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

by

Jeremy Gibb, Angela Sheffield, and Gregory Foster

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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.

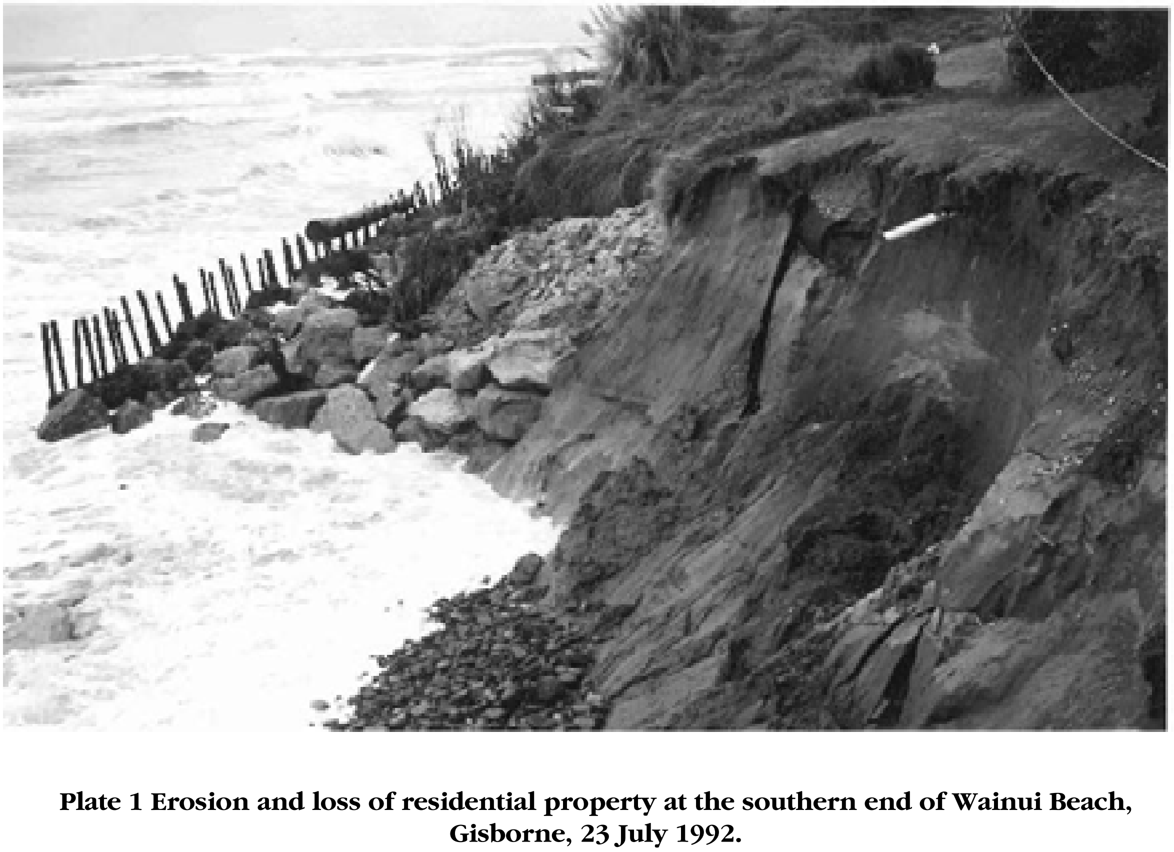

Plate 1 Erosion and loss of residential property at the southern end of Wainui Beach, Gisborne, 23 July 1992.

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.

