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Te Tari Rerekētanga Āhuarangi o Aotearoa

Coastal Hazards and Climate Change

A guidance manual for local government in New Zealand

May 2004

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Executive Summary

Climate change will not introduce any new types of coastal hazards, but it will affect existing hazards. Coastal hazards in many areas are expected to increase as a result of the effects of climate change. As development of coastal areas and property values increase, the potential impacts of coastal hazards increase.

There is increasing confidence in the predictions of the effects of climate change. Sea level has risen in New Zealand by about 0.25 m since the mid-1800s (historical sea-level rise has been approximately 0.16 m per century), and this rise is expected to accelerate. Under the most likely mid-range projections, sea level is projected to rise a further 0.14 – 0.18 m by 2050, and 0.31 – 0.49 m by 2100. In developing scenarios, it is recommended that *at least* the most likely mid-range scenario for sea-level rise is used: it is recommended that council staff use a figure of 0.2 m by 2050 and 0.5 m by 2100 when considering sea-level rise in projects or plans.

Sea-level rise and other climate change effects, such as increased intensity of storms and changes in sediment supply to coastlines, are expected to modify coastal hazards in many areas around New Zealand.

Because climate change effects are very gradual, land-use planning decisions must have long-term horizons to accommodate the lifetimes of structures. It is vital that planning occurs *now* for climate change effects, particularly where decisions are being made on issues and developments that have planning horizons and life expectancies of 50 years or more.

This Guidance Manual is intended to help local authorities manage coastal hazards by:

- providing information on the effects of climate change on coastal hazards;
- presenting a decision-making framework to assess the associated risks;
- providing guidance on appropriate response options.

Three main types of coastal hazard are addressed:

- coastal erosion caused by storms and/or long-term processes;
- coastal inundation caused by storms or gradual inundation from sea-level rise;

- coastal inundation caused by tsunami.

This document recommends Risk Management standard AS/NZS 4360 as the undergirding standard for all risk assessment procedures and processes relating to coastal hazards in a changing climate.

This document is a companion to "*Climate change effects and impacts assessment*", a further climate change guidance manual published by the New Zealand Climate Change Office. "*Climate change effects and impacts assessment*" is an 'umbrella' document that addresses the effects of climate change on the whole range of local authority functions. It can be found at: http://www.climatechange.govt.nz/resources/local-govt/effects-impacts-may04/index.html.

What are the potential impacts on New Zealand's coastal areas?

In general terms, accelerating **sea-level rise** around New Zealand may result in:

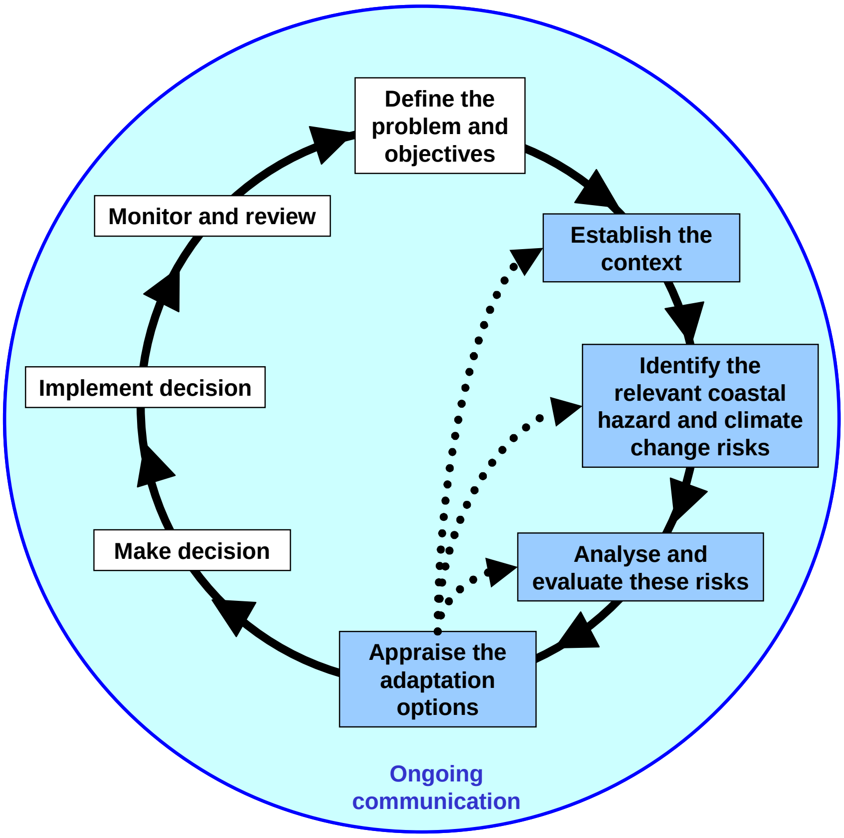
- increased coastal erosion in some areas. Parts of the coastline that have historically been eroding may experience increased erosion trends; other areas that may have been relatively stable may begin to erode;
- permanent high-tide inundation of very low-lying margins that may at present experience only episodic inundation;
- episodic sea flooding of higher coastal and estuarine margins;
- salinisation of adjacent rivers and streams and landward intrusion of saline groundwater;
- drainage problems in adjacent low-lying areas, especially where gravity is relied on;
- increasing 'coastal squeeze', where shorelines are held and constrained by structures such as seawalls and stopbanks, resulting in a reduction of intertidal area and loss of beach; and
- increased rates and frequency of episodic wave run-up and overtopping of both natural and man-made coastal defences.

Other aspects of climate change will also affect many of the other physical 'drivers' that shape coastal margins and ecosystems, such as winds, waves, storms, sediment supply, and sea temperature. For example:

- increase in storm rainfall intensities may lead to increased or more frequent lowland river flooding and impacts on water quality from increased sediment loads to estuaries, although sediment availability will depend on catchment land-use and construction practices;
- change the way sediment is distributed along a coastline through changing longshore transport patterns and 're-aligning' of beaches;
- altered hydrological soil processes (e.g., greater extremes of drought versus intense rainfall), that may exacerbate erosion and landslips on unconsolidated coastal cliffs;
- changes in wind, ocean currents and waves may alter coastal sediment movement and coastal upwelling of cooler nutrient-rich ocean waters that is important for coastal productivity, including fisheries; and
- aquatic ecosystems will be affected by rising temperatures (air and water), potential loss of habitat from constraining stopbanks in some areas, while in other areas, will be impacted by possible increases in sediment loads entering estuaries during storms.

The magnitude of the impacts on coastal margins will differ between regions and even between localities within regions, depending on the localised impacts of climate change on the physical 'drivers' that shape the coast, the natural coastal characteristics, and the influence of man-made coastal developments.

This Guidance Manual provides a risk-based decision-making framework, following the cyclical steps in the diagram below.



A risk 'screening' process is advocated, where the level of detail in the analysis is consistent with the perceived degree of risk. The process can be used to prioritise hazards in a district or region, although it is not intended for detailed analysis of risks.

This document recommends Risk Management standard AS/NZS 4360 as the undergirding standard for all risk assessment procedures and processes relating to coastal hazards in a changing climate.

Risk assessment requires analysis of the **probability** of a particular hazard event (e.g., erosion or inundation) occurring, and its **consequences** on people, the natural and built environment and local economy. An important feature of coastal hazards and climate-change effects is that **both** the probability and consequences of coastal hazards – and hence the associated risks – are likely to increase in the future. The probability of hazards is likely to increase due to climate-change effects, while at the same time the consequences are likely to increase because of increasing coastal development and property values.

This manual provides guidance on assessing the probability of the hazard event, which is a function of the hazard 'drivers' (e.g., storms), the climate-change effects on those hazard drivers, and the morphology of the coastline (e.g., sandy beaches, gravel beaches, cliffs and estuaries). While the Guidance Manual is primarily intended for use by local authority planners, the assessment of coastal hazards should also involve an experienced coastal hazards practitioner. Back-of-the-envelope calculations are not usually possible for coastal hazard assessments because of the complexity of the problems.

Once the coastal hazards are prioritised, the next step is to assess and decide on the most appropriate response options to the hazards through the preparation of a "Response Strategy". The underlying premise in the "Response Strategy" is to manage the **consequences** of potentially hazardous coastal processes. While it is very difficult to reduce the **likelihood** of a particular coastal hazard event occurring, it needs to be remembered that the **frequency** of a particular hazard may increase as a result of climate change. This Manual identifies principles and management options that can be used to address climate change-induced coastal hazards and mechanisms currently available to implement these options.

A general hierarchy of response options is advocated in this Guidance Manual:

1. activities and land-use practices to protect natural defences such as sand dunes, gravel ridges, cliffs, salt marshes, and vegetation;

2. management of land use to avoid areas of coastal hazard (e.g., location of development away from coastal hazards, retreat or relocate infrastructure);

3. undertake 'soft defence works' such as re-vegetation, beach access-ways, beach nourishment, or drainage; and

4. undertake 'hard structural works' such as seawalls, rock armoring or groynes.

The first two options are more easily applied where there is little existing development but land use intensification is proposed (e.g., greenfield developments). In such areas it is prudent to provide an appropriate buffer between the shoreline and the development to maintain natural defences against coastal erosion and inundation, preserve the natural character of the coastline, and maintain public access to the shore.

The situation is more difficult where the coastline is already well developed. Focus is often put on protecting assets using hard structures such as seawalls or rock armouring. If protection options are to be used, 'soft' options should generally be given priority over 'hard' options.

Structural options may be appropriate when used as part of a management 'package', where the structural works are a short-term solution in conjunction with a longer-term planning option. For example, temporary works (e.g., sand sausage) might be implemented as an interim measure, designed to last until a planning technique, such as managed retreat, has progressively relocated at-risk development.

Long-term monitoring of the effects of coastal hazards should be undertaken to improve our understanding, and ensure that response options are effective and sustainable. Monitoring techniques need not be expensive (e.g., a regular photographic record), but in high-risk situations, robust monitoring programmes that will provide useful information for future assessments of coastal hazards and response options should be considered.

1. Introduction

This chapter:

- explains the key role that local authorities play in coastal hazard management;
- sets out the objectives, scope and structure of the Guidance Manual;
- introduces a risk-based approach to managing coastal hazards.

1.1 The role of local authorities

A good proportion of New Zealand's development has occurred in coastal areas, some of which are vulnerable to erosion and inundation. As coastline development intensifies and property values increase, the potential impacts of coastal hazards also increase.

Climate change will not introduce any new types of coastal hazards, but it will affect existing coastal hazards by changing some hazard drivers.

The effects of climate change will increase coastal erosion and inundation in many areas, and will thus further increase the impacts of coastal hazards.

In attempting to achieve sustainable management of the coast (as required under Section 6 of the Resource Management Act), local authorities face increasing pressures and difficulties, such as:

- the need to provide for the natural character and the ecological, landscape, amenity, and cultural and spiritual values of the coast;
- the increasing social, economic and political pressures to intensify use and development of coastal areas, particularly with respect to redevelopment and sub-division;
- the lack of regional or nationwide strategic planning processes to manage the long-term risks associated with coastal hazards in a sustainable manner;
- the public's perceptions of existing use rights, permanence of property, and local government responsibilities for protection from impacts of coastal hazards;
- the lack of guidance on the range of land-use management options available and how to apply them effectively over longer planning horizons; and

- the complex nature of assessing risks associated with coastal hazards and climate change, and the lack of a decision-making framework using uncertain knowledge.

Figure 1.1: Effects of coastal erosion adjacent to a tidal inlet. (Note railway-iron stakes offshore – an earlier attempt to protect shoreline.) [*Source*: R.K. Smith].

Figure 1.2: Coastal inundation from a high storm-tide. [*Source*: Southland Times].

Climate-change effects are very gradual. However, land-use planning decisions usually have long-term horizons because of the permanency of structures (e.g., buildings, roads, network utilities etc). Climate-change effects will therefore eventually have major implications for those decisions. It is vital that planning begins *now* for climate change effects, particularly where decisions are being made on issues and developments that have planning horizons and life expectancies of 50 years or more.

Territorial authorities' role in addressing the effects of climate change on coastal hazards (and managing coastal hazards in general) stems from:

- land-use planning, subdivision consenting and building permitting functions (including the need to take natural hazards into account in these processes);
- infrastructure planning, construction and maintenance; and
- natural hazards management, education and response.

Regional councils' role stems from:

- responsibilities for the avoidance and mitigation of natural hazards; and
- responsibilities (in conjunction with the Minister of Conservation) for controlling the effects of the use of land and water in and adjacent to the coastal marine area.

Accordingly, coastal hazards should be taken into account by:

- considering coastal hazards and climate variability and change in the preparation of district and regional plans, and when considering individual proposals for development and subdivision;
- recognising that the natural coastal margin (beach, dunes, cliffs and immediate hinterland) has a natural role of defence against the sea;
- consulting with the community when sustainable response options need to be considered to protect, adapt or retreat from worsening coastal hazard impacts;
- applying the precautionary principle to the decision-making process where uncertainty exists, so that risk is minimised with 'no regrets'; and
- providing information to the public about the risks of development within the coastal margin.

1.2 Aims and objectives of the Guidance Manual

This Guidance Manual aims to strengthen the integration of coastal hazards and climate change within the land-use planning process. The key audience is local authority staff (policy and planning staff, consents staff and engineers), but it will also assist consultants, policy analysts, and other interested individuals.

The primary objectives of the Guidance Manual are to:

- provide regional and territorial authorities with information on the key effects of climate change on coastal hazards;
- provide a decision-making framework to assess the associated risks;
- provide criteria to appraise and decide on appropriate responses to the risks.

The main purpose of the Guidance Manual is to address the effects of climate change on coastal hazards. However, it also aims to help local authorities identify, assess and respond to coastal hazards generally.

This document is a companion to the "*Overview of climate change effects and impacts assessment*" Guidance Manual (NZCCO, 2004). The Overview Guidance Manual is an 'umbrella' document that addresses the range of effects of climate change on the whole range of local authority functions. Readers of the Coastal Hazards Guidance Manual should also refer to the Overview Guidance Manual. [Note that the term 'Guidance Manual' in this document always refers to this Coastal Hazards Guidance Manual rather than the Overview Guidance Manual, unless stated otherwise].

The Guidance Manual addresses the three main types of coastal hazards:

- coastal erosion caused by storms and/or long-term processes;
- coastal inundation caused by storms or gradual inundation from sea-level rise; and
- coastal inundation caused by tsunami.

1.3 Managing coastal hazards: a risk-based approach

The overall process recommended for managing coastal hazards, including climate change effects on those hazards, is summarised in Figure 1.3. The steps highlighted in blue comprise a risk assessment process, which has been adopted in this Guidance Manual to assist local authorities in decision-making by addressing the following questions:

1. What coastal hazards and climate-change risks are important to the decision?
2. What are the possible consequences and impacts of "doing nothing", and should climate change influence the decision?
3. What and where are the most vulnerable localities in the district or region?
4. What response options are available?
5. Within the wider community or region, what response options are most appropriate to manage the risks?

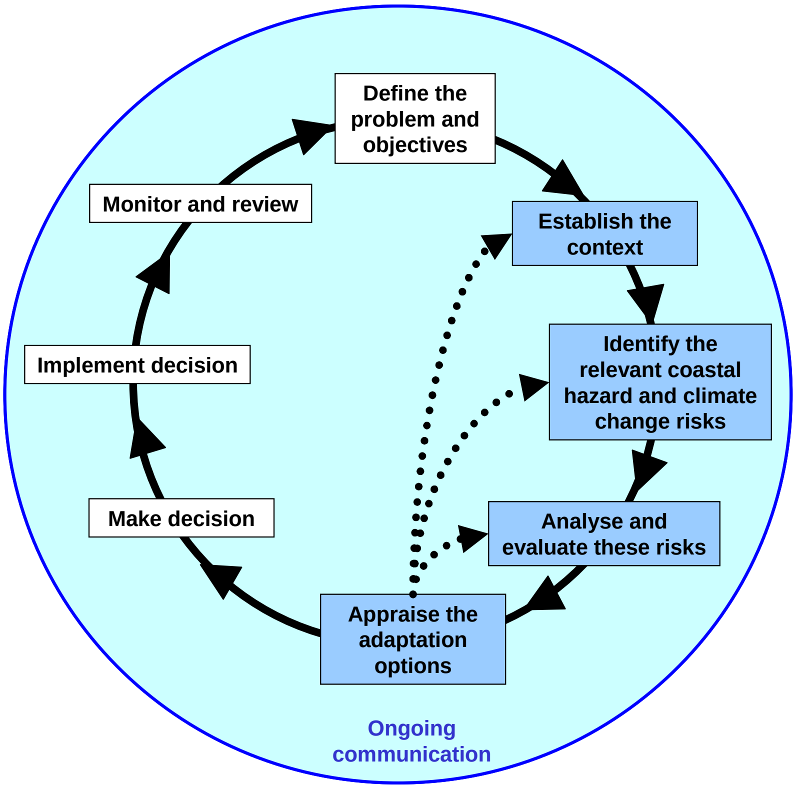


Figure 1.3: The process of managing coastal hazards, including climate-change effects.

A key feature of coastal hazards and associated risks is that they are not constant, but change over time. Risk management decisions therefore need to be based not only on the current risks, but incorporate changes over the lifetime of the infrastructure or building in question. The effects of climate change typically become relevant whenever the lifetime of the development exceeds 50 years.

As part of the risk assessment process, guidance is provided on assessing numerical values for various coastal hazards, but this is intended purely to assist with prioritising hazards. The methods suggested must not be used for design purposes, which require more detailed and site-specific assessments.

1.4 Structure of the Manual

This Guidance Manual is set out as follows:

- Section 2 covers what is known about climate change, the main causes of coastal hazards, and the likely effects of climate change on those coastal hazards.
- Section 3 summarises the legislation that is relevant and/or requires the assessment of coastal hazards and climate change. It also sets out the key

values and significance of the coastal environment, which need to be borne in mind in any decision-making process.

- Section 4 sets out the appropriate process of how to go about assessing risks in the coastal area from climate change-induced hazards.

- Section 5 is the critical part of this Manual. After identifying the hazards (Section 2) and determining the risk (Section 4), Section 5 provides a range of options of how local authorities can respond to those risks and hazards. Specifically it identifies:

    - the range of functions local authorities undertake that may need to take climate change-induced effects into account;

    - the range of planning options available to local authorities as a means of responding to the climate change and coastal hazard issues (e.g., set-back areas, relocation, retro-fitting etc). These are provided both for undeveloped (‘greenfield’) areas, and for areas where development is already in place;

    - the mechanisms available to put the above response options into place (e.g., plans, policy documents, resource consent decisions etc).

- Section 6 outlines the basic requirements of a monitoring programme, given that the effectiveness of any planning response must be able to be monitored and reviewed in an ongoing and iterative process.

- Section 7 incorporates the most relevant case law about responding to climate change effects.

Note that although considerable technical detail is provided in the Guidance Manual, coastal hazard processes are often complex and site-specific, so any detailed assessment must involve an experienced coastal hazards practitioner.

2. Climate Change and Coastal Hazards

This chapter identifies:

- current evidence for climate change and where the uncertainties exist;
- causes of coastal hazards;
- potential impacts of climate change on the coastal areas of New Zealand.

2.1 Predicting future New Zealand climate change

Literature and scientific studies suggest that not only is global climate subject to significant fluctuations, it is also rapidly *changing*, indicating an overall warming of the earth's surface and of its oceans and atmosphere. The third assessment report from the Intergovernmental Panel on Climate Change (IPCC) recently concluded that:

> *"There is new and stronger evidence that most of the global warming observed over the last 50 years is attributable to human activities."* (Intergovernmental Panel on Climate Change, 2001)

The broad conclusion from a number of different approaches and scientific disciplines is that the world is warming at a rate faster than at any other time in the last 1000 years, coincident with a rapid rise in greenhouse gases. Sea level has also been steadily rising since the early to mid 1800s. In the future, sea-level rise is projected to accelerate.

Although significant uncertainties exist in projecting these changes into the future, overall it is likely that even at the lower end of projections, the changes over the next 100 years will be more rapid than natural variations over the last 10,000 years.

What has occurred in New Zealand?

- Surface temperature has increased by around 0.7ºC during the 20th century.
- Sea temperatures have risen by 0.4-0.5ºC since 1870.
- Mean sea level has risen 0.25 m since the mid 1800s.

Changes in climate parameters can only be estimated. For many parameters (such as temperature and sea level) the direction of change is virtually certain (i.e., increasing), but the magnitude of that change is less certain. With other parameters, the direction of change may vary with region (e.g., rainfall is likely to reduce in many eastern regions but increase in the west). For others (such as wave structure and ocean currents) there is only limited understanding of how climate change may affect them, both in terms of magnitude and direction.

The Overview Manual provides the most up-to-date information on the expected changes in the range of climate parameters.

2.2 Causes and “drivers” of coastal hazards

2.2.1 Introduction

Hazards are created by a conflict between human use of the land, and physical processes at the coastline. The nature and extent of human use of the coastline must therefore be taken into account in a hazard assessment. For example, erosion of a cliffed coastline may not constitute a significant hazard in a pastoral farming area, but could be more significant in an urbanised area.

The three main types of natural coastal hazards are considered in this Guidance Manual. These are:

- coastal erosion caused by storms and/or long-term processes;
- coastal inundation caused by storms or gradual inundation from sea-level rise;
- coastal inundation caused by tsunami.

These hazards are influenced by a range of natural causes and hazard “drivers”. The main drivers that govern coastal erosion and inundation are shown in Figure 2.1. Both coastal inundation and coastal erosion arise from intricate interactions between several drivers, as also shown in Figure 2.1.

