and platforms to sand beaches and dunes, to gravel beaches and ridges. A corresponding wide range of lithologies was also present ranging from sands and gravels to mudstones and siltstones to unconsolidated sands and gravels. Data on horizontal shoreline movements were made available by the Wellington Regional Council.

Where access was easy sites could be rapidly assessed (from Whareama to Uruti), but where access to the coast required permission from farmers and land owners to travel across farms (Uruti to Flat Point), there was some time spent in reaching the sites.

Results

Site elevations reflected the differing nature of the landforms, ranging from >30m for the cliffs north of the Kaiwhata River down to a sand barrier 0.7 m above MHWS adjacent to the Kaiwhata River mouth.

Average erosion rates ranged from 0.2 m/yr (gravel beach at Site 4) up to 1.3 m/yr (high cliffs at Kaiwhata, Site 13). Accretion was only recorded at two sites visited along the Wairarapa coast at average rates of 0.5 m/yr (Orui Station homestead, Site 18) and 1.2 m/yr (Riversdale

Beach, Site 20). Short-term fluctuations differed considerably, from those associated with river mouths (>100m at Kaiwhata, Site 15) to those associated with beaches (20 m at Riversdale, Site 20) and cliff failure (up to 30 m along the high cliffs north of Kaiwhata, Site 13).

Tsunami information was extrapolated from the observations made at Castlepoint (1.8 m) associated with the 22 May 1960 tsunami derived from the Chilean earthquake (de Lange and Healy 1986a).

Coastal sensitivity indices
CSIs ranged from 18 (low) to 36 (very high) out of 40 (Figure 12). The results illustrate the wide variety of conditions occurring along the Wairarapa coast, with the most sensitive areas being those with unconsolidated sediments, fluctuating natures, and susceptibility to inundation (Kaiwhata River mouth CSI = 36 (very high)).

The lowest [CSI = 18 (low)] was achieved on a hard rock platform formed of greywacke which has remained static with respect to adjacent landforms and lithologies. The soft rock cliffs formed of siltstones and mudstones encountered during field work were susceptible to failure by slumping caused by undercutting and erosion by waves.

2. The Kapiti Coast

In one day (13 March 1992), 32 km of coast from the Otaki River mouth to Paekakariki was assessed over 10 sites. The region possesses predominantly sand beaches with sections of gravel beach and New Zealand's largest cuspate foreland (at Paraparaumu). Rate data in the form of cadastral maps overlain by aerial survey information was made available by the Wellington Regional Council. Storm wave run-up levels were recorded by Gibb (1978a).

Field estimation of elevation and calculation of rates from the supplied maps took the most time. Each site was selected to correspond with the end of a known road for ease of access, or to correspond with existing beach profile sites established by Gibb (1979).

Results
Site elevations ranged from an average of 1.6 m for low sand dunes up to 8 m for high sand dune areas. Erosion occurred at five sites, although at Rosetta Road, Raumati, was protected by a seawall reducing the rate of erosion, and ranged from an average of 0.4 m/yr at Paekakariki to an average of 2.5 m/yr at Raumati South (Site 29). The Raumati South site also exhibited accelerated erosion owing to the end effects of a seawall adjacent to the site. Accretion occurred at six sites, and ranged from 0.16 m/yr (Rua Road, Site 27) to 1.25 m/yr (Site 23, Te Horo).

Tsunami information for the Kapiti Coast is scarce. The nearest available information is for the Manawatu and Wanganui Rivers which have previously had tidal bores of <1 m associated with small tsunami events (de Lange and Healy 1986a). These events have been used in the absence of more localised data.

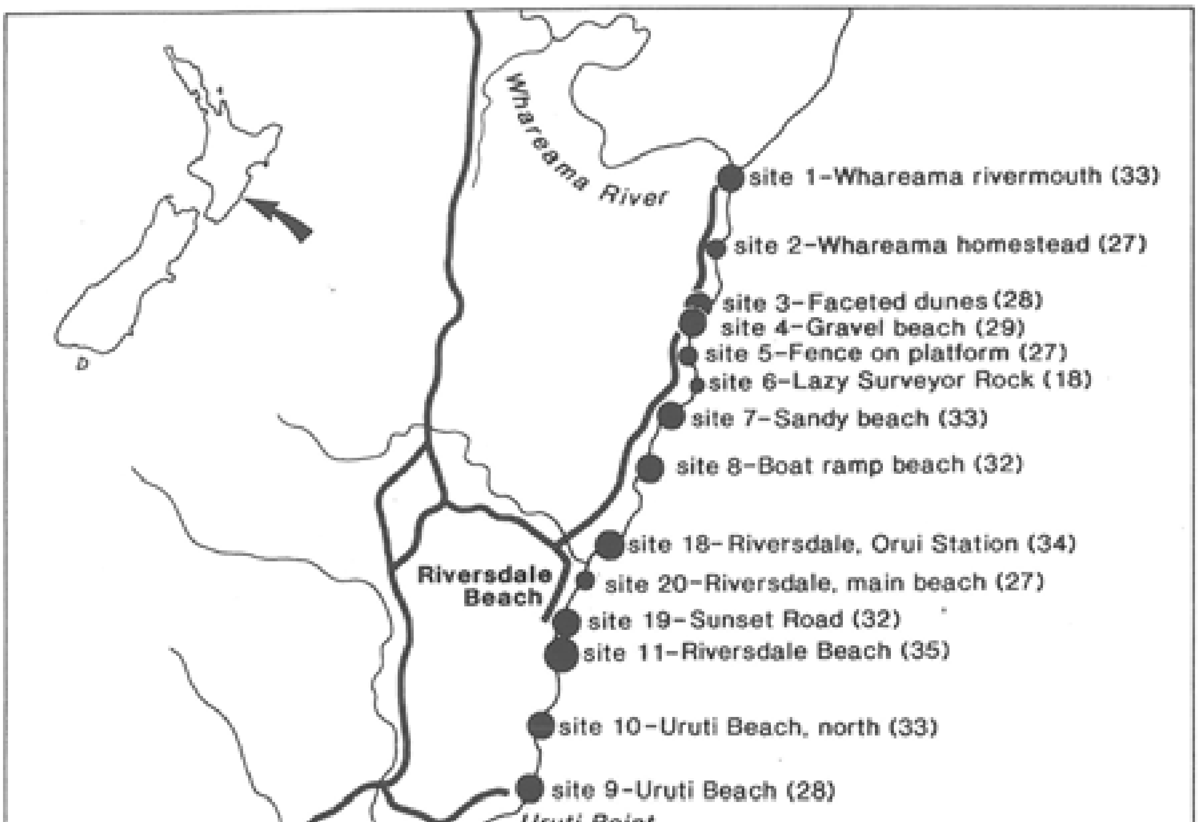


Figure 12 Sketch map showing the distribution of CSI ratings for 17 sites along the Wairarapa coast.

Coastal sensitivity

CSIs ranged from 26 (medium) to 35 (very high) out of 40 (Figure 13). The results reflect the nature of the lithological materials (sands and some gravels), and the landforms (river mouths, gravel beach, sand beaches and dunes, and the foreland at Paraparaumu). The area immediately south of the Raumati seawall has the highest sensitivity (CSI = 35) owing to the seawall accelerating natural erosion. The Otaki River mouth has the next highest sensitivity (CSI = 33) owing to its highly fluctuating nature and is also sensitive to inundation of low-lying swale areas by both storm wave run-up and river flooding.

3. Wellington South Coast

The south coast of Wellington was tested over 1.5 days (19-20 March 1992), primarily to test the CSI technique on a rapidly uplifting area, although the vertical trend variable became redundant at a later date. Ten sites were visited, and one site at Lyall Bay Surf Club was protected by a seawall. This coast ranges in landform types from sand to gravel beaches. Horizontal trend data for this area were supplied courtesy of the Wellington Regional Council.

Results

Elevations ranged from low (1.6 m at Camp Bay, Site 32) to medium (6 m at Baring Head, Site 35, and Bluff Point, Site 33). Storm wave run-up levels ranged from 2.5 m (Lyall Bay, Site 44) to 6 m (Baring Head). Information from de Lange and Healy (1986a) shows that 3.05 m tsunami accompanied the 1855 Wairarapa earthquake.

Average erosion was recorded for two sites (0.2 m/yr at Lyall Bay, 0.2 m/yr adjacent to the Wellington Airport, Site 45), static horizontal trends at four sites, and average accretion at three sites (0.7 m/yr at Fitzroy Bay (Site 34), and 0.4 m/yr at both Turakirae (Site 37) and Baring Head). Short-term fluctuations of <2 m (Turakirae Head) and up to >30 m were recorded (Bluff Point, Baring Head, Camp Bay).

Coastal sensitivity indices

CSIs for this region ranged from 21 (medium) to 33 (high) out of 40 (Figure 14). The results reflect the sensitive nature of the gravel and sand beaches to the hazards of erosion and short-term fluctuations. Baring Head also has the potential to be inundated, although no structures or houses are at risk. Turakirae Head which is uplifting at 4 m/1000 years was the most stable part of the coast.

4. Pauatahanui Inlet

This estuary was selected for CSI assessment owing to its low energy and sheltered wave environment. One morning (20 March 1992) was required to assess five sites around the inlet, with each site needing only an assessment of the elevation, photograph, and storm wave run-up level measurements.

Sites were located where easy access to the water's edge was available from the road and could be easily returned to (Motukaraka Point) if further information was needed.

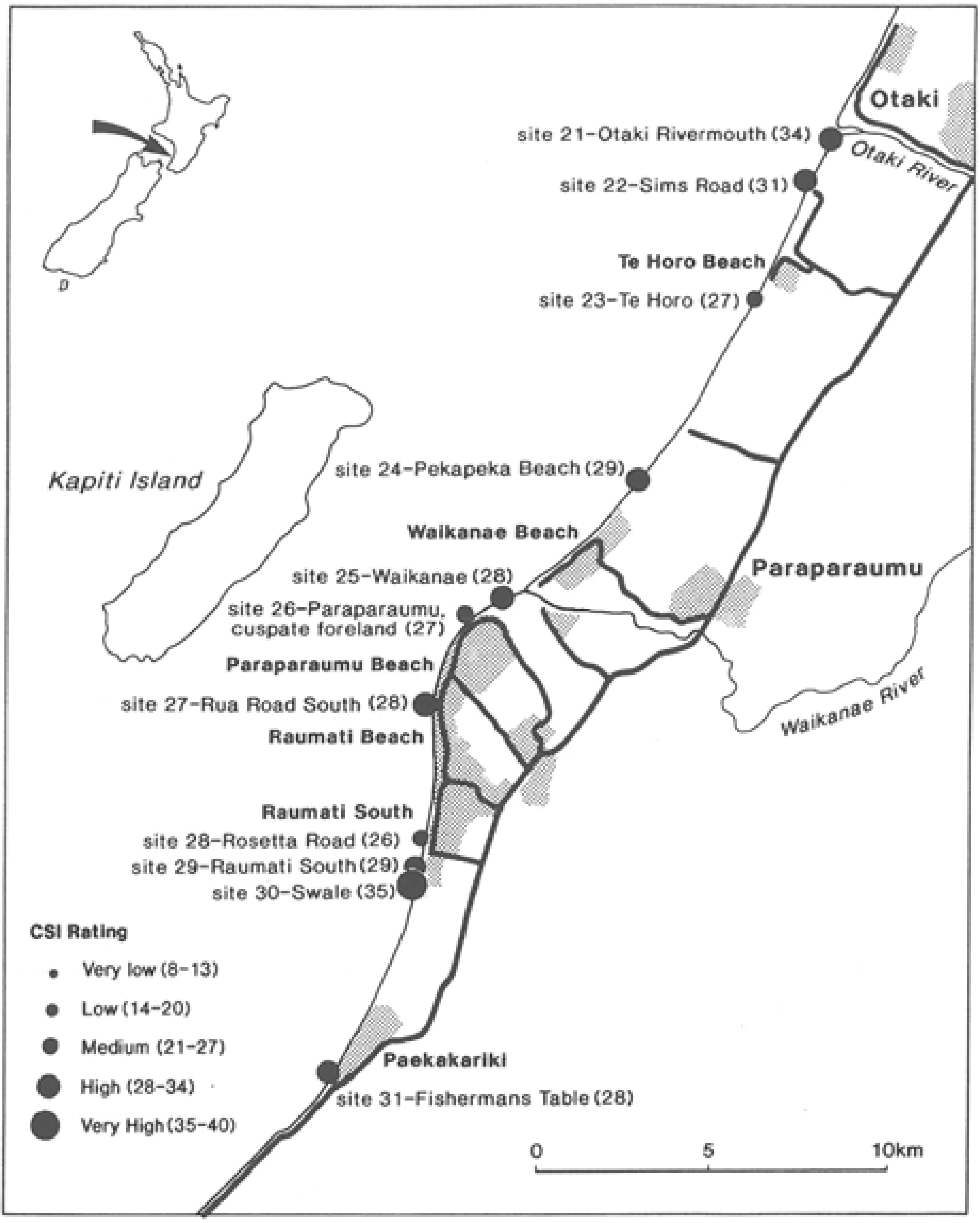


Figure 13 Sketch map showing the distribution of CSI ratings for 11 sites along the Kapiti Coast.

Results

Elevation ranged from 0.4 m up to only 1.5 m above MHWS. Landform types included saltmarsh (Wildlife Management Reserve, Site 39), alluvial outwash fans (Motukaraka Point, Site 41), and a sandy barrier (Paremata, Site 42). Long-term horizontal rates were estimated from anecdotal evidence and were shown to range from static to very low rates of erosion.

Storm wave run-up levels were measured on the day of field survey. Higher water levels were associated with strong westerly winds and equinoctial tides which occurred on that day. Storm wave run-up levels of 0.75 m near the inlet entrance up to 1.2 m near the back of the inlet were recorded. No tsunami information is available for this inlet, although likely effects could be associated with tidal bores near Paremata and raised water levels.

Coastal sensitivity indices

CSIs ranged from 23 to 26 out of 40 (medium rating), reflecting the main effect of inundation of low-lying areas adjacent to the inlet by storm wave run-up and higher tides (Figure 14).

5. Manukau Harbour

Franklin was visited to make CSI assessments in the relatively low energy environment within the Manukau Harbour. Franklin District Council possesses very little information about the effects of coastal hazards. Horizontal trend data existed for two beaches where protection works had been undertaken (Grahams and Hudsons Beaches, Sites 51 and 53) and along the cliff section of Racecourse Rd (Waiuku) where residences are threatened by cliff failure and erosion.

Eight sites were tested in one day (27 March 1992).

Results

Landform types ranged from sandy beaches, to soft rock cliffs composed of mudstones and alluvium, to similar cliffs composed of Plio-Pleistocene relict sands. Erosion predominated at all sites ranging from static (Wattle Bay, Site 54) to 0.3 m/yr (Grahams Beach).

Storm wave run-up levels were obtained from anecdotal evidence of waves associated with storms in 1978-1981, resulting in a 2.2 m storm wave run-up level above MHWS. One tsunami (0.3 m) has been recorded within Manukau Harbour as a result of the 22 May 1960 Chilean tsunami (de Lange and Healy 1986a). These waves were believed to be the result of the reflection of the primary waves off the coast of Australia.

Coastal sensitivity indices

CSIs ranged in value from 19 (low) to 30 (high) out of 40 (Figure 15), reflecting the low beach elevations with respect to storm wave run-up levels and inundation, and the overall erosive nature of the landforms.

