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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 *(^{o})*	$>20^{o}$	20^{o}-11^{o}	10^{o}-6^{o}	5^{o}-2^{o}	$<2^{o}$ (including <0)

User guidelines

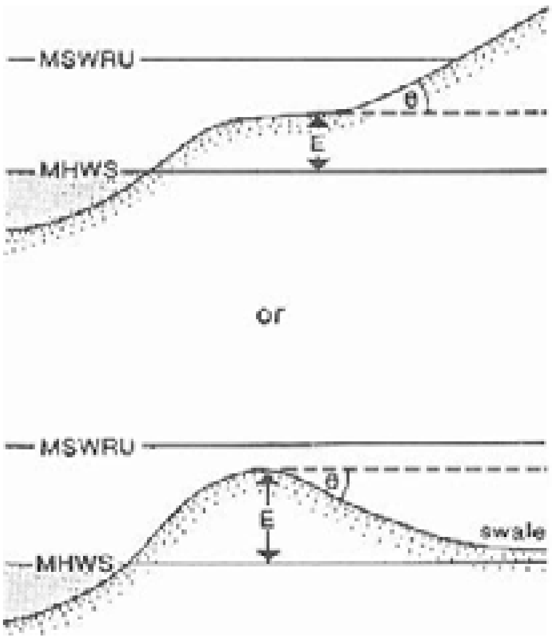
1. The gradient is determined **after** establishing whether or not storm wave run-up exceeds the initial elevation, as it is the gradient of the coastal hinterland which is **inundated** or has the potential to be inundated which is of interest.

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 $<2^{o}$ (at highest risk).

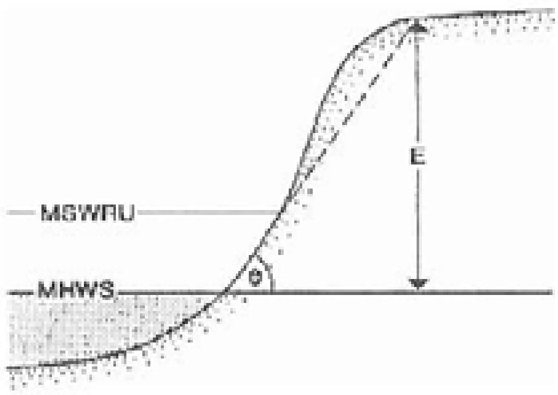
A. Overtopping (MSWRU>E)

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

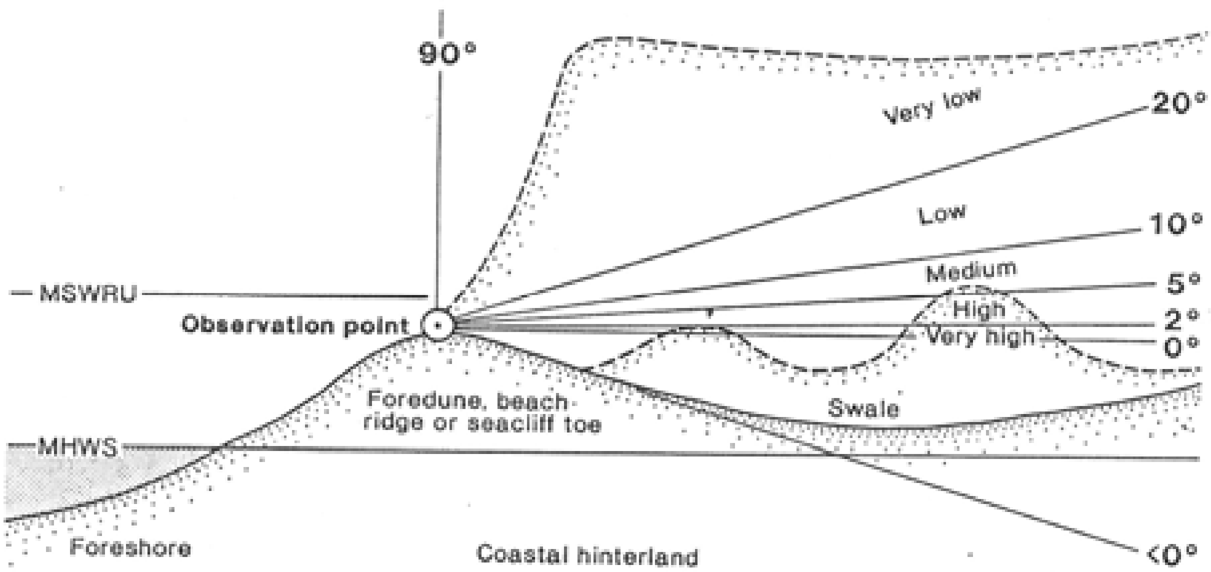


Figure 7 Gradient of the hinterland is measured in degrees and can be estimated by protractor and from surveyed cross-sections (see Figure 2).