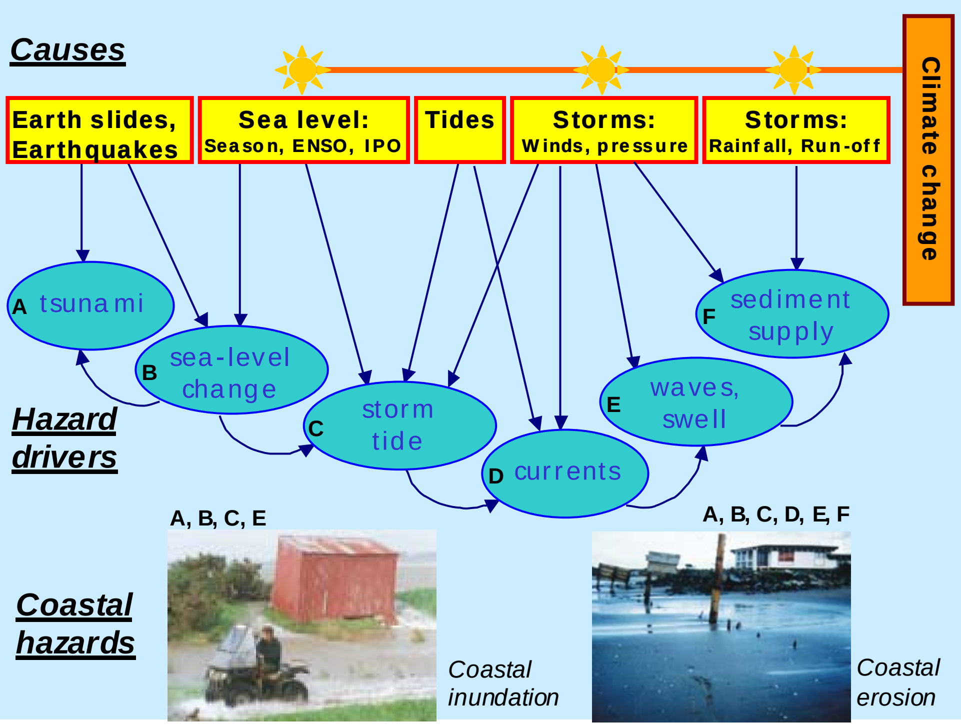


Figure 2.1: Natural causes and hazard drivers for coastal inundation and coastal erosion hazards, together with those drivers likely to be affected by climate change (marked with a sun symbol). Note: ENSO= El Niño–Southern Oscillation cycle; IPO= Interdecadal Pacific Oscillation.

Human-induced factors can worsen the risk posed by coastal hazards. Examples of these are the effects of:

a) dams on rivers and irrigation abstraction that reduce sediment supply to the coast;

b) extraction of sand or shingle from the coastal zone, which can reduce the buffering ability of beaches to absorb storms;

c) ill-conceived shoreline protection works that worsen or shift the erosion problem ‘downstream’ or increase the wave run-up height;

d) dredging of harbour entrances and channels;

e) removal of coastal vegetation; and

f) the artificial lowering of dunes for sea-views or access.

A brief summary of the hazard causes and drivers shown in Figure 2.1 is provided below. More background information is provided in Appendix 2.

2.2.2 Sea-level fluctuations

‘Sea-level fluctuations’ refers to the fluctuations in the mean level of the sea, after taking out the influence of tides and without the influence of long-term sea-level rise. In terms of heightened inundation and coastal erosion risk, for any one month the mean level of the sea could reach up to 0.25 m above the average sea level. This is most likely to occur during La Niña episodes in decades when the 20 to 30-year Interdecadal Pacific Oscillation (IPO) cycle is in its negative phase. In this respect, we are currently in a negative IPO phase, which appears to have started in 1998 and may last until 2020 to 2030. Effects of IPO can mask or increase long-term sea-level rise for 20 to 30 year periods.

2.2.3 Tides

The height of a tide governs the likelihood of coastal inundation from a storm surge or river flooding. In addition, tidal currents at estuary entrances and constricted straits play a key role in supplying sediment to estuary beaches and adjacent open-coast beaches.

The mean high water springs (MHWS) level is a useful upper-limit against which to assess coastal inundation hazards. However, along central-eastern coasts from East

Cape to Banks Peninsula, MHWS is exceeded quite frequently (20-50% of the time) by high tides. In these eastern areas, a ‘pragmatical’ MHWS that is exceeded only 10–12% of the time, or alternatively a mean high water perigean-spring level (MHWPS), should be used to assess the coastal inundation hazard (refer to Appendix 2 for further details).

2.2.4 Storms

Storms lead to two main hazard drivers[1]:

- waves and swell, which de-stabilise and move large quantities of sediment, leading to erosion, and cause coastal inundation and even structural damage; and
- storm surges, where adverse winds and low barometric pressure produced by storms temporarily elevate the ocean level well above the predicted tide level (up to an upper limit of just over 1 m in New Zealand).

“Storm tide” level is a useful measure for inundation from the sea, and comprises MHWS + storm surge + wave set-up (refer to the diagram in Factsheet 2, Appendix 2). Wave set-up is the increase in sea level inside the surf zone (landward of the first wave breaks) relative to the offshore storm-induced ocean level. (See Appendix 2 to estimate wave set-up for the purposes of a screening risk-assessment.)

Wave run-up is the extra height reached, over and above the storm-tide level, as the broken waves run up the beach and coastal barrier (if present) until their energy is finally expended. Wave run-up is treated separately from storm-tide level because it varies widely along the coast, even in the same locality, due to differences in shoreline steepness and type of natural or artificial coastal barrier. In contrast, storm-tide levels can be calculated for large stretches of coast within a district. (See Appendix 2 to estimate wave run-up for the purposes of screening risk-assessment.)

2.2.5 Tsunami & subsidence/uplift

Although infrequent events, New Zealand faces a risk of inundation and damage from both *local* and *remote* tsunami sources, particularly along the entire east coast, Southland and Greater Cook Strait (including the South Taranaki Bight and Tasman/Golden Bay). Remotely-generated tsunami from across the Pacific will seldom exceed 5–10 m in maximum wave height at the coast, but there would be a wide area affected e.g., most of the eastern coast of both islands. Locally-generated tsunami will affect a more localised area, but wave heights could exceed 10 m. It is likely that there would be a reasonable warning time (of several hours) for remote tsunami, but there would be little warning of local tsunami because of the short travel distance to the coastline. The risk from tsunami may also be affected by the level of the tide and whether a local storm-surge is likely to be present.

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[1] For more information, see the Tephra article by Bell & Gorman (2003).

Coastal margins may also be affected by fast-acting subsidence or uplift resulting from an earthquake (e.g., the 0.75 m subsidence of the coast at East Clive south of Napier in the 1931 earthquake). Areas near the coast may also experience slow subsidence as a result of groundwater abstraction (e.g., Christchurch).

2.3 Impacts of climate change on coastal hazard drivers

Climate change will not introduce any new types of coastal hazards, but it will affect existing coastal hazards by changing some hazard drivers. In general, localities that are currently subject to occasional coastal hazards are likely to suffer increased risks with a warming climate, while areas that are currently in a delicate balance may begin to experience more damaging coastal hazards in future.

This subsection summarises the effects of climate change on hazard drivers. More detail on these factors is provided in Appendix 2**.**

Table 2.1 shows the likely effects (direction and/or magnitude of climate change on the various drivers of coastal hazards. It shows the degree of present confidence in these predictions as follows:

***	indicates that climate change is generally accepted as impacting on the driver and that the direction of change is known, even if the magnitude is uncertain;
**	indicates that a realistic and consistent allowance should be made, but there is low confidence in the actual magnitude of change;
*	implies that there is little present-day evidence or future projections that change will occur, but that possible scenarios should be considered in any analysis.

Table 2.1: Projections of climate-change effects.

Driver	Variable	Direction and Magnitude of Change	Confidence
Sea level change	Mean sea level	Rise of 0.14-0.18 m by 2050 (most-likely mid-range) Rise of 0.3-0.5 m by 2100 (most-likely mid-range)	***
	Extreme & spring tide level	Similar rise as mean sea level for open coasts; may vary in shallow estuaries depending on siltation rates.	**
Waves, swell	Wave climate	Potential increase of swell conditions on south and west coasts (through increased windiness from westerlies).	**
	Extreme waves	Some indication of increased wind intensity of storms that could affect most coasts. Frequency of storms likely to be similar (certainty very low).	**
Storm tide	Storm surge height	Some indication that storm-surge magnitude may increase (through increased storm intensity).	**
	Extreme storm-tide level	Increases from mean sea-level rise (see above) and some indication storm-surge magnitude may increase.	**

Driver	Variable	Direction and Magnitude of Change	Confidence
Currents	Tidal currents	Effects likely to be minimal and very localised e.g., estuary tidal inlets.	*
Sediment supply	Sediment supply from rivers	Likely to be changes in sediment delivery to the coast, but magnitude or direction of change uncertain (droughts in eastern areas may hold back sediment in rivers, but higher intensity rainfall may increase sediment run-off).	*
	Cliff erosion	Possible increase in erosion or land-slipping of unconsolidated cliffs from extremes in soil hydrological processes (drought vs. intense rainfall).	*
	Longshore transport	Changes likely to vary depending on location, and related predominantly to wave climate (magnitude and direction).	*
Tsunami	-	Climate change will not impact on the occurrence or frequency of tsunami events. Run-up and inundation extent likely to be increased slightly due to higher mean sea levels.	**

2.3.1 Climate change effects on sea level

Since the early to mid 1800s, sea level around New Zealand has been rising at an average linear rate of 0.16 m per century. However, as global warming is now occurring and the oceans are beginning to warm, the rate of sea level rise is expected to accelerate in the near future.

For the purposes of a screening risk assessment, it is recommended that future sea-level rises of **0.2 m by 2050** and **0.5 m by 2100** (relative to 1990 levels) are used.

Sea level can however vary considerably from year-to-year about the long-term trend, due to seasonal, El Niño–Southern Oscillation and IPO cycles. The extent of this is demonstrated in Appendix 2.

It is important to note that the IPCC expects that sea level will continue to rise for several centuries, even if greenhouse gas emissions are stabilised, due to long lag times for the deep oceans to respond. The expected continued melting of ice sheets or increase in iceberg calving from land-based ice sheets is expected to lead to a sea-level rise in the order of several metres over the next several centuries to millennia, even for the lower range of projected future climate-change scenarios. Apart from sea-level rise, a range of other climate changes can be relevant (summarised below). More detail and quantitative projections can be found in the manual Climate Change Effects and Impacts Assessment.

2.3.2 Climate change effects on storms

It is not clear from current modelling whether the frequency of ex-tropical cyclones reaching central and northern New Zealand will change, but when they do their impact on the coast might be greater due to a higher storm intensity. At the same time, ‘storminess’ is likely to increase in the Southern Hemisphere this century, so that both the intensity and frequency of mid-latitude storms might also increase in the New Zealand region. However, the levels of certainty for these New Zealand projections are currently low.

2.3.3 Climate change effects on currents, winds, waves, and tides

Ocean currents affect our climate and can influence the way storms develop. For ocean currents, the most likely future outlook for New Zealand is for little change to warm-ocean currents, but perhaps some modification of cold-ocean currents e.g., Antarctic Circumpolar Current.

The average westerly wind component across New Zealand may increase by approximately 10% in the next 50 years. As a result, there would be an increase in the frequency of heavy seas and swell along western and southern coasts, and possibly higher extreme waves during more intense ex-tropical cyclones and mid-latitude storms.

Deep ocean tides will not be directly affected by climate change, but tidal ranges in shallow harbours, river mouths and estuaries could be altered by deeper channels (following sea-level rise) or conversely by shallower channels if increased run-off from more intense storms increases sediment build-up in estuaries.

2.3.4 Climate change effects on sediment supply to the coast

Climate change will affect the intricate array of factors that govern the supply of sediment to the coast – some factors leading to more sediment delivery (e.g., more frequent heavy rainfall), others to less (e.g., likelihood of more droughts in eastern areas). The overall future effects on sediment supply to the coast for different regions of New Zealand are as yet poorly defined and likely to vary significantly between different locations. However, in vulnerable areas the overall impact on sediment supply to the coast and estuaries needs to be assessed by detailed investigations, which involve not just the coastal system, but also contributing rivers and their catchments.

2.3.5 Climate change effects on tsunami

The geological causes of tsunami (such as earthquakes, underwater landslides and volcanic activity) will not be directly affected by climate change. However, the coastal effects of tsunami will be altered somewhat by sea-level rise, increasing the risk of coastal inundation. A more important factor in assessing risks will be the height of the tide at the time a tsunami wave hits the coast.

2.4 Coastal hazard effects on different coastline types

Coastal hazards are not only dependent on the ‘hazard drivers’, but also on the *geomorphology* of the coast. Geomorphology relates to the features, sediment/geology composition, shape and topography of the coastal margins and beaches. There are four main types of geomorphology on the New Zealand coast:

- open-coast sand beaches;
- open-coast gravel (shingle) beaches;
- cliffed coasts; and
- estuary shorelines.

Each of these responds to coastal hazards differently. The key features that determine the vulnerability of a coast to erosion and inundation hazards are:

- the elevation of the coast above mean sea level;
- the geology of the coast (e.g., hard and soft rock, gravel and sand beaches);
- sediment supply and its availability for beach building;
- the width of the coastal barrier (if present);
- coastal setting and orientation (e.g., exposure to wave energy);
- the stabilising effect of vegetation; and
- shape, slope and height of any pre-existing coastal protection works.

The details of how different types of coast respond to hazards are given in Appendix 3.

Human activities can exacerbate these coastal hazards. Some of the more common ways that this can occur are summarised below. In some cases it is quite obvious where human modifications to the shoreline will increase the hazards, while in other cases the effects on the hazard risk are more subtle, and may take a long time to manifest.

- the lowering or total removal of foredunes lowers the height and width of the coastal barrier, reducing the buffering effect.
- ‘hard’ coastal protection works such as seawalls and stopbanks cut off supplies of sand to the beach and cause erosion in front of the walls, worsening the overall erosion. Erosion at the end of the wall is also increased.
- removal or changing the species of dune vegetation can increase sand loss through wind erosion, reducing sand storage and the system’s buffer against erosion.
- mining of the beach or shallow nearshore for aggregate removes material from the sediment system and reduces the protection from dunes, gravel ridges and beach foreshores.

- stormwater discharges cause direct scour of the beach, and the accompanying rise in the water table increases erosion during storm events.

- dams or large water extractions from rivers interrupt sediment supplies to the coast.

- large structures such as breakwaters can affect beach orientation, exposure and sediment supply. Sand may accumulate up-drift against the structure, due to interference with the littoral transport system, while beaches down-drift of the structures may be ‘starved’ of sediment and erode.

2.5 The response of different coastline types to climate change

Some shoreline types, such as depositional sand and gravel beaches, are more vulnerable to the effects of climate change than others. *How* different shores may respond is relatively well understood, but it is far more difficult to *quantify* the effects. The key responses to various drivers of change are summarised below.

2.5.1 Response to long-term sea level rise

Figure 2.2 summarises the potential impacts of sea level rise on shoreline movement for different types of coastal geomorphology. In general, shorelines that have historically exhibited erosion will continue to erode, but faster, under accelerating sea level rise.

Sandy coasts

Sandy open coasts that have been relatively stable over time are likely to show a bias towards erosion under a higher sea level, unless the sand supply to the beaches can keep pace with erosion. In some parts of New Zealand this balance between erosion and sediment supply is quite possible. With sea level rise, accreting open coast beaches may continue to accrete, but more slowly, depending on sediment supply.

It is very difficult to quantify the amount of shoreline retreat for a given rise in sea level, and there are different theories on how to attempt this. Locations with higher dunes may suffer less retreat than locations with low dunes. However it is generally accepted that climate change will increase shoreline erosion for sandy beaches, particularly ‘bounded’ beaches with low dunes. In some situations, the width of the present foreshore or beach will not be sufficient to accommodate this erosion. Where the beach is ‘bounded’ this may result in the loss of the beach.

It is important to remember that sea level rise will continue for several centuries beyond 2100, even if greenhouse gas emissions are stabilised. Erosion of sandy beaches is therefore likely to continue well beyond this century.

Gravel beaches

Gravel beaches generally have steeper slopes than sandy beaches, so they are likely to suffer less erosion due solely to sea-level rise. For example, for a 6 m high gravel ridge the estimated increase in erosion rate over existing retreat rates is in the order of 0.1-0.2 m/yr for the next 50 years, and 0.1 to 0.3 m/yr for the next 100 years. However, where shoreline retreat is by sediment ‘rollover’ due to wave overtopping, rates of retreat may increase more with a higher mean sea level and more intense extreme storms.

Cliffs

Erosion of cliffs that comprise sedimentary rocks and clays/silts will, in most cases, continue at similar or slightly higher rates under climate change for moderate to high cliffs.

For cliffs with a gravel barrier beach at the base, positive changes in the barrier may result in no changes to current cliff retreat rates.

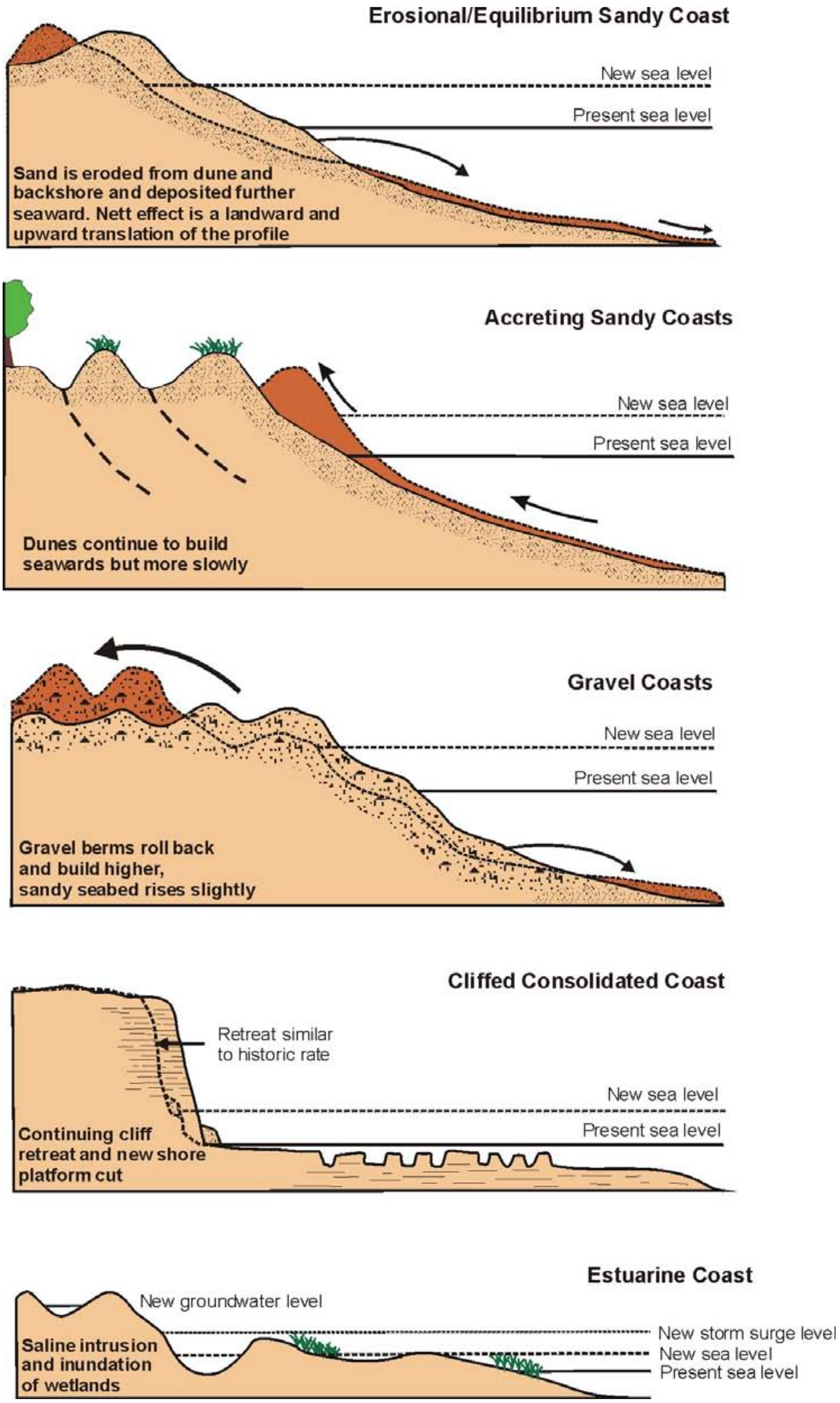


Figure 2.2: Generalised impacts of sea level rise on different types of coastal morphology. These are only indicative, as local conditions and changes to the sediment supply may produce different responses. Figure adapted from Gibb (1991).

Estuaries

The effects of sea level rise on estuarine erosion will depend on a complex interrelationship between the topography of the estuary, sand storage in the estuary, river inputs of sand, and erosion of adjacent beaches. Shorelines will retreat as a result of both inundation and slow but steady erosion. Erosion will be slow because, compared to open coast beaches, estuaries have a less energetic wave environment and limited exposure time (around high tide) for waves to develop.

Sedimentation rates in most North Island estuaries have been 2–4 mm/year, keeping up with the present rise in sea level of 2 mm/year. Eventually however, the acceleration in sea-level rise is likely to outstrip sedimentation.

In spite of the compensating effect of sedimentation, sea-level rise is likely to cause an increase in the amount of water that flows in and out of estuaries during each tide (the ‘tidal prism’), along with larger increases in freshwater run-off during heavier rainfall events. Increased flow volumes will correspond to increases in tidal velocities and scour in the main channels and particularly at tidal entrances. This is because estuary surface areas (and hence volumes) will increase greatly if surrounding flat land is inundated by high tides on the back of higher sea levels. These changes might be quite marked because of the shallowness of New Zealand estuaries. Although there are large uncertainties involved, current thinking is that sea-level rise could lead to increases in shoreline erosion within many estuaries. There is also concern that estuarine ecosystems may be ‘squeezed out’ if there is no space for them to retreat landwards as sea level rises.

2.5.2 Response to changes in wave climate

Wave direction changes

Changes to wave direction could be caused by a shift in the wind climate, and/or a reduction in wave refraction associated with an increase in water depth. This would be most pronounced where deep water waves are heavily refracted, such as around prominent headlands (e.g., Banks Peninsula and off the East Cape). Longshore sediment transport potential could be increased due to changes in wave direction, increasing the rate of shoreline retreat.

It is difficult to quantify potential changes to wave direction. However, subtle changes in wave direction will have greatest effect on pocket sand beaches by moving sand from one end of the beach to the other, and on cuspate forelands (salients) that form in the wave-lee of an offshore island (e.g., the Paraparaumu–Waikanae coast in the lee of Kapiti Island).

For estuaries, the effect of changes in predominant wind direction on the wave climate will depend on the size and shape of the estuary. The greatest effect will occur in wide shallow estuaries where there is a large wind fetch.