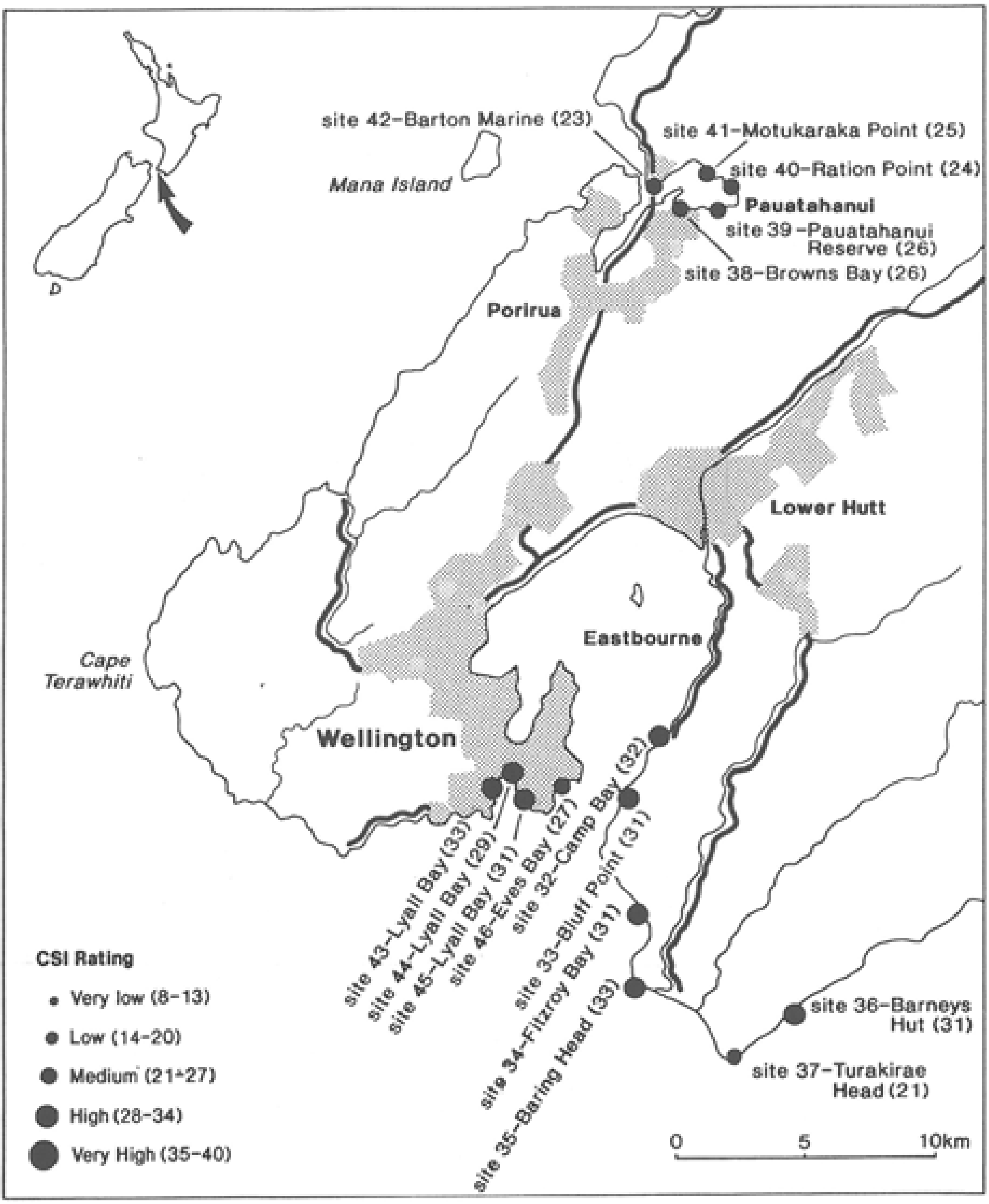


Figure 14 **Sketch map showing the distribution of CSI ratings for 9 sites along Wellington's South Coast and 5 sites around Pauatahanui Inlet.**

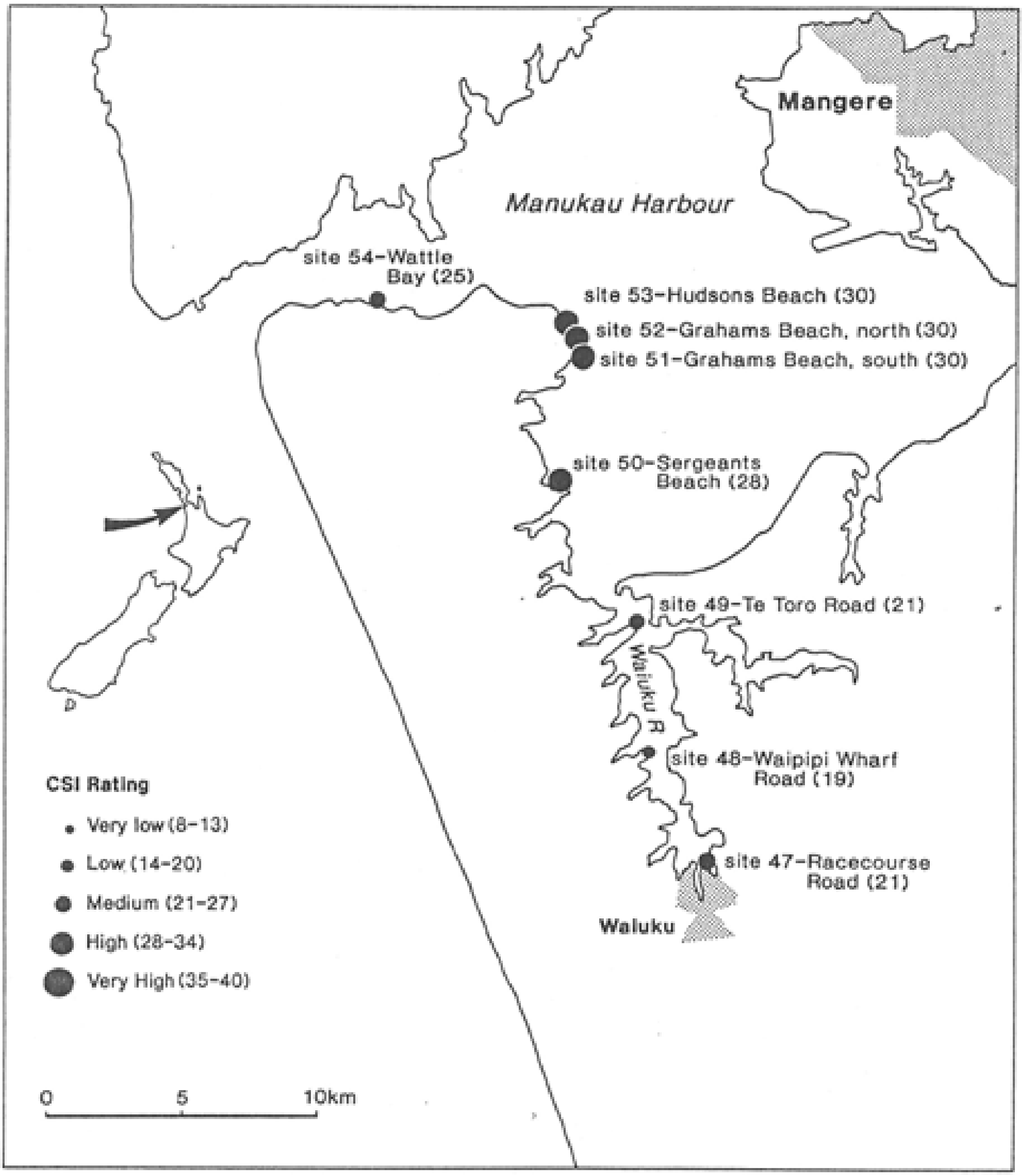


Figure 15 Sketch map showing the distribution of CSI ratings for 8 sites around the Manakau Harbour.

6. Hawkes Bay

Four beaches and sections of the Central Hawkes Bay region (Pourerere to Kairakau) and four beaches in Hawkes Bay were tested in one day (31 March 1992) with the majority of time being spent travelling between sites.

Horizontal trend and storm wave run-up data were available from Gibb (1978) and courtesy of the Hawkes Bay Regional Council (R. Black, pers. comm., March 1992).

The beach and coastal sections visited ranged from sand and gravel beaches to soft rock cliffs and platforms formed from mudstones. One beach site (Kairakau) has a seawall built to protect the local caravan park and motor-camp 15 years ago and is in a healthy state.

Results

Static to erosional horizontal trends were the norm for this section of coast, ranging from static at Kairakau (sand beach) and Pourerere South, Site 55 (soft rock cliff and platform), to rapid erosion at Te Awanga, Site 59 (1.05 m/yr in gravels), and to very high erosion opposite the Te Awanga Outfall, Site 60 (2.79 m/yr in gravels). Only two beaches showed long-term accretion, being at Awatoto, Site 61 (0.28 m/yr of gravels) and adjacent to the Port of Napier, Site 62 (0.78 m/yr of gravel material).

Storm wave run-up levels changed markedly from low levels (1.5 m at Pourerere South) to high levels (>3.5m at Te Awanga and along Hawke Bay). The effects of storm wave run-up have lead to inundation of coastal settlements (Te Awanga) and subsequently to the erection of sea exclusion walls to protect the townships and the fertile, low-lying, Heretaunga Plains.

The largest recorded tsunami (de Lange and Healy 1986a) has been a 3 m tsunami associated with the 22 May 1960 Chilean earthquake, which resulted in many coastal settlements along Hawke Bay being inundated, such as Te Awanga.

Coastal sensitivity indices

CSIs ranged from 22 (medium) to 35 (very high) out of 40 (Figure 16). The two highest results were recorded along the Te Awanga section of coast in Hawke Bay, where high rates of erosion of the gravel beaches, and high sensitivity to inundation by storm waves and tsunami events exist.

The lowest rating coastal site was that at Pourerere South. This site derives its low ranking from the high elevation and low sensitivity to storm wave run-up, **but** this section of coast is subject to mass land movements, slipping and landslides (>30m in size) of the mudstones which make up most of its lithology.

The remaining sites rated from 29 to 32 (high) out of 40, and were sensitive to inundation from storm wave run-up and tsunami, and erosion of the unconsolidated gravels and sands.

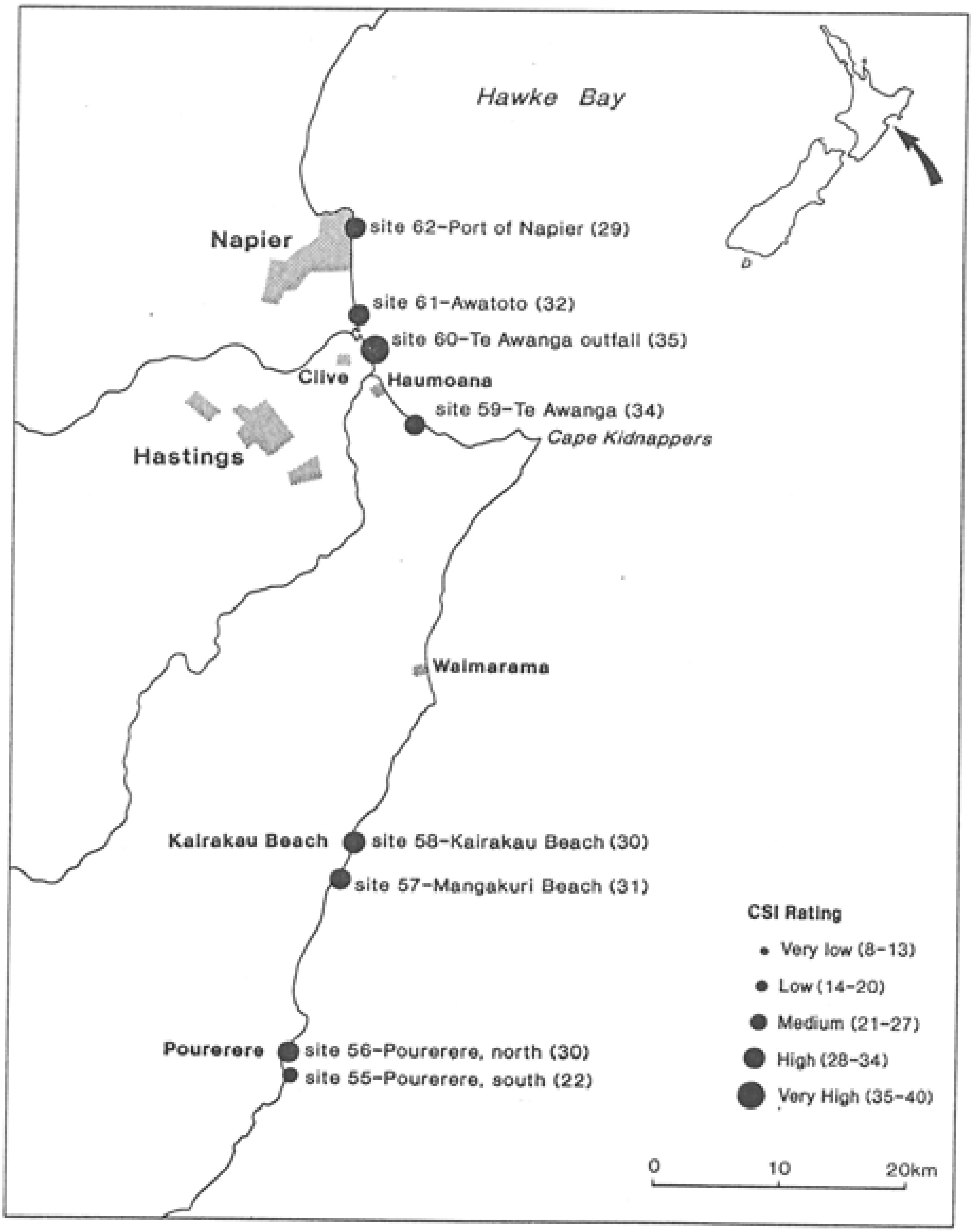


Figure 16 Sketch map showing the distribution of CSI ratings for 8 sites in southern Hawkes Bay.

7. East Cape

Twelve sites between Te Araroa and Torere were visited. This region provided a wide range of lithological (volcanics, greywackes, sands, gravels) and landform conditions (very hard and hard rock platforms, sand beaches, gravel beaches), as well as having good quality horizontal trend and short-term fluctuation data, supplied by the Gisborne District Council, and Gibb (1981). One day (1 April 1992) was used to assess 12 sites, which included travel time. The area between Gisborne and Te Araroa was not tested.

This region also gave an opportunity to make separate CSI assessments along beaches which have changing horizontal trends (from erosion to accretion) along their length (Te Araroa).

Results

Site elevations ranged from as low as 0.65 m (Hicks Bay South, Site 68) up to >30m (Lottin Point, Site 70) reflecting the change in landform type of a sand beach to very hard rock platform respectively.

Storm wave run-up levels of 2.2 to 3.3 m for the Te Araroa, Sites 63, 64, 65, Onepoto Bay, Site 67 and Hicks Bay, Sites 68 and 69, were calculated by Frisby and (1981) for Gibb (1981), reporting on Waiapu County. The calculated levels from the Wahine Storm of April 1968 indicate inundation of these low-lying beaches. Other storm wave run-up levels were estimated from storm debris and flotsam (>5 m at Hawai, Site 73 and Torere, Site 74) and from the lowest level of vegetation along shore platforms and cliffs (-1.5 m at Lottin Point, Whitianga, Site 72 and Whanarua Bays, Site 71). The latter levels indicate little inundation at these sites.

The largest recorded tsunami in the area was 3 m high noted at Cape Runaway on 15 August 1868 (de Lange and Healy 1986a).

Two sites suffer from high long-term rates of erosion (0.93 m/yr at Te Araroa B, Site 64, and 1.57 m/yr at Te Araroa A, Site 63). Six sites had average long-term rates of accretion, ranging from 0.2 m/yr (Torere) up to 1.2 m/yr (Hicks Bay South). The remaining sites were static as a result of their hard lithology (Whanarua and Whitianga Bays, greywacke, Lottin Point, basalts), although at Te Araroa C this rate reflected the “hinge point” where erosional trends changed to accretionary trends along the beach.

Short-term fluctuations ranged from negligible (0m at Lottin Point) to extreme over 100 m at Hicks Bay reflecting the unstable nature of the Wharekahika River.

Coastal sensitivity indicies

CSIs ranged from 13 (very low) to 36 (very high) out of 40 (Figure 17A). The highest CSIs were recorded at Te Araroa A and B (CSI = 36) where high erosion rates occur on the sand/gravel beach and at low elevations, which are very susceptible to inundation by storm waves and tsunami. The remaining sand and gravel beaches of the region score high CSIs (CSI = 31 to 34) and reflecting their low-lying relief and high fluctuations, although at some sites accretion is occurring.

Three of the lowest CSIs encountered during this project were found at Lottin Point (CSI = 13), Whanarua (CSI = 14) and Whitianga Bays (CSI = 15). These sites have very stable landforms and lithologies and are not affected by inundation or tsunami events.

8. Bay of Plenty

150 km of coastline and 21 sites from Ohiwa Harbour to Whangamata Harbour plus one site at Te Puru, Firth of Thames, were assessed and tested over a period of four days (2 - 4 April 1992). The predominant landforms along this coast are sand beaches, dunes and barriers. Other landforms encountered were associated with Ohiwa Harbour (saltmarsh/mangroves, sand spit), Maketu and Tauranga Harbour (soft rock cliffs of poorly welded ignimbrite), Whangamata Harbour (hard rock cliffs) and at Te Puru (an alluvial outwash fan/delta).

Results

Landform elevations ranged from 0.5 m (Munro Subdivision, Ohope) to >30m at Whangamata (Sheffield 1991). Storm wave run-up level estimates ranged from 1.44 m (Munro Subdivision, Site 78) up to 5 m above MHWS (along the Whakatane to Matata coastline).

Tsunami heights ranged from 0.9 m in 1883 (tidal bore at Maketu) to 1.8 m recorded on 15 August 1868. A 1.4 m tsunami accompanying the 22 May 1960 Chilean earthquake has also been recorded along this coast. For Te Puru (Firth of Thames, Site 97) a 0.9 m tsunami was recorded at Coromandel on 27 August 1883.

Average erosion ranged in magnitude from 0.1 m/yr (Maketu Caravan Park, Site 89) up 3.15 m/yr (Ohiwa Spit) and occurred at seven sites. Seven sites illustrated approximately static horizontal trends (with four sites being on sandy beaches, one saltmarsh/mangroves and one very hard rock cliff) while the remaining sections of coast were accreting. Average rates of accretion ranged from 1.28 m/yr (Ohiwa south) up to 1.78 m/yr (Golf Links Rd, Whakatane). Short-term fluctuations ranged from 0m (inner Whangamata Harbour, Site 96) up to >100m (Ohiwa Spit, Site 75).

Coastal sensitivity indices

CSIs ranged from 11 (very low) to 36 (very high) out of 40 (Figure 17A and B).

The highest CSI occurred at Ohiwa Spit (CSI = 36) where erosion (-3.15 m/yr), high fluctuations (>100m), and inundation by storm waves presented the greatest hazards. The lowest CSI occurred for the inner Whangamata Harbour (CSI = 11) where little effect of inundation or erosion could occur owing to its very hard volcanic rock nature and low rate of erosion or fluctuation.

The remaining sites range from CSI = 19 (low) to 32 (high). The high ranking sites reflect the sandy nature and sensitivity of the landforms to change, although some sites are in fact accreting, while the low rank sites reflect the more stable nature of the landform and lithology and little effect from storm wave run-up.