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”.

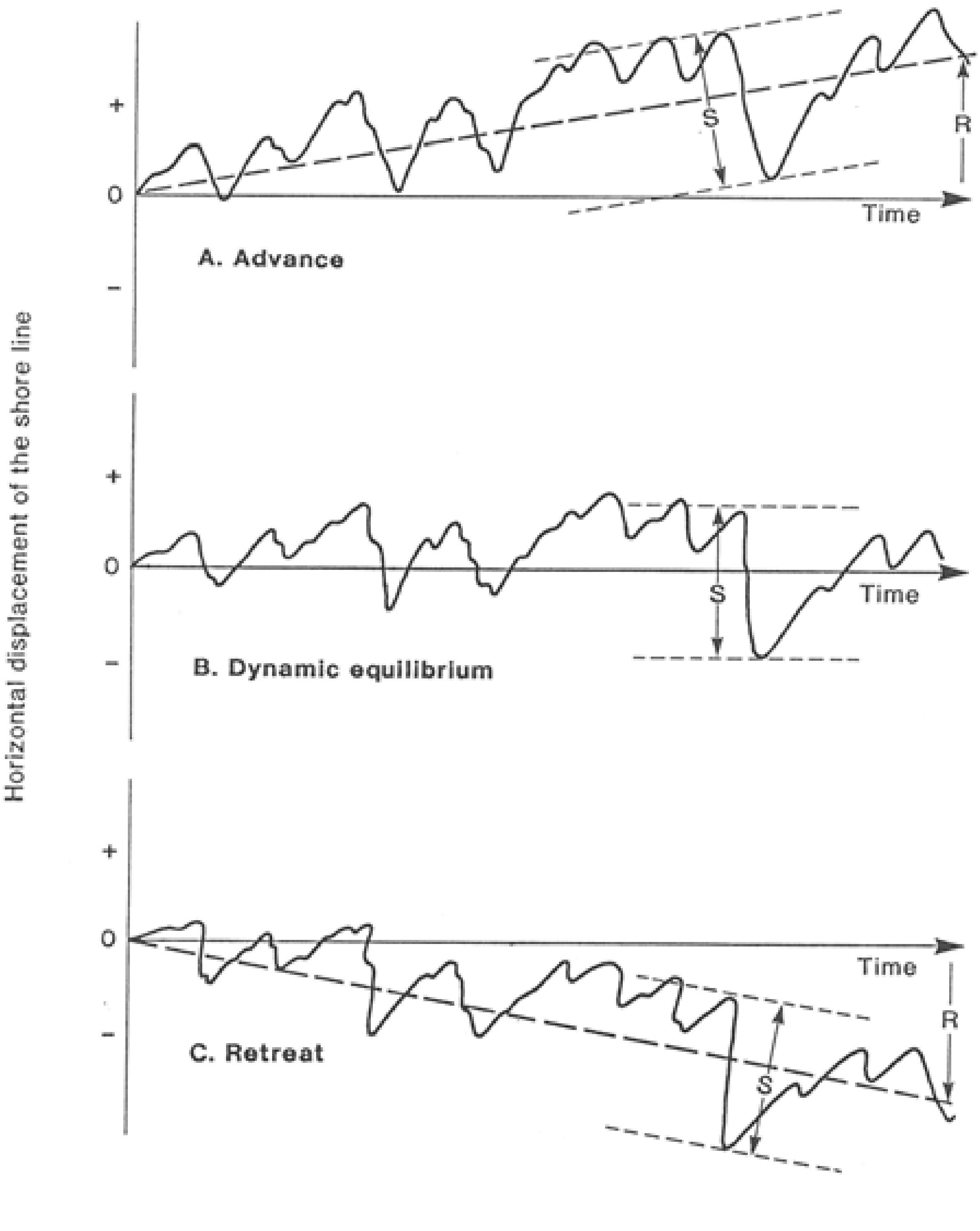


Figure 8 Conceptual diagram (after Gibb and Aburn 1986) illustrating the horizontal trend, where (R) is the net rate of movement in m/year calculated by dividing the horizontal distance (A), by the survey time interval (T). The short-term fluctuation (S), represents the maximum fluctuation in the position 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.