Wave height changes

It is unlikely that a modest increase in storm wave heights will increase erosion markedly on sandy beaches, since bigger waves would break at a similar position or further offshore with a higher mean sea level. However, in combination with rising sea level and possible higher storm tides, waves will generally be able to attack the backshore and foredunes more readily in many localities, leading to a combined adverse effect on beaches from sea-level rise and increased wave height.

For gravel beaches and cliffs where there is not large deposition on the nearshore bed, a slight increase in breaker height is expected as a result of increases in water depth. A small increase in the run-up elevation, and therefore inundation, is likely.

For cliffs, any increases in sea level and wave height will result in erosion at slightly higher levels. However rates of undermining may not increase markedly, except on low cliffs (several metres height).

In estuaries, significant changes in wave height are unlikely to occur in the foreseeable future, until such time as sedimentation rates no longer keep pace with the projected acceleration in the rate of sea-level rise.

2.5.3 Response to changes in storm intensity

Some climate change scenarios suggest that the frequency of low-pressure troughs and depressions passing over New Zealand might increase slightly. This could result in more frequent moderate coastal storms.

These changes cannot be quantified at present (other than the possible direction of change), but there is likely to be greater short-term erosion of sand and gravel beaches at many locations. The recovery of foredune or gravel ridges between storms will also be more limited, particularly during unfavourable El Niño–Southern Oscillation and IPO cycles. Somewhat increased erosion of sedimentary cliffs may occur, especially when combined with more adverse soil-hydrological processes from greater extremes of drought and heavy rainfall. Estuary shores are also likely to suffer from more erosion, with the increased frequency and magnitude of shoreline inundation from storm tides and associated wetting and drying of soils likely to be major factors.

2.5.4 Response to changes in sediment supply and transport

The effect of climate change on fluvial erosion and sediment transport processes will have a large influence on the behaviour of depositional sand and gravel beaches. In some areas (e.g., West Coast), increases in rainfall intensity will increase erosion in upper catchments and sediment transport. In these locations, the additional supply may be sufficient to offset other climate-change effects. However, in areas where there is decreased rainfall (e.g., some east coast areas), sediment supply is likely to be reduced, and shoreline erosion is likely to be exacerbated even further.

2.5.5 Response to changes in beach water tables

Higher water tables increase wave run-up and backwash velocities, increasing both run-up elevations and sediment losses to the nearshore.

Coastal water tables may rise as a consequence of sea level rise, increasing the potential for beach erosion. However, these effects are dependent on how the beach profile adjusts to the higher water table regime, and cannot be easily quantified.

2.6 Other climate-change effects on the coastline

While the direct effects of climate change on coastal erosion and coastal inundation are the main focus of this Guidance Manual, other climate-change impacts should also be considered in any long-term planning process. These include:

- *Flooding and drainage of low-lying coastal land*—caused by:
    - increased frequency of storm-tides exceeding a specific level or barrier height;
    - greater rainfall intensity of storms (and hence river floods);
    - longer parched or drought periods in some areas (which create run-off problems during an intense storm); and
    - increase in the intensity of severe storms.

- *Salinisation of surface freshwaters, groundwater and land* —caused by:
    - sea-level rise, which allows saline marine water to encroach further up river and creek watercourses;
    - longer parched or drought periods in eastern areas (leading to reduced river flows, allowing the tidal flows to reach further upstream);
    - sea-level rise, with higher marine water levels in the sea, estuaries and lower river reaches, exerting a higher hydraulic head of saline water on groundwater aquifers; and
    - increase in the frequency and peak levels of storm tides, leading to more frequent inundation of arable land by saline waters – eventually very low-lying lands will naturally convert to salt marshes if not constrained by coastal defences.

Coastal Hazard Factsheet (1): Coastal erosion

Hazard Description:

Coastal erosion hazards arise where human activity or settlement is threatened by a **temporary or permanent cut-back of the shoreline**. (Coastal accretion is the opposite, where the shoreline builds out over time.)

In many instances, an entire beach-ocean system in a region (e.g., Canterbury Bight) may be balanced in terms of **sediment 'credits'** and **'debits'**. This means that sand or gravel can be moved around within the coastal system in large quantities, but with little net loss or gain of sediment from the system as a whole. However, from the property owner's viewpoint the temporary or permanent retreat of the coastline at their locality is coastal erosion, even if the coastal system as a whole is in balance. Cliffs mostly are erosional features, but the erosion rate can vary greatly.

Coastal erosion poses many problems to established coastal communities in that valuable property can occasionally be lost to a dynamic beach-ocean system. Where there are 'hard' protection structures and a long-term trend of erosion, valuable natural assets such as beaches, dunes and wetlands can be lost as the continuing erosion results in 'coastal squeeze' between the sea and housing or infrastructure. Additionally, human activity may exacerbate the process of coastal erosion through poor land-use methods or the downstream effects of poorly-designed protection works.

Because there are so many factors involved in coastal erosion (see below), **shoreline change** from sediment "re-distribution" within a beach-ocean system **will <u>not</u> be consistent year after year** in the same location, but can occur in **alternate erosion and accretion cycles** over seasonal cycles up to several decades. This means the **prediction** of future coastal erosion at any locality is very **difficult** without adequate data, historic information, and good estimates of future climate-change impacts.

Natural Factors:

Natural factors that affect coastal erosion or coastal stability are a complex interaction of:

Weather (wind, waves and storm surge); **oceanography** (tides, offshore and alongshore currents); **climate** (seasonal, El Niño–Southern Oscillation, Interdecadal Pacific Oscillation, sea-level rise, catchment run-off); **geomorphology** (type of beach/barrier system and how it responds, e.g., mixed gravel/sand versus sandy beach, stability of sandspits, intertidal estuary beaches, cliff erosion processes); **sediment supply** to the shore zone from cliffs, rivers, estuaries, winds, and the offshore seabed; and **seismic/tectonic** factors (e.g., coastal uplift or subsidence, tsunami).

Removal and deposition of sediment by natural sediment "drivers" continually changes beach shape, volume and structure. Sediment may be transported landwards of the dunes by wind or overwash during storms, temporarily moved to nearshore bars during storms, moved further along the coast, or lost offshore to the continental shelf.

Human Factors:

Human intervention can markedly alter natural coastal sediment processes through:

- Catchment activities e.g., land-use practices, urbanisation, dams, water abstraction;
- Dredging of tidal entrances and harbour channels;
- Sand or gravel extraction from the coastal marine area;
- Coastal protection works e.g., groynes, breakwaters, artificial reefs, seawalls;
- Beach nourishment;

- Permanent modification of coastal margins e.g., dune removal, vegetation removal or change, reclamations, waterways, wharfs and marinas.

Climate-change Influences:

Global warming will impact on most of the above natural factors that affect coastal erosion, apart from the seismic/tectonic group. The most commonly known effect is that of **sea-level rise**, but climate change will also alter **rainfall and run-off patterns** (which may cause a change in **sediment supply** to the coast) and **storms** may increase in their **intensity** for a given return-period event, increasing the impacts of waves, wind and storm-surge.

Typical Ranges of Coastal Erosion Rates:

Sandy beaches: highly variable, even within a locality, but mostly < 5 m long-term retreat p.a., but the impact of extreme storm events in some areas can result in erosion of 10+ m and the end of unstable sandspits can experience erosion of 100+ metres.

Gravel: <1 m p.a. in many areas, but up to 2 to 3 m p.a. (average) in vulnerable areas. Retreat usually occurs episodically during extreme storms (up to 5 to 10 m retreat), with stable periods between storms.

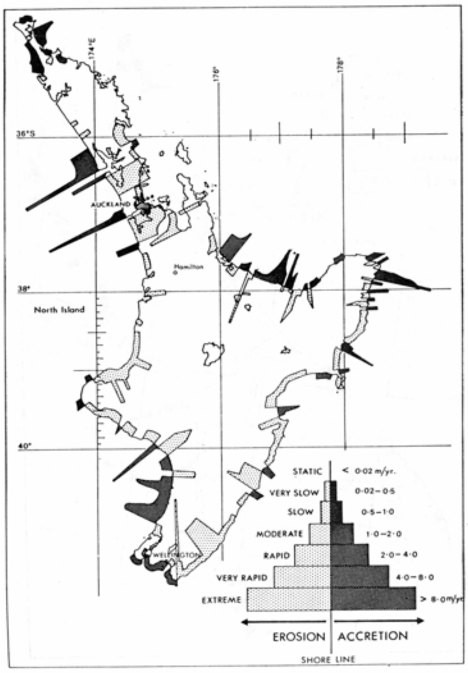
Cliffs: high variable, depending on soil/geology composition and hydrologic processes; hard-rock erosion can be negligible, but unconsolidated materials may reach several cms to a metre or so p.a.

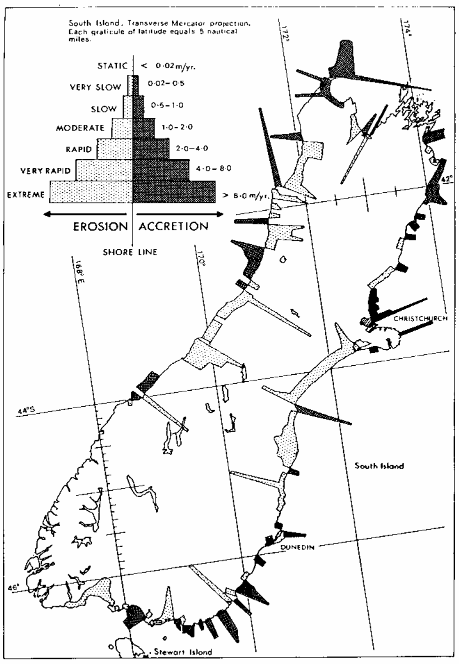
Frequency of Occurrence:

Coastal erosion occurs across a wide range of timescales, ranging from individual storms, through annual and El Niño cycles up to long-term retreat at decadal or century scales. Normal practice is to deal with erosion on two timescales: **short-term** fluctuations (days to a few months, including storm cut-back) and **long-term** trend (seasonal to decades/centuries).

Hotspot Regions around NZ:

The only national overview to date of long-term erosion and accretion rates around the New Zealand coast are from the Gibb study published in 1984, but work is in progress to update this work with the latest information.





Gibb (1984). Coastal erosion. In: *Natural hazards in New Zealand* (Eds. I Speden & M Crozier). NZ National Commission for UNESCO, Wellington.

Erosion vulnerability checklist based on geo-indicators

This table indicates the potential for erosion based on geo-indicators for different morphology types – refer to Section 7.5 for further details (based on Bush et al. 1999):

	Sand coast	**Gravel coast**	**Cliffs**	**Estuary**
Severe erosion likely if ….				
Dunes or gravel barrier absent with overwash by waves or storm tides common	✓	✓		✓
Active wave scarping of dune or gravel-barrier “remnants”	✓	✓		✓
Active cliff scarping and slope slumping			✓	
Vegetation absent	✓			✓
Older shoreline protection structures now on beach, offshore or collapsing	✓	✓	✓	✓
Locality near to estuary inlet or river mouth	✓	✓	✓	✓
Coastal feature is a narrow spit that may be breached	✓	✓		
Erosion likely if …				
Dunes or gravel barriers low, scarped or breached in places	✓	✓		
Cliffs steep with no talus ramp at the toe (i.e., no pile of debris)			✓	
Tree stumps, peat, mud exposed on beach occasionally	✓	✓		✓
Beach narrow or steep with minimal high-tide (dry) beach	✓	✓		
Overwash passageways with overwash fans of sediment or low access way gaps	✓	✓		
Vegetation comes and goes or toppled along scarp line	✓		✓	✓
Estuaries/harbours with large wind fetch lengths at high tide or open to ocean swell				✓
Marsh, swamp or mangrove areas landward of beach		✓		✓
Long-term stability or accretion likely if …				
Dunes or beach barriers are robust, unbreached, vegetated	✓	✓		✓
Cliffs vegetated, with stable (vegetated) talus ramp at the cliff toe			✓	
Beach is wide, with well-developed berm seaward of the dune/gravel barrier	✓	✓		
No or little evidence of overwash	✓	✓		✓
Vegetation well developed down to shoreline (maritime forest, shrubs, grasses)	✓		✓	✓

Coastal Hazard Factsheet (2): Storm inundation

Hazard Description:
Storm inundation is an acute natural event arising from extreme weather events (storms), where normally dry land is flooded occasionally. Most people associate flooding with rivers, but sea flooding can occur in low-lying coastal lands, and sometimes both river and sea-flooding combine to increase the hazard.

Sea flooding is caused by a temporary increase of mean sea level (called "**storm surge**") and energetic wave activity, over and above the predicted **high tide** height. Storm surge is generated by a combination of **adverse winds** and **low barometric pressure**. Waves contribute to coastal inundation by a combination of **wave set-up** in water level in the surf zone and **wave run-up** across the beach, which may overtop low coastal barriers. "**Storm tide**" is the term used to quantify the total height in sea-level reached at the shore, combining tide, storm surge and wave set-up (refer to diagram on following page), to which wave run-up is added. The force of wave run-up and overtopping can also inflict damage on properties and cause injuries. In some instances, sea flooding can occur during local fair weather, when large swells from a distant storm ride in on the back of a very high tide.

Riverine flooding of coastal and estuarine margins is exacerbated by high tides, especially the fortnightly spring tides or monthly perigean tides (when the Moon is closest to the Earth). In relatively flat low-lying coastal margins (e.g., Lower Heathcote at Christchurch, South Canterbury Plains, Hauraki Plains), land may stay flooded with seawater for several days after an extreme event. This type of occurrence has a dramatic effect on vegetation and pasture production, which can sometimes last for a number of years.

Natural Factors:
Natural factors that affect coastal storm inundation are a complex interaction of:

Winds (strong persistent on-shore winds that "pile up" water along the coast); **barometric pressure** ("inverted barometer" effect, where sea level rises by 0.1 m for every fall of 10 hPa in barometric pressure below the average pressure); **sea-level fluctuations** (increased elevation of mean sea-level at seasonal, 3 to 5 year El Niño–Southern Oscillation, and 20 to 30 year Interdecadal Pacific Oscillation cycles); **tides**—timing and height of high tide is critical; **waves & swell** cause: a) wave set-up – the elevation in water level across the surf zone caused by energy expended by breaking waves, and b) wave run-up – the ultimate height reached by waves after running up the beach and barrier (both are highly dependent on wave height, but also beach slopes and sediment type); **river levels** near estuaries, lagoons and river mouths following heavy rainfall; **geomorphology** (type of beach/barrier system, slope of beach and backshore barrier, size of beach sediments, how porous or free draining the sediments are); and **seismic/tectonic** factors (coastal uplift or subsidence of coastal barrier).

Human Factors:
Human intervention can exacerbate storm inundation hazards through:

- River training works (straightening, stopbanking) that increase river levels at the coast;
- Poor design of existing coastal protection structures (type, slope, smoothness of surfaces, wave focusing by offshore structures or groynes);
- Coastal property development in flood-prone areas (low-lying estuary margins or shore-front properties without an adequate buffer);
- Physical removal, reduction or damage to natural coastal barriers such as sand dunes, gravel barriers (e.g., lower access ways, removal of vegetation, trimming or removing dunes);
- Permanent modification of coastal margins e.g., waterways, canals, marinas, boat ramps.

Climate-change influences:
Global warming will impact on many of the above natural factors that drive coastal storm inundation. The best known effect is the direct contribution of an accelerated sea-level rise, which will lead to two impacts:

- higher likelihood (or probability) that coastal inundation during storms could occur, given the same specific ground level or barrier height
- gradual encroachment of seawater at high tides on low-lying coastal and estuarine land by rising sea levels.

For the latter, low-lying areas will transform into a coastal marsh and eventually become a permanent part of the coastal or estuarine system if the process is not constrained by coastal protection works.

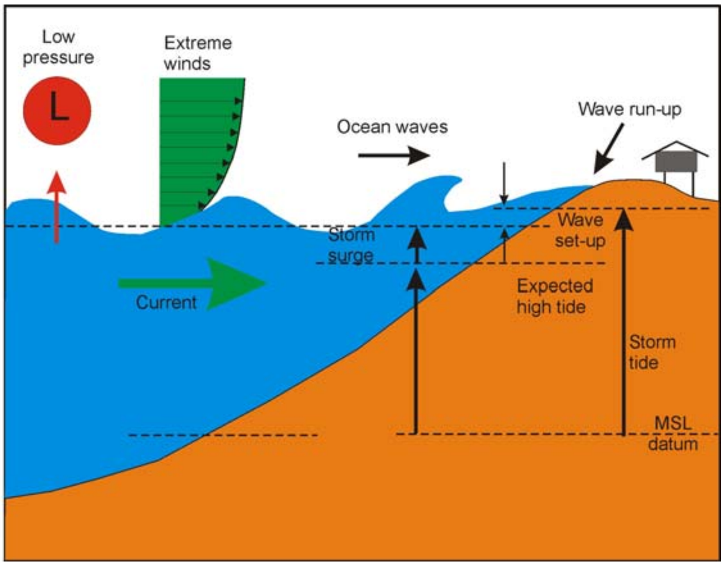
Climate change is likely to affect storms by increasing their intensity for a given return-period event, and therefore increasing the contributors to storm tides (wave, wind and barometric pressure). At present it is uncertain whether climate change will affect storm frequencies. Climate change is likely to alter rainfall and run-off patterns, with the downstream effect of increased river levels. Tide heights may also increase in shallow estuaries and harbours, where siltation by catchment sediments doesn't keep pace with sea-level rise.

Typical Range of Contributors to Coastal Storm Inundation Heights:
Tides: fortnightly spring or monthly perigean high tides range from 2.1 m above the mean level of the sea in Golden Bay to only 0.3 m in Cook Strait at Oteranga Bay, west of Wellington.

Sea-level fluctuations: on seasonal to multi-decade scales, fluctuations of up to ±0.25 m can occur in the mean level of the sea. Historic sea-level rise in New Zealand has been linear at approximately 0.16 m per century.

Storm surge: storm-surge heights above the predicted tide can reach around 0.5 m on a yearly return period, and potentially can reach an upper limit of just over 1 m around New Zealand.

Waves: on a typical sandy coast with offshore wave heights ranging from 4 to 7 m, **wave set-up** in the surf zone from breaking waves would add an extra 0.6 to 1 m respectively to storm-tide levels at the shore. Finally, **wave run-up** in storms can add a further 2 to 6 m vertical height onto the storm-tide level (but councils should be aware that various formulae for estimating wave run-up may or may not include wave set-up as well). The large variability arising from widely-differing local shoreline features such as beach slope, type and slope of coastal barrier, presence of a coastal protection structure and its steepness, and the width of the surf zone (e.g., a wave breaking right in close to a seawall will produce high wave run-up heights). Typical sandy coasts with an unmodified backshore will generate wave run-up heights from 2 to 4 m for offshore wave heights in the range 4 to 7 m.



Storm-tide = expected high tide + storm surge (low barometric pressure/onshore winds) + wave set-up in the surf zone. Final inundation height = storm tide + wave run-up.

3. The Legislative and Planning Context

This chapter:

- summarises the legislative context for coastal hazard and climate change effects management;
- briefly describes the range of values that we ascribe to our coastline, which must be taken into account when managing coastal hazards, including land use.

3.1 Introduction

The range of land uses that can be vulnerable to coastal hazards include:

- residential and industrial activities;
- network utilities and associated infrastructure, including roads, telecommunications, water, gas etc, many of which may be ‘lifelines’;
- ports and ancillary activities;
- commercial activities, including tourism related retail activities;
- agricultural activities, including pastures, horticultural and arable crops, indigenous and managed forests, and associated infrastructure;
- terrestrial and coastal ecosystems, including estuaries, lagoons, and their constituent ecosystems;
- heritage and cultural sites including waahi tapu, urupa, historic buildings and other sites; and
- recreational activities, including beach access and boating facilities, including marina developments.

These are direct hazards from the coast, but indirect hazards further inland may arise, such as increased salt water intrusion affecting aquifers and ground water use. This is already an issue in the Tasman region and may occur elsewhere in New Zealand.

3.2 Relevant legislation and its context

This section summarises the legislative provisions relevant to coastal hazards.

Further discussion on each of the legislative statutes considered is provided in Appendix 1. Examples of case law are provided in Section 7.

3.2.1 Resource Management Act 1991

The purpose of the Resource Management Act (RMA) is to promote the sustainable management of natural and physical resources. The RMA imposes a hierarchy of planning instruments[2] which are intended to manage the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being. This requires particular attention to avoiding, remedying, or mitigating the actual or potential adverse environmental effects of activities.

The RMA recognises the significance of the coastal environment in Part II (purpose) and various other sections of the Act, as well as through the New Zealand Coastal Policy Statement (NZCPS), district and regional plans, and regional policy statements.

The principles of the RMA include 'Matters of National Importance', such as "*The preservation of the natural character of the coastal environment (including the coastal marine area) ...*", "*The protection of outstanding natural features and landscapes ...*", *and "The maintenance and enhancement of public access to…the coastal marine area"*, and also 'Other Matters', such as *"The maintenance and enhancement of amenity values"*.

Under the RMA, regional councils are responsible for activities within the coastal marine area (defined as the area below mean high water springs (MHWS) to the 12 mile limit), whereas territorial local authorities are responsible for activities on the landward side of MHWS. Although this delineation suggests a concise management regime, coastal issues constantly cross jurisdictional boundaries, and thereby require an integrated management approach.

The RMA requires that district plans must not be inconsistent with regional plans, and that each level of authority consult with the other when preparing plans under the RMA.

There are some key issues with regard to district and regional plans that affect the consideration of climate change effects. These include:

- only district plans and regional coastal plans are mandatory. Although regional councils may prepare other plans to fulfil their functions under section 30, including controlling the use of land in relation to natural hazards, this is not mandatory[3];

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[2] Refer to Appendix 1 for a diagrammatic illustration of these RMA instruments.

[3] *Section 65(3)(c) states that a regional council must consider the desirability of preparing a regional plan where any threat from natural hazards is likely to arise.*

- many controls can be used in relation to the function of avoiding or mitigating the effects of natural hazards; e.g., controls on buildings or earthworks. However, only territorial authorities (not regional councils) have the ability to use subdivision and building controls (section 31(c)); and

- if controls on building in a hazard area are contained in district plan rules, then 'existing use rights' will apply, and the reconstruction of a building which has been destroyed may be allowed. On the other hand, if controls on building in a hazard area are contained in regional plan rules then 'existing use rights' can not be relied on to reconstruct the building[4].