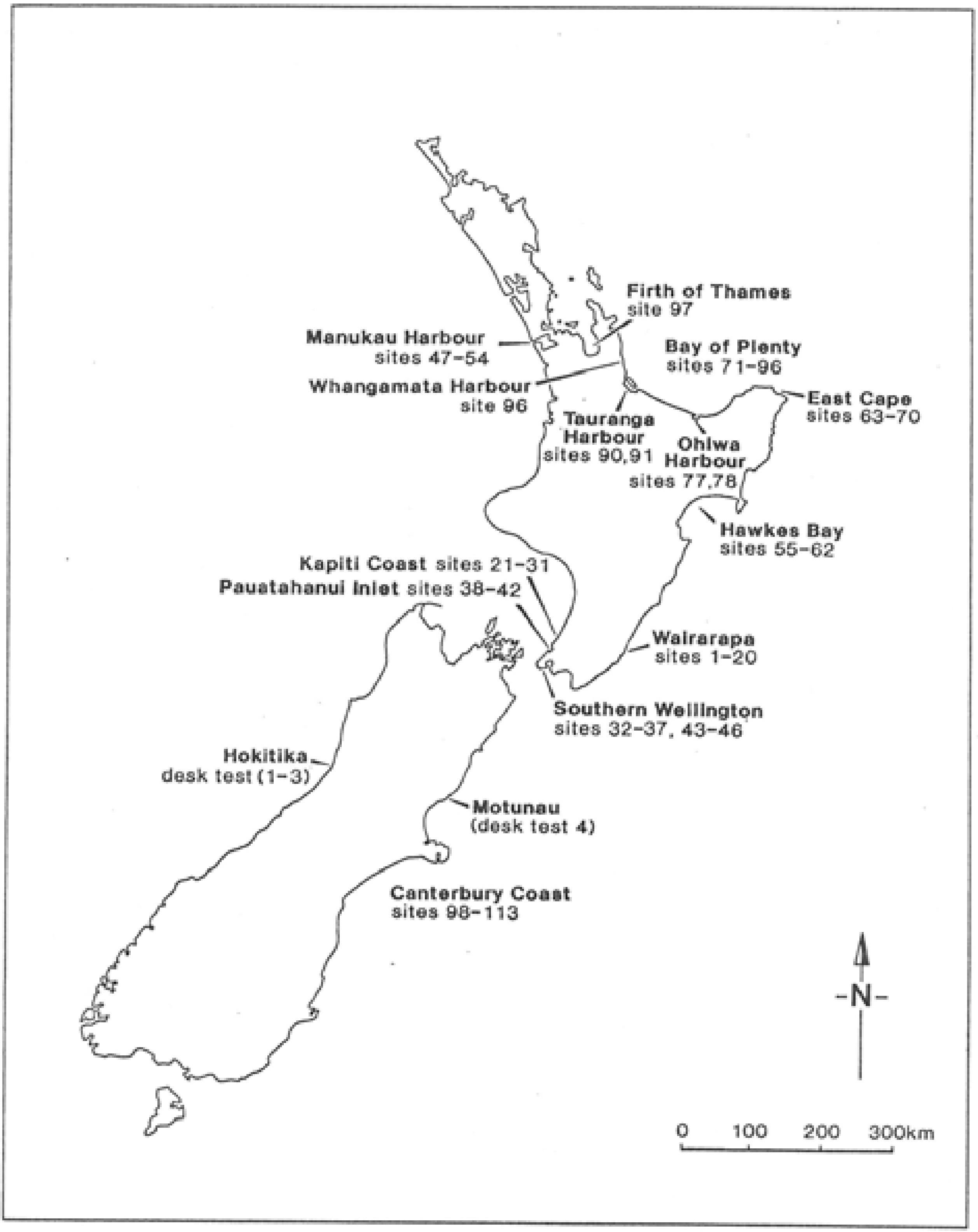

Figure 1 The site numbers and localities of both exposed and sheltered test area visited during the development and testing of the Coastal Sensitivity Index (CSI).

- 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.