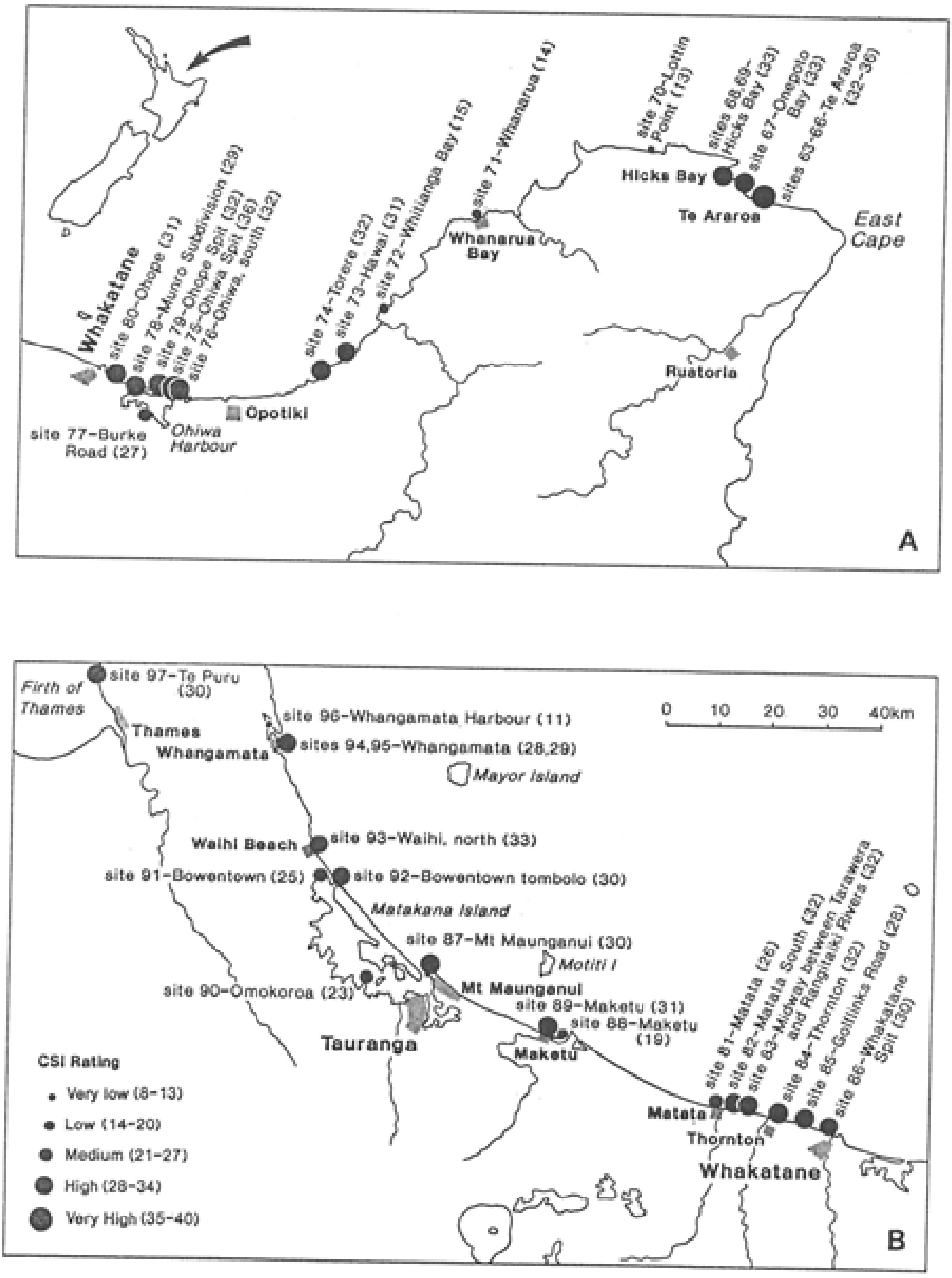


Figure 17 The distribution of CSI ratings for (A) sites 63-80 near East Cape and eastern Bay of Plenty; and (B) sites 81-97 in Bay of Plenty, and the Firth of Thames.

9. Canterbury

Approximately 250 km of coastline from Amberley Beach, Site 113, in the north to Waitaki Boys High School, Site 98 (Oamaru) in the South, excluding Banks Peninsula, was visited and tested over a 2 day period (14-15 May 1992). This region possesses a variety of landform types (sand beaches, mixed sand gravel beaches, soft rock cliffs) and lithologies (alluvium, sand, gravel, loess). Rate data for erosion/ accretion, short-term fluctuation information and beach profile data was made available courtesy of the Canterbury Regional Council. A desk test involving the calculation of a CSI based on all available published information, (but not an actual visit to the area), for the Motunau Cliffs (North Canterbury) was also undertaken using information provided in Lumsden and Kirk (1991).

It took two days to rapidly test the region. Site tests took approximately 10-15 minutes to complete, allowing for reconnaissance, confirmation of lithology and landform and a site photograph. The time spent at each site was considerably shortened by having the information for horizontal trend, short-term fluctuation and elevation already calculated in records held by the Canterbury Regional Council. Extra time in the field would have been required to complete elevation measurements using the sea-horizon technique or levelling, if the surveyed cross-sections did not exist. The majority of time was spent travelling between sites, since each site had to be reached via minor roads.

Each site corresponded to a known beach profile location surveyed by the Canterbury Regional Council. These sites are representative of similar adjacent coastline and the CSI results can be applied along that portion of coast until the next survey location or until a geomorphic break occurs (beach to cliff, cliff to river mouth, cliff to beach).

Results

Site elevations correlated with the landform type, in that soft rock cliffs formed of loess or alluvium ranged in size from 10 to 30 m in height, while sand and gravel beaches and ridges ranged in elevation from 3.5 to 6 m.

Erosion occurred at 11 sites and ranged from 0.32 m/yr (Pareora-now affected by a rip-rap seawall) to 2.5 m/yr (Washdyke, Timaru, Site 104). Accretion occurred at 5 sites and ranged from 0.24 m/yr (Brighton, Christchurch) to 5.91 m/yr (Caroline Bay, Timaru, Site 103). Erosion occurred on both soft rock cliffs and sand/ gravel beach ridges, while accretion occurred predominantly on sandy beaches where progradation is prevalent Pegasus Bay) or where port developments have occurred (Caroline Bay, Timaru).

Tsunami information from de Lange and Healy (1986a) showed that three tsunamis were recorded along the Canterbury Coast. For Timaru and South Canterbury a 1.8 m tsunami recorded on 13 August 1868 was used; for Oamaru a 2.8 m and for North Canterbury a 3.3 m tsunami was recorded on 22 May 1960.

Coastal sensitivity indices

CSI results ranged from 25 (medium) to 35 (very high) out of a possible 40 (Figure 18A). The results illustrate that the Canterbury coast is very susceptible to erosion and to inundation from overtopping by storm wave run-up for the lower lying beach areas.

Washdyke Lagoon has the highest sensitivity rating of the Canterbury region (CSI = 35 very high). The high rating reflects its highly eroding state and fluctuating nature (2.5 m/yr and short-term fluctuation of 20 m), its vulnerability to inundation by storm waves (storm wave run-up of 4 m which easily overtops the 3.5 m gravel barrier to inundate the low-lying area behind), and its lithological and landform make-up (unconsolidated sandy beach). The other highly rated areas reflect similar characteristics to Washdyke (being highly susceptible to inundation, erosion or short-term fluctuations).

Caroline Bay has a high sensitivity rating (CSI = 30, high). Although the beach is accreting at almost 6 m/yr and is located in a fairly low energy environment adjacent to the Port of Timaru, the rating reflects its lithological make-up (unconsolidated sands), its landform type (sand beach) which is susceptible to change, and its low elevation (3.8 m) which is susceptible to storm wave run-up (3.0 m) and possible inundation from tsunami events. Caroline Bay may be accreting, but there is no vertical build-up of dunes at the rear of the beach, which would render the beach very sensitive to any change in regime.

The Motunau cliffs have the lowest sensitivity rating (CSI = 25, medium). As a result of cliff failure affecting local residential properties this area is regarded as being at high risk by the Canterbury Regional Council. Any change in regime would have very little effect on this area, unlike Caroline Bay. From studying the original data, Motunau has a negligible susceptibility to flooding by both the river and inundation from storm waves.

10. Hokitika

Three desk tests were carried out for Hokitika during the course of this project. Information about this area was derived from Gibb (1987).

Results

The elevation and storm wave run-up data were derived from measured profiles in Gibb (1987). Streets and houses close to the barrier front have been inundated in the past. Tsunami data from de Lange and Healy (1987) show that the nearest tsunami was recorded on 13 August 1883 at Westport (1.2-1.5 m).

Accretion occurred at two sites and ranged from 0.08 (Hampden Street) to 1.34 m/yr (Camp Street), while a low average erosion rate occurred at Tudor Street (-0.02 m/yr).

Short-term fluctuations range from 60 m (Hampden Street), up to 200 m (Camp Street), and reflect the highly mobile nature of the Hokitika River.

Coastal sensitvity indices

The three test sites (Figure 19) all had high CSI ratings (CSI-32-33). These results reflect the highly fluctuating nature of the Hokitika river mouth and adjacent beaches, and susceptibility to flooding by both the river and inundation from storm waves.

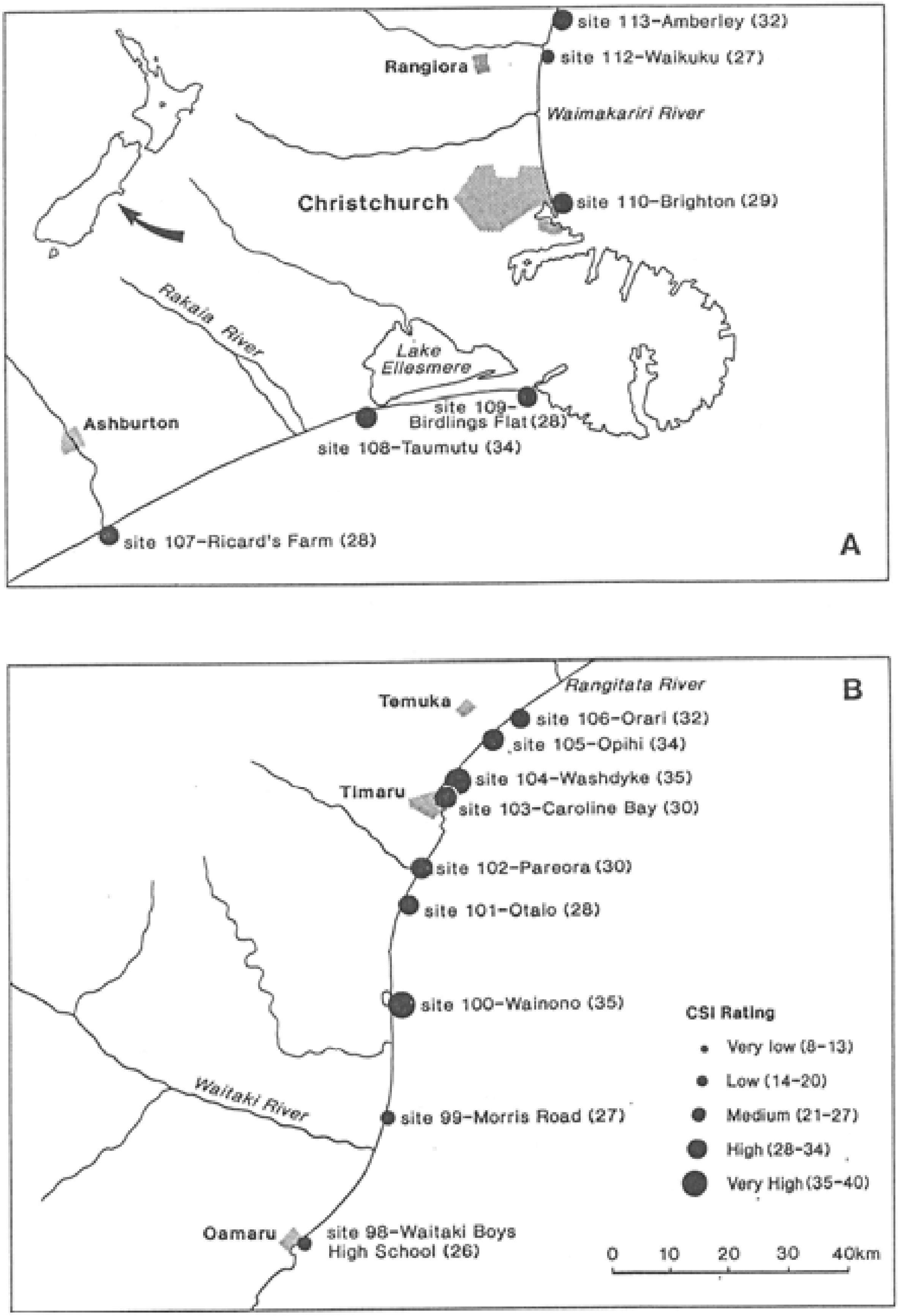


Figure 18 The distribution of CSI ratings for (A) sites 107-113 on the Cantebury coast; and (B) sites 98-106 in south Cantebury

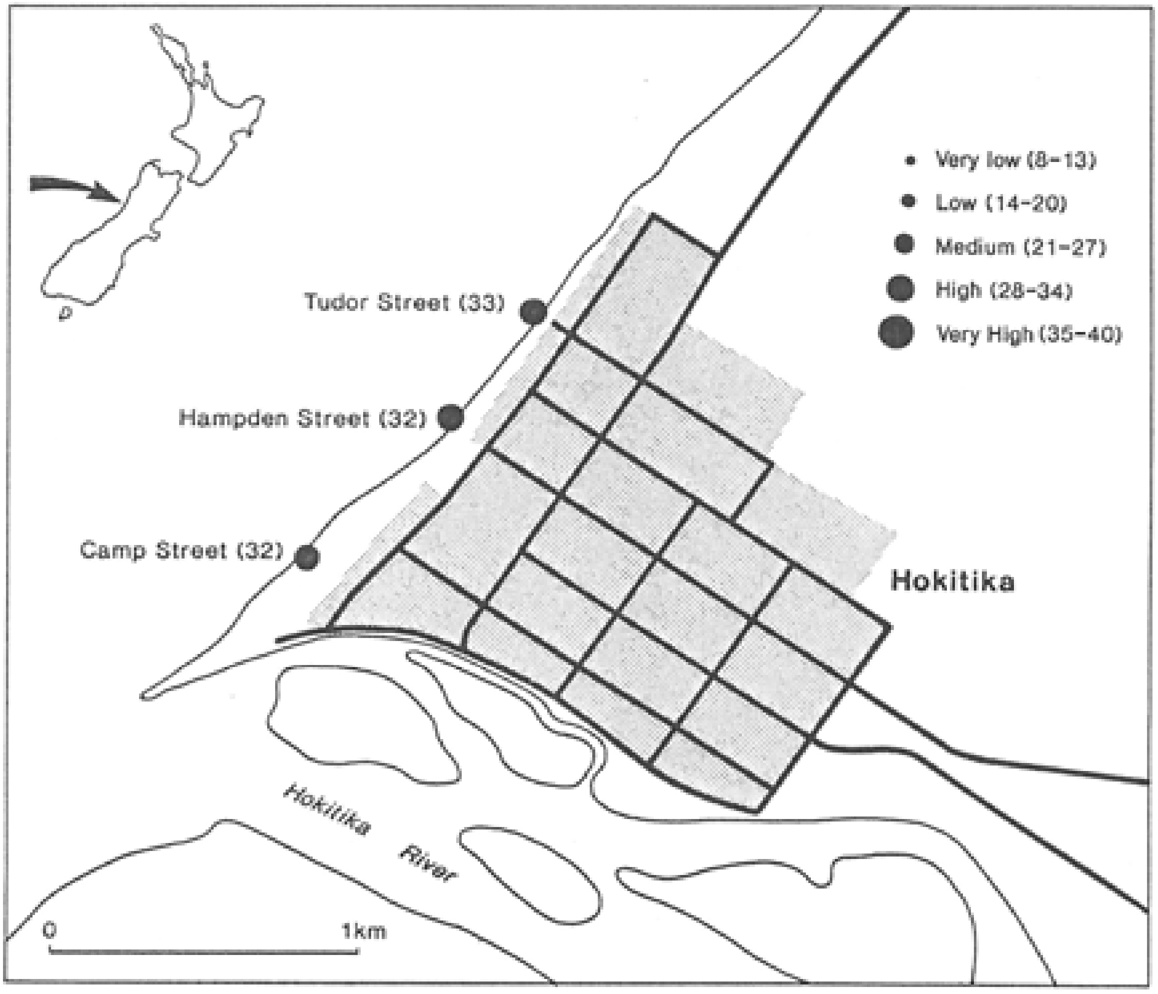


Figure 19 The distribution of CSI ratings for 3 sites along the Hokitika foreshore.

Summary
Table 6 summarises CSIs (max/min) for each study area. The highest CSIs occurred predominantly on highly fluctuating, eroding sandy shorelines (Te Araroa, Ohiwa Spit), as a result of river channels changing course, from the movement of spits or from the large scale movement of sand during storm events. The highest ranking sites also tended to have low elevations and be highly sensitive to inundation by storm waves.

Lowest CSIs occurred on landforms which are very stable in nature, that is, very hard rock platforms and cliffs. These reflect their lithological make-up (volcanics, greywackes) and have low horizontal trends and fluctuations.

Medium ranked CSIs occurred on a variety of landforms, generally being sensitive to one main hazard, but not the combination which would raise the rating to a high level.

Table 6 Summary of maximum and minimum Coastal Sensitivity indices from each study area.

Region	CSI Minimum	CSI Maximum
Wairarapa	18 low	36 very high
Kapiti Coast	26 medium	35 very high
Wellington	21 medium	32 high
Pauatahanui	23 medium	26 high
Manakau	19 low	30 high
Hawkes Bay	22 medium	35 very high
East Cape	13 very low	36 very high
Bay of Plenty	11 very low	36 very high
Cantebury	25 medium	35 very high
Hokitika	32 high	33 high

The testing of the field areas and assessment of CSIs resulted in the full range of ranks being encountered (from very low to very high sensitivities), and have provided a good documented background for the basis of this study. This published information is held in the DOC central library, entitled "Supplementary Appendix site forms for the regions tested during the development of the Coastal Sensitivity Index".