This regime works best when working agreements have been reached between regional councils and territorial local authorities, and responsibilities between these organisations have been clearly delineated. However, there is potential to improve the management of the coastal environment through amending various planning documents to recognise overlap and jurisdictional exclusivity, and reviewing daily activities.

Resource Management (Energy and Climate Change) Amendment Act

This Guidance Manual provides information on climate change effects to enable councils to implement the Resource Management (Energy and Climate Change) Amendment Act which came into effect on 2 March 2004. Under the Act, three new matters were inserted into section 7 under Part II of the RMA:

(ba) – the efficient use of energy from minerals and other sources of energy;
(i) – the effects of climate change;
(j) – the benefits to be derived from the use and development of renewable energy.

These changes provide stronger direction so that local planning decisions better reflect New Zealand's national Climate Change Policy. For example, local authorities now need to have specific regard to the effects of climate change when making decisions under the RMA.

The NZ Coastal Policy Statement

The NZCPS is a guiding document under the RMA and is required to be considered when drafting district or regional plans, or in deciding on resource consent applications. The NZCPS advocates a precautionary approach for decisions affecting the coastal environment.

The NZCPS addresses the effects of climate change through a number of policies, in particular Policies 1.1.2 to 1.1.5 (which address features and components of natural

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[4] *McKinlay v Timaru District Council C 24/2001, refer to section 8 for case notes on this case.*

character), 3.2.1, 3.2.2, 3.2.4 (which consider appropriate subdivision, use and development of the coastal environment), 3.3 (which addresses the precautionary approach), and 3.4 (which recognises natural hazards, and makes provision for avoiding or mitigating their effects). All of these policies are pertinent to the assessment of response options to coastal hazards, including sea level rise, and other climate change induced hazards.

The NZCPS is currently under review. Hence any reference in this Guidance Manual to specific policies may be subject to change as part of that review.

3.2.2 Building Act 1991

The Building Act (BA) addresses building work in the interests of ensuring the safety and integrity of the structure through its construction and subsequent use (as distinct from the RMA which addresses the effects of that structure (or any activity within it) on the environment, and of the environment on that structure (or activity within it)).

Most buildings require a land use consent under the RMA as well as a building consent under the BA. If controls are imposed under both the RMA and the BA, the more stringent control prevails.

The BA raises questions of whether the land *"is likely to be subject to erosion, avulsion, alluvion, falling debris, subsidence, inundation, or slippage";* or whether the works are likely to *"accelerate, worsen, or result in erosion, avulsion, alluvion, falling debris, subsidence, inundation, or slippage of that land or any other property"*. Under the BA (section 36) the existence of these natural hazards can be noted on the title of a property.

The theme throughout RMA and BA case law appears to be that although district councils can exercise some judgement about whether to allow a subdivision or development, councils cannot ignore responsibilities for avoiding or mitigating effects of natural hazards in favour of reliance on controls under the BA. The RMA process is important because its outcome will generally decide whether a building can be sited in the relevant area in the first place. The BA (specifically section 36) is particularly important where coastal (or other) hazards are discovered after titles have been created or even after development is already established.

3.2.3 Local Government Act 2002

The Local Government Act (LGA) outlines administrative and management responsibilities for regional and district councils, including matters such as land management, utility services, recreation assets, transportation and the associated provision of services.

The LGA requires stopped roads along the margins of the coast (along MHWS) to be vested in Council as esplanade reserves. The LGA also establishes the means by which territorial local authorities may collect financial contributions for funding the acquisition, maintenance and development of reserves.

Section 650A1(i) of the Local Government Amendment (No 2) Act allows for district councils to undertake various works in the coastal environment including the erection and maintenance of: quays, docks, piers, wharves, jetties, launching ramps, and any other works for '*the improvement, protection, management, or utilisation of waters within its district (subject to the controls established by the RMA)*'.

Community planning is a cornerstone of the LGA, with the requirement to prepare Long Term Council Community Plans (LTCCP). There are also specific consultation requirements when preparing these plans, or bylaws under the Act. This has particular significance for coastal strategies, or other management plans that are adopted as part of the response to coastal hazards, including climate-induced coastal hazards. These strategies and plans can be prepared to meet some of the requirements, particularly the consultative requirements of LTCCP's.

3.2.4 Civil Defence Emergency Management Act 2002

The Civil Defence Emergency Management Act 2002 (CDEMA) is intended to:

- promote sustainable management of hazards;
- encourage and enable communities to achieve acceptable levels of risk;
- provide for planning and preparation for emergencies, and for response and recovery;
- require local authorities through regional groups to coordinate planning and activities;
- provide a basis for the integration of national and local civil defence emergency management;
- encourage coordination across a wide range of agencies, recognizing that emergencies are multi-agency events; and
- focus on reduction, readiness, response and recovery.

The CDEMA requires that a risk management approach be taken when dealing with hazards. In considering the risks associated with a particular hazard, both the likelihood of the event occurring and its consequences must be considered. The CDEMA is largely an enabling mechanism, that can complement both the BA and RMA. In particular, integration between regional and district councils is achieved with the formation of Civil Defence and Emergency Management (CDEM) Groups comprising representatives from each of the territorial local authorities and the regional council within a region. The CDEMA (Section 17(1)) outlines the functions of a CDEM Group in relation to relevant hazards and risks. These include:

(i) identify, assess, and manage those hazards and risks;

(ii) consult and communicate about risks; and

(iii) identify and implement cost-effective risk reduction…"

The CDEMA (Section 48) provides that each CDEM Group must provide a CDEM Group plan and that plan must state the hazards and risks to be managed by the Group and the actions necessary to do so[5]. The CDEMA therefore anticipates that regional and territorial authorities will cooperate in the management of hazards and risk, including coastal hazards.

3.2.5 Reserves Act 1977

The Reserves Act (RA) makes provision for the acquisition, control, management, maintenance, preservation, development and use of public reserves, and makes provision for public access to the coastline and rural areas. Administering bodies are required to prepare management plans for their reserves, which are open for public comment and review (except most government and local purpose reserves).

While the RA is aimed at providing public use areas and access, these reserve areas may also be useful as providing buffers from coastal hazards. However, councils must manage reserves to fulfil their purpose(s) under the RA (e.g., whether historic reserve, scientific reserve, scenic reserve etc). If buffer functions are not specifically mentioned in a reserve management plan, it is questionable whether reserve areas can be treated in this way by TLAs, as their buffering function may have an effect on their specified use for reserve or open space recreation. For example, the purpose of an esplanade reserve is defined in the RMA, but it does not refer to hazards. There is some debate whether managing an esplanade reserve for the purpose of hazard reduction on adjoining land is actually within the scope of the Reserves Act. One option is to refer to a reserve's hazard buffer functions within a reserve management plan. However at this stage there is no case law to support this approach.

3.2.6 Public Works Act 1981

The Public Works Act (PWA) deals with the rights of central and local government to acquire private land for public purposes including for reserves (within the meaning of the Reserves Act), and the procedures for acquiring and disposing of this land. The

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[5] *Section 49(2) of the CDEM Act*

acquisition of land for reserve purposes is one way of providing for buffer mechanisms.

3.3 Uses of coastal areas, values and perceptions

This section briefly summarises the key values and the significance of the coastal environment. Climate change and the effects on coastal hazards have the potential to have an impact on any of these uses, values and perceptions. They should therefore be borne in mind in any decision-making process.

The RMA requires the protection of the natural character of the coastal environment and the protection of significant values and perceptions for the cultural, social, and economic well-being of people and communities. It also requires that the actual and potential adverse effects due to, for example, coastal hazard management, are avoided, remedied or mitigated.

In each case, values and perceptions contribute to the use and enjoyment of the coastal environment, so the protection of significant values and perceptions provides for the cultural, social, and economic well-being of people and communities.

3.3.1 Natural character

The natural character of an area is derived from natural elements and features, including the dynamic functioning of the physical coastal processes, the presence of indigenous vegetation along the coastal margin, and unmodified coastal landforms (e.g., cliffs and beaches)[6]. Natural landscapes, features and ecosystems (considered below) are all components of natural character. Although natural character is defined by the presence of natural elements, even where human activities have modified a landscape, its natural character is not necessarily destroyed. The assessment of natural character will always be subjective, and relies on the views of the community.

3.3.2 Landscapes and seascapes

Natural features comprise landforms and geological sites. They record and are formed by past and present geological and geomorphological processes and give the coastal environment its physical form and identity. They are also of visual importance, being key elements in the coastal landscape, and contribute to the recreational and amenity values of the coast.

The visual and scenic qualities of coastal landscapes contribute to amenity, recreational, and tourism values, enhancing the social and economic well-being of the

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[6] *Refer to section 6(a) of the RMA and Policies 1.1.1 to 1.1.5 of the NZCPS 1994.*

community. Landscapes are not only important for their scenic qualities but also as representative examples of landscape heritage and their scientific significance[7].

3.3.3 Ecosystems

The range of habitats created by the combination of natural coastal features supports a rich array of terrestrial and marine species. The continued health of coastal ecosystems, and in particular indigenous vegetation and habitats of indigenous fauna[8] is a fundamental prerequisite for maintaining the life-supporting capacity and the quality of the coastal environment. Maintaining biodiversity is a national priority.

Natural features and ecosystems also contribute towards the natural character of an area.

3.3.4 Intrinsic values

The intrinsic values of ecosystems can result from biological and genetic diversity, or characteristics that determine an ecosystem's integrity, form, functioning, and resilience[9]. These values can be defined as those aspects of ecosystems (and their constituent parts) which have value in their own right.

3.3.5 Coastal matters of significance to Tangata Whenua

The coastal marine area and associated resources comprise some of the most important taonga to Maori. The well-being of the coastal marine area and associated resources, and the ability to use, develop and protect such resources according to Maori culture and traditions is fundamental to all aspects of Maori well-being. Accordingly it is recognised by Tangata Whenua that all of the coast has characteristics of special spiritual, historical, and cultural significance to them[10].

3.3.6 Public access

At the time of preparing this Guidance Manual, the Government is reviewing the issue of ownership of the foreshore and seabed, and access to it. It is proposed that most of the coastal marine area remains generally available for free public use and enjoyment.

While structures or activities along the landward margin of the coast often enhance access for particular users, they may also result in obstruction or loss of access to, within, or along the coast for other users. Likewise, the provision of coastal 'buffer' reserves may also create expectations of continued access. Coastal buffer reserves

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[7] *Refer to section 6(b) of the RMA and Policy 1.1.3 of the NZCPS 1994.*

[8] *Refer to section 6(c) of the RMA and Policy 1.1.4 of the NZCPS 1994.*

[9] *Refer section 7(d) of the RMA*

[10] *Refer to section 6(e) of the RMA and Policies 2.1.1 to 2.1.3 of the NZCPS 1994.*

will contribute to public access, but may over time disappear as they serve their primary function.

3.3.7 Cultural heritage

The historic significance of New Zealand's coastal environment as trading ports, whaling stations, historic settlements etc reflects the cultural heritage[11] of the coast. Historically the coastal environment has been extensively modified by human influences, making cultural heritage an important element in the character of the coastal environment. Many cultural heritage sites, buildings, places or areas in the coastal environment are under threat of being compromised or lost through increasing pressure for subdivision, use and development or through natural processes of erosion or inundation.

3.3.8 Amenity

Amenity values[12] are the physical qualities and characteristics of an area. These include urban form (building design, parks, infrastructure, and other physical resources), and those features that contribute to pleasantness, aesthetic coherence, and/or cultural and recreational attributes of an area. Amenity values are almost always subjective, and like natural character, will depend on the views of the community.

3.3.9 Land use

The use of an area, either existing or potential, has a strong influence on its perceived value. Areas that are already developed or are highly used by the community may be under added pressure for protection from coastal hazards, including any increased hazard brought about by climate change. Already developed areas are the most difficult to manage in terms of finding environmentally, socially and economically acceptable and practicable protection mechanisms.

The level of development also determines values and perceptions of the coast. These values should be identified in regional and district plans and policy documents with the future development implications of land use, in sufficient detail to guide planning decisions. Assets within areas that are highly used often carry expectations of continued protection on account of the value of land that is under threat.

Areas that are not subject to high levels of development are often valued for ecological or other 'natural' reasons. Areas that may be considered to be 'undeveloped' by some sectors of the community may have high agricultural or other values, either on a district basis or on an individual economic farm unit basis, depending on the mix of

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[11] *Refer to section 7(e) of the RMA and Policies 3.1.1 to 3.1.3 of the NZCPS 1994.*

[12] *Refer for example to Section 7(c) of the RMA*

climatic and topographic conditions on the unit. Undeveloped areas can also be under significant pressure to be developed. In such cases, land use planning can be affected by expectations to capitalise on the possible economic value of the land.

The range of response methods applicable for both developed and undeveloped land is considered further in Section 5 of this Manual.

4. Risk assessment

This chapter describes:

- the fundamental concepts of the risk assessment process;
- a framework for applying risk assessment to coastal hazards and climate change within the decision making process;
- a method for summarising and documenting the risk appraisal.

4.1 Introduction

A sound risk assessment process is fundamental to ensure that climate change is appropriately taken into account in local authorities' planning and decision-making processes.

The purpose of the risk assessment is to identify risks and hazards in the coastal area that may be induced or exacerbated by climate change, and to evaluate their effects and likelihood. This allows the risks and the responses to those risks to be prioritised and compared equitably with other risks, resource availability and cost issues.

This document recommends Risk Management standard AS/NZS 4360 as the undergirding standard for all risk assessment procedures and processes relating to coastal hazards in a changing climate.

It is important that your council decides and works within a pre-selected planning or response period before evaluating climate change-related risk. That is to say, it matters whether your council is considering a 50-year return period hazard or a 100-year return period event, and this needs to be consistent across all hazards under consideration.

Risk assessment can be appropriately commenced with an initial screening process. This can show whether climate change impacts are likely to be material for a particular council function, activity or service. Table 4.1 contains a list of questions which may ascertain whether adopting a risk based approach to incorporate coastal hazards and / or climate change is required. If the answer to any of the questions in Table 4.1 is 'yes' or 'maybe', then it is likely that the procedures outlined within this Guidance Manual may be of use.

Table 4.1: Screening assessment for coastal hazards.

Characteristics	Issue	Yes	Maybe	No
Current driver	Is there an existing problem (e.g., erosion or inundation) that could be exacerbated by climate change?			
Future driver	Is there a foreseeable problem that may be caused or exacerbated by climate change?			

Complexity	Is this a complex issue (e.g., many different stakeholders, new suburb vs one house)?
Location	Could the location be sensitive to coastal hazards and / or the effects of climate change?
Duration	Does the decision involve a long-term, permanent change?
Extent	Does the decision involve substantial infrastructure or public services

How to undertake a suitable risk assessment process is briefly summarised below. A more detailed description is provided in the companion guidance manual "Climate Change Effects and Impacts Assessment".

4.2 Terminology

For the purpose of this Guidance Manual, the following definitions apply:

Risk:	the chance or likelihood (probability) of an event, such as a coastal hazard, occurring that will have an impact (or consequence) on something of value to the present and/or future community.
Hazard:	a source of potential harm to people and/or property. Examples are erosion or inundation.
Event:	a coastal hazard incident that occurs in a particular place during a particular interval of time. This is distinct from merely a 'storm event', for example; it is an event that perhaps occurs during a storm (e.g., erosion that occurs which results in loss of private property).
Consequence: (or impact)	the outcome of an event, expressed qualitatively in terms of the level of impact. Consequences can be measured in terms of economic, social, environmental or other impacts.
Uncertainty:	exists where there is a lack of knowledge concerning outcomes. It may result from imprecise knowledge of risk (i.e., the hazards and / or the consequences), or where the 'relationship' between the hazards and the consequences is imprecisely known.
Probability:	the chance or likelihood of a particular event occurring (in relation to all other events within the same dataset). It is dimensionless and is normally expressed as a decimal or percentage (e.g., 1% of the time). Probability can refer to a specific time frame. For example ***Annual Exceedance Probability (AEP)*** refers to the chance of a

	particular threshold being equalled or exceeded in any one year. AEP is expressed usually as a percentage. For example, an AEP of 1% means there is a 1% chance that a particular threshold is equalled or exceeded in any one year. This terminology is now preferred over the use of the "return period" concept, which can be confusing when, for example, two 100-year return period events occur in successive years.
Event probability:	refers to the probability of a particular threshold (e.g., an extreme sea level of XX m above datum) being equalled or exceeded.
Return period:	can be approximated to the reciprocal of the AEP (e.g., a 2% AEP, in decimal form 0.02, would give a return period of 50 years). This terminology is not recommended – rather, the use of AEP is encouraged.

4.3 Fundamental concepts for the risk assessment process

There are several fundamental concepts that should be borne in mind in a risk assessment process. These are:

1. Risk varies over time. This reflects both the changing probability of the risk occurring, and the changing scale of consequence should the risk occur. For example, the factors below are likely to increase risk probability and impact over time:

   - changing climate (both natural variability and longer term climate change);
   - changing (usually intensifying) land use, sub-division or development;
   - changing (usually increasing) value of human assets at risk; and
   - changing natural defences, e.g., beach or dune width.

   Consequently, a fundamental consideration when incorporating the risks associated with coastal hazards and climate change into the planning process is the notion of *time*. A risk may not exist at present but may evolve, for example due to climate change, over the duration of a particular decision. The time/horizon that must be considered (and how the risks may change within this timeframe) is, at a minimum, the lifetime of the development, service or infrastructure (this is discussed further in Section 5).

2. Risk varies spatially (again in terms of both probability and consequence), even over relatively small distances. For example:
    - changing coastal morphology along a coast (e.g., open coast/estuary; sand beach/shingle beach), resulting in differing erosion rates, storm response etc;
    - differing hinterland elevations, e.g., variation in inundation risk;
    - varying land use, sub-division density, value of human assets; and
    - cultural and environmental assets.
3. Risk assessment needs to be appropriate. It needs to be:
    - conducted at a level of detail appropriate to the scale of the decision;
    - consistent with the level of data or information available.

A tiered approach is normally adopted, as shown in Table 4.2.

Table 4.2: The tiered approach to determining the level of detail for the risk assessment.

Tier	Description	Scope	Nature	Scale
1	Risk screening	Broad	Qualitative	Policy, national, regional, local, project
2	Qualitative & semi-quantitative risk estimation	Specific	Qualitative + quantitative	Policy, regional, local, project
3	Quantitative risk assessment	Specific, detailed	Quantitative	Local, project

This Guidance Manual is aimed primarily at performing a Tier 1 risk-screening assessment. The Tier 1 assessment should be able to be conducted chiefly by local authority personnel, but some input from coastal hazard specialists is desirable – as a minimum, regional council coastal hazard personnel should be consulted.

The risk-assessment procedure is also amenable to a more detailed Tier 2 assessment, where sufficient data or information is available to make informed choices on the likelihood and consequences. Some input from a suitably qualified and experienced coastal hazard specialist (possibly available from the regional council) is strongly recommended for a Tier 2 assessment.

Although the framework provided here should still be appropriate for a Tier 3 assessment, Tier 3 will require more detailed risk assessment methodologies than are described in this Guidance Manual, and specialist coastal hazard assistance will be required.

4. Risk needs to be communicated. The purpose of the risk assessment process is to aid decision-making,so the process needs to be communicated in clear and concise language. Within all risk assessments there is a need to:

   - define the overall approach;
   - clearly define all key assumptions made;
   - identify all uncertainties and their potential impact of the overall decision;
   - outline the scope and impact of any sensitivity testing;
   - be accountable and transparent; and
   - report in a way that the non-specialist can understand the significance of the results.

5. Uncertainty and the need for more detailed analysis of specific areas should be assessed. Many areas of risk assessment can only be partly covered by the approach detailed in the following sections. In any assessment of the occurrence and impact of coastal hazards and the influence of climate change, uncertainty will be a significant issue. Such uncertainty can be categorised under two headings:

   - *Natural variability,* which refers to the randomness and longer-term “cycles” observed in nature. For example it is not possible to predict when the next 50-year return period storm-tide level will occur. A time period of 100 years could pass without observing such and event, but then two could occur within the space of a year; and

   - *Knowledge uncertainty,* which refers to the state of knowledge of a physical system and our ability to measure it and reproduce the significant features within a model. For example not all the physics are understood of how climate change will affect future coastal erosion hazards and hence some assumptions need to be made to account for such effects.

   A full assessment of uncertainty is beyond the scope of this Guidance Manual. However, it is important to be aware of where major uncertainty exists within the risk assessment process, and where such uncertainty could be reduced, for example by:

- more rigorous (or quantitative) risk assessment process (e.g., Tier 2 or Tier 3 type assessment);
- using a range of climate change scenarios (refer to the companion manual to this document "Climate Change Effects and Impacts Assessment") to better understand sources and range of uncertainties;
- use and interpretation of available datasets, e.g., sea-level data or beach-profile surveys, to provide quantitative predictions of extreme conditions;
- collection of additional data through a monitoring programme (see Section 6);
- use of numerical modelling tools (e.g., wave modelling) to simulate and extend existing measured datasets or to simulate hazard processes, e.g., inundation or coastal erosion; and
- use of scenario techniques where, based on the degree of uncertainty, a range of different scenarios are used to assess the range of possible outcomes. An example could be to assess the potential magnitude of future coastal erosion due to changes in the wave climate by assuming potential (but realistic) shifts in the wave climate.