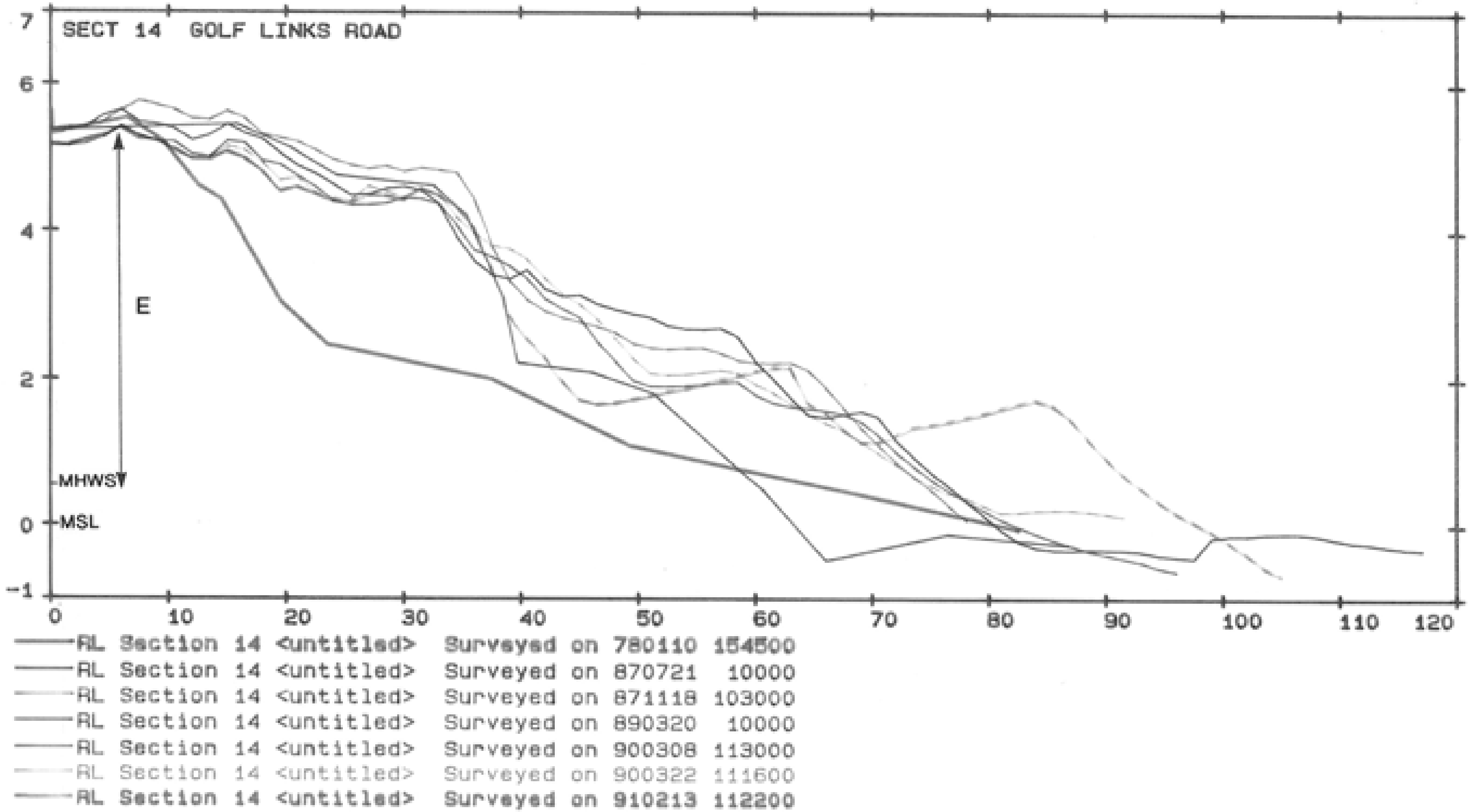

Figure 2 An example of a beach cross-section from Golf Links Road, Whakatane, supplied by the Bay of Plenty Regional Council, showing how elevation (E) is measured in relation to MHWS.