4.3.2 Examples characterising very high to very low sensitivity areas

After the boundaries were set it was possible to place the 113 test sites into five broad groups which possessed the potential ranging from very high to very low for physical change. The following areas represent a sample selected from and characterising these broad groups. The complete appendix is held at the Department of Conservation central library in Wellington.

Very high (rated 35-40)
These areas are typically characterised by unconsolidated sediments, very low-lying landforms such as spits, river mouths and beaches, which have a very highly fluctuating nature and high to very high rates of erosion. (Plates 8, 9, and 10)

High (rated 28-34)
This group contains some areas which at first glance may appear to be at very high risk, but when the actual data is investigated, the area may in fact be accreting in the long-term. These sites are also typically characterised by unconsolidated sediments which may be eroding or accreting, in addition to moderate/ high short-term fluctuations. (Plates 11, 12, 13, and 14).

Plate 8 Ohiwa spit (foreground), Bay of Plenty, looking west to Ohope spit, 2 April 1992, rated 36. Characterised by its low-lying nature (4.7 m), high storm wave run-up (5 m), and low gradient behind the foredune. It suffers from erosion (3.15 m/yr) and high fluctuations due to the repositioning of the spit tip. On Ohiwa Spit two subdivisions have been lost to erosion this century.

Plate 9 Eastern Te Araroa beach (Site 63), East Cape, 1 April 1992, rated 36. This low-lying sand/gravel beach (1.5 m above MHWS) suffers from inundation from storm events, high fluctuations (50 m) and a high rate of erosion.

Plate 10 Looking north at Site 100, Wainono Lagoon, Waimate Creek, Canterbury, 14 May 1992, rated 35. Gravel beach ridge has a medium elevation (6 m), but it is eroding and is regularly overtopped, inundating the lagoon behind. It also from high fluctuations and cut-back during storms.

Plate 11 Site 67, Onepoto, Horseshoe Bay, East Cape, 1 April 1992, rated 33. This accreting (0.5 m/yr) sandy beach has a very lowland elevation and gradient, and experiences high storm wave run-up levels which frequently extend inland through the houses to the road paralleling the beach.

Plate 12 Looking east, Site 83, midway between the Rangataiki and Tarawera rivers on the Bay of Plenty coast, 3 April 1992, rated 32. This sand beach has a low elevation which is overtopped by storm wave run-up. While experiencing very high short-term fluctuations it is accreting at the rate of 1.4 m/yr.

Plate 13 Looking east, Site 33, Bluff Point, Wellington, 19 March 1992, rated 31. This gravel beach site is characterised by a medium elevation (6 m), but is overtopped by very high storm wave run-up m). While the long-term trend remains approximately static, it experiences very high fluctuations as a result of pulses of gravel entering and leaving the bay from longshore drift.

Plate 14 Site 103, Caroline Bay, Timaru, 14 May 1992, rated 30. This sandy beach site, while exhibiting accretion, is low-lying, inundated by storm wave run-up and experiences high fluctuations.

Plate 15 The head of Pauatahanui Inlet, Site 39, Pauatahanui Wildlife Management Reserve, Wellington, 20 March 1992, rated 26. This low-lying shelly gravel ridge backed by a saltmarsh is found within sheltered estuarine conditions which contribute to low levels of storm wave run-up and very small short-term fluctuations.

Plate 16 Looking north of Site 13, high cliffs north of the Kaiwhata River, Wairarapa, east coast, 11 March 1992, rated 26. This site is characterised by eroding, steep gradient, high cliffs composed of mudstones which are susceptible to large slumps resulting in the retreat of the cliff top by over 30 m.

Plate 17 Looking south of Site 23, Te Horo beach, Kapiti Coast, 13 March 1992, rated 25. This accreting sandy beach has a low foredune that has not been overtopped by recorded storm wave run-up levels, but does experience high short-term fluctuations.

Medium (rated 21-27)

These sites exhibit moderate rates of erosion or accretion, low to moderate short-term fluctuations, moderate to high elevations and may be composed of a variety of types. (Plates 15, 16, and 17)

Low (rated 14-20)

Low sensitivity areas exhibit a wide range of rock types but are generally characterised by moderate to high elevations, are not susceptible to overtopping by storm wave run-up and may be accreting or eroding at very low to low rates. (Plates 18 and 19)

Very low (rated 8-13)

These sites are typically characterised by high elevations, steep gradients, very hard rock composition, very low erosion rates and no short-term fluctuations. (Plates 20 and 21)

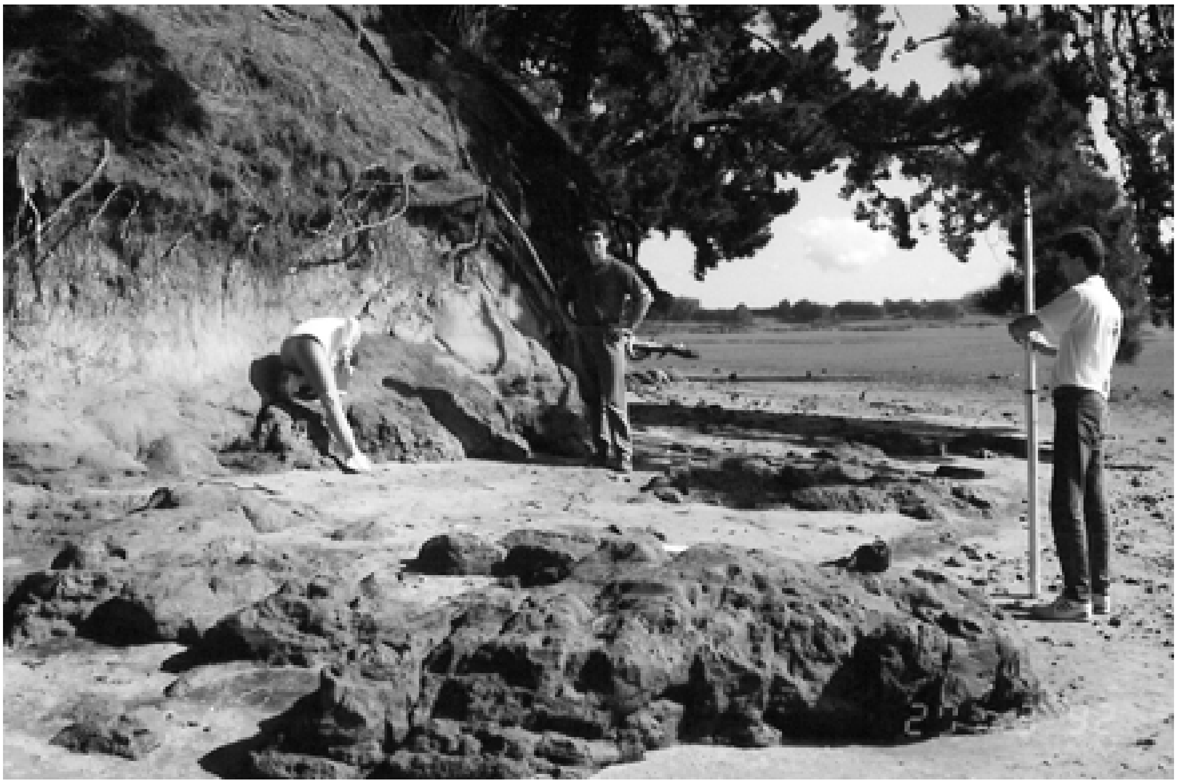


Plate 18 Photo taken 27 March 1992 of Site 48, Waipipi Wharf Rd, Manakau Harbour, Franklin District, rated 19. the low rating reflects the moderate elevation, low storm wave run-up (due to its sheltered nature), and the steep gradient of the soft rock, Pliocene sand cliffs. The site experiences small short-term fluctuations and a low erosion rate.

Plate 19 Photo taken 2 April 1992 of Site 71, Whanarua Bay, Eastern Bay of Plenty, rated 14. Whanarua Bay is composed of steep greywacke hard rock and platforms, which are eroding very slowly and are not to slumps or fluctuations.

Plate 20 Photo taken 4 April 1992 looking east at Site 96, Whangamata upper harbour, Coromandel, rated 11. This area rates very low owing to its steep, hard rock nature, and its situation within the sheltered confines of the Whangamata Harbour. It is not susceptible to inundation by storm wave run-up or short-term fluctuations or failures.

Plate 21 Photo taken 4 April 1992, of Site 70, Lottin Point, East Cape, rated 13. This site is composed of very hard basalts, has a steep cliff and rock platform and is not susceptible to inundation by storm wave run- up or short term fluctuations despite having full exposure to very heavy seas at times from the northerly quadrant.

4.3.3 Sea-level rise

Depending on it's magnitude and rate sea-level rise can be a major contributing facto to accelerated shoreline retreat (Gibb 1988; 1991). Sea-level can also influence the type and magnitude of such processes as tidal range, breaker type, longshore current velocities, and sedimentation rates (Pethick 1984). A change in sea-level will modify coastal processes, affecting the relative magnitude or causing a complete change in processes which operate on a particular landform. Carter (1988) noted that a gradual rise in sea-level would enhance the landward penetration of surges and storm waves, and would lead to shoreline erosion.

Greenhouse affected weather patterns couls alter the amount of sediment supplied to the coast, altering sediment transport rates. Storm frequency, intensity and predominant wave direction may also be affected, causing significant reversals in longshore drift directions. In some cases, the enhanced greenhouse effect may cause a coast to react 'favourably' (e.g., by accreting).

Historic rates of sea-level rise for New Zealand have been calculated by Hannah (1990) who analysed mean sea-level data obtained from tide gauges at the ports of Auckland, Wellington, Lyttelton, and Dunedin over the period 1899 to 1988. hannah's results indicated rising trends in sea-level on 1.3, 1.7, 2.3 and 1.4 mm/yr for Auckland, Wellington, Lyttelton and Dunedin,

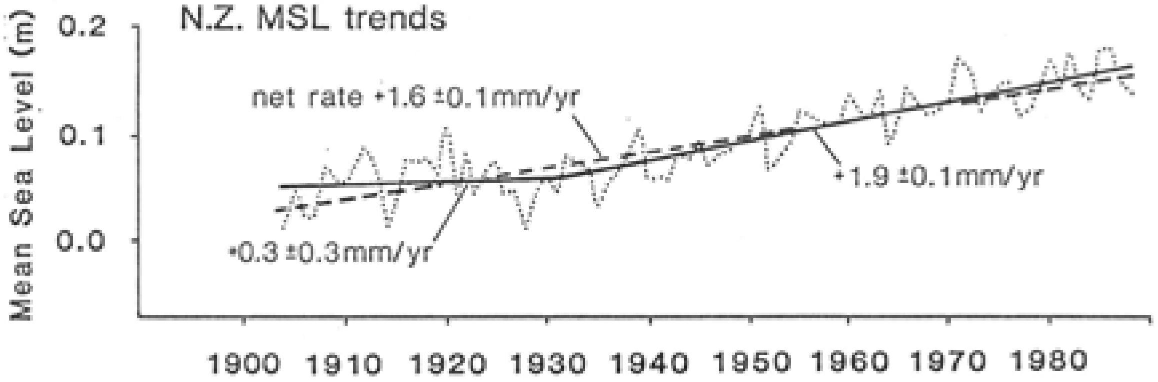


Figure 20 sea-level trend for New Zealand (1904-1988) adapted from Gibb (1991).

respectively which together gave a mean trend of 1.7 mm/yr for the east coast of New Zealand as a whole. From the same datasets Gibb (1991) derived an historical sea-level curve for New Zealand for the period 1904 to 1988 (Figure 20), and a mean trend of 1.6 ± 0.1 which agreed favourably with Hannah (1990).

Projections made by the Intergovernmental Panel on Climate Change (IPCC 1990) based on an assessment of climate change and the enhanced greenhouse effect suggest that under the IPCC Business-as-Usual scenario global mean temperatures are predicted to rise to about 1°C above the present value by 2025 A.D. and 3°C before 2100. Based on these projections, sea-level rise around New Zealand may increase 2-6 times above the present rate of ~1.7 mm/yr, within a range of 3-12 mm/yr by 2100 A.D. (Figure 21).

Local relative sea-level on a global scale differs from place to place however, and measurements have been recorded over a variety of time spans. Changes in local relative sea-level are regional; therefore it is advisable to use local trends such as those published by Hannah (1990) and Gibb (1991) for New Zealand when assessing the likely impacts of sea-level changes on the coast.

Average sea-level rise of 2.4 mm/yr at Lyttelton has culminated in a 20 cm elevation of the sea surface since the 1900s, yet Christchurch beaches have maintained a dynamic equilibrium and have actually risen vertically rather than been eroded landwards (R. Kirk, pers. comm., June 1992). The tidal prism of the Avon-Heathcote estuary has doubled with about half of this expansion attributed to sea-level rise, although this has not markedly affected the estuary (Findlay and Kirk 1988). An increase in rainfall may in fact have a greater effect on the coast than a rise in sea-level owing to raised water table effects causing increased beach scour.

Using Hannah (1990) and Gibb (1991) sea-level rise values for New Zealand and the projections made by IPCC an attempt was made to assess the change that would occur to the CSI, in order to identify areas of the coast which may be most susceptible to an increase in sea-level rise. The following case study illustrates an example to incorporate sea-level rise into the CSI, with limited success.

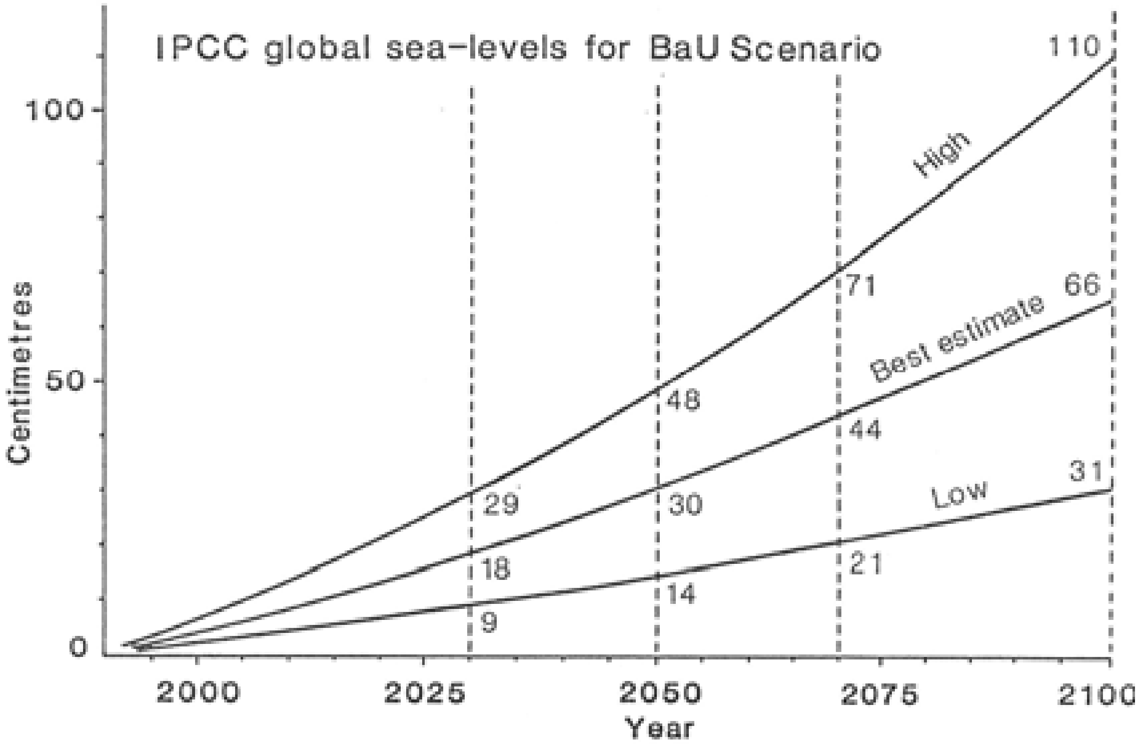


Figure 21 Graphs showing low, best estimate and high projections of global sea-level rise for the period 1990-2100 adapted from Gibb (1991).

Methods and results
A number of tests were conducted for the following scenarios:

1. Sea-level continues to rise at the historic rate of 1.7 mm/yr, (Figure 20) and with local rates as follows: Auckland 1.2 mm/yr, Wellington 1.7 mm/yr, Lyttelton 2.4 mm/yr and Dunedin 1.4 mm/yr (after Gibb 1991). Where a site was located near any of the major recording sites the local rate was used for accuracy, otherwise the national average rate was used.

2. Based on the IPCC projections the historical rate of sea-level rise (Figure 21) accelerates 2 to 6 times (i.e., from 3.4 to 10.2 mm/yr) during the next century.

To conduct the tests the following criteria were also applied:
1 That a rise in sea-level equates to a corresponding relative fall in elevation. This assumes that beaches or ridges will not have the time or sediment supply to prograde in response to an accelerating rise in sea-level.

2 That storm wave run-up levels will remain of the same magnitude. Low-lying areas that had previously not been flooded may become more susceptible to the effects of inundation.

3 That no appreciable changes in horizontal trend occur. Erosion or accretion may increase or abate with increasing sea-level. However, it is not possible to predict what changes to horizontal trend may occur with any confidence at this stage.

As a first step the rise in sea-level that may occur by the year 2050 **A.D.** and 2100 **A.D.** was calculated using the 1.7 mm/yr average for New Zealand, and the IPCC scenarios of 2 and 6 times the present rates (3.4 and 10.2 mm/yr). Assuming sea-level rise from present (1992) the rise in mm by 2050 A.D. (58 years) and 2100 A.D. (108 years) was calculated (Table 7).

Table 7 Total rise in sea-level (in cm) to 2050 A.D. and 2100 A.D. using the average rate of sea-level rise for New Zealand and the IPCC scenarios of 2 and 6 times the present rate.