It is important to clearly define where uncertainty exists and the possible steps that could be taken to reduce it. It may be that the scale of the decision does not warrant detailed investigation to reduce such uncertainty, or that adopting a precautionary approach is appropriate. Within the context of the Guidance Manual, adopting a simple rating system is often sufficient to communicate uncertainty, e.g.:

Low: *Little uncertainty, confident that change / hazard / impact will occur.*

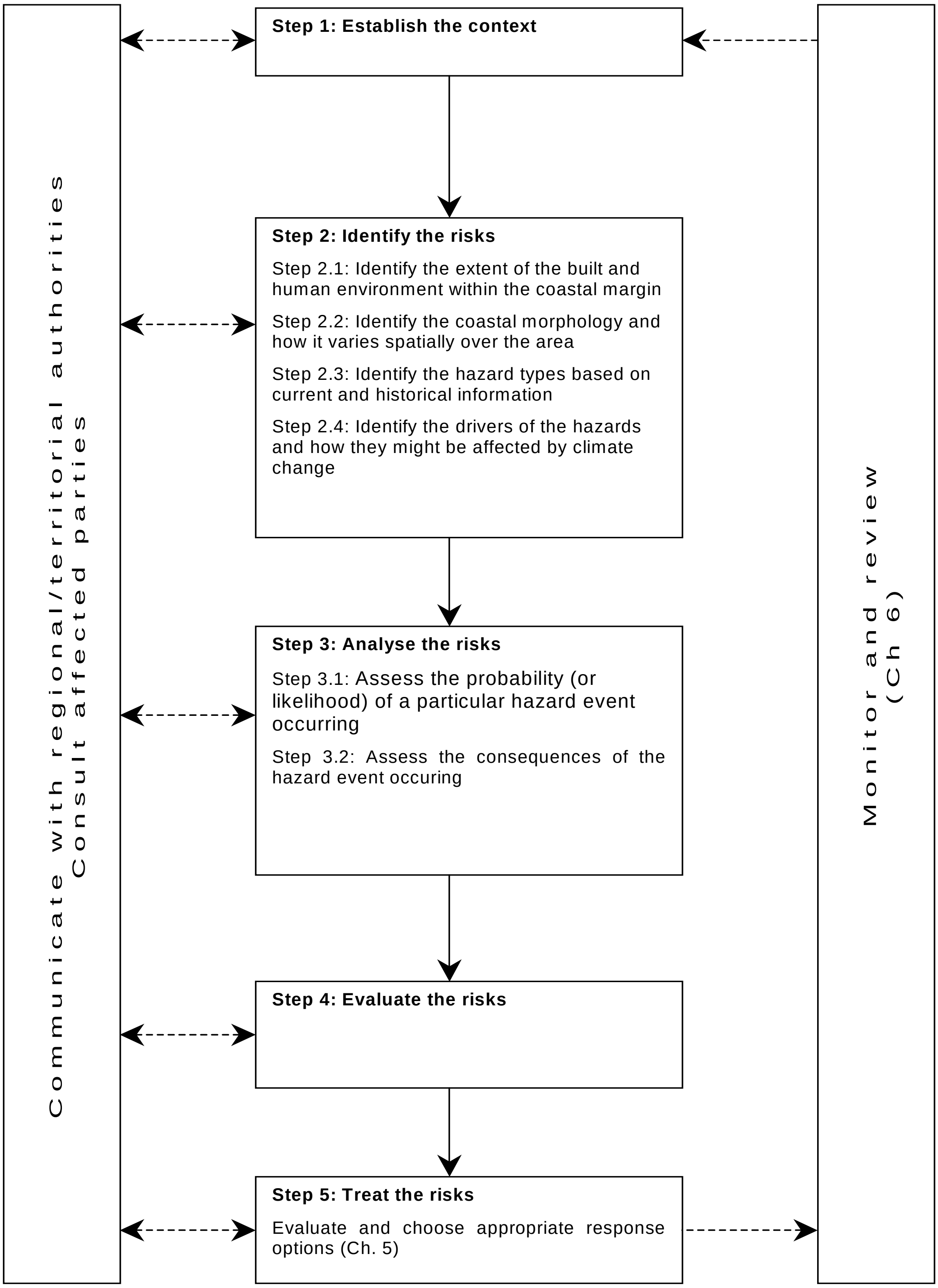
Moderate: *Some uncertainty.*

High: *Major uncertainty.*

It is also important to identify which uncertainties have the most impact on the decision to be made. For example there may be high uncertainty on a particular issue, but if the issue is minor then the high uncertainty may not be particularly important.

4.4 Applying the risk assessment process

Figure 4.1 provides a format for conducting a risk assessment, concentrating on qualitative approaches to assessing risk. The remainder of this section introduces the various steps within the risk assessment process.



Step 1: Establish the context

Step 2: Identify the risks

Step 2.1: Identify the extent of the built and human environment within the coastal margin

Step 2.2: Identify the coastal morphology and how it varies spatially over the area

Step 2.3: Identify the hazard types based on current and historical information

Step 2.4: Identify the drivers of the hazards and how they might be affected by climate change

Step 3: Analyse the risks

Step 3.1: Assess the probability (or likelihood) of a particular hazard event occurring

Step 3.2: Assess the consequences of the hazard event occuring

Step 4: Evaluate the risks

Step 5: Treat the risks

Evaluate and choose appropriate response options (Ch. 5)

Figure 4.1: The risk assessment process

4.4.1 Step 1: Define the problem and establish the context

This step 'sets the scene' within which the risk assessment process takes place and the context within which coastal hazards and climate change effects fit. It involves defining what the local authority is responsible for, what it owns, what services it provides, its structure, and its objectives in relation to coastal hazards, and which of those may be affected by climate change, as well as those other facilities and structures that are essential to a community's functioning (e.g., schools, ports, lifelines etc).

It should take into account:

- mechanisms available (e.g., district, community, strategic plans etc);
- assets, functions and services provided; physical environment; stakeholders; organisational context (e.g., the staffing, locations, resources and systems availability, and goals/objectives).

It also should involve:

- defining the current or foreseen problem or activity to be undertaken (including assessment of the planning or response period (or "period of concern" – see Table 4.4)
- the climate change variables and climate change variability
- specifying the outcomes anticipated from the risk assessment process and how they will be used in planning and decision making.

Depending on the scale of the issue, the process may involve only one person (e.g. local authority planner), a few people, or all key personnel (e.g., local authority planners, chief building inspector, engineers, and emergency management co-ordinator, with input from regional council planners and scientists, and possibly other stakeholders such as tangata whenua, business people, local residents, and lifeline utilities managers such as Transit New Zealand).

Typical techniques that can be applied at this stage include:

- brainstorming;
- consultation exercises; and

- focus groups

Establish the context – key considerations

What is the problem or objectives that need to be addressed?

Where does the need to make a decision comes from?

What are the primary drivers behind the problem?

What is the planning timeframe? (Ie, are you considering a 50-year return period hazard or a 100 year return period hazard?)

What are the boundaries (both spatially, e.g., potential area affected by decision, and temporally, e.g., the period over which the decision will be applied)?

What constraints and decision criteria can be identified?

What is the level of risk analysis to be adopted?

What legislative constraints or requirements may apply?

What similar decisions and other guidance available for this issue have occurred?

Have coastal hazards and climate change been incorporated within the decision making process before, or accounted for at a higher level (e.g., policy or strategic)?

How will the risk assessment be utilised within the decision-making process?

What is the approach to risk, e.g., should a precautionary approach be adopted?

This is a vital stage in the risk assessment process, as it is against these considerations that the significance of the risk and the appropriateness of the adaptation measures can be judged.

4.4.2 Step 2: Identify the relevant coastal hazards and climate change risks

The components of Step 2 could also be conducted by one person with a good overall knowledge of the area and issue, but preferably should include personnel with specialist technical or local knowledge.

Step 2.1: Identify the potential extent of the built and human environment within the coastal margin likely to be impacted by the development or issue under consideration and how this may change over time.

Identifying the hazards – key considerations

What is the land use and where does it occur?

What is the density of development?

What are the approximate/relative values of the assets, in terms of $\$/m^2$/m length of coastline?

Is any lifeline infrastructure located within the area (e.g., hospitals, ports, key transportation or network utilities which provide lifeline connections and for which there is no alternative)?

Is the value of the assets likely to rise markedly in the future (e.g., because of redevelopment of residential property)?

Are assets easily re-locatable – e.g., cabins at a camping ground with no plumbing/drainage services, compared with concrete slab-on-grade houses?

Are there particular environmental issues to be considered? (e.g., significant mangroves, wetlands or dune ecosystems).

What level of access is available, how is this access affected?

Are there any cultural/heritage sites?

How may these criteria change over the period that the particular decision is to be applied?

Step 2.2: Identify the coastal morphology and how it varies spatially over the area

This step involves characterising the coast in terms of its physical form (e.g. sandy beaches, cliffs, estuaries etc). *(See also Appendix 3 for considering the response of different coastline types to coastal hazards).*

Identifying the coastal morphology – key considerations

How does the general coastal morphology vary along the coast (e.g., beach, cliff, estuary etc)?

What is the dominant beach type (e.g., sand, shingle etc.) and how does this change along a coast?

What is the width of the beach or intertidal area?

How does the exposure, to particular wave conditions (e.g., swell or locally generated waves) and wave directions, change along the coastline?

What is the height and width of natural frontal barriers (e.g., dunes)?

How do these natural barriers vary along the coast and how may they change over time (e.g., reduction in width due to erosion)?

What are the characteristics of the coastal hinterlands?

Are there any known vulnerable locations (e.g., spits, estuaries or river mouths, levelled dunes)?

What particular low-lying areas are there (e.g., marsh, swamp or mangrove areas, or previous such areas that may have been drained for agriculture or development)?

Step 2.3: Identify the hazard types based on current and historical information

This step involves identifying the coastal hazards that could presently affect the existing coastal margin identified in Step 2.1 and identifying where different hazards may occur due to variations in the coastal morphology (Step 2.2).

In general the hazards will be categorised as:

- coastal erosion caused by storms and/or long term processes;
- coastal inundation caused by storms or gradual inundation from sea level rise; and
- coastal inundation caused by tsunami.

Step 2.4: Identify the long-term changes in coastal hazards due to climate change

This step involves identifying the particular drivers of the coastal hazards identified in Step 2.3 and the potential effects climate change could have on that hazard. It should take into account the planning horizon or timeframe over which the particular decision is to be applied (see Section 5). For example over a 100 year planning timeframe the potential for a particular magnitude of coastal hazard event occurring could increase substantially.

Step 2.3 should be re-visited to re-assess the hazard types in response to the potential effects of climate change.

Use a range of scenarios if drivers other than sea-level rise are important (e.g., sediment supply). Refer to the Guidance Manual on Climate Change Effects and Impacts Assessment for quantitative input.

4.4.3 Step 3: Analyse the risks

As with previous steps, this part of the risk assessment process should be undertaken in conjunction with people with specialist coastal knowledge (e.g., regional council or specialist consultants) or detailed analysis of historic data.

Step 3.1: Assess the consequences of the hazard occurring

The level of the impact (consequence) on the land, built environment, and people for each hazard scenario should be assessed. This can be achieved by assigning a level of impact, on a relative or scaling basis as outlined in Table 4.3. It may be appropriate also to use actual consequences (e.g., monetary values).

Table 4.3 Level of impact for locality/hazard scenario

Designation	Impact	Examples
1	Catastrophic	Huge financial losses involving many people and/or corporations and/or local government; large long-term loss of services; permanent loss of many people's homes; large-scale loss of employment
2	Major	Major financial losses for many individuals and/or a few corporations; some long-term impacts on services; some homes permanently lost; complete loss of an important natural environment
3	Moderate	High financial losses, probably for multiple owners; disruption of services for several days; people displaced from their homes for several weeks; major impacts on valued natural environment
4	Minor	Moderate financial losses for small number of owners; disruption of services for a day or two; moderate distress to some individuals; some impacts on significant natural environment
5	Insignificant	Minimal financial losses; short term inconvenience

The choice of the appropriate impact designation is somewhat subjective. However, as long as the approach is applied consistently for each locality or feature, the choice of the *relative* level of impact should be consistent.

Step 3.2: Assess the likelihood (or probability) of a particular hazard occurring

Having identified the potential hazards and the consequences if they occurred, the next step is to identify the likelihood (or the probability) of the particular hazard occurring and impacting on a particular feature (e.g., a road) or location (e.g., area to be subdivided). In doing this, the nature of the hazard is important. For example, inundation and tsunami hazards tend to be episodic events whereas coastal erosion can be episodic, periodic and/or continuous.

Information or data on hazard probabilities for a particular location should be used wherever it is available. However, for situations where it is not available, an assessment for each location could be made based on judgement of a knowledgeable individual or group. A suggested five-point scale for initial probability is given in Table 4.4.

When carrying out the likelihood assessment, the following questions should be considered:

- is there a history of hazard experience at this site? Can this history be objectively assessed to determine the likelihood of future impacts?
- are certain parts of the locality more exposed than others to specific hazards such as predominant winds/storm directions?
- is local knowledge based on an adequately long timeframe (e.g., how long ago was the last major storm and how large was it)?
- do other organisations have any relevant information?
- is the planning horizon sufficiently long (say >30 years) that climate change effects will increase the likelihood of the event?
- how will climate change affect the hazard?

Table 4.4: Probability scale for hazard event scenario

Designation	Likelihood	Description	Frequency of occurrence (IPCC definition)[1]
			Virtually certain (>99% chance that a result is true)
A	Almost certain	Is expected to happen, perhaps more than once during the period of concern	Very likely (90-99%)

B	Likely	Will probably happen during the period of concern	Likely (66-99%)
C	Possible	Might occur some time during the period of concern (50/50 chance)	Medium (33-66%)
D	Unlikely	Unlikely to occur, but possible (e.g., one in ten times the duration of concern)	Unlikely (10-33%)
E	Rare	Highly unlikely, but conceivable	Very unlikely (1-10%) Exceptionally unlikely (<1%)

Note [1]: The IPCC definitions of likelihood are included for comparison – they are very similar to the scale recommended in this Manual.

To investigate the relative potential impact of climate change, it is suggested that this process be conducted firstly by assessing risks while *ignoring* climate change effects, and secondly, assessing risks while *allowing for* climate change effects. Use a range of scenarios if drivers other than sea-level rise are important (e.g., sediment supply). Refer to the companion guidance manual “Climate Change Effects and Impacts Assessment”.

4.4.4 Step 4: Evaluate the risks

Based on the assessment of the potential consequence of a hazard occurring (Step 3.1), and the likelihood of it occurring (Step 3.2), the degree of risk can be determined. Use the results from Tables 4.3 and 4.4 to position the activity in Table 4.5 to give the risk of each hazard scenario. For example, an activity with moderate (3) consequence but which is likely to occur (D) has a moderate risk (M) – it should be included in the response planning but at a lower priority. Note that this is an example only, and each local authority may wish to independently decide the risk classifications and which squares are H, M, or L.

Table 4.5: Risk Table

	Consequence				
Likelihood	**1 (Catastrophic)**	**2 (Major)**	**3 (Moderate)**	**4 (Minor)**	**5 (Insignificant)**
A. Almost certain	E	E	E	H	M
B. Likely	E	E	H	H	M
C. Possible	E	E	H	M	L
D. Unlikely	E	H	M	L	L
E. Rare	H	H	M	L	None

Legend:

E: Extreme risk; immediate action required.
H: High risk; high priority for action, begin planning as soon as practicable.
M: Moderate risk; include in response planning, but lower priority.
L: Low risk; minimal action likely to be required; monitor the situation.
None: Negligible risk; no response required.

It is important to stress that “no climate change” is purely hypothetical because climate change *will* occur – it is a question of “how much”, not “if”.

Again, the risk evaluation process should be carried out in two phases; firstly, ignoring the effects of climate change, then again, taking into account the effects of climate change. This may result in a different risk rating for the climate change and non-climate change scenarios. Using this approach, risks can be prioritised and different risks compared. Note also that the risks will change depending on how far the risk assessment looks into the future. Planning decisions need to be based on the risk over the entire expected lifetime of the development. New residential subdivisions are composed of houses with individually limited lifetimes, but are essentially there forever when the subdivision as a whole is considered.

There may also be a different risk rating assigned for different timeframes. For example, a risk may a have a consequence of 4 (minor), a present likelihood of D (unlikely), but will become possible (C) in the next 30 years, and B (Likely) in 100 years. As a result the risk rating will go from low to high in the next 100 years.

4.4.5 Step 5 – Assess appropriate response options to treat the risk

Steps 1-4 should result in a good understanding of the implications and risk of climate change impact on coastal areas. The next step is to assess how these risks should be responded to, and treat the risk. The options are addressed in Section 5 of this Manual.

4.4.6 Step 6 - Document and communicate risk and uncertainty

The hazard identification and the information about the risks identified should be documented in some way, as risks that may not be important at the outset may become significant at a later stage (e.g., as our understanding of particular issues related to climate change increases). A common method of documentation is in the form of a risk register. An example of a simplified risk register is provided in Table 4.6.

Table 4.6: Example of simplified 'risk register'

<table>
<tr><td colspan="2">Locality:</td><td colspan="5">Windy Cove</td></tr>
<tr><td colspan="2">Step 1
Identification of the issue:</td><td colspan="5">Application for the re-development of properties at Nos. 5 & 6 Shore Road.</td></tr>
<tr><td colspan="2">Step 2.1
Extent of built environment</td><td colspan="5">• Existing residential housing built in late 1960s. 35 properties and public car park located along Shore Road generally located 25 m from present vegetation line.
• Access road to other properties, and network utilities located landward of properties.
• Property values currently $250k–$300k.
• No other re-development has yet occurred.
• Re-development likely to result in permanent (100 year) high value ($500k +) properties. Further re-development of other properties likely.
• Limited scope for development further landward on plots due to location of access road.</td></tr>
<tr><td colspan="2">Step 2.2
Coastal morphology & processes</td><td colspan="5">• Sandy beach.
• Frontal dunes flattened during initial development of property in 1960s.
• No known studies of beach processes other than analysis of 10 years of beach profiles indicates long term erosion of around 0.4 m per year and beach levels can drop by up to 1m resulting in a steep scarp along vegetation edge.
• Immediate hinterland levels are around 6.5 m MSL dropping to 5.5 m MSL along the access road.
• Minor overtopping of beach resulted in gardens damaged and water ponding on road at least twice over the last ten years. No inundation of housing noted and disruption and damage costs minimal.
• No tsunami events known to have impacted on frontage.</td></tr>
<tr><td colspan="2">Step 2.3
Identify hazards and scenarios</td><td colspan="5">1. Coastal erosion leading to loss of gardens over next 100 years.
2. Coastal erosion leading to damage or loss of some property over next 100 years.
3. Coastal erosion leading to loss of all property and infrastructure over next 100 years.
4. Coastal inundation leading to property flooded above floor level.</td></tr>
<tr><td colspan="2">Step 2.4
Identify drivers and effects of climate change</td><td colspan="5">Sea level: 0.5 m rise in mean and extreme sea level by 2100.
Storm magnitude – assume slight increase.
Wave climate – no change accounted for in present analysis.
Sediment supply – assume no change.</td></tr>
<tr><th colspan="7">Analysis and evaluation of risks</th></tr>
<tr><th rowspan="2">Hazard Scenario</th><th colspan="3">With no allowance for climate change</th><th colspan="3">With climate change</th></tr>
<tr><th>Likelihood Step 3.1</th><th>Consequence Step 3.2</th><th>Risk Step 3.3</th><th>Likelihood Step 3.1</th><th>Consequence Step 3.2</th><th>Risk Step 3.3</th></tr>
<tr><td>1</td><td>Likely</td><td>Minor</td><td>High</td><td>Frequent / certain</td><td>Minor</td><td>High</td></tr>
<tr><td>2</td><td>Possible</td><td>Moderate</td><td>High</td><td>Likely</td><td>Moderate</td><td>High</td></tr>
<tr><td>3</td><td>Unlikely</td><td>Major</td><td>High</td><td>Possible</td><td>Major</td><td>Extreme</td></tr>
<tr><td>4</td><td>Possible</td><td>Moderate</td><td>High</td><td>Likely</td><td>Moderate</td><td>High</td></tr>
<tr><th colspan="6">Uncertainties</th><th>Level</th></tr>
<tr><td colspan="6">Future coastal erosion rate due to lack of knowledge of existing beach processes and sediment supply + uncertainty over future climate change impacts on beach response notable wave climate changes.</td><td>High</td></tr>
<tr><th colspan="7">Methods to reduce uncertainty</th></tr>
<tr><td colspan="7">Uncertainty could be reduced by regional study of beach processes coupled with scenario testing of future wave climate changes. Unlikely to be justifiable given scale of present decision but possible for long term land-use planning for Windy Cove.
Peer review of present risk assessment by coastal hazard experts.</td></tr>
</table>

4.5 Best Practice guidance – Risk Assessment

- It is recommended that a coastal hazard risk assessment incorporate the effects of climate change if the lifetime of the development, asset, infrastructure, or service function exceeds 30 years. Climate change effects should not be limited to sea-level rise, but include the potential effects of other climate changes outlined in this Manual and in the companion Climate Change Effects and Impacts Assessment.

- To evaluate climate change risks, use at least the most likely mid-range scenario for sea-level rise (it is recommended that council staff use a figure of **20cm by 2050** and **50cm by 2100**). If a mid-range scenario indicates the potential for noticeable negative impacts, evaluate the sensitivity of this result by assuming both high-end and low-end scenarios for a range of climate and sea-level rise parameters and check the change in the resulting impacts.

- Climate change risks evolve over time, so note that your response options may become locked in if you delay decisions because a risk is low initially but will increase (due to existing use rights, or increasing costs of responses due to increasing development).

- Climate change risk assessment is most effective and presents the lowest costs if it is done in the context of an overarching plan review, asset or infrastructure upgrade or redesign.

- Use expert help to assess coastal hazards where the costs or significance of the development, asset or service in question is significant.

5. Integrating Coastal Hazard Assessment and Climate Change into Council Planning and Decisions

This chapter aims to:

- identify mechanisms available to local authorities to implement management options;
- develop a context for the selection of management options;
- identify principles and management options to address coastal hazard risks assessed in Section 4;
- evaluate the advantages/disadvantages of the management options;
- provide guidance on the preparation of a “Response Strategy”;
- briefly address liability and insurance issues.

5.1 Introduction

This Guidance Manual has the underlying premise of trying to manage the consequences of potentially hazardous coastal processes. While it is very difficult to reduce the likelihood of a particular coastal hazard event occurring, it needs to be remembered that the frequency of particular hazards occurring may increase because of climate change.

A range of circumstances can be identified (including physical, political, demographic) that will influence the degree of success of managing the consequences of coastal hazard events. Management of the consequences can be achieved by preparing a response strategy that manages the effects of hazards (including climate change-induced coastal hazards), and recognizes the various timeframes to implement each response option.

This Manual establishes a model for developing a response to climate change-induced coastal hazards and generally involves:

- determination of the context;
- assessment of the risks;
- analysis and evaluation of risk (including scenario loss studies);
- appraisal and treatment.