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

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.

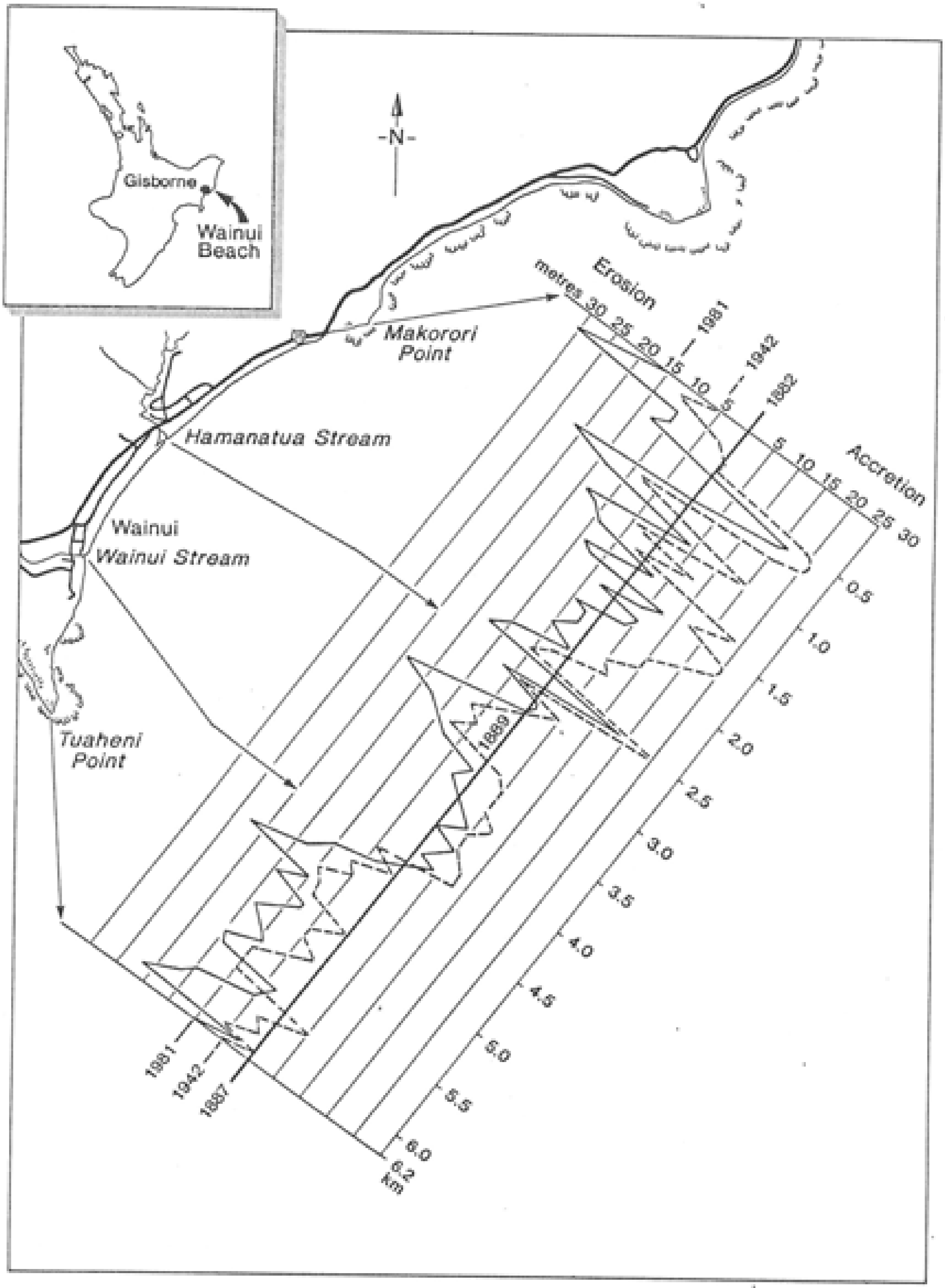


Figure 9 Sketch map of Wainui Beach, Gisborne, showing an example of detailed horizontal trend data that can be collected for a single beach (after Gibb 1981).