Year	**Average New Zealand rise in sea-level** Rate= 1.7 mm/yr	**Rise in sea-level** (IPCC accelerated rates)	
		2 times (3.4 mm/yr)	6 times (10.2 mm/yr)
2050	9.9cm	19.7 cm	59.2 cm
2100	18.4 cm	36.7 cm	110.2 cm

As a second step the changes to CSI between present and future were assessed, for selected test areas which may illustrate increasing sensitivity to sea-level rise (i.e., low-lying beaches and ridges). This assumed that criteria 2 and 3 above are met and that only elevation will decrease relative to the rise in sea-level.

Detailed results are given in Appendix 10. In general, the results from these tests did not significantly change the CSI values or classes. The main changes however, occurred with the largest IPCC projections for sea-level rise. Significant change in the CSI occurred only where sea-level rise caused increased overtopping, and therefore a change in the position where gradient is measured. Generally however, the change was not great enough to alter the rating, from high to very high sensitivity, or medium to high sensitivity.

The greatest unknown in this assessment however, is whether the coast will advance or retreat in response to sea-level rise. Much of this unknown centres on a lack of knowledge of coastal sediment budgets and their response to sea-level changes. Geologic evidence from New Zealand and Australia revealed that during the postglacial marine transgression from about 18,000 years B.P. to about 6,500 years B.P. there was widespread retreat of coastlines everywhere. During this 11,500 year period sea-level rose at 10-15 mm/yr, a rate projected to occur with the worst case greenhouse scenarios. Should that rate occur again then it is highly likely that coastlines will once again retreat everywhere, overwhelming positive sediment budgets and tectonic uplift. Under this scenario most if not all sand and gravel coasts would increase to a very high CSI rating.

5. CONCLUSIONS

1. The Resource Management Act 1991 establishes a partnership for coastal management between the Minister of Conservation as the Crown's representative and regional and district councils. Under the Act, regional councils shall control the use of land for the purpose of the avoidance or mitigation of natural hazards. For the area seaward of MHWS that function is shared with the Minister of Conservation with respect to controlling any actual or potential effects of the use, development, or protection of the land including the avoidance or mitigation of natural hazards.
2. The Coastal Sensitivity Index (CSI) developed here satisfies the requirements of the Resource Management Act by providing a standardised method for assessing the relative sensitivity of areas of the New Zealand coastline to existing physical processes, which may become hazardous to human property and values. The major hazards considered were flooding from tsunami, storm wave run-up and sea-level rise, and erosion from shoreline retreat and landslip. Natural hazards not considered included earthquake, volcanic and geothermal activity, subsidence, wind, drought and fire. Human induced hazards not considered included pollution and the adverse effects of coastal protection works.

3. The CSI and initial framework for physical coastal hazards information were developed through a process of rigorous field testing at 113 sites, representing different types along both the open-exposed and sheltered coasts of New Zealand. Test sites included the coastlines of Wairarapa, Wellington's south and west coasts, Pauatahanui Inlet, Manukau Harbour, Hawkes Bay, East Cape, Bay of Plenty, and Canterbury regions. The development process was followed by extensive consultation and feedback from coastal practitioners and specialists.

4. The CSI matrix evolved from an initial 13 variables to 8, each representing the end effect of many interacting processes. The 8 variables adopted were; elevation, maximum storm wave run-up level, gradient, maximum tsunami wave height, lithology, natural landform, horizontal shoreline trend, and short-term shoreline fluctuation.

5. Each of the 8 variables requires reliable, professionally defensible data which is subdivided into 5 classes. The CSI for a section of coast is derived by adding the specific class (1-5) allocated to each of the 8 variables. Coastal Sensitivity Indices potentially range from a minimum of 8 to a maximum of 40 for a specified site, the numerical class boundaries being 8-13 (very low), 14-20 (low), 21-27 (medium), 28-34 (high), and 35-40 (very high).

6. For the 113 coastal sites tested, CSI's covered the full spectrum ranging from very low to high (30) for sheltered coasts, and from very low (13) to very high (36) for open exposed coasts. Coastlines with very high CSIs (35-40) were typically low-lying coastal landforms of unconsolidated sediments with a history of shoreline retreat, high to very high shoreline fluctuations, and inundation from storm wave run-up and tsunami. Coastlines with very low CSI's (8-13) were typically hard rock landforms of steep elevation, with a history of low to very low shoreline movements and inundation from the sea.

7. The CSI assessment technique is rapid and easily applied if good quality data are available. Sites take about 15-30 minutes to assess. Depending on travel time and coastal access it is possible to assess about 10 sites per day over 30 km of coast.

8. The identification of very low to very high sensitivity areas of coast on a local, regional or national scale provides a useful basis for both more detailed monitoring of specific areas and basic information to assist with the development of regional and district plans by local authorities. Because the CSI technique has been tested and standardised it will be possible to compare high to very high sensitivity areas nationally, including measures taken by regional councils to avoid or mitigate the adverse effects of natural hazards in such areas.

9. The coastal hazards database underpinning the CSI provides an essential framework to assess the potentially adverse effects of accelerated sea-level rise next century in response to enhanced greenhouse warming. Further work is required in this area however, because of the uncertainty of how coastlines with different sediment budgets and physical characteristics will respond to rises in local relative sea-level.

6. ACKNOWLEDGMENTS

The following people and organisations are gratefully acknowledged for either providing information, participating in field work or constructively criticising the manuscript:

Department of Conservation
Tony Seymour, East Coast Conservancy.
Bruce Dix, Wellington Conservancy.
Don Neale, West Coast Conservancy.
Warren Sisarich, Legal Section, Head Office.

Other Government Agencies
Bruce Thompson, Geoff Gregory and Alan Hull, National Institute of Geological and Nuclear Sciences Ltd., (formerly DSIR Geology and Geophysics).
Murray Hicks, Terry Hume, Dick Pickrill, Basil Stanton, Rob Bell, National Institute of Water and Atmospheric Research Ltd., (formerly DSIR Marine and Freshwater and the New Oceanographic Institute).
Garth Eyles, National Institute of Land Resources Ltd., (formerly DSIR Land Resources). Steve Reid, Andrew Laing, N.Z. Meterological Service.
John Hannah, N.Z. (DOSLI).

Local Authorities
Sharon Parker, Auckland Regional Council
Noel Reardon, Franklin District Council
Paul Dell, Bay of Plenty Regional Council
David Peacock, Gisborne District Council
Robin Black, Hawkes Bay Regional Council
Wayne Hastie, Wellington Regional Council Derek
Todd, Canterbury Regional Council

Universities
Kevin Parnell, University of Auckland.
Terry Healy, Willem de Lange, Roger Briggs, University of Waikato.
Brad Pillans, Victoria University of Wellington.
Bob Kirk, Alex Sutherland, David Bell, University of Canterbury.

7. REFERENCES

American Geological Institute 1962. Dictionary of Geological Terms. Dolphin Reference Books edn, U.S.A. 545p.

Ballance, P.F., and Williams, P.W. 1982. The geomorphology of Auckland and Northland. Chapter 7 in Soons, J.M. and Selby, M.J. (Eds): Landforms of New Zealand. Longman Paul. 392p.

Carter, R.W.G. 1988. Coastal Environments: an introduction to the physical, ecological and cultural systems of coastlines. Academic Press. 617p.

Crozier, M.J. 1992. Hazard assessment terminology.

de Lange, W.P. 1983. Tsunami hazard- an investigation into the potential hazards of the Bay of Plenty region using numerical models. M.Sc. thesis, Earth Science Dept, University of Waikato.

de Lange, W.P., and Healy, T.R. 1986a. New Zealand tsunamis 1840-1982. *New Zealand Journal of Geology and Geophysics* 29: 115-134.

de Lange, W.P., and Healy, T.R. 1986b. Tsunami hazards in the Bay of Plenty, New Zealand. An example of hazard analysis using numerical models. *Journal of Shoreline Management* 2 (1986): 177-197.

DSIR 1979. The New Land Resource Inventory. Department of Scientific and Industrial Research, Wellington. 38p.

Evans, A.W. 1992. The application of geomorphology in coastal marine studies. *Ocean and Coastal Management.* 17: 47-55.

Foster, G.A. 1991. Beach nourishment from a nearshore dredge spoil dump at Mount Maunganui Beach. M.Sc. thesis, Earth Sciences Department, University of Waikato.

R.B., Goldberg, E. 1981. Storm wave run-up levels at Onepoto Bay, East Coast, North Island, New Zealand. *Water and Soil Technical Publication 21:* 59-63.

Joint Earth Science Working Group 1989. New Landform Inventory First Approximation. Joint Earth Science working group on geopreservation. *Research School of Sciences, Occasional Paper No. 4.* University of Wellington. (see also Geological Society of New Zealand)

Gibb, J.G. 1978a. The problem of coastal erosion along the "Golden Coast", western Wellington, New Zealand. *Water and Soil Technical Publication No. 10.* 20p.

Gibb, J.G. 1978b. Rates of coastal erosion and accretion in New Zealand. *New Zealand Journal of Marine and Freshwater Research.* 12 (4): 429- 456.

Gibb, J.G. 1979. Late Quaternary shoreline movements in New Zealand. Ph.D. thesis, Victoria University of Wellington. 217p.

Gibb, J. G. 1981. Coastal hazard mapping as a planning technique for Waiapu County, East Coast, North Island, New Zealand. *Water and Soil Technical Publication no. 21.* 63p.

Gibb, J.G. 1983. Combating coastal erosion buy the technique of coastal hazard mapping. *New Zealand Engineering, 1 Feb 1983:* 15-19.

Gibb, J. G. 1984. coastal erosion. Pp 134-158 in I. Speden and M.J. Crozier (Eds): *Natural Hazards in New Zealand.* New Zealand National Commision for UNESCO, Wellington.

Gibb, J. G. 1987. A coastal hazard management plan for Hokitika. *Water and Soil Technical Publication no. 29.* 44p.

Gibb, J. G., and Aburn, J. H. 1986. Shoreline fluctuations and an assessment of a coastal hazard zone along Pauanui Beach, eastern Corimandal Peninsula, New Zealand. *Water and Soil Technical Publication no. 27.* 48p.

Gibb, J.G. 1988. If sea-level is rising what are its likely impacts on the New Zealand coast? Pp. 371-383 in: Water in Society- Policy and Practice. *Proceedings of the Fifth National Water Conference, 1988.* Institute of Professional Engineers New Zealand/ Royal Society of New Zealand.

Gibb, J.G. 1991. Implications of greenhouse-induced sea-level rise for coastal management. Pp. 47-54 in Bell, R.G., Hume, T.M., and Healy, T.R. (Eds): Coastal Engineering -Climate for Change. *Proceedings of the 10th Austraulasian Conference on Coastal and Ocean Engineering. Water Quality Centre Publication No. 21.*

Gomitz, V. 1991. Global coastal hazards from future sea level rise. *Paleogeography, Paleoclimatology, Paleoecology (Global and Planetary Change Section)* 89: 379-398.

Gornitz, V., and Kanciruk, P. 1989. Assessment of global coastal hazards from sea-level rise. *Coastal Zone '89.* 15p.

Hannah, J. 1988. Analysis of mean sea-level trends in New Zealand from historical tidal data. Department of Survey and Land Information, Wellington. 41p.

Hannah, J. 1990. Analysis of mean sea-level data from New Zealand for the period 1899-1988. *Journal of Geophysical Research* 95: 12399-12405

Hay, D.N. 1991. Storm and oceanographic databases for the western Bay of Plenty. M.Sc. thesis, Earth Sciences Department, University of Waikato, Hamilton.

Healy, T.R. 1975. The equilibrium beach- a model for real estate development and management of the coastal zone in northeast New Zealand. Pp. 319-324 in: *Proceedings of the International Geographical Union Regional Conference, Massey University, New Zealand, December 1974.*

Healy, T.R. 1981. Mistakes at Omaha. *Soil and Water, 1981:* 22-24. NWASCO.

Healy, T.R., and Kirk, R.M. 1982. Coasts. Chapter 5 in Soons, J.M., and Selby, M.J. (Eds): *Landforms of New Zealand.* Longman Paul. 392p.

Healy, T.R., Harray, K.G., and Richmond, B. 1977. The Bay of Plenty Coastal Erosion Survey. *Occasional Report No. 3.* Earth Science Department, University of Waikato, Hamilton.

Heath, R.A. 1979. Significance of storm surges on the New Zealand coast. *New Zealand Journal of Geology and Geophysics* 22(2): 259-266.

Hume, T.M., Bell, R.G., de Lange, W.P., Healy, T.R., Hicks, D.M., and Kirk, R.M. 1992. Coastal Oceanography and sedimentology in New Zealand, 1967-91. *New Journal of Marine and Freshwater Research* 26: 1-36.

IPCC 1990. Scientific assessment of climate change. Intergovernmental Panel on Climate Change, Geneva.

Johnson, P.N. 1992. The sand dune and beach vegetation inventory of New Zealand. I. South Island. *DSIR Land Sciences Report No. 16.*

Kirk, R.M. 1983. Measuring and monitoring the coast: problems of assessing hazard for land-use planning in New Zealand. *New Zealand Surveyor:* 342-359.

Kirk, R.M., and Todd, D. 1992. Coastal Hazards. Chapter 4 in: Natural Hazards in Canterbury. Canterbury Regional Council, Christchurch.

Komar, P.D. 1976. Beach processes and sedimentation. Prentice Hall, New Jersey.

Water and Soil 1971. Land Use Capability Survey Handbook. Water and Soil Division, Ministry of Works, Wellington. 139p.

Lumsden, J.L., and Kirk, R.M. 1991. Cliff protection at Motunau -a low cost approach. In Bell, R.G., Hume, T.M. and Healy, T.R. (Eds): Coastal Engineering - Climate for Change. *Proceedings of the 10th Australasian Conference on Coastal and Ocean Engineering, December 1991.*

McLean, R.F. 1978. Recent coastal progradation in New Zealand. Chapter 8 in Davies, J.L. and Williams, M.A.J. (Eds): Landform evolution in Australasia. [As cited by Kirk, R.M. 1983 in references above.]

Moore, W.G. 1976. A Dictionary of Geography. 5th edn. Penguin Reference Books. 286p.

Marine Division, M.O.T. 1985. *New Nautical Almanac.* Prepared by the Marine Division, Ministry of Transport, Wellington.

Otago Regional Council 1991. East Otago coastal hazards mapping. *Otago Regional Council Discussion Paper Series No. 5.* 45p.

Partridge, T.R. 1992. The sand dune and beach vegetation inventory of New Zealand. I. North Island. *DSIR Land Resources Sciences Report No. 15.*

Pethick, J. 1984. An introduction to coastal geomorphology. Edward Arnold. 260p.

Pillans, B. (1986) A late Quaternary uplift map for North Island, New Zealand. *Royal Society of New Zealand Bulletin* 24: 409-415.

Pillans, B. 1990. Pleistocene marine terraces in New Zealand: a review. *New Zealand Journal of Geology and Geophysics* 33: 219-231

Resource Management Act 1991. An Act to restate and reform the law relating to the use of land, air, and water. *Appendix to the Journal of the House of Representatives* 1991, No.69. 382p.

Selby, M.J. 1982. Hillslope materials and processes. Oxford University Press. 264p.

Sheffield, A.T. 1991. The sedimentology and hydrodynamics of the Whangamata Harbour. M.Sc. thesis, Earth Sciences Department, University of Waikato, Hamilton.

U.S. Army Corps of Engineers (n.d). Help yourself -a discussion of the critical erosion problems on the Great Lakes and alternative methods of shore protection. Pamphlet produced by United States Army Corps of Engineers.

Varnes, D. 1984. Landslide hazard zonation: a review of principles and practise. UNESCO Special Report, Paris. [cited in Appendix 2]

Wellman, H.W. 1979. An uplift map for the South Island of New Zealand and a model for uplift of the Southern Alps. Pp. 13-20 in Walcott, R.L. and Cresswell, M.M. (Eds): The Origin of the Southern Alps. *Royal Society of New Zealand Bulletin No. 18.*

APPENDIX 1
Hazards assessment terminology

Coastal hazard: a natural phenomenon that exposes the littoral zone to risk of damage or other adverse effects (Gomitz 1991). [This definition is not used in this study.]

Coastal hazards database: a database containing information on the 8 variables used to define a CSI, with the capacity to incorporate information on other variables.

Coastal Sensitivity Index (CSI): an estimation of the relative sensitivity of the natural coast to natural hazards.

Coastal vulnerability: the liability of the shore to respond adversely to a hazard (Gomitz 1991) -this definition is not used in this study.

Sensitivity: readily responding to or recording slight changes of condition; being affected by external stimuli (Concise Oxford Dictionary).

Natural hazard (Resource Management Act 1991): any atmospheric or earth or water related occurrence including earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire or flooding), the action of which adversely affects or may adversely affect human life, property or other aspects of the environment.

Hazard agent: a (damaging) physical process. [Same definition by the UN and engineers.]

Natural hazard: the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon. [Defined as risk by engineers (IPENZ)].

Vulnerability: the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude. It is expressed on a scale from 0 to 1. [Defined as by engineers (IPENZ)].

Specific risk: the expected degree of loss due to a particular natural phenomenon.

Elements at risk: the population, properties, economic activities, including public services etc, at risk in a given area [Defined as hazards by engineers (IPENZ)]

Total risk: the number of lives lost, persons injured, damage to property, or disruption of economic activity due to a particular natural phenomenon. [Defined as risk of hazard by engineers (IPENZ)].

> *'The main difference between the two terminologies is that the UN term hazard is equivalent to the IPENZ term risk, with reference to the physical process. Whereas IPENZ use of the term hazeard refers to the damaging impacts of that process. The ultimate gain of any hazard assessment is to make a statement on the probability of specified impacts occurring in a given place.'*
>
> Crozier (1992)

The CSI does not attempt to do that, but an indication of the relative sensitivity of the natural coast to physical processes that may, or may not pose hazards to human assets and values.