Section 4 of this Manual sets out the process of assessing the risks posed by coastal hazards on a district or region-wide basis. This current section addresses the ‘treatment’ of the assessed risks through the development of a “Response Strategy” to integrate coastal hazard assessment and climate change into council planning and decisions. It has the following stages:

- identification of mechanisms available to respond to issues;
- issue identification and context (including potential loss assessment);
- determining Principles and Management Options;
- formulation of Response Strategy.

The challenge is to address climate change-induced coastal hazards recognising that a range of circumstances exist, for example ranging from areas where there is no development or development pressure through to established developed areas where sensitive activities already exist. It is acknowledged that the more developed the area, the greater is the challenge to address the hazards. There are also usually fewer options available to manage the consequences of the hazard event.

Other influences on the management of coastal hazards include insurance and liability – these are discussed in Sections 5.7 and 5.8.

5.2 Mechanisms available

A range of mechanisms is available to local government to implement the management options for addressing climate change-induced coastal hazards. The choice of mechanisms will be determined by several factors including:

- the nature of the coastal hazard and level of information available;
- the nature of the coastal area (developed vs undeveloped);
- the assessed level of risk;
- time frames of changing risks and response options;
- community expectations
- political assumptions;
- costs and benefits;
- what mechanisms already exist in the community;
- insurance issues;

- liability issues.

Set out below is a list of those mechanisms that are currently available, based on present statutory and jurisdictional requirements. Depending on the above factors, one or several mechanisms may be appropriate in a region or district. In addition, the appropriateness of specific mechanisms may change over time as issues change, and as (for example) the frequency of hazards changes as a result of climate change.

- Coastal strategies – identification of values, threats and hazards/risks, specific responses and policies for specific areas etc. These can be developed for specific areas. A coastal specialist should be involved in this process. The strategy for a particular area may, for example, go through the process of considering the hierarchy of response options required under the NZ Coastal Policy Statement (NZCPS) which considers the management of hazards within the coastal environment according to the potential environmental effects of the selected technique. In so doing it outlines a broad hierarchy of response options[13]. These options are summarised in a simplified order of priority, as shown in Figure 5.1.

- Growth strategies – setting out the predictions for growth over given timeframes, identifying areas which may come under pressure, predictions for infrastructure expansion and location requirements etc.

- Policy statements and plans prepared under statute including regional and district plans, strategic plans, annual plans, long-term financial plans, community plans – these plans can include objectives, policies and methods to manage adverse effects of climate change-induced coastal hazards. They can identify future management strategies, allocate funding for specific works and identify community aspirations and expectations.

- Planning mechanisms incorporated in plans including building set-backs, restriction areas, special zones etc.

- Resource consent decisions – the resource consent process can be used to implement the objectives and policies in regional and district plans, and coastal strategies, and can be used to restrict or control further development in already developed areas, to manage development where no development currently exists, and to address adverse environmental effects that may arise from climate change-induced coastal hazards;

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[13] *Refer to Outcomes 3 and 3.3 or Policies 3.3.1 and Policy 3.3.2 of the NZCPS*

- Building Act requirements – compliance with specific structural and engineering standards for buildings or structures subject to certain coastal hazards using NZS standards or building Codes of Practice.

- Structure and development plans may be required for specific developments on ‘greenfield’ sites – these mechanisms provide an opportunity for large developments to be designed and managed taking coastal hazards into account, including the location and provision of infrastructure and placing the onus on the developer to include provisions addressing coastal hazards in their development plans.

- Civil Defence Plans – these plans prepared under the Civil Defence Act can identify specific coastal hazards and evacuation and support strategies including training needs and community education;

- Emergency Response Plans/Recovery Plans – these plans identify appropriate responses to specific events and what the needs of the community will be in the near future after an event – these mechanisms are likely to be required regardless of the management option chosen.

- State of the Environment Reporting – this process of monitoring and reporting on the state of the environment can identify climate change-induced coastal hazards, trends in coastal processes, changes in risk, and further monitoring required to fill information gaps. Specifically it can identify long-term research and investigation needs.

- Covenants on land titles – this mechanism can be used to ensure that development on any site that is at risk from coastal hazards is undertaken appropriately and can influence the ability of the owner to develop the site.

- Non-statutory agreements – this involves reaching non-statutory agreements with property owners or managers on how existing or proposed developments may be managed in the future, or to set-up “first option” agreements to ensure properties at risk can be purchased by local authorities in the future when sale is contemplated.

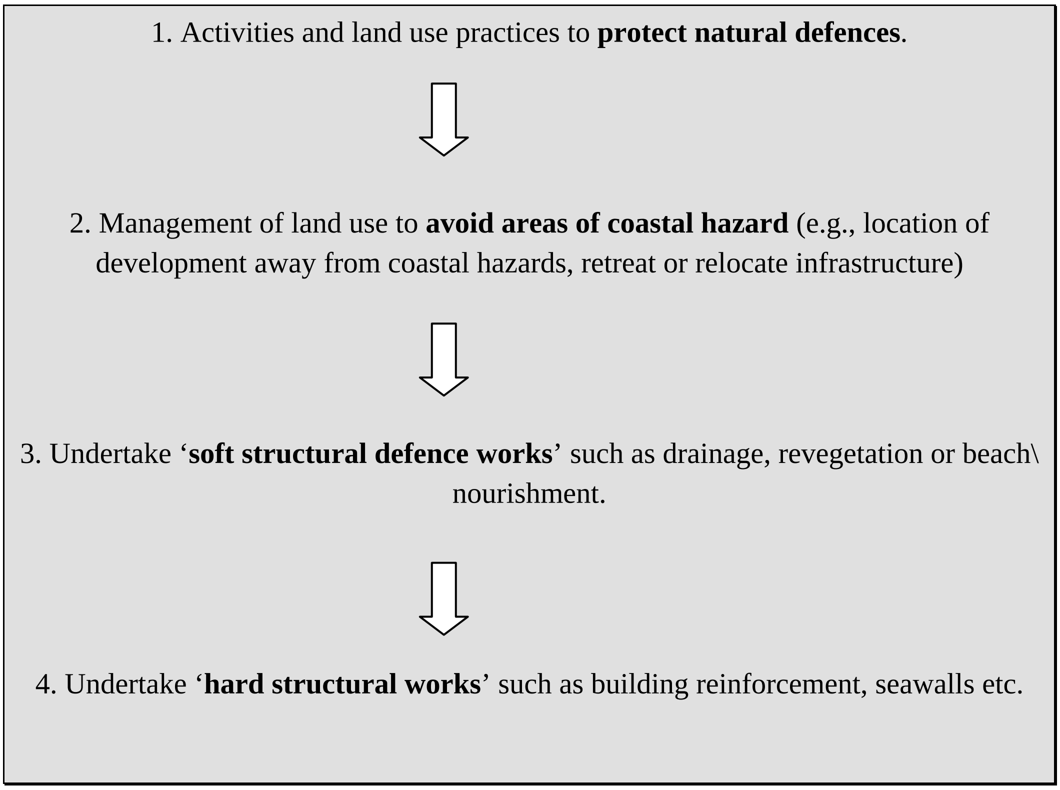
- Increasing public awareness through education programmes, publications, and signage (in vulnerable locations) – these mechanisms are effective in raising the community’s understanding and expectations in relation to climate change-induced coastal hazards, and can help local authorities determine directions to be incorporated in plans and infrastructure investments. This can involve specifically listing climate change-induced hazards as an issue to be addressed, for example on a consent application form or in a consent processing manual.

- NZS/Codes of Practice – these mechanisms are engineering solutions that can be adopted to manage certain coastal hazards in certain circumstances and give some degree of certainty.

- Availability of specialist advice – ensuring adequate recognition is given in budgets and work programmes to involve coastal specialists in assessing specific development proposals or undertaking research and investigations. This has links back to Annual Plans and long-term financial strategies.

- Input to other organisations’ development plans and strategies – e.g. ongoing consultation and input to Conservation Strategies or State Highway Strategies.

- Investigations and research – this covers a range of activities, such as ensuring regular and close interaction with research organisations, links with local education providers, regular consultation with lifeline providers and managers etc.



1. Activities and land use practices to **protect natural defences**.

2. Management of land use to **avoid areas of coastal hazard** (e.g., location of development away from coastal hazards, retreat or relocate infrastructure)

3. Undertake ‘**soft structural defence works**’ such as drainage, revegetation or beach\ nourishment.

4. Undertake ‘**hard structural works**’ such as building reinforcement, seawalls etc.

Figure 5.1: **Hierarchy of Response Options as Recommended in NZCPS**

Risk management fits comfortably into plan preparation and review processes at the stages where issues are being identified and a range of possible response options are being evaluated. With the advance knowledge of climate change effects, an unplanned response should rarely be needed.

The iterative process of plan administration, monitoring and review allows for modification of plans over time to take account of improved understanding of risks and effects associated with climate change. Planning for climate change needs to take into account the combined effect of future climate change and superimpose natural climate variability.

5.3 Issue identification and context

5.3.1 Background

Local authority planning and decision-making is guided by a number of legislative requirements (as described in Section 3) that develop a range of principles that they must operate within. These include:

- sustainability – sustainable development (LGA) and sustainable management (RMA);
- the reasonably foreseeable needs of future generations;
- identification and avoidance, remedy and mitigation of adverse environmental effects;
- precautionary principles (discussed further below);
- the ethic of stewardship (Kaitiakitanga);
- consultation and participation;
- financial responsibility;
- liability.

The extent to which the effects of climate change on coastal hazards need to be taken into account depends on:

- the duration of the issue being addressed;
- whether there is a particular ‘driver’ present (such as a major investment decision);
- the location of the issue being addressed;
- the extent of the issue being addressed;
- the nature of the issue being addressed.

These issues are relevant whatever the type of hazard (and are addressed in the companion guidance manual “Climate Change Effects and Impacts Assessment). However each is addressed below specifically in relation to coastal hazards.

5.3.2 The duration of the issue being addressed

In considering the effects of climate change in the coastal area, the period over which any decision will have effect is important to the overall success of the management option chosen. As a general rule of thumb, whenever a decision is likely to have effects that will last 30 years or more, the implications of climate change should be taken into account in making the decision. This is because the effects of climate change noticeably start to exceed the normal bounds of climatic variability within this rough timescale.

Local government instruments have a range of implications in terms of time. For example:

- district land use resource consents and subdivision consents are, in effect, permanent (unless restricted to a set period), as existing use rights generally apply;
- regional resource consents may be issues for up to 35 years;
- building consents assume new structures have a life of 50 years, but many structures are intended to, or do, last much longer;
- infrastructure projects generally assume a life of 50–80 years. They may be able to be designed to provide extra capacity in the future, being built on a staged basis taking climate change into account or they may need to be designed for the conditions at the end of their lifetime right from the beginning;
- land care, biodiversity, and pest management strategies may be in the context of a 3, 5 or 10-year strategy;
- Community Plans have a focus of greater than 10 years;
- the most reliable climate change information available at the time should be taken into account in terms of the duration of the decision being made. While the general trend of climate change is relatively robust, projections of specific changes do and will evolve over time.

As a general principle, it is recommended that all proposals in the vicinity of the coast be evaluated in terms of expected sea level rise over the next century, as well as other ‘downstream’ effects including increased coastal erosion, salt water intrusion, and increased flooding in the vicinity. Longer time scales may be appropriate for coastal greenfield developments because of the establishment of existing use rights.

5.3.3 Whether there is a particular driver present

Climate change considerations become particularly important when specific decisions are required that involve already developed areas, or areas (where coastal hazards are evident) which are now under pressure of new development. In such cases, it is recommended that any significant investment in infrastructure be preceded by a risk assessment which builds in climate change implications and a cost benefit analysis.

When climate change is factored into new investment decisions, the resulting asset "life-cycle" costs should be less than the additional costs from premature retirement of the asset or later unprogrammed upgrades. In some situations, the design of new infrastructure may "lock in" resource requirements in a way that makes later upgrading virtually impossible.

There is a danger of a similar "lock in" in greenfield subdivision for new housing developments. On receipt of consent applications councils are required to make decisions within short statutory timeframes. However, it is worth considering these decisions in the context that climate change effects will possibly exacerbate natural hazards through the consequences and/or the increased frequency of hazard events. If a council considers there is inadequate consideration of climate change factors in an application and that such factors are relevant, it is recommended that further information be sought rather than making a hasty decision.

One of the biggest challenges in planning for climate change is the change in risk over time. An example would be a 20 metre set-back placed in a district plan to address sea level rise. With changes in the sea level rise predictions and subsequent risks over time, the 20 metre set-back could prove to be more than adequate, or very inadequate. This process would need to be regularly reviewed at the plan review stage, incorporating a review of the risk profile for a given location and land use. However, complications would arise when planning decisions for "lock in" land uses are made based on the 20 metre set-back that proves inadequate. It is therefore useful if set-back zones are combined with more flexible measures such as relocatable buildings, or options for additional protection of natural defences, including dune protection.

5.3.4 The location of the issue being addressed

Some locations are more vulnerable than others to climate change-induced coastal hazards. The risk assessment process can determine the vulnerability of a location when considering the causes and drivers of coastal hazards, including the nature of the coastal area. The level of development will be a challenging factor when determining the nature of the coastal area.

Existing development and potential future development of an area is significant in determining the appropriate coastal hazard management technique, as is the extent of land between the coastline and that development, and the rate of erosion[14]. The expectations of protection (continued or otherwise), political pressures, and existing use rights that are afforded by section 10 of the RMA have to be considered within the wider context of Part II of the RMA. Section 10 allows a building to remain in a no-build hazard area (provided that there are no regional rules requiring otherwise[15]), and this is generally not legally contentious. The difficulty and the conflict between landowner expectations and Part II generally arise when new buildings, extension works or protection works are proposed by property owners. These new projects and alternatives need to be considered on their merits under Part II.

This Guidance Manual advocates a management approach that recognises the level of coastal development as but one factor of risk assessment. In each case, there is a range of options beyond the conventionally preferred hard structural works that can be applied to both developed and undeveloped coastlines, with the intention of satisfying Part II of the RMA. In any event, caution based on informed judgement should be the guiding principle.

5.3.5 The extent of the issue being addressed

It is important to properly define the extent of the issues relating to any proposed development where the consequences of climate change-induced coastal hazards will have to be managed. For example, where a proposal is for a single building or a small part of an infrastructure asset (unless the latter constrains the rest of the system), such proposals are less likely to have fundamental and long-term implications than projects that affect larger areas or are for major developments. The exception is where a small development has the potential to contribute to the cumulative effects of coastal hazards. In this case it is recommended that councils look past the ‘case by case’ principle of considering consent applications, and place more weight on cumulative effects associated with coastal hazards.

5.3.6 The nature of the issue being addressed

It is important to clearly identify whether a single climate parameter (such as sea level rise) needs to be considered when making decisions, or whether there are complex

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[14] *Refer for example to Policy 1.1.1 and Policies 3.1.1 to 3.5.4 of the NZCPS 1994*

[15] *Refer for example, to McKinley v Timaru DC C24/2001, which considers the application of regional and district plan provisions to existing use rights. This case is considered further in section 8 of this guide.*

climate parameters (sea level rise, plus higher rainfall and increased flood events etc) with multiple effects and implications over time. The risk management assessment (outlined in Section 4) would determine this matter, and the principles and management options adopted would reflect the nature of the issue being addressed.

5.4 Principles and management options

After assessing the risks as outlined in Section 4, the management options for different scenarios that are developed need to be assessed. It is considered that the following seven principles provide a basis for determining the management options[16].

Each principle is followed by the strategies recommended to give effect to it. The means to implement these strategies are suggested, using the mechanisms available as set out in Section 5.2. Note that some of the principles are more clearly applicable to some coastal hazards (e.g., periodic inundation) than to others (e.g., erosion and sea level rise).

The costs to councils of considering the effects and response options to climate change can be minimised when and where they are integrated in wider coastal hazards assessments.

5.4.1 Principle 1 – Know your community's coastal risks: hazard, vulnerability, and exposure

Background

Understanding the community's coastal hazards, vulnerability and exposure to damage is the foundation for land use and building strategies that can mitigate risk. Coastal hazard risk is a function of four factors:

- the nature and extent of the coastal hazard
- the vulnerability of facilities and people to damage
- the amount of development or the number of people exposed to the hazard
- the time (year/decade) for which the assessment applies

Previous sections, especially Sections 2 and 4, have described how to go about assessing these. In summary, investigations are required to provide a basis for

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[16] The principles are based on the *Seven Principles for Planning and Design for Tsunami Hazards* developed as part of the National Tsunami Hazard Mitigation Programme (March 2001). This programme is a multi-state mitigation project funded by the US Department of Commerce and National Oceanic and Atmospheric Administration (NOAA). A close examination of these principles show they are applicable to climate change induced coastal hazards in general, as outlined.

identifying the nature and extent of the coastal hazard in an area or region. The classification of key elements at risk around an area or region identifies the amount of development or number of people exposed to the hazard.

Such an investigation could develop a Coastal Hazard Loss Scenario Study for a region/district to assess potential loss to important buildings and structures, transportation systems and utility services, and provide the basis for reducing potential loss. Such a study would be a mechanism to address vulnerability of facilities and people to damage, and therefore the risk (consequences) from climate change-induced coastal hazards.

Management Option 1 – Identification of risk: hazard, vulnerability and exposure

The following strategies can be developed for applying hazard information to reducing future losses:

- incorporate hazard information into short and long term planning processes;
- use hazard information to build public and political support for mitigation measures;
- estimate reduced future losses by evaluating the effectiveness of loss-prevention measures;
- periodically re-evaluate community vulnerability and exposure;
- continue to manage, monitor and assess the risk, and modify the response option(s) as appropriate.

Implementation

Implementation of these strategies would be through:

- use of coastal hazard information in local authority strategic, annual, community, and management plans;
- incorporation of coastal hazard information into natural hazard planning in regional and district plans;
- incorporation of coastal hazard information into community education programmes, and publications, and resource consent, manuals;
- initiation of Coastal Hazard Loss Scenario Studies for regions/districts;
- initiation of public awareness and co-ordination through regional/district councils' Emergency Management Officer roles – information, signs etc;

- ensuring annual plans provide financial support for these initiatives;
- preparation and implementation of monitoring programmes, including review processes.

Advantages and Disadvantages

Advantages:

- clear indication of potential losses from coastal hazard events allows the community to appreciate their vulnerability and exposure of facilities, and gives councils a planning mandate that can also feed into strategic, annual and community plans;
- raised community awareness and increased political support for forward hazard planning;
- identification of information gaps through Loss Scenario Studies;
- clear evaluation of future losses and cost/benefits of strategies;
- coastal hazards induced by climate change are given regional issue status in regional plans and direction to district plans;
- cost-effective, as information and plan based work use existing mechanisms (some with statutory basis);
- allows continual review and response in an iterative process.

Disadvantages:

There are no real disadvantages of knowing the risks to a community from coastal hazards. There may, however, be implications or ‘side-effects’, including:

- no clear outcomes with set timeframes – any benefits are likely to be long term;
- reliance on regional/district councils to commit resources to incorporate hazard information into plans and decisions;
- possible inconsistencies between regions/districts with different priorities and resources available;
- implications of liability related to actual or perceived accuracy of hazard and risk determination;

- political or other pressure to act on certain information.

5.4.2 Principle 2 – Avoid new development in coastal hazard areas to minimise future losses

Background

The effects from a coastal hazard event can be mitigated most effectively by avoiding or minimising the exposure of people and property through land use planning. This can be achieved by preventing development in risk areas wherever possible, and protecting the natural defence systems. This recognises the first two principles of the NZCPS.

Management Option 2 – Avoid new development in coastal hazard areas

The following specific land use planning strategies are suggested to reduce risk:

- require protection of natural defences;
- designate or zone coastal hazard areas for protection or open space uses – recreational access, parks and recreation, horticulture/agriculture etc;
- acquire coastal hazard areas for protection or open-space uses - could also include purchasing development rights and requiring easements, and/or land swaps;
- restrict development through land use regulations – strategically control the type of development and uses allowed in hazard areas and avoid high-value and high-occupancy uses; could also use large-lot zoning requirements for subdivision or clustering of activities on site areas where risks are lowest;
- require minimum floor heights to address inundation by storm surges; building setbacks etc;
- support land use planning through Capital Improvement Planning and Budgeting – control community facilities and infrastructure in areas where coastal hazards exist to discourage development; integrate hazard risk mitigation into infrastructure policy.

Implementation

Implementation of these strategies could be through:

- regional plans – identify coastal hazards as regionally significant issue and state preference for avoidance of new development in hazard areas; review risk management provisions for coastal erosion and sea level rise in light of any new hazard or risk information; co-ordination of integrated management;

- district plans - specific zoning of hazard areas with policies to avoid or control development, rules to prohibit development, and regulation (such as subdivision rules); build on existing plan provisions for coastal erosion and sea level rise (building line restrictions/setbacks); require financial contributions to address coastal hazards – including easements;
- strategic, community and annual plans – identification of areas that should be open space and a purchase programme for land or development rights;
- public education programmes - ensure that throughout these and other processes, the level of risk is communicated accurately and without exaggeration;
- facilitation of inter-agency and community volunteer initiatives, such as Coastcare or Landcare groups.

Advantages and Disadvantages

Advantages:

- provides the most robust mechanism of avoiding future problems, particularly for erosion hazard;
- reduces long-term risk, and likelihood of insurance claims;
- increases public awareness of issue;
- provides opportunity to create and maintain a natural protective buffer and viable beach area, including provision for public access to coastal resources, and retention of ecological resource.

Disadvantages:

- requires justifiable assessment of level of risk and identification of hazard line;
- may restrict areas available for development and cause increasing pressure and land prices elsewhere in the district;
- may cause conflict between different sectors of the community;
- cost implications from obtaining tenure and maintenance requirements.

5.4.3 Principle 3 – Locate and configure new development that occurs in coastal hazard areas to minimise future losses

Background

If avoidance is not possible or there is a degree of existing use, the physical configuration of structures and uses on-site can reduce potential loss of life and property damage. Techniques include progressive strategic location of structures and open spaces, interaction of uses and landforms, design of landscaping, and the erection of barriers. A development plan, for example, could include site planning that determines the location, configuration, and density of development on particular sites in a way that reduces risk.