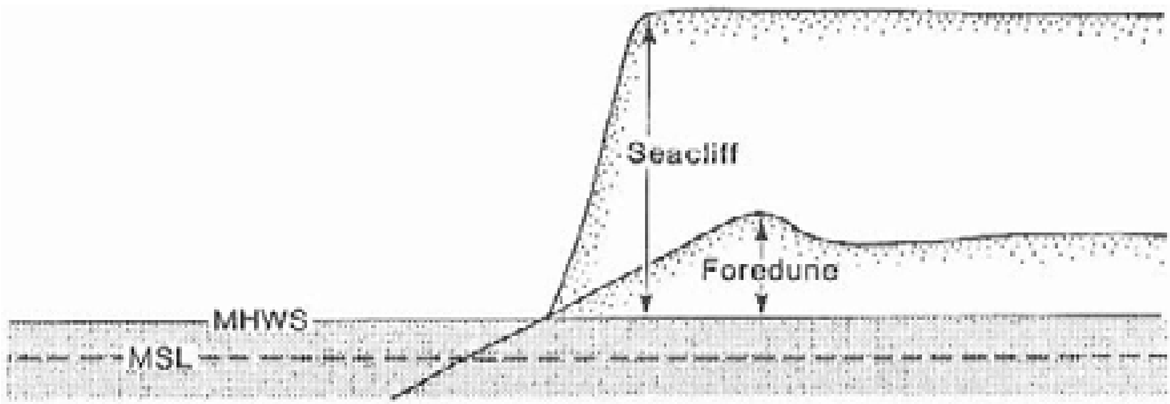

Figure 3 Diagram showing measurement of elevation in metres above MHWS

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

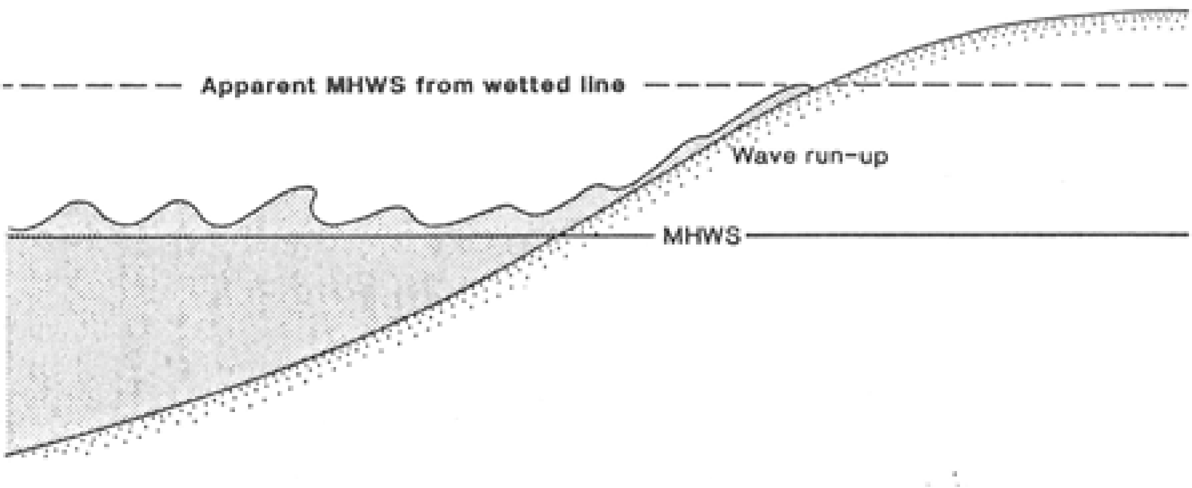

Figure 4 An estimation of mean high water spring level on steep beaches where the "wetted line" is higher than the actual (still water) level required.

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.

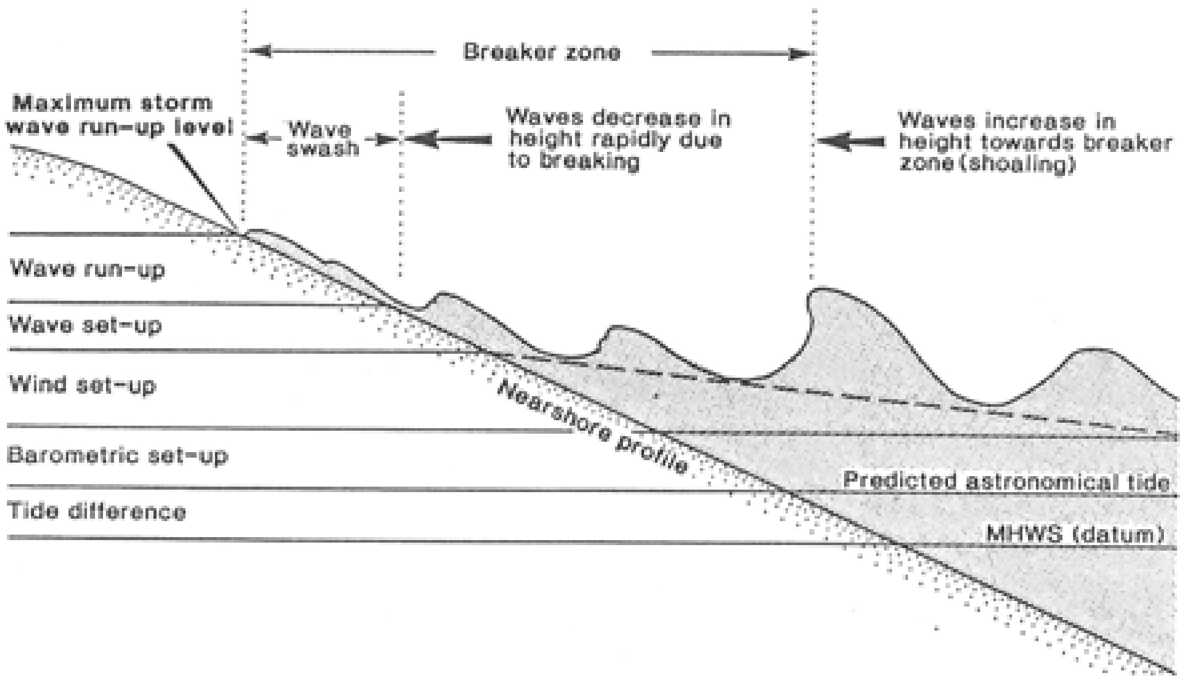

Figure 5 Schematic diagram showing the components determining maximum storm wave run-up level. (Detailed methodology is given in Frisby and Goldberg, in Gibb 1981).

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