APPENDIX 2
Abbreviations, Definitions and Terminology

Bentonite: a clay derived from the weathering and decomposition of volcanic ash material and composed of smectite. It has a great ability to absorb water and to swell accordingly (Moore 1976).

Coastal erosion: the process of episodic removal of material at the shoreline leading to a loss of land as the shoreline retreats landward (Gibb 1984).

Coastal accretion: the product of deposition of material at the shoreline, leading to a gain of land as the shoreline advances seaward (Gibb 1979, 1981).

Coastal hazard: a natural phenomenon that exposes the coastal environment to risk of damage or other adverse effects.

Coastal hazard zone: the land adjacent to the coast being highly vulnerable to hazards (Gibb 1981).

Erosion: ... "the group of processes whereby earthy rock material is loosened or dissolved and removed from any part of the earth's surface"...(American Geological Institute 1962).

Elevation: height (metres) above mean sea level of the land immediately adjacent to the coast.

IPENZ: Institution of Professional Engineers, New Zealand.

Maximum significant wave height: the maximum significant wave height for more than one wave record. This is dependent on the length of record, and how frequently the measurement is made (W. de Lange, pers. Comm., February 1992).

Mean high water spring (MHWS): the average of the levels of each pair of successive high waters during that period of about 24 hours in each semi-lunation (which is approximately every 14 days) when the range of the tide is greatest.

Mean sea level (MSL): the average level of the sea, as calculated from a large number of observations at equal intervals of time.

NZLRI: New Zealand Land Resource Inventory (developed by DSIR, now Land Resources New Zealand).

R: the net long-term rate of accretion or erosion (m/yr) (Gibb 1983).

S: the maximum range of short-term fluctuations (m) as a result of one or a cluster of onshore storms (Gibb 1983).

Shoreline displacement: horizontal advance or retreat of the shoreline (m/yr) (Gornitz 1991).

Static shorelines: those where net erosion was <0.02 m/yr over approximately the last 100 years (Gibb 1984).

Tsunami: long-period waves generated by large short-duration disturbances of the sea-floor (Hume *et al.* 1992).

APPENDIX 3
Composite matrix of all variables tested during development

CLASS *VARIABLE*	*1 VERY LOW*	*2 LOW*	*3 MEDIUM*	*4 HIGH*	*5 VERY HIGH*
Elevation above MHWS (m)	>30.0	30.0-10.1	10.0-5.1	5.0-2.0	<2.0
Max. storm wave runup level above MHWS (m)	<1.0	1.0-1.5	1.6-2.5	2.6-5.0	>5.0
Gradient (degrees)	>20	20-11	10-5	5-2	<2 (including <0)
Max. tsunami wave height (m)	<0.5	0.5-1.5	1.6-4.0	4.1-10.0	>10
Lithology	Plutonics. Intrusives. Metamorphics (high to medium grade). Volcanics (lava, dikes).	Low grade metamorphics. Dense indurated sedimentary rocks (greywacke, solid argillite, conglomerate). Very densely and densely welded ignimbrites. Volcanic breccia.	Moderately indurated sed. Rocks (sandstones, argillite, conglomerate). Partially welded ignimbrite. Sheared metamorphics.	Weakly indurated sed. Rocks (mudstones, argillite, weak conglomerates). Non-welded ignimbrite. Lahars. Lignite. Relict snads. Consolidated volcanic ash. Loess.	Unconsolidated sediments (alluvium, gravels, sands, silts, muds). Swelling bentonites. Unconsolidated volcanic ash. Peat.
Natural landform	Very hard rock platforms and sea cliffs.	Hard rock platforms and seal cliffs.	Moderately hard rock platforms and sea cliffs. Moraines.	Soft rock platforms and sea cliffs. Alluvial deltas. Saltmarsh/ mangroves.	Sand barriers, beaches, dunes, and spits. Gravel barriers, beach ridges and spits. River mouths. Cuspate forelands.
Horizontal trend (m/yr)	> + 0.50	+0.50 to -0.02	-0.03 to -0.49	-0.50 to -2.00	> -2.00 Retreat
Short-term fluctuation (m)	<2	2-5	6-10	11-30	>30
Mean spring tidal range (m)	0.00-0.69	0.70-1.09	1.10-2.09	2.10-4.00	>4.00
Overtopping height (m)	0	0.1-0.2	0.3-0.5	0.6-1.0	>1.0
Vertical trend (mm/yr)	> + 2.0	2.0 to -0.1	-0.2 to -0.9	-1.0 to -3.0	>-3.0 Submergence
Max wave height (m)	0.1-1.5	1.6-3.0	3.1-6.0	3.0-10.0	>10.0
Max. storm surge level (m)	<0.1	0.1-0.3	0.4-0.8	0.9-1.5	>1.5

APPENDIX 4
Quotes for horizontal trend information (1992)

The following are quotes for the collection of horizontal trend data as at July 1992.

As an estimate, DOSLI normally allows $500 per kilometre per photographic survey for coastal erosion mapping, e.g., where a 1958 and 1969 survey was overlain on 1985 imagery, this would equate to three photo surveys at a scale of 1:5000. For mapping at larger scales, e.g., 1:1000, allow for additional material costs. Conversely for a 1:10 000 a cheaper rate would be envisaged. It would be impracticable to use a scale of 1:50 000 as this would not show any detail. It will be up to the user to discuss with DOSLI that they require maximum coverage incorporating a minimum error, of as many different records of coastline position that exist.

APPENDIX 5
Data entry procedure

To store the information collected during this study the Coastal Hazards Database using dBase IV V1.1 was developed. The procedures for using the database are given below.

Minimum computer requirements
To run the database an IBM compatible computer (and printer) with at least a 2 Mb hard drive with access to run-time dBASE IV or full dBASE IV package is required. If dBASE IV or "run-time" is already installed then the program will run from a floppy disk.

Familiarity with dBASE IV would also be a minimum requirement for using the database.

Data input
After loading the program, at the control screen run then the following commands can be used within the program.

1 When the program begins, the last record entered is automatically shown. Pressing the page down [PgDn] key displays a prompt asking for new records to be added.

2 To SAVE information after adding or amending records, hold down the control [Crtl] and press the End key [End].

3 To move from one record to another the following keys can be used:
[PgUp] Page Up moves to the previous record.
[PgDn] Page Down moves to the next record.

4 To move quickly from one record to another, a browse mode can be used. By pressing the [F2] key a spreadsheet/list mode appears. To move up or down this list use the Up or Down arrows until the required record is reached. Pressing [F2]again returns to the highlighted record.

Data entry screen format

1 Location: contains the site name and number.

2 Grid Reference: includes the sheet number (from NZMS 260 sheets), northing (3 digits) and easting (3 digits).

3 Date: date that the field survey was conducted.

4. Variable and sensitivity class: class values 1-5 are input first depending on the relevant site information for each of the eight variables. Notes up to 60 characters can be written on each of the variables, with final
followed by summary notes and sources of information.

5 Notes: any supplementary notes (up to 254 characters or 5 lines long) about the site, section profile number.

6 The CSI is calculated and displayed on the screen when viewing a record with a qualifier as to which hazard the area is most sensitive to. The calculation is not saved directly to disk or updated in the database until a listing of high-low CSI values is run (see below).

Data output
A data output form has been created for filing and reference purposes. This sheet contains all the information that has been entered into the input data screen and also contains space for a site photograph to enable easy comparison and site recognition. Each site record can be printed out by pressing the
key while in the database. To do this use the program "DRIVE" which will create and print while in the database.

Lists of sites and CSIs (in descending order) can also be obtained for comparison by pressing the F5 key while in the database (Appendix 7). The database is updated and the CSI stored within the database after this procedure has been undertaken. Completed site forms can be generated for files.

APPENDIX 6
Database information collection sheet

LOCATION:
Grid Reference: Sheet: East: North: Date: / /

VARIABLE	VALUE	DATA
Elevation above MHWS (m)	0	
Storm wave run-up (m)	0	
Gradient	0	
Max tsunami wave height (m)	0	
Lithology	0	
Landform	0	
Horizontal trend (m/yr)	0	
Short-term fluctuation (m)	0	

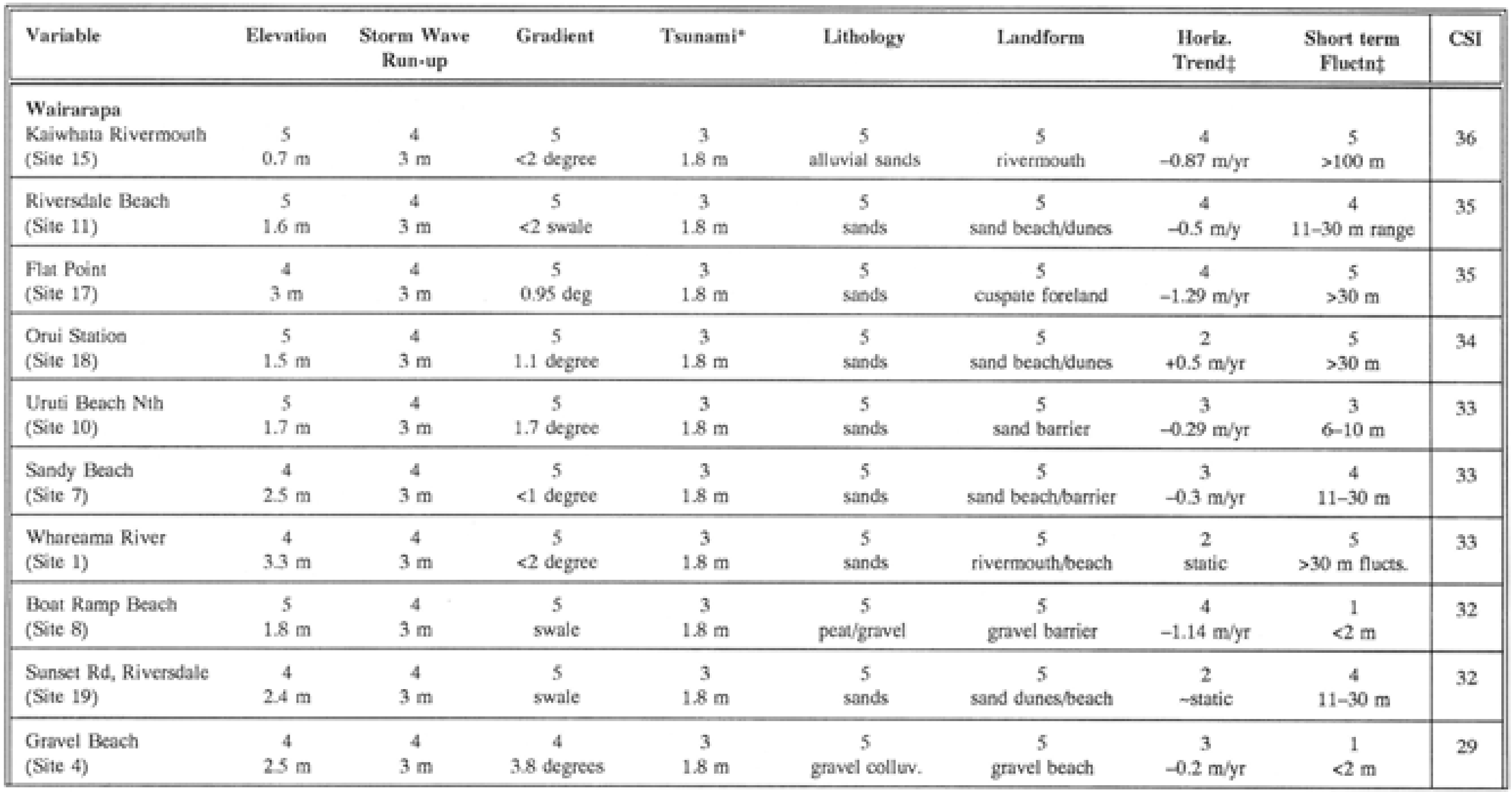
CSI = 0 Rating:

Notes:

APPENDIX 7
Complete summary data for each test area

The following tables summarise the information collected for each field area visited during testing and list the CSIs derived from the Coastal Hazards Database in order from highest to lowest CSI. The complete set of information is stored on the database held by the Science and Research Division, Department of Conservation, Wellington, and is in dBase IV format.

APPENDIX 7
Complete summary data for each test area



Variable	Elevation	Storm Wave Run-up	Gradient	Tsunami*	Lithology	Landform	Horiz. Trend‡	Short term Fluctn‡	CSI
Wairarapa Kaiwhata Rivermouth (Site 15)	5 0.7 m	4 3 m	5 <2 degree	3 1.8 m	5 alluvial sands	5 rivermouth	4 –0.87 m/yr	5 >100 m	36
Riversdale Beach (Site 11)	5 1.6 m	4 3 m	5 <2 swale	3 1.8 m	5 sands	5 sand beach/dunes	4 –0.5 m/y	4 11–30 m range	35
Flat Point (Site 17)	4 3 m	4 3 m	5 0.95 deg	3 1.8 m	5 sands	5 cuspate foreland	4 –1.29 m/yr	5 >30 m	35
Orui Station (Site 18)	5 1.5 m	4 3 m	5 1.1 degree	3 1.8 m	5 sands	5 sand beach/dunes	2 +0.5 m/yr	5 >30 m	34
Uruti Beach Nth (Site 10)	5 1.7 m	4 3 m	5 1.7 degree	3 1.8 m	5 sands	5 sand barrier	3 –0.29 m/yr	3 6–10 m	33
Sandy Beach (Site 7)	4 2.5 m	4 3 m	5 <1 degree	3 1.8 m	5 sands	5 sand beach/barrier	3 –0.3 m/yr	4 11–30 m	33
Whareama River (Site 1)	4 3.3 m	4 3 m	5 <2 degree	3 1.8 m	5 sands	5 rivermouth/beach	2 static	5 >30 m flucts.	33
Boat Ramp Beach (Site 8)	5 1.8 m	4 3 m	5 swale	3 1.8 m	5 peat/gravel	5 gravel barrier	4 –1.14 m/yr	1 <2 m	32
Sunset Rd, Riversdale (Site 19)	4 2.4 m	4 3 m	5 swale	3 1.8 m	5 sands	5 sand dunes/beach	2 ~static	4 11–30 m	32
Gravel Beach (Site 4)	4 2.5 m	4 3 m	4 3.8 degrees	3 1.8 m	5 gravel colluv.	5 gravel beach	3 –0.2 m/yr	1 <2 m	29

Variable	Elevation	Storm Wave Run-up	Gradient	Tsunami*	Lithology	Landform	Horiz. Trend‡	Short term Fluctn‡	CSI
Low Cliff, Kaiwhata (Site 14)	4 4 m	4 3 m	1 60 degrees	3 1.8 m	5 alluvium	4 softrock cliffs	4 -0.87 m/yr	4 11–30 m	29
Faceted dunes (Site 3)	4 4.5 m	4 3 m	2 14 degrees	3 1.8 m	5 sand	5 sand dunes/beach	2 ~static	3 5–10 m	28
Uruti Beach (Site 9)	3 6 m	4 3 m	2 17 degrees	3 1.8 m	5 sand	5 sand dunes/beach	2 ~static	4 11–30 m	28
Riversdale Beach (Site 20)	3 5.6 m	4 3 m	2 14 degrees	3 1.8 m	5 sand	5 sand dunes/beach	1 +1.2 m/yr	4 11–30 m	27
Fail slope, Flat Pt (Site 16)	3 5–10 m	4 3 m	1 40 degrees	3 1.8 m	5 sand	4 softrock cliff/platf.	1 +1.2 m/yr	4 20 m slump	27
Low cliffs, Homewood (Site 12)	4 2.5 m	4 3 m	1 60 degrees	3 1.8 m	5 mudst. colluv.	4 softrock cliff	3 -0.25 m/yr	4 15 m slump	27
Platform with fence (Site 5)	3 5–6 m	4 3 m	1 60 degrees	3 1.8 m	5 colluvium	4 softrock platf./cliff	4 -0.5 m/yr	3 10 m slump	27
Whareama Homestead (Site 2)	4 3.1 m	4 3 m	2 15 degrees	3 1.8 m	5 gravels	5 gravel ridge	2 ~static	2 2–5 m	27
Highcliffs, Kaiwhata (Site 13)	1 ~100 m	4 3 m	1 60 degrees	3 1.8 m	4 mudstones	4 softrock cliffs	4 -1.3 m/yr	5 30 m slumps	26
''Lazy surveyor rock'' (Site 6)	3 6 m	4 3 m	1 27 degrees	3 1.8 m	2 greywacke	2 hardrock platform	2 static	1 static	18

* Tsunami recorded on 13 August 1960 at Castlepoint.

‡ Horizontal trend and short term fluctuation data courtesy of Wellington Regional Council.

Variable	Elevation	Storm Wave Run-up*	Gradient	Tsunami†	Lithology	Landform	Horiz. Trend‡	Short term Fluctn‡	CSI
Kapiti Coast Otaki Rivermouth (Site 21)	4 2.5 m	4 2.6 m	5 0.5 degrees	2 <1 m	5 gravels	5 river mouth	4 –0.8 m/yr	5 >100 m	34
Raumati South (Site 30)	5 1.6 m	4 2.6 m	5 1.4 degrees	2 <1 m	5 sand	5 beach/dunes	5 –2.5 m/yr	4 20 m	35
Sims Road, Te Horo (Site 22)	4 3 m	4 2.6 m	5 swale	2 <1 m	5 gravels	5 gravel/beach	2 0.5 m/yr	4 20	31
Raumati South (Site 29)	3 7–8 m	4 2.6 m	1 28 degrees	2 <1 m	5 sand	5 beach/dunes	5 –2.5 m/yr	4 20	29
Pekapeka Beach (Site 24)	4 3.6 m	4 2.6 m	3 8.2 degrees	2 <1 m	5 sands	5 sand beach	2 0.4 m/yr	11–30 m	29
Waikanae Rivermouth (Site 25)	4 4.5 m	4 2.6 m	2 12 degrees	2 <1 m	5 sands	5 rivermouth	1 1.14 m/yr	5 >100 m	28
Rua Rd South (Site 27)	4 5 m	4 2.6 m	1 42 degrees	2 <1 m	5 sands	5 sand beach	2 0.16 m/yr	5 >30 m	28
Paekakariki (Site 31)	3 6 m	4 2.6 m	2 13 degrees	2 <1 m	5 sands	5 sand dunes	3 –0.4 m/yr	4 11–30 m	28
Paraparaumu (Site 26)	4 4 m	4 2.6 m	1 22 degrees	2 <1 m	5 sands	5 cusp.foreland	1 0.92 m/yr	5 >30 m	27
Te Horo beach (Site 23)	4 5 m	4 2.6 m	2 14 degrees	2 <1 m	5 sands	5 sand beach	1 1.25 m/yr	4 11–30 m	27

* Storm wave run-up recorded by Gibb (1978).