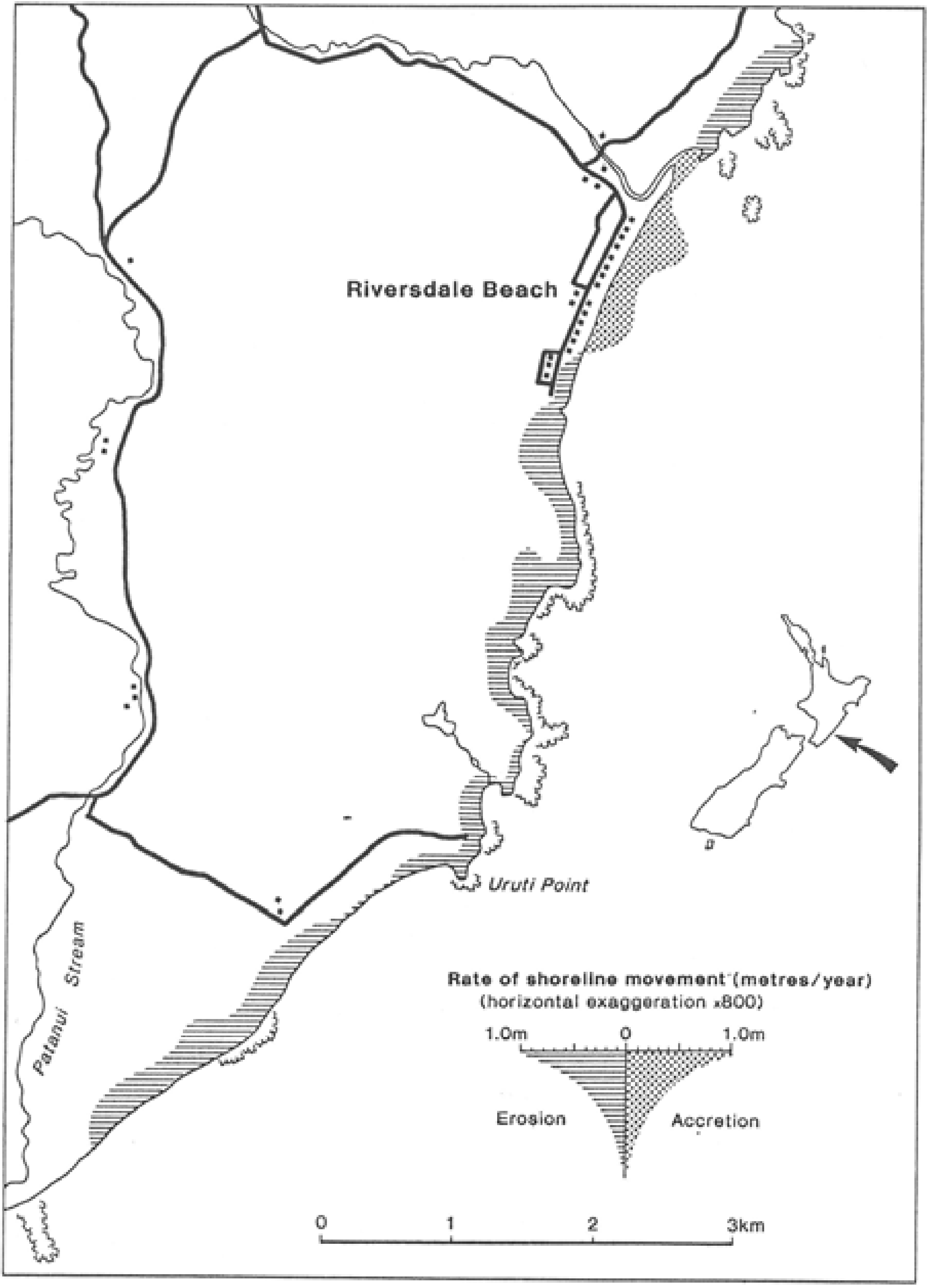


Figure 10 Sketch map of the east Wairarapa coast showing an example of long-term rates of shoreline erosion/accretion over the last century.

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