Management Option 3 – Control the location and nature of new development

The following specific site planning and mitigation strategies can be considered to reduce risk particularly from periodic coastal hazards (e.g., storm surges), but also from erosion and sea level rise in some circumstances:

- site buildings and infrastructure on the high side of a site or raise structures above likely inundation levels on piers or hardened podiums;
- encourage landscaping that will slow or steer water away from vulnerable structures and people (e.g.,. by strategically designed vegetation, ditches, walls, slopes and berms);
- use hard structures such as walls, compacted terraces and berms, parking structures and other rigid construction to prevent inundation;
- require new buildings to be relocatable;
- restrict use septic tanks for sewage disposal;
- infill housing – raise buildings above inundation levels, add engineering features to their design, and require new structures to be built as far back on sections as possible;
- new subdivisions –maximise setbacks; elevate buildings above inundation levels; place houses behind vegetation or hardened buildings; site primary access roads outside hazard areas and secondary access roads perpendicular to the shore;
- high-rise buildings – lower levels can be designated for public areas such as lobbies and support uses (car parking); buildings can be designed to allow waves to pass through the ground floor without damaging upper floors;

- resorts – open space and vegetated areas, elevating or locating structures above estimated inundation levels, and buffering smaller buildings with larger buildings and waterfront structures;

- industrial – destruction or flooding of industrial facilities can add another environmental dimension to a coastal hazard event with hazardous materials, and floating debris – protect industrial facilities by walls and stronger anchoring is one option; locating these types of facilities outside of hazard zone is the most effective approach;

- essential and critical facilities – fire stations, power stations, hospitals, sewage treatment facilities etc should be located outside of hazard zones; relocation of existing facilities or retrofitting should be considered;

- consider hard protection works in specific areas;

- design off-shore/coastal structures and infrastructure (pipelines, breakwaters etc) to withstand additional forces and frequencies of hazards (e.g. sea level rise, storm frequency).

Implementation

Implementation of these strategies would be through:

- district plans - specific zoning of hazard areas with policies and rules to control location and nature of development, development of Design Guidelines associated with the zone requiring development plans, and regulation;

- regional plans – require consideration of climate change-induced effects to be taken into account in consent applications for coastal structures and infrastructure;

- Building Act/consents – LIMs and PIMs identifying coastal hazard area, building consents consider structural integrity of calming measures;

- development plans – require comprehensive development plans for new developments; determine location of structures and high occupancy buildings and measures to mitigate the effects of inundation and erosion;

- community plans – control community facilities and infrastructure;

- public education programmes.

See Principle 6 for critical facilities.

Advantages and Disadvantages

Advantages:

- particularly appropriate for areas subject to periodic inundation (e.g., storm surges);
- may allow development of some areas, reducing pressure on limited land resources.

Disadvantages:

- certain degree of risk still apparent;
- not as appropriate for areas subject to erosion, apart from those structures and/or infrastructure that must be located in coastal zone;
- limited (timeframes) applicability to land areas vulnerable to gradual sea level rise;
- have cost implications for existing land uses and property owners if required to put mitigation works in place.

5.4.4 Principle 4 – Design and construct new buildings and structures to minimise damage

Background

Where buildings and/or structures are to be located in a coastal hazard area, their design and construction (including construction materials, building configuration and specific design features) can reduce loss of life, property and structural damage particularly from hazard events involving periodic inundation. Performance objectives for buildings and structures will depend on several matters including:

- location of building/structure and configuration;
- intensity and frequency of the hazard selected for design;
- structural and non-structural design standards;
- choice of structural and finished materials;
- reliability of utilities;
- professional abilities of designers;
- quality of construction;

- level of confidence in these factors.

Management Option 4 – Regulate the design and construction of buildings/structures in coastal hazard areas

The following specific design and construction strategies can be considered to reduce risk caused by coastal hazards:

- choose appropriate design solutions based on expected effects – design and construction of new buildings and structures should address forces associated with water pressure, buoyancy, currents and waves, debris impact, undermining and scour etc until such time remedial works can be put into place if appropriate;

- require qualified architects and engineers to design large buildings – competent engineering, design, construction and quality assurance. Involve coastal specialist in process to ensure hazards are correctly understood;

- inspect construction to ensure requirements are met.

Implementation

Implementation of these strategies would be through:

- district plan - specific zoning of coastal hazard areas with policies and rules to control the design and construction of buildings through Design Guidelines associated with the zone requiring development plans, and regulation;

- Building Act/consents – LIMs and PIMs identifying coastal hazard area, building consents consider structural integrity of buildings to withstand a hazard event;

- regional plans – require consideration of climate change-induced effects to be taken into account in consent applications for coastal structures and infrastructure;

- public education programmes;

- a building code, adopting performance objectives for buildings in coastal hazard areas, should be considered.

Advantages and Disadvantages

Advantages:

- appropriate for areas subject to periodic inundation (storm surges);

- may allow development of some areas, reducing pressure on limited land resources;

- may 'buy time' allowing remedial works to delay eventual relocation/removal.

Disadvantages:

- certain degree of risk still apparent;

- not as appropriate for areas subject to erosion apart from those structures and/or infrastructure that must be located in coastal zone;

- limited (timeframes) applicability to areas vulnerable to gradual sea level rise;

- potential for conflict with property owners on what is considered to be appropriate design. May include cost implications.

5.4.5 Principle 5 – Protect existing development from losses through redevelopment, retrofit, and land reuse plans and projects

Background

For existing coastal communities, protecting existing resources may be the only real mitigation option available. Changes in land uses, buildings, and infrastructure create opportunities to incorporate loss-prevention measures to help make communities less vulnerable in the future. Techniques for renewal of communities include redefining permitted land uses, changing zoning standards, changing building uses and occupancies, retrofitting and rehabilitation of buildings and structures, and redeveloping districts to improve their economic vitality.

Some special considerations in coastal hazard vulnerable areas are:

- protecting landmarks and historic structures;

- creating scenic vistas;

- providing improved access to coastal amenities;

- improving services;

- accommodating needed housing and commercial activities.

A process for reducing vulnerability through renewal efforts might include:

- preparing an inventory of at risk areas and properties;

- evaluation and revision of plans and regulations to address redevelopment, retrofit and reuse issues, including identifying areas for various types of protection with priority given to ‘soft protection’, planned or ‘managed retreat’ (i.e., recognising the long-term vulnerability of certain areas and specifically accepting their eventual loss).

Management Option 5 – Protect existing natural and physical resources

The following specific strategies can be considered to reduce risk:

- adopt special programmes (including soft protection programmes such as through coastcare groups) and development regulations;

- redesignate and rezone land in coastal hazard areas for uses more consistent with the risk, as non-conforming uses are phased out;

- limit additions to existing buildings in coastal hazard areas;

- buy specific properties in coastal hazard areas and removing or relocating buildings;

- identify areas for managed retreat, and implement programme, including consultation with affected parties;

- use redevelopment strategies to reduce risk – reconfigure uses or infrastructure, retrofit specific buildings or remove buildings altogether, install additional pumping facilities, raise stopbanks and other infrastructure, etc;

- use incentives and other financial measures to support loss prevention – e.g., reduced property rates, waiving application, permit and inspection fees, waiving financial contributions;

- adopt and enforce special provisions for the retrofit of existing buildings – require retrofitting of all buildings within a defined hazard zone, or may be mandatory only when substantial modifications are made to existing structures or where there are changes to the building occupancy;

- require qualified architects and engineers to design effective measures to protect existing development – important when considering measures to strengthen existing development where experience and judgement are paramount;

- provide protection at key locations (e.g., dune protection or beach renourishment), or hard structures as interim measure, until other more permanent responses can be appropriately carried out.

Implementation

Implementation of these strategies would be through:

- regional plans – identifying existing development in coastal hazard areas is a regionally significant resource management issue that needs to be addressed; provide direction regarding regionally significant resources; co-ordination of integrated management of resources;
- regional council landcare priorities and programmes - coastal protection programmes (e.g., revegetation and retirement of areas as part of operations programmes);
- district plan changes - redesignating or rezoning land in coastal hazard area; policies and rules to control change in land uses and building extensions;
- community plans – consider redevelopment of community resources and infrastructure when due for renewal or replacement;
- building consents – require compliance with Code of Practice for retrofitting of existing buildings;
- strategic and annual plans – financial incentives to encourage change in land uses – rates relief and fee waiver;
- public education programmes;
- coordinating community coastcare groups

Advantages and Disadvantages

Advantages:

- may be the most practicable option in the short-term;
- allows varying degree of continued existing use.

Disadvantages:

- hard protection may have limited success (both long-term and spatially) and create false sense of security;
- requires good communication and buy-in from community to implement and accept some options (e.g. managed retreat and/or rezoning);
- may have high cost implications for community and/or individuals;

- may cause conflict in different sectors of the community.

5.4.6 Principle 6 – Take special precautions in locating and designing infrastructure and critical facilities to minimise damage

Background

Key infrastructure such as transport systems for people and goods, and utility systems such as communication, natural gas, water supply, power generation and transmission/distribution networks are essential to the continued operation of a community. These facilities need to be planned and designed to minimise any damage from coastal hazards.

In addition, critical facilities such as fire stations, hazardous facilities (chemical and fuel storage tanks) and buildings with high occupancy or occupants who are difficult to evacuate also need careful planning and design.

Management Option 6 – Planning and design of key infrastructure and critical facilities

The following specific infrastructure and critical facility location and design strategies can be considered to reduce risk:

- locate new infrastructure and critical facilities outside the coastal hazard area or design to resist coastal hazards;
- examine plans to see if alternative locations, alignments and routes can be used; designate/zone sites outside coastal hazard area for these facilities;
- develop standards for facilities in coastal hazard area (coastal location dependent; risk reduced by mitigation and emergency planning measures; need for facility outweighs the consequence of loss);
- control infrastructure improvements that will encourage construction of other facilities;
- employ design professionals qualified in key areas – coastal, structural, geotechnical engineering;
- where location is essential in hazard zone, ensure mechanisms to isolate damage such as shut off valves, detours etc;
- protect or relocate existing infrastructure and critical facilities – only allow expansion or renovation of existing facilities in coastal hazard areas with measures to reduce risk; construct barriers to protect against impact forces and

scour; elevate existing facilities above inundation level; relocate high-risk facilities; relocate facilities that require renewal or incorporate new design standards;

- plan for emergency and recovery – prepare emergency response plans to cope with the emergency situation and expedite recovery; plan for evacuation, emergency response, recovery and replacement facilities.

Implementation

Implementation of these strategies would be through:

- district plans - to control location and design of key infrastructure and critical facilities, and information to be included with consents to assist with decision making;
- community and strategic plans - to provide a strategic approach to locating and/or protecting these facilities;
- Building Act/consents – to ensure integrity of buildings and structures;
- emergency response plans;
- public education programmes.

Advantages and Disadvantages

Advantages:

- ensures appropriate recognition of key facilities, lifelines etc.

Disadvantages:

- there are no real disadvantages of adopting this option.

5.4.7 Principle 7 – Plan for evacuation

Background

This principle relates mainly to 'non-gradual' coastal hazards; e.g. periodic storm surges and/or tsunami, or severe coastal erosion brought about by storm events. A key strategy to saving lives before a coastal hazard event either arrives or causes significant damage is to evacuate people from the hazard area. This may be through horizontal evacuation by moving people to more distant locations or higher ground, or vertical evacuation by moving people to higher floors in buildings for events which are expected to be short-term (e.g., tsunami wave). Vertical evacuation is linked to issues of land use, siting, and building design and construction.

Management Option 7 – Emergency Response Plans

The following specific strategies can be considered to reduce danger to people:

- ensure procedures exist to receive and disseminate warnings;
- implement effective information and education programmes;
- maintain the programme over the long term;
- identify the most likely coastal hazard for specific locations and its likely duration, to enable identification of response needs (e.g., severe erosion and residence losses, leading to short to medium term housing requirements, or short term inundation requiring temporary shelter in community facilities);
- identify specific locations to serve as shelters or safe distances;
- work out agreements and procedures with building and/or landowners and occupiers to ensure access to shelter is able to be achieved in an emergency.

Implementation

Implementation of the above strategies would be through:

- emergency response/recovery plans;
- establishment of appropriate warning systems;
- annual plans – to provide financial support;
- public awareness, education and signs etc.

Planning and management for evacuation and emergency responses need to recognise that due to the nature of some coastal hazard events, there may not necessarily be adequate time to warn and evacuate people.

Advantages and Disadvantages

Advantages:

- reduces disruption to community and individuals;
- allows rapid response and minimising of losses and costs.

Disadvantages:

- may be required to be repeated with increasing frequency as climate change effects increase;
- may have substantial cost implications to community and individuals.

5.5 Evaluation of management options

The identification of management options and implementation techniques provides a basis to determine which management option(s) may be appropriate to adopt at any particular place to minimise the risk of climate change induced coastal hazards on people and facilities (the ‘elements at risk’).

The choice of the best management option, including the possibility of doing nothing, depends initially on the context of the hazard and an assessment of the risk. Before management options are chosen for a specific location, the risk also needs to be evaluated in relation to the values and benefits that are seen to be derived from living in a particular locality, as described in Section 4. In other words the benefits may make a given level of risk acceptable or tolerable; or alternatively dictate that mitigation methods are necessary. Part of the decision for any particular management option is also an assessment of the cost/ effectiveness of the proposed measure, and the likely change in frequency of a hazard over time brought about by climate change.

The following criteria are suggested to guide the evaluation of management options:

- legislative requirements that will be met (as outlined in Section 5.2);
- consistency of the timeframes with the degree of risk assessed;
- identification of clear environmental and social outcomes;
- identification of vulnerability and exposure to risks, and how these may change over time;
- identification of costs of implementation and ongoing monitoring/review, and reassessment;
- identification of clear benefits to the community (and future generations) and the community’s expected response;
- ease of implementation including whether the mechanisms are existing or new; whether the options are statutory or non-statutory; whether there are conflicts with key stakeholders;
- identification of roles and responsibilities for the option to succeed;

- any liability issues;
- any insurance issues.

The following preferred Management Options may be considered for different land uses (or elements at risk) located along the coast.

5.5.1 Lifelines/essential infrastructure

Management Option 6 primarily addresses these elements at risk. In essence, it is considered that the preferred options are:

- any new critical facilities should be located outside of a coastal hazard area wherever possible;
- any new critical facilities that cannot be located outside the coastal hazard area should be specifically sited and designed to withstand a climate change induced coastal hazards;
- any existing critical facilities should be relocated where possible, or assessed for vulnerability and retrofitted if relocation is not possible;
- any existing non-critical facilities should be assessed to determine vulnerability and retrofitted if required.

The above options can be implemented through Community, Strategic, Infrastructure, Regional and District Plans, and consent decision-making processes.

It is also considered that a Coastal Hazard Loss Scenario Study referred to in Management Option 1 is desirable for all lifelines/essential infrastructures.

5.5.2 Urban residential

Management Options 2, 3, 4, 5 and 7 are relevant to urban residential areas. It is considered that the following are the preferred approaches, depending on the nature of the residential areas:

- avoid new development in coastal hazard areas (Management Option 2);
- if avoidance is not possible, place an emphasis on location, configuration and building design (Management Options 3 & 4) and purchase of vulnerable areas for open spaces and coastal hazard protection mitigation (Management Options 2 & 3);

- for those residential areas with vulnerable communities and facilities, protect existing facilities (Management Option 5) and plan for evacuation and recovery (Management Option 7).

These options can be implemented through Regional and District Plans, Community Plans, building and resource consent decisions, Annual Plans and Emergency Response Plans.

5.5.3 Urban industrial/commercial

Management Options 2, 3, 4, 5, 6 and 7 are relevant to urban industrial/commercial areas. It is considered the following are the preferred approaches, depending on the nature of the industrial/commercial areas:

- avoid new development (particularly high value and occupancy uses) in coastal hazard areas (Management Option 2);

- if avoidance is not possible, place an emphasis on location, configuration and building design (Management Options 3 & 4) and purchase of vulnerable areas for open spaces and coastal hazard protection mitigation (Management Option 2 & 3), and protection of existing facilities (Management Option 5);

- for those industrial/commercial areas with critical facilities including hazardous facilities, take special precautions with existing facilities (Management Option 6) and plan for evacuation and recovery (Management Option 7).

These options can be implemented through Regional and District Plans, Community Plans, building and resource consent decisions, Annual plans and Civil Defence/Emergency Response Plans.

5.5.4 Semi rural/semi urban

Management Options 2, 3, 4, 5 and 7 are relevant to semi rural/ semi urban areas. It is considered that the following are the preferred approaches, depending on the nature of the semi rural/semi urban areas:

- avoid new development in coastal hazard areas or restrict development through land use regulations including large-lot zoning requirements (Management Option 2);

- if avoidance is not possible, place an emphasis on location, configuration and building design (Management Options 3 & 4);

- for those semi rural/semi urban areas with vulnerable communities and facilities, protect existing facilities (Management Option 5) and raise public awareness through information (Management Option 7).

These options can be implemented through Regional and District Plans, Community Plans, building consents, Annual plans and public awareness programmes.

5.5.5 Potential/future development

Management Option 2 is relevant to potential/future development areas. Even in areas that are currently rural and unlikely to have pressure from development for some time, it is recommended that potential development demands are still monitored, and coastal hazard areas identified.

On the assumption that people may still use such areas (as distinct from develop and reside in such areas), Option 7 still needs to be kept in mind. It is considered that the following are the preferred approaches, depending on the nature of the potential/future development areas:

- avoid new development in coastal hazard areas is the most preferred option through zoning with land use restrictions and controls (Management Option 2);

- public awareness of the coastal hazard risks through information, including warning and signs for people using these areas (Management Option 7).

These options can be implemented through regional and district plans, building consents, and public awareness programmes.

5.5.6 Coastal infrastructure

Management Options 3, 4, 5 and 7 are relevant to coastal infrastructure areas. The following are the preferred approaches, depending on the nature of the coastal infrastructure areas:

- place an emphasis on location, configuration and building/structure design (Management Options 3 & 4);

- for those coastal infrastructure areas with vulnerable communities and facilities, protect existing facilities (Management Option 5) and plan for evacuation and recovery (Management Option 7).

These options can be implemented through regional and district plans, building consents, and Emergency Response Plans.

5.6 Preparing a response strategy

This Manual advocates that local authorities consider preparing a Response Strategy that builds on the risk assessment undertaken in Section 4, and incorporates the relevant principles and management options developed in Section 5.4 for particular areas of their region or district that are exposed to climate change induced coastal hazards.

5.6.1 Key elements of a response strategy

In undertaking and preparing a response strategy, the key elements include:

- participation of and partnership between regional and district councils, infrastructure and service providers, key stake holders and the community;
- information gathering, identification of information deficiencies, understanding of coastal processes and identifying coastal hazard areas;
- consultation, with the community, tangata whenua and key stakeholders, to identify the range of preferred response options and identify community based and stakeholder based information;
- consideration of a range of options (including corresponding issues, objectives and policies) and their relative merits and costs, and the selection of the appropriate response option(s) - this includes those provisions outlined in section 32 of the RMA;
- education on the range and implications of each response option;
- monitoring and review, including amend response options.

5.6.2 Response timeframes

The selection of a realistic planning timeframe relies on the extent to which future activities can be anticipated and provided for within the context of anticipated environmental effects. In this regard, case law contemplating the purpose of the RMA, (in particular section 5), provides some guidance.

In the case *Christchurch Regional Council and others v Christchurch City Council* C 127/01, the Environment Court considered that two generations is a minimum to consider when planning for the reasonably foreseeable needs of future generations. This is flexible upwards depending of the nature of the resource and the threat.

A minimum 40 – 50 year planning horizon is considered as providing sufficient certainty to address the needs of future generations, whilst recognising the limitations on current information in predicting the level of future climate change and future living environments and lifestyles.

Nonetheless this timeframe is indicative only and based on the timeframes for implementation of regional and district planning documents. Timeframes of up to 100 years have been identified through the Courts as being suitable based on technical evidence at particular coastal locations[17], and on this basis both the 50 and 100 year timeframe are considered as part of any general council strategy.

Councils could consider strategies for particular sites that look beyond 100 years where it is foreseeable that climate change is likely to have significant impacts on a wide range of development scenarios for those sites.

In practical terms, the timeframe should also consider the lifetime of the asset or infrastructure that will be affected. If this is temporary, then it may be appropriately located within a vulnerable area (subject to understanding impacts on natural character and the environmental effects of its removal), provided that it is relocated or removed before being placed at risk. This approach should be adopted with caution, however, as there are often expectations of continued use rights with assets expressed as having a short-term (for example 20 year) horizon. Likewise, the temporary status of land use can often be made more permanent, and temporary activities can have adverse effects and impact natural character. If limits are not imposed on the lifetime of the asset under RMA consent conditions, there may be rights of continued use, notwithstanding the likelihood of damage, under existing use right provisions[18]. Even consents of specified duration will not avoid occupiers and their successors developing expectations.

This response strategy timeframe is illustrated diagrammatically in Figure 5.2 below.

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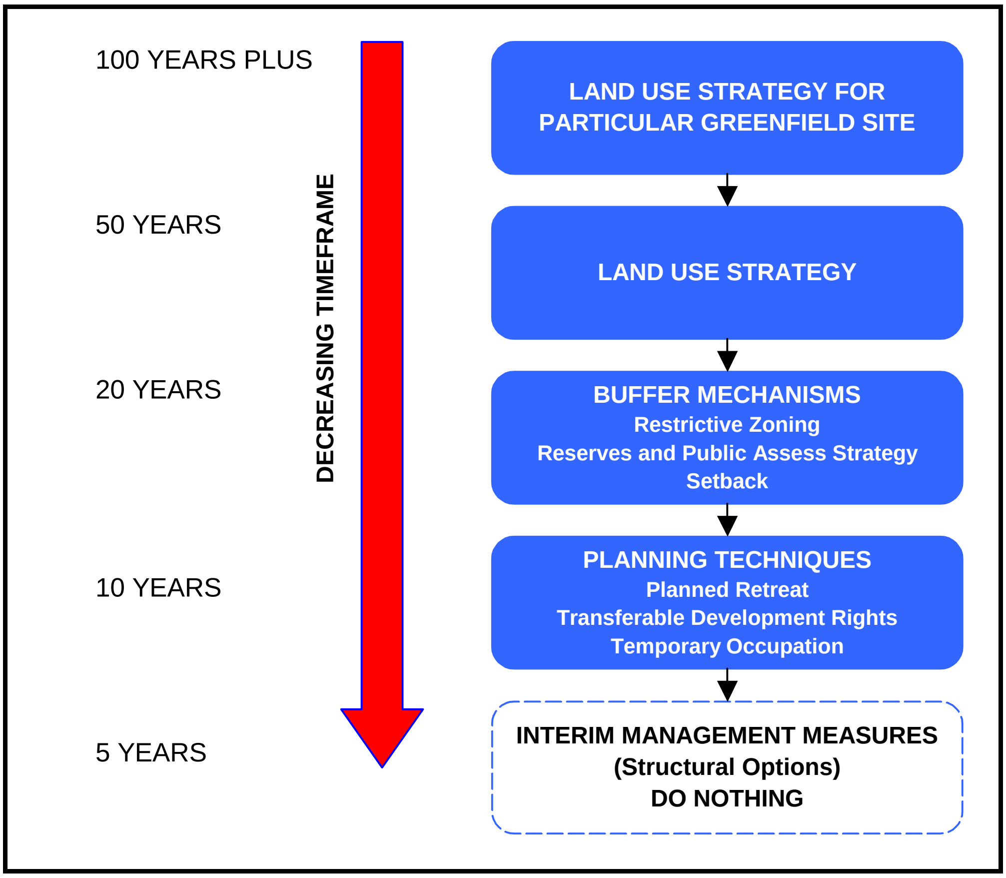
[17] *Refer for example to Bay of Plenty v Western Bay of Plenty District Council A 27/02 and Skinner v Tauranga District Council A 163/02, case notes on which are provided in section 7.*

[18] *Refer for example section 10 and 10B of the RMA.*



Source: Based on Auckland Regional Council Coastal Erosion Management Manual.