† All recorded tsunami on the West Coast have been <1 m (tidal bores, e.g., Wanganui, Manawatu rivers).

‡ Horizontal trend and short term fluctuation data courtesy of Wellington Regional Council.

Variable	Elevation	Storm Wave Run-up*	Gradient	Tsunami†	Lithology	Landform	Horiz. Trend‡	Short term Fluctn‡	CSI
Wellington Baring Head (Site 35)	3 6 m	5 6 m	4 3.2 degrees	3 3.05 m	5 gravels	5 gravel beach	2 0.4 m/yr	5 >30 m	32
Camp Bay (Site 32)	5 1.6 m	3 1.6 m	4 4.5 degrees	3 3.05 m	5 gravels	5 gravel beach	2 static	5 35 m pulses	32
Bluff Point (Site 33)	3 6 m	5 5–6 m	3 10 degrees	3 3.05 m	5 gravels	5 gravel beach	2 static	5 >30 m	31
Airport South, Lyall Bay (Site 45)	4 2 m	3 2.5 m	4 2.3 degrees	3 3.05 m	5 gravels	5 gravel beach	3 –0.2 m/yr	4 20 m	31
Barneys Hut (Site 36)	4 2.5 m	4 5 m	5 1.4 degrees	3 3.05 m	5 gravels	5 gravel beach	2 static	3 5–10 m	31
Fitzroy Bay (Site 34)	4 4 m	4 4.2 m	5 <1 degree	3 3.05 m	5 gravels	5 gravel beach	1 0.7 m/yr	4 11–30 m	31
Lyall Bay (Site 44)	4 4 m	3 2.5 m	2 12 degrees	3 3.05 m	5 sand	5 sand beach	3 –0.1 to –0.3	4 20 m	29
Turakirae Head (Site 37)	4 3.5 m	4 3.5 m	3 6 degrees	3 3.05 m	2 greywacke	2 rock platform	2 0.4 m/yr	1 <2 m	21
Eves Bay, Seatoun (Site 46)	4 3.5 m	4 3 m	1 25 degrees	3 3.05 m	5 gravel	5 gravel beach	2 static	3 5–10 m	27

* All storm wave run-up measurements based on field observations.

† Tsunami recorded after the 1855 Wairarapa Earthquake.

‡ Horizontal trend and short term fluctuation data courtesy of Wellington Regional Council.

Variable	Elevation	Storm Wave Run-up	Gradient	Tsunami†	Lithology	Landform	Horiz. Trend	Short term Fluctn	CSI
Pauatahanui Inlet Management Reserve (Site 39)	5 0.4 m	2 1.2 m*	5 salt marsh	1 Unknown	5 sand/shells	4 saltmarsh	3 –0.03 to –0.49	1 <2 m	26
Motukaraka Point (Site 41)	5 0.4 m	2 1.2 m	5 1 degree	1 Unknown	5 shells/sand/alluv.	4 saltmarsh	2 static	1 <2 m	25
Ration Point (Site 40)	5 1.5 m	2 1.2 m	4 2.3 deg.	1 Unknown	5 shells/sand/alluv.	4 alluv. outwash fan	2 static	1 <2 m	24
Barton Marine, Paremata (Site 42)	5 1 m	1 0.75 m*	2 20 deg.	1 Unknown	5 dune sand	5 sand barrier	3 –0.03 to –0.49	1 <2 m	23

* Storm wave run-up recorded during field work in March 1992.

† No known tsunamis recorded in this location. Other West coast tsunamis have been <1 m (Manawatu, Wanganui Rivers).

Variable	Elevation	Storm Wave Run-up*	Gradient	Tsunami†	Lithology	Landform	Horiz. Trend‡	Short term Fluctn	CSI
Manukau Harbour Grahams Beach Sth (Site 51)	5 1.55 m	3 2.2 m	5 1 degree	1 0.3 m	5 sands	5 sand barrier	3 –0.3 m/yr	3 8 m	30
Hudsons Beach (Site 53)	5 1.2	3 2.2 m	5 1 degree	1 0.3 m	5 sands	5 sand barrier	3 –0.05 m/yr	3 8 m	30
Sergeants Beach (Site 50)	5 1.5 m	3 2.2 m	4 3 degrees	1 0.3 m	4 relict sands	5 sand barrier	3 –0.1 m/yr	3 6 m	28
Wattle Bay (Site 54)	4 2.1 m	2 1.5 m	2 16 degrees	1 0.3 m	5 sands	5 sand barrier	2 static	4 20 m	25
Racecourse Rd, Waiuku (Site 47)	3 8 m	2 1 m	1 69 degrees	1 0.3 m	4 mudstone	4 softrock cliffs	3 –0.26 m/yr	3 6 m slumps	21
Te Toro Rd (Site 49)	4 4 m	2 1.3 m	1 55 degrees	1 0.3 m	4 relict sands	4 softrock cliffs	3 –0.04 m/yr	2 2–5 m	21
Waipipi Wharf Rd (Site 48)	3 6 m	2 1.5 m	1 52 degrees	1 0.3 m	4 relict sands	4 softrock cliffs	2 –0.02 m/yr	2 <5 m	19

* Storm wave run-up level from residents observations, and later from field observations along cliffs.

† Tsunami recorded as 0.3 m in 1960 in the Manukau Harbour.

‡ Horizontal trend data courtesy of Franklin District Council.

Variable	Elevation	Storm Wave Run-up*	Gradient	Tsunami†	Lithology	Landform	Horiz. Trend‡	Short term Fluctn‡	CSI
Hawkes Bay									
Te Awanga Outfall (Site 60)	4 2.7 m	4 3.5 m	5 swale	3 3.0 m	5 gravels	5 gravel beach	5 –2.79 m/yr	4 20 m	35
Te Awanga (Site 59)	4 2.2 m	4 2.5–3.0 m	5 swale	3 3.0 m	5 gravels	5 gravel beach	4 –1.05 m/yr	4 20 m	34
Awatoto (Site 61)	4 2.7 m	4 3–3.5 m	5 swale	3 3.0 m	5 gravels	5 gravel beach	2 0.28 m/yr	4 11–30 m	32
Mangakuri Beach (Site 57)	4 2 m	4 2–4 m	4 3 degrees	3 3.0 m	5 sands	5 sand beach	2 static	4 11–30 m	31
Pourerere Bay Nth (Site 56)	4 2 m	3 2.5 m	4 3 degrees	3 3.0 m	5 sands	5 sand beach	2 static	4 11–30 m	30
Port of Napier (Site 62)	4 2.7 m	4 3.5 m	3 5–10 deg.	3 3.0 m	5 gravels	5 gravel beach	1 0.78 m/yr	4 11–30 m	29
Pourerere Bay Sth (Site 55)	1 >30 m	2 1.5 m	1 35 deg.	3 3.0 m	4 mudstones	4 softrock cliff	2 static	5 30–100 m	22

* Storm wave run-up estimates courtesy of Hawkes Bay Regional Council.

† Tsunami measured 22 May 1960 in Napier, no others recorded from Cape Kidnappers south to Castlepoint.

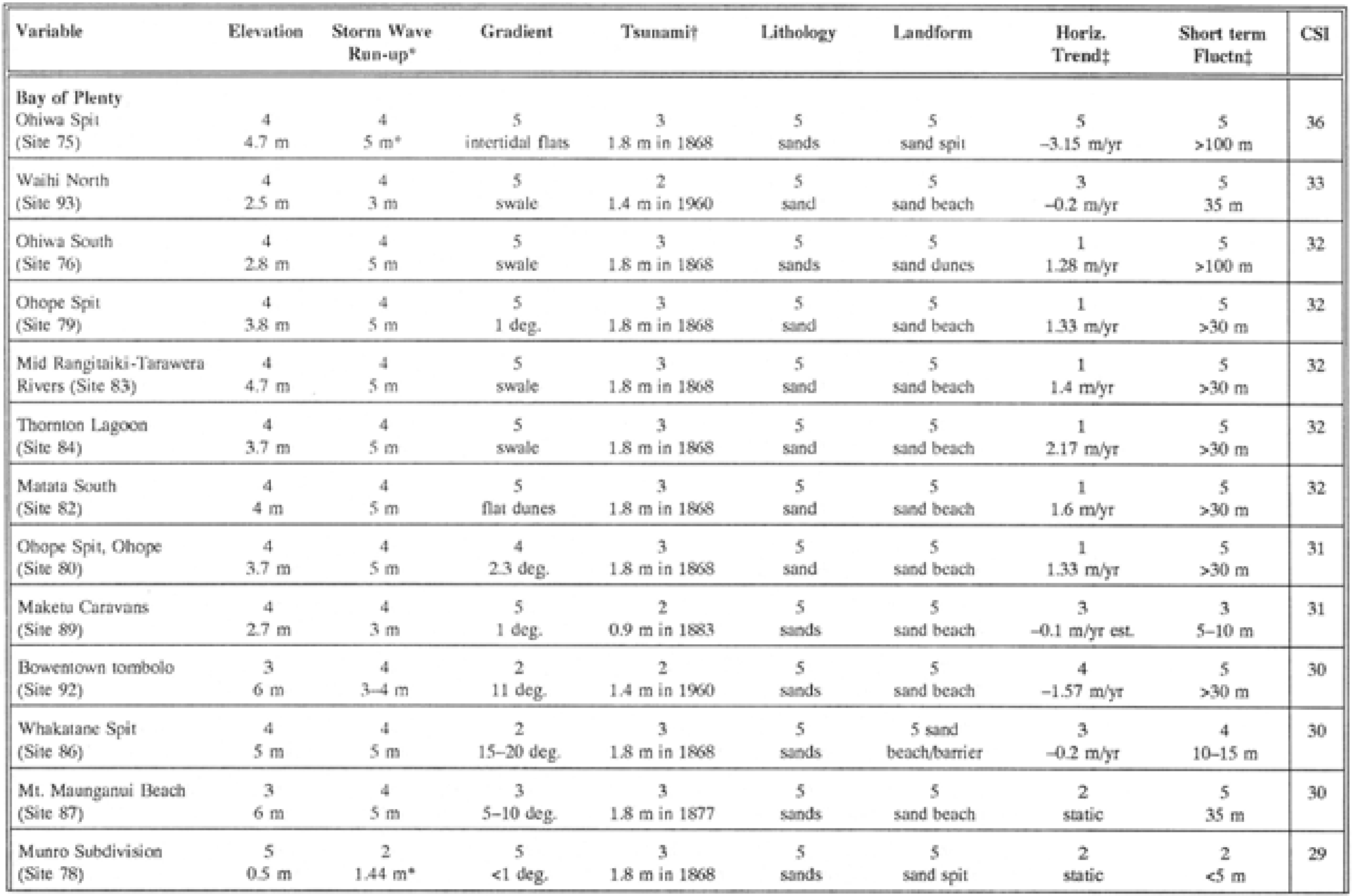
‡ Horizontal trend and short term fluctuation data supplied by Hawkes Bay Regional Council.

Variable	Elevation	Storm Wave Run-up	Gradient	Tsunami†	Lithology	Landform	Horiz. Trend‡	Short term Fluctn‡	CSI
East Cape Te Araroa A (Site 63)	5 1.5 m	4 2.2–3.3 m*	5 1 degree	3 3 m in 1868*	5 sands/gravels	5 sand/gravel beach	4 –1.57 m/yr	5 50 m	36
Te Araroa B (Site 64)	5 1.7 m	4 2.2–3.3 m	5 1 deg.	3 3 m in 1868	5 sands/gravels	5 sand/gravel beach	4 –0.93 m/yr	5 50 m	36
Te Araroa C (Site 65)	5 1.8 m	4 2.2–3.3 m	5 1 deg.	3 3 m in 1868	5 gravels	5 sand/gravel beach	2 static	5 50 m	34
Hicks Bay South (Site 68)	5 0.65 m	4 2.2–3.3 m	5 1 deg.	3 3 m in 1868	5 sand	5 sand beach	1 1.21 m/yr	5 > 100 m	33
Hicks Bay North (Site 69)	5 0.8 m	4 2.2–3.3 m	5 1 deg.	3 3 m in 1868	5 sand	5 sand beach	1 0.8 m/yr	5 > 100 m	33
Onepoto Bay (Site 67)	5 1.6 m	4 2.2–3.3 m	5 1 deg.	3 3 m in 1868	5 sand	5 sand beach	2 0.5 m/yr	4 11–30 m	33
Torere Beach (Site 74)	3 6 m	5 > 6 m*	5 1.5 deg.	3 3 m in 1868	5 gravels	5 gravel beach	2 0.2 m/yr	4 30 m	32
Te Araroa D (Site 66)	4 2.3 m	4 2.2–3.3 m	5 1 deg.	3 3 m in 1868	5 sands	5 sand beach	1 0.55 m/yr	5 50 m	32
Hawai Beach West (Site 73)	3 5–6 m	5 5–6 m	3 7 deg.	3 3 m in 1868	5 gravels	5 gravel beach	2 0.30 m/yr	5 > 30 m	31
Whitianga Bay (Site 72)	1 20–30 m	3 2–3 m	1 30 deg.	3 3 m in 1868	2 greywacke	2 hardrock platform	2 static	1 0 m	15
Whanarua Bay (Site 71)	1 20–30 m	2 1.5 m	1 50 deg.	3 3 m in 1868	2 greywacke	2 hardrock platform	2 static	1 0 m	14
Lottin Point (Site 70)	1 20–30 m	3 2.5 m*	1 50 deg.	3 3 m in 1868	1 basalts	1 v. hard rock platf.	2 static	1 0 m	13

* Storm wave run-up level calculated in Gibb (1981).

† Tsunami recorded at Cape Runaway on 15 August 1868.

‡ Horizontal trend and short term fluctuation supplied by Gisborne District Council.



Variable	Elevation	Storm Wave Run-up*	Gradient	Tsunami†	Lithology	Landform	Horiz. Trend‡	Short term Fluctn‡	CSI
Bay of Plenty Ohiwa Spit (Site 75)	4 4.7 m	4 5 m*	5 intertidal flats	3 1.8 m in 1868	5 sands	5 sand spit	5 –3.15 m/yr	5 >100 m	36
Waihi North (Site 93)	4 2.5 m	4 3 m	5 swale	2 1.4 m in 1960	5 sand	5 sand beach	3 –0.2 m/yr	5 35 m	33
Ohiwa South (Site 76)	4 2.8 m	4 5 m	5 swale	3 1.8 m in 1868	5 sands	5 sand dunes	1 1.28 m/yr	5 >100 m	32
Ohope Spit (Site 79)	4 3.8 m	4 5 m	5 1 deg.	3 1.8 m in 1868	5 sand	5 sand beach	1 1.33 m/yr	5 >30 m	32
Mid Rangitaiki-Tarawera Rivers (Site 83)	4 4.7 m	4 5 m	5 swale	3 1.8 m in 1868	5 sand	5 sand beach	1 1.4 m/yr	5 >30 m	32
Thornton Lagoon (Site 84)	4 3.7 m	4 5 m	5 swale	3 1.8 m in 1868	5 sand	5 sand beach	1 2.17 m/yr	5 >30 m	32
Matata South (Site 82)	4 4 m	4 5 m	5 flat dunes	3 1.8 m in 1868	5 sand	5 sand beach	1 1.6 m/yr	5 >30 m	32
Ohope Spit, Ohope (Site 80)	4 3.7 m	4 5 m	4 2.3 deg.	3 1.8 m in 1868	5 sand	5 sand beach	1 1.33 m/yr	5 >30 m	31
Maketu Caravans (Site 89)	4 2.7 m	4 3 m	5 1 deg.	2 0.9 m in 1883	5 sands	5 sand beach	3 –0.1 m/yr est.	3 5–10 m	31
Bowentown tombolo (Site 92)	3 6 m	4 3–4 m	2 11 deg.	2 1.4 m in 1960	5 sands	5 sand beach	4 –1.57 m/yr	5 >30 m	30
Whakatane Spit (Site 86)	4 5 m	4 5 m	2 15–20 deg.	3 1.8 m in 1868	5 sands	5 sand beach/barrier	3 –0.2 m/yr	4 10–15 m	30
Mt. Maunganui Beach (Site 87)	3 6 m	4 5 m	3 5–10 deg.	3 1.8 m in 1877	5 sands	5 sand beach	2 static	5 35 m	30
Munro Subdivision (Site 78)	5 0.5 m	2 1.44 m*	5 <1 deg.	3 1.8 m in 1868	5 sands	5 sand spit	2 static	2 <5 m	29

Whangamata (Site 94)	4 4.5 m	4 3 m	4 2–5 deg.	2 1.4 m in 1960	5 sands	5 cuspate foreland	2 static	3 5–10 m	29
Golf Links Rd (Site 85)	3 5.5 m	4 5 m	3 5–10 deg.	3 1.8 m in 1868	5 sands	5 sand beach	1 1.78 m/yr	4 20 m	28
Whangamata Beach (Site 95)	3 5.7 m	4 4–5 m	4 2–5 deg.	2 1.4 m in 1960	5 sands	5 sand beach	2 static	3 5–10 m	28
Burke Rd, Ohiwa (Site 77)	5 2.0 m	3 2.1 m*	4 2 deg.	3 1.8 m in 1868	5 peat	4 salt marsh/mangrove	2 static	1 0	27
Matata Barrier (Site 81)	3 6.1 m	4 5 m	2 11 deg.	3 1.8 m in 1868	5 sands	5 sand barrier	1 1.33 m/yr	3 5–10 m	26
Bowentown Inner Harbour (Site 91)	4 3.5 m	2 1.5 m	2 16 deg.	3 1.8 m in 1877	4 relict sands	5 sand barrier	3 –0.2 m/yr estd.	2 <5 m	25
Omokoroa Headland (Site 90)	3 10 m	3 2 m	1 35 deg.	3 1.8 m in 1877	3 poor weld. ign.	4 softrock cliff	3 –0.2 m/yr estd.	3 5–10 m	23
Maketu Cliffs (Site 88)	2 20 m	3 2 m	1 >35 deg.	2 0.9 m in 1883	3 poor weld. ign.	4 softrock cliff	2 static	2 <5 m	19
Whangamata Harbour (Site 96)	1 >30 m	2 1 m	1 >35 deg.	2 1.4 m in 1960	1 volcanics	1 v. hard cliff	2 static	1 0	11

* Storm wave run-up recorded by Gibb (1977), rest from field estimations.

† Tsunamis recorded on 15 August 1868, 10 May 1877 (Tauranga), 27 August 1883 (Maketu), 22 May 1960 (Tairua).

‡ Horizontal trend and short term fluctuation data courtesy of Bay of Plenty Regional Council.

Variable	Elevation	Storm Wave Run-up	Gradient	Tsunami*	Lithology	Landform	Horiz. Trend	Short term Fluctn	CSI
Firth of Thames Te Puru (Site 97)	5 1.75 m	3 2.5 m	5 1 deg.	2 0.9 m	5 alluvial gravel	4 alluvial fan	2 static	4 11–30 m	30

* Tsunami recorded at Coromandel on 27 August 1883.

Variable	Elevation	Storm Wave Run-up	Gradient	Tsunami*	Lithology	Landform	Horiz. Trend‡	Short term Fluctn‡	CSI
Canterbury									
Washdyke (Site 104)	4 3.5 m	4 4 m	5 swale <2	3 1.8 m in 1868	5 sand/gravels	5 sand/gravel beach	5 -2.5 m/yr	4 20 m	35
Taumutu, Kaitorete (Site 108)	3 5.5 m	5 6 m	5 swale <2	3 1.8 m in 1868	5 sand/gravels	5 sand/gravel beach	3 -0.42 m/yr	5 50 m	34
Connellys Rd (Site 105)	4 4.49 m	4 5 m	5 swale <2	3 1.8 m in 1868	5 sand/gravels	5 sand/gravel beach	4 -1.27 m/yr	4 20 m	34
Wainono Lagoon (Site 100)	4 5 m	5 6.5 m	5 swale <2	3 3.3 m in 1960	5 gravels	5 gravel ridge	3 -0.42 m/yr	5 30 m	35
Orari River (Site 106)	4 5 m	5 6.1 m	5 swale <2	3 1.8 m in 1868	5 sand/gravels	5 sand/gravel beach	4 -1.0 m/yr	1 0 m	32
Amberley Beach (Site 113)	4 3.8 m	4 4 m	5 swale <2	3 3.3 m in 1960	5 gravels	5 sand/gravel beach	2 +0.32 m/yr	4 25 m	32
Caroline Bay (Site 103)	4 3.8 m	4 3 m	4 4.2 degrees	3 1.8 m in 1868	5 sands	5 sand beach	1 +5.91 m/yr	4 25 m	30
Tern St, Brighton (Site 110)	3 6 m	4 3.5 m	3 9 degrees	3 3.3 m in 1960	5 sands	5 sand beach	2 +0.24 m/yr	4 25 m	29
Birdlings Flat (Site 109)	3 10 m	5 6 m	2 12 degrees	3 1.8 m in 1868	5 gravels	5 gravel beach	1 +0.62 m/yr	4 25 m	28
Rickards Farm (Site 107)	2 20 m	5 6 m	1 ~vertical	3 1.8 m in 1868	5 alluvium	4 soft rock cliff	4 -0.56 m/yr	4 13 m	28
Otaio River South (Site 101)	3 9.87 m	5 6 m	1 ~vertical	3 1.8 m in 1868	4 loess	4 soft rock cliff	4 -0.5 m/yr	4 12 m	28
Morris Rd (Site 99)	3 11.9 m	5 6 m	1 ~vertical	3 1.8 m in 1868	5 alluvium	4 soft rock cliff	4 -0.79 m/yr	2 2–5 m	27
Waikuku Beach (Site 112)	3 10 m	4 3.5 m	2 11–20 deg.	3 3.3 m in 1960	5 sands	5 sandy beach	1 +0.84 m/yr	4 25 m	27
Waitaki Boys High (Site 98)	2 10–12 m	5 6 m	1 ~vertical	3 2.8 m in 1960	5 alluvium	4 soft rock cliff	4 -0.58 m/yr	2 5 m slumps	26
Motunau Cliffs (Desk test 4)	1 30–40 m	4 ~4 m	1 ~vertical	3 3.3 m in 1960	4 mudstones	4 soft rock cliff	4 -0.57 m/yr	4 14–20 m	25

* Tsunami recorded in Timaru on 13 August 1868, and in Lyttelton/Oamaru on 22 May 1960.

‡ Horizontal trend and short term fluctuation data courtesy of Canterbury Regional Council.

Variable	Elevation	Storm Wave Run-up	Gradient	Tsunami*	Lithology	Landform	Horiz. Trend†	Short term Fluctn†	CSI
Hokitika Tudor St (Desk Test 2)	4 5 m	5 5–6 m	5 swale	2 1.5 m	5 sand/gravel	5 sand/gravel beach	2 –0.02 m/yr	5 70 m	33
Camp St (Desk Test 1)	4 4 m	5 5–6 m	5 swale	2 1.5 m	5 sand/gravel	5 sand/gravel beach	1 + 1.34 m/yr	5 200 m	32
Hampden St (Desk Test 3)	3 5.3 m	5 5–6 m	5 swale	2 1.5 m	5 sand/gravel	5 sand/gravel beach	2 0.08 m/yr	5 60 m	32

* Tsunami recorded in Westport on 13 August 1868. † Horizontal trend and short term fluctuation data from Gibb (1987).

Variable	Elevation	Storm Wave Run-up*	Gradient	Tsunami*	Lithology	Landform	Horiz. Trend	Short term Fluctn	CSI
Seawalls† Lyall Bay Surf Club (Site 43)	5 1.5 m	3 2.5 m	5 1 degree	3 3.05 m in 1855	5 sand	5 sand beach	3 –0.2 m/yr	4 20 m	33
Kairakau Beach, Hawkes Bay (Site 58)	4 4 m	4 2–4 m	2 28 degrees	3 3 m	5 sands	5 sand beach	3 –.03 to –0.49	4 11–30 m	30
Grahams Beach, Manukau (Site 52)	5 1.2 m	3 2.2 m	5 1 degree	1 Unknown	5 sands	5 sand beach	3 –0.4 m/yr	3 8 m	30
Pareora, Canterbury (Site 102)	3 6 m wall	5 6 m	5 swale	3 1.8 m in 1868	5 gravels	5 gravel beach	3 –0.32 m/yr	1 4 m	30
Browns Bay, Pauatahanui (Site 38)	5 0.7 m	2 0.75	5 1.1 degree	2 Unknown	5 reclaimed area	4 alluvial outwash	2 static	2 <5 m	26
Rosetta Rd, Raumati (Site 28)	2 15 m	4 2.6 m in 1976	1 35 degrees	2 Unknown	5 sand	5 sand dunes/beach	3 –0.28 m/yr	4 20 m	26

* Storm wave run-up and tsunami data is taken from original source areas. † All these sites have seawalls or structures affecting them, and this fact should be recorded on any surveys.

APPENDIX 8

List of various test areas in order of decreasing CSI

Site	CSI
Te Araroa B, Site 64	36
Te Araroa A, Site 63	36
Ohiwa Spit, Site 75	36
Kaiwhata Rivermouth, Site 15	36
Washdyke Lagoon, Site 104	35
Te Awanga outfall, Site 60	35
Riversdale beach, Site 11	35
Cuspate foreland, Flat Point, Site 17	35
Raumati South, Site 30	35
Wainono lagoon, Site 100	34
Te Awanga, Site 59	34
Te Araroa C, Site 65	34
Taumutu, Kaitorete Spit, Site 108	34
Orui Station Homestead, Site 18	34
Otaki Rivermouth, Site 21	34
Connellys Rd, Opihi, Site 105	34
Waihi beach, Site 93	33
Uruti beach north, Site 10	33
Sandy beach, Site 7	33
Otaki Rivermouth, Site 21	33
Horseshoe Bay, Site 67	33
Tudor St, Hokitika	33
Hicks Bay south, Site 68	33
Hicks Bay north, Site 69	33
Torere beach, Site 74	32
Thornton lagoon, Site 84	32
Te Araroa D, Site 66	32
Riversdale beach, Sunset road, Site 19	32
Orari River, Site 106	32
Ohope spit entrance, Site 79	32
Ohiwa south, Site 76	32
Mid Rangitaiki, Tarawera rivers, Site 83	32
Matata south, Site 82	32
Hampden St, Hokitika	32
Camp St, Hokitika	32
Boat ramp beach, Site 8	32
Baring Head, Site 35	32
Awatoto, Site 61	32
Amberley Beach, Site 113	32
Whareama Rivermouth, Site 1	31
Ohope spit, Site 80	31
Mangakuri beach, Site 57	31
Maketu caravans, Site 89	31
Hawai beach west, Site 73	31
Fitzroy Bay gravel beach, Site 34	31
Bluff Point, Site 33	31
Sims road, Site 22	31
Airport south, Site 45	31
Te Puru, Site 97	31
Barneys Whare, Site 36	31
Pourerere bay north, Site 56	30
Grahams/Hudsons beach, Site 53	30
Caroline Bay, Site 103	30
Camp Bay, Eastborne, Site 32	30
Bowentown tombolo, Site 92	30
Whakatane spit, Site 86	30
Tern St, Brighton Site 110	29
Protected dunes, Lyall Bay, Site 44	29
Port of Napier, Site 62	29
Munro subdivision, Site 78	29
Mount Maunganui, Site 87	29
Pekapeka beach, Site 24	29
Whangamata cuspate foreland, Site 94	28
Uruti beach, Site 9	28
Sergeants beach, Site 50	28
Rickards Farm, Site 107	28
Queen Elizabeth Park, Raumati, Site 29	28
Otaio River, Site 101	28
Morris Rd, Sth Canterbury, Site 99	28
Gravel beach, Site 4	28
Golf links road, Site 85	28
Waikanae rivermouth, Site 25	28
Rua road south, Site 27	28
Fishermans Table, Paekakariki, Site 31	28
Birdlings Flat, Kaitorete Spit, Site 109	28
Whangamata main beach, Site 95	27
Waikuku Beach, Site 112	27
Riversdale beach, Site 20	27
Ohiwa harbour, Site 77	27
Management Reserve, Site 39	27
Low cliffs, Kaiwhata river north, Site 14	27
Homewood Station low cliffs, Site 12	27
Failed slope, Flat Point north, Site 16	27
Faceted dunes, Site 3	27
Paraparaumu cuspate foreland, Site 26	27
Waitaki Boys High, Oamaru, Site 98	26
Sims Rd south, Site 23	26
Platform headland with fence, Site 5	26
Motukaraka Pt, Site 41	26
Matata barrier, Site 81	26
High cliffs, Kaiwhata north, Site 13	26
Eves Bay, Seatoun, Site 46	26
Bowentown, Tauranga Harbour, Site 91	26
Whareama Homestead, Site 2	25
Wattle Bay, Site 54	25
Ration Point, Site 40	25
Motunau Cliffs, DT4	25
Barton Marine, Site 42	24
Omokoroa, Tauranga Harbour, Site 90	23
Pourerere beach, Site 55	22
Turakirae Head, Site 37	21
Waipipi wharf road, Site 48	20
Te Toro road, Site 49	20
Racecourse road, Waiuku, Site 47	20
Maketu ignimbrite, Site 88	19
Lazy surveyor rock, Site 6	18
Whitianga Bay, Site 72	15
Whanarua Bay, Site 71	14
Lottin Point, Site 70	13
Whangamata upper harbour, Site 96	11

APPENDIX 9
Worked example of the CSI technique using Te Araroa, East Cape

1. Record the date, time, location.	1 April 1992: 1500hrs Te Araroa A (Z14 839 826)
2. Bcome familiar with the test site, looking for (a) evidence of landslip, and (b) the presence of dune control or restoration works, and recording this.	
3. Measure the elevation of the first immediate feature	Elevation = 1.5m above MHWS, rating = 5
4. Assess the level of storm wave run-up from field and anecdotal evidence and reports.	Te Araroa (Site 63): a 2.2-3.3 m level has been Calculated for Onepoto Bay (5km NW of Te Araroa), accompanying evidence in the form of logs and flotsam, rating 4.
5. Is the first immediate feature exceeded by the storm wave run-up level? **Yes:** the gradient is determinedas that behind the first feature **No:** overtopping= zero so the gradient is determined as the slope face of the first feature.	Te Araroa inland slope of approximately 1°, rating= 5.
*6. From de Lange and Healy (1986a) determine the largest tsunami on record	Te Araroa: 3m tsunami wave observed in March 1868 from Chilean earthquake, rating= 3.
7. Confirm the lithology and landform by field.	Unconsolidated sands (and gravels) forming a observation. Sand/gravel beach, ratings= 5.
*8. From the long-term horizontal trend data, for each field site (can be done while travelling).	Te Araroa A (Site 63) is retreating at an average of 1.5m/yr assess the rate of erosion or accretion rating= 4 Gibb 1981).
*9. From the long-term trend data and from field inspection make an assessment of the short term fluctuation variable.	50m from Gibb (1981), rating= 5.
10. Take a photograph.	
*11. Calculate an initial CSI.	CSI= 36 out of a possible total of 40, very high sensitivity.

APPENDIX 10
Sea-level rise case study results

Results for Te Awanga, Hawkes Bay (Site 59) illustrating change in CSI only at the extreme IPCC level rise prediction.

Site	Elevation	Storm Wave Run-up (m)	Gradient (degrees)	CSI
Te Awanga (Site 59)	2.70	3.5	swale	35 (v. high)
2050 A.D. N.Z. average	2.60	3.5	swale	35
2050 A.D. x 2	2.50	3.5	swale	35
2050 A.D. x 6	2.11	3.5	swale	35
2100 A.D. N.Z. average	2.52	3.5	swale	35
2100 A.D. x 2	2.33	3.5	swale	35
2100 A.D. x 6	1.60	3.5	swale	36 (v. high)

Results for the Port of Napier (Site 62) showing a change in CSI only at the highest IPCC prediction.

Site	Elevation	Storm Wave Run-up (m)	Gradient (degrees)	CSI
Port of Napier (Site 62)	2.70	3.5	10	29 (high)
2050 A.D. N.Z. average	2.60	3.5	10	29
2050 A.D. x 2	2.50	3.5	10	29
2050 A.D. x 6	2.11	3.5	10	29
2100 A.D. N.Z. average	2.52	3.5	10	29
2100 A.D. x 2	2.33	3.5	10	29
2100 A.D. x 6	1.60	3.5	10	30 (high)

Results for the Matata Barrier (Site 81) illustrating that a change in CSI only occurs for the highest sea-level rise prediction of the IPCC.

Site	Elevation	Storm Wave Run-up (m)	Gradient (degrees)	CSI
Matata Barrier (Site 81)	6.10	5	11	26 (med.)
2050 A.D. N.Z. average	6.00	5	11	26
2050 A.D. x 2	5.90	5	11	26
2050 A.D. x 6	5.50	5	11	26
2100 A.D. N.Z. average	5.92	5	11	26
2100 A.D. x 2	5.73	5	11	26
2100 A.D. x 6	5.00*	5	11	27 (med.)

* Change in elevation + change in class and change in CSI

Results for Whakatane Spit (Site 86) illustrating an initial change in CSI due to inundation caused by sea-level rise but no further change.

Site	Elevation	Storm Wave Run-up (m)	Gradient (degrees)	CSI
Whakatane Spit (Site 86)	5.00	5	15 -20	29 (high)
2050 A.D. N.Z. average	4.90	5	swale*	32 (high)
2050 A.D. x 2	4.80	5	swale	32
2050 A.D. x 6	4.40	5	swale	32
2100 A.D. N.Z. average	4.82	5	swale	32
2100 A.D. x 2	4.63	5	swale	32
2100 A.D. x 6	3.90	5	swale	32 (high)

* The site became overtopped so the gradient was taken of the area inland which would be inundated.

Results for Whangamata Beach (Site 95) illustrating a change in CSI occurring at the highest IPCC predictions.

Site	Elevation	Storm Wave Run-up (m)	Gradient (degrees)	CSI
Whangamata Beach (Site 95)	5.70	4 -5	5 -10	27 (medium)
2050 A.D. N.Z. average	5.60	4 -5	5 -10	27
2050 A.D. x 2	5.50	4 -5	5 -10	27
2050 A.D. x 6	5.10	4 5	5 -10	27
2100 A.D. N.Z. average	5.50	4 -5	5 -10	27
2100 A.D. x 2	5.30	4 -5	5 -10	27
2100 A.D. x 6	4.60	4 -5	5 -10	28 (high)