Figure 5.2: **Response Strategy for Climate Change Induced Coastal Hazards.**

In considering Figure 5.2, structural options such as seawalls should only be adopted after considering planning or soft-engineering options as part of a comprehensive assessment of the full range of response options, and demonstrating that these alternatives are not viable (refer to Section 5 for consideration of these options). Structural options may be included with a planning option to manage an erosion problem until planning techniques such as managed retreat have relocated development at risk. This is likely to occur where coastal hazards have already been identified, and climate change is likely to make the situation worse. Interim measures may involve temporary works (e.g., sandbag seawalls), or works designed to last until planning techniques are fully implemented. Of course, such interim measures will only be appropriate if the natural character and values of the coast are protected. In this manner a hierarchy of options is established. Such an approach is consistent with the principles of the RMA and in particular the policy direction of the NZCPS.

5.7 Insurance issues

The approach of insurance companies towards meeting the cost of hazard-induced asset loss has, in the past, been largely reactive. Insurance rate premiums and refusal of reinsurance are based on previous losses incurred. These can provide a disincentive for asset investment within high-risk hazard areas that have previously suffered financial loss, or on the other hand can result in extreme pressure on councils to provide ‘protection’ against the hazard. This approach does not send a clear market signal to property owners, as at risk areas will not necessarily be affected by insurance premiums, if there has not already been a hazard event.

Some insurance companies are, however, adopting a more proactive approach in the risk management process by partnering with councils to identify mitigation options for flood management and encouraging the adoption of suitable response options. Depending on the success of this approach in ‘test cases’, insurance companies may take a greater role in future coastal hazard risk management, including hazards induced by climate change effects.

In particular, insurance could be an efficient market-based economic tool to distribute and reflect actual risk for coastal properties. However, it does not necessarily reflect long-term changes in risk, and its efficient application may require intervention and collaboration between councils and insurance companies. Even if insurance is applied as a risk management tool, it will also have to have social consequences (e.g. following from withdrawal of insurance cover) or environmental consequences (e.g. a stop bank may be cost-effective to protect property but destroy important habitat) that councils need to deal with.

While s.36(4) provides protection for a council from civil liability in the circumstances specified, the result of a s.36(2) notification on a title is that an insurer may refuse insurance. That decision, however, is not one which can be made by anyone other than the insurer, and this leaves a degree of uncertainty as to the likely impact a s.36 certificate on a title will have.

6. Monitoring and review

This chapter identifies:

- the types and scope of coastal hazard monitoring;
- the need for reviews of the risk and response options at agreed milestones.

6.1 Introduction

With the onset of climate change, effects on coastal hazards are likely to accelerate with time. As a result, any response strategy needs to be adjustable. As vulnerability may change with time, it is essential that appropriate monitoring is undertaken, interspersed with regular reviews or audits of the adaptation measures, and adjustments made where necessary.

Many monitoring and review programmes have foundered because the initial conceptual design of a tailored programme was not adequate. It is essential that a tight set of specific objectives is agreed on before designing a monitoring and review programme. Generic guidance on the conceptual design of monitoring and review programmes is available in publications such as NZWERF (2002)[19].

With climate change likely to exacerbate coastal hazards, the risk assessment process provided by this Guidance Manual will help local authorities prioritise the effort on monitoring and reviews. Where there is a high degree of uncertainty of the risk, monitoring might be instituted as the first stage of a "response option", enabling a better chance of avoidance, before committing the community to a more expensive option in the future.

Definitions

- ***Monitoring*** is the regular gathering and analysis of information and data to detect any specific change. It can cover coastal "drivers", coastal environmental response, performance of response options, and societal perceptions of the risk or response options.
- ***Reviews*** are agreed milestones where the coastal hazard risk, response options, adaptation needs and monitoring programme are re-assessed on the basis of updated monitoring information, and adjustments made where necessary.

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[19] Although this document relates to wastewater discharge monitoring, the monitoring principles are generic and can be applied to coastal hazards.

6.2 Designing monitoring programmes

Comprehensive monitoring of coastal environments is difficult and expensive, since the timescales of responses to natural “drivers” can vary from hours (e.g., storms) to decades (e.g., IPO cycles). The key is to provide sufficient resolution (time interval and distance) to be in a position to differentiate a “change” from “natural variability”. This means that both the natural variability and the anticipated change need to be detectable and quantified before they can be separately identified. The “change” that requires monitoring can be:

- the effect of climate change on a beach, shoreline or cliff e.g., possible alteration in long-term erosion due to an accelerating sea-level rise;

- the effect of climate-change and sea-level rise on a selected response option that is implemented;

- the effect of the selected response option on the environment e.g., the impact of a rock wall on natural character and public access, and the potential to exacerbate erosion via “edge” effects, downstream effects or beach loss in front of the structure;

- the effect of a response option or the change of a beach or cliff system on the ability of communities to access, use and enjoy the coastal environment.

A well-designed coastal monitoring programme needs to address:

- who should do monitoring? – specialist coastal hazards practitioners, local authority staff, a surveyor, the local community, iwi groups etc.
- what should be monitored? - beach profile, beach width and volume, scour depths around protection structures, upper bluff, dune or cliff retreat, sand size and colour, sediment supply, wave climate, etc.
- why should measurements be taken? - determine long-term change, judge effectiveness, etc.
- when should monitoring occur? - monthly, annually, seasonally, etc.
- where should monitoring occur? - specific locations, general areas, on-site, off-site, etc.
- how should monitoring be done? - follow specified guidelines or procedures, visual inspections, etc.
- so what? - results of monitoring; how are they presented; triggers for maintenance or reviews; evaluation of performance, etc.

It is recommended that a specialist coastal engineer or scientist be involved in setting the objectives for any monitoring programme and (depending on the scale and importance of the issues) determining the details of the programme. In some cases existing historical data owned by the council or other agencies may provide a valuable baseline, including the effects of natural climate variability, against which future changes can be compared.

Short Example 1 - Monitoring coastal erosion at Windy Cove

The objective is to assess, in the future, the risk of coastal erosion of the shoreline or to establish or revise a coastal erosion hazard zone (CEHZ). The main interest for territorial authorities is the vulnerability of the coastal-margin land above MHWS, but there is a strong link between the health of the beach and the degree of vulnerability to storm cut-back or long-term erosion. To monitor this situation, sufficient measurements of both the beach and backshore/dune at Windy Cove are required to establish the characteristic range of short-term fluctuations (at days to month timescales) and long-term trends (years to decades, and including sea-level rise).

The findings of Smith & Benson (2001) indicate that beach-profile surveying should be undertaken at least bi-monthly to render a true picture of short-term fluctuations, particularly to capture cut-back from large storm events and seasonal cycles. Long-term trends in shoreline movement can be obtained from annual beach-profile surveys, and can be complemented by historic rectified aerial photographs, longitudinal shoreline survey traverses, cadastral maps, and more expensive approaches such as remote-camera monitoring, aerial photogrammetry or LiDAR surveys, and ground-based GPS surveys.

Short Example 2 - Monitoring beach re-nourishment response option at Sandy Bay

A one-off beach re-nourishment scheme has been implemented as the initial response option to cope with an increasing coastal erosion problem at the well-established coastal resort of Sandy Bay. The ongoing impact and success of the scheme needs to be able to be assessed. The *General Objective* therefore is to measure the state before and after the commencement of the scheme(*baseline monitoring)*, and relies on prior monitoring information for the locality. To achieve this, the monitoring programme for Sandy Bay needs to have a very *Specific Objective*. For example—"To determine, after the beach re-nourishment, if the state of the beach profile and dune-crest position recovers to the March 1998 benchmark situation and for how long, by monitoring profiles at two sites (X and Y)".

The detailed design of the monitoring programme to meet the specific objective would then specify details of sampling frequency, methodology, accuracy, repeatability, compliance conditions for an environmental monitoring plan, how the data is presented, triggers to determine when the March 1998 situation is re-gained, and what should be done next if it does not happen e.g., a review process.

Communities can be involved in the effects monitoring process in a variety of ways, such as:

- involvement of community or iwi representatives in the actual monitoring activities, including data gathering and recording visual observations (perhaps as part of a beach or dune-care programme);
- evaluation by the community of the monitoring results, and involvement in reviews;
- monitoring the impacts of coastal hazards, climate change and "side-effects" of any adaptation option on people's perceptions of the risks and their usage and enjoyment of the coast.

6.3 Monitoring techniques

Table 6.1 outlines some of the types of coastal or estuary environmental monitoring that can be carried out to provide background information (e.g., to support a risk assessment) or to detect change. For more technical details on monitoring techniques, consult articles such as Gorman et al. (1998) and Morang et al. (1997).

Table 6.1: Summary of types and methods of coastal monitoring, with possible alternative sources of that information and a relative rating of cost.

Hazard or Driver	Method	Possible alternative source of information	Relative cost
Coastal hazards	Local observer programme e.g., post-storm erosion and inundation impacts, photos from same spot on a regular basis and after storms		*
Coastal erosion or monitoring response options	Beach/backshore/dune/cliff profile surveys (Emery poles/tape, total station, GPS, RTK)	RCs, coastal consultants	**
	Shoreline traverses (GPS, total station), defined by vegetation, cliff edge or toe, or MHWS mark.	RCs, coastal consultants, LINZ	**
	Differences in aerial photos (historic rectified verticals)	Aerial mapping companies	**
	Aerial surveys to derive coastal/beach topography (photogrammetry or LiDAR)	RCs, aerial mapping and laser scanning companies	***
	Nearshore bathymetry surveys (echo-sounder or sea-sled)	RCs, LINZ, NIWA	**
	Remote video or digital camera monitoring of beach volumes, offshore bar movements and rips	RCs, NIWA	**
Sediment budgets	Requires detailed monitoring of inputs from rivers, cliff erosion, shell production, wind blow, offshore sea-bed supply, plus sinks (offshore, extraction, groynes, breakwaters)	Coastal consultants	***
Winds (storms)	Automatic weather stations	NIWA Climate Database	*
Waves	20-yr wave climate, wave buoys	Some RCs, NIWA	***
Sea level and tides	Sea-level gauges	NIWA, port companies., LINZ	**

Note: Relative cost rating for monitoring is: * = minor cost; ** = moderate cost; *** = major cost.
Abbreviations are: RCs = Regional Councils, LINZ = Land Information NZ;

6.4 Guidance on reviews and audits

Reviews or audits of a monitoring programme should be planned at pre-determined milestones or when pre-set trigger levels are reached. Review mechanisms should be built into a monitoring plan and any response strategy right from the beginning – at the stage of conceptual design and setting of objectives.

Reviews or audits are undertaken for a variety of reasons, such as:

- checking compliance for the impacts of a response option;
- peer-review of results, analysis and interpretation;
- possible re-design of the scope, objectives or design of a monitoring programme;
- being required as part of statutory consents;
- checking the cost-effectiveness of the monitoring approach.

Objectives also need to be set for the review or audits of various components of a monitoring programme and should involve a specialist practitioner. Some examples based on NZWERF, 2002 are:

- interim monitoring could be put in place with a dated review clause to cover the uncertainties in the impacts that may arise from a response option;
- establishing milestones for a review of monitoring plan objectives and how well they are being met; asking questions such as “is the sampling frequency or number of sites sufficient to resolve any changes or impacts occurring?”;
- periodic technical reviews, analysing trends and variability in monitoring data or before versus after differences where adaptation measures have been implemented;
- occasional reviews of data analysis techniques, software and reporting format. However, any mid-course change in statistical or survey techniques or software will mean previous results may be different (e.g., calculation of beach profile volumes or change of datum). Consequently, entire datasets may need to be re-analysed;
- community surveys on best methods and media for dissemination of monitoring information (e.g., web-based, newsletter, poster), which can be combined with steps to raise public awareness of the level of impacts from climate change and adaptation options.

7. Relevant case law

NOTE: The case law in this section pre-dates the application on 2 March 2004 of the Resource Management (Energy and Climate Change) Amendment Act (see Section 3.2.1).

This chapter:

- reviews case law that is of relevance to hazards;
- investigates the implications of this case law on responses to climate-change induced coastal hazards.

Maruia Society v Whakatane District 15 NZPTA 65 (1991) (High Court, Judge Doogue presiding).

This case was decided under section 274(1) of the Local Government Act 1974, which was a similar provision to section 106 of the RMA. The case involved subdivision of land fronting Ohiwa Harbour at Port Ohope. The minimum ground levels imposed by the Council had been set on the basis of the effects of the 1968 Wahine storm. The Council's engineer considered that section 274(1) of the LGA did not allow Council to recognise the possible effects of rising sea levels in determining conditions relating to the subdivision. This was a judicial review of the Council's decision. In relation to interpreting section 274(1), the Court said:

"I find it difficult to see … that any decision-making body faced with that particular language is meant to put aside what it is known by it to be likely to occur within the immediate or foreseeable future, regardless of the fact that the event may not have occurred in the historical past."…

"That is not to say that an authority would have to go to any particular lengths to determine what are clearly difficult areas in respect of likely future changes in sea or ground level. Whether the evidence at present available in respect of matters such as the 'greenhouse' effect is anything more than conjectural I do not know. …It would be a matter entirely for the council or the Planning Tribunal as to the extent to which it took such information into account." (Emphasis added)

The Court also held that the council does not have to protect every part of the land in the subdivision from inundation. Section 274(1) gave the council a discretion to determine whether sufficient protection is made against inundation suitable for subdivision. Although this case was decided under the predecessor to section 106 it is still useful in interpreting section 106. However, the options available under the RMA may be wider than those discussed under that case.

Bay of Plenty Regional Council v Whakatane District Council A003/94, (Environment Court, Judge Bollard presiding).

This case was also decided under the provisions of the LGA because the proceedings were initiated before the RMA came into force. The case also concerned a subdivision at Port Ohope. The Regional Council appealed the District Council's decision to grant the subdivision based on the effects of sea level rise.

The Council's witness (Professor Kirk) referred to sea level rise predictions published by the Inter-governmental Panel on Climate Change (IPCC); and in this country, the New Zealand Climate Change Programme (Ministry for the Environment). The Court said:

"W*e were told that the IPCC estimates are expected to be reviewed in the next year or two. Be this as it may, Professor Kirk asserted that the climate models used to make predictions in country-wide, let alone global, terms are 'crude in respect of ocean/atmosphere interactions and spatial resolution, especially in the southern hemisphere'. In short, he considered that reliance placed on IPCC global estimates by other witnesses was misconceived."*

Professor Kirk recommended a forecasting period of 2050 in preference to 2100 on the basis that reliable predictions cannot be made much past the year 2050. He noted the IPCC global average sea-level projections carry an uncertainty range of +50%.

The Regional Council's witness (Professor Healy) referred to the IPCC (1990) best estimate sea level rise of 66cm by the year 2100. He said that shoreline retreat would likely be accelerated by the 'Bruun' effect. He recommended a coastal hazard zone line. Other Council witness (Dr Gibb and Mr Pemberton) regarded the IPCC best estimate data as important for reference purposes.

Court's decision

"…we are of the view that, in this case at least, a forecasting period to 2050 AD is reasonable. Given the present state of understanding of the factors causing global and regional sea level changes, we accept the 2050 AD time horizon for present purposes - that being, in our view, as far as the "foreseeable future" may reasonably be extended, allowing for the uncertainties of scientific knowledge and balancing the interests of the applicant and succeeding landowners. By adopting such a time frame in this instance, it should not be thought that in another planning context a different time frame ought not to apply. We simply say that, on the evidence before us and against the background of this particular case, such a forecasting period seems to us appropriate. We thus adopt Professor Kirk's evidence on this aspect. On the other hand, we are persuaded by Dr Gibb and others that the IPCC "best estimate" for general sea level rise of 0.3m as at 2050 AD should be taken heed of.

We accept… that it is notoriously difficult to make a reliable prediction as to the sea level change that will affect the subject land as far ahead as 2050, let alone beyond that. Nevertheless, we consider that the best prediction currently available of the likely sea level rise that will affect the country generally as at 2050 should be adopted.”

The Court accepted Dr Gibb’s evidence on predicted rates of coastal erosion over the Regional Council witnesses. The Court adjourned the proceedings to allow the developer to prepare an amended scheme plan with a scaled-down proposal with an amended minimum building platform.

Opotiki Resource Planners v Opotiki District Council A15/97 (Environment Court, Judge Bollard presiding).

This case involved an appeal against a consent granted to construct a new integrated primary health care centre in the main shopping street of Opotiki. It was argued that the proposal should be rejected for a number of reasons, including due to the site’s susceptibility to flood risk (sea level rise, aggradation of local rivers over time, lack of a guarantee that the stopbanks would not fail during a major flood event).

The Court did not consider that this hazard risk warranted declining the consent.

“One cannot overlook that, in reality, the district has a considerable investment incorporated in the commercial area, of which the former post office building, in itself a relatively modern and substantial building, forms part. We do not regard upholding the proposal as some sort of unreserved and final endorsement of the town being located in perpetuity where it is. Rather, our decision recognises the substantial infrastructure of present urban development and associated facilities/services - including the stopbank protection works and the ongoing scheme directed to their maintenance and improvement.

“Much of the evidence we heard was really pertinent to the basic question whether the location of the town itself is appropriate on account of the flood risk element, despite the measures taken to protect the town. It lies well beyond the realm of this appeal to draw so bold a conclusion on an "across the board" footing, and then go on to illustrate such a finding by rejecting the proposal.”

The consent was granted with a condition relating to the floor level of the new building. With regard to the Court's comments on the location of the town, this issue would more properly be considered during a reference proceeding or plan creation phase, not a resource consent hearing.

Judges Bay Residents Association v Auckland Regional Council & Auckland City Council A72/98 (Environment Court, Judge Sheppard presiding).

Resource consents had been granted by the Auckland Regional Council and Auckland City Council for extension of the Fergusson Container Terminal of the Ports of Auckland. Five parties appealed the decisions.

The Proposed Auckland Regional Policy Statement contained provisions regarding natural hazards - identified as including erosion, inundation of low-lying areas, land instability, rising sea levels and tsunami. Policy 11.4.1(10) stated that location and design of new subdivision, use or development should be such that the need for hazard protection measures is avoided. Policy 11.4.1(12) required a "precautionary approach" to be used in avoiding, remedying or mitigating the adverse effects of natural hazards on development.

Expert evidence presented at the hearing addressed matters of extreme events such as sea level rise and tsunamis. The witness for Auckland Regional Council gave the opinion that the proposed wharf level would be adequate to cater for extreme events. The extension was proposed to have the same levels as the existing build port environment, and therefore the same protection from natural hazards.

The opinion was given that the standard design (particularly in regard to possible sea level rise) was considered appropriate and that inundation and erosion were not relevant risks to a built port environment. The Court found that the proposal would not cause any adverse wave effects or any other adverse effects in extreme events.

Auckland City Council v Auckland Regional Council A28/99 (Environment Court, Judge Sheppard presiding).

This case involved appeals against refusal of resource consents required for the proposed Britomart underground transport and parking centre in central Auckland.

The proposed 5 level underground development involved construction below groundwater level and thus diversion was required. The appeals opposed the consents for earthworks and the diversion of groundwater, based on potential damage to land and buildings in the vicinity from ground movement resulting from excavation and groundwater diversion.

A submitter urged that consideration be given to the possibility of tsunamis and storm surges causing the water of the harbour to overtop seawalls and flood the Quay Street underpass, although acknowledging that it would be unlikely that seawater would enter the Britomart transport centre itself. The Court held that sea level and climate change issues were relevant only to the extent that the bases for ground water modelling had been properly prepared, having regard to contingencies.

The key witness explained that effects on groundwater levels would fully manifest themselves within 10 years of the start of construction which is a relatively short period within the context of sea level rise. Sea level rise due to climate change would have no effect on the validity of the groundwater model predictions.

Kotuku Parks Ltd v Kapiti Coast District Council A 73/00 (Environment Court, Judge Sheppard presiding).

This was an application for consents for subdivision and earthworks and involved an appeal against some of the conditions imposed by Council. Ultimately the consents were declined by the Court on grounds including failing to protect significant habitat or indigenous fauna, adverse visual effects, and impairment to kaitiakitanga.

It was argued by the Waikanae Estuary Guardians that the land proposed to be subdivided would be likely to be subject to material damage by subsidence as a result of earthquake, and by inundation and erosion from the sea in conditions of storm surge, tsunami, and sea level rise. This was relevant for consideration under section 106 RMA.

The Court found that although a major event causing extensive inundation or erosion could occur on this coast at any time, it is not standard practice to design for such extreme events as those described by witnesses for the Waikanae Estuary Guardians. The evidence about catastrophic events had been in relation to the next hundreds of years, and would have effects along the entire Kapiti Coast. Another witness gave evidence of catastrophic events having a return period of at least on every 250 years, and larger saltwater inundation events one every 400 years.

Sufficient provision to avoid or mitigate the likelihood of damage was made by the building platform levels that had been set by the Council. This building platform level had been based on:

- river flooding event of 1% probability combined with a storm sea-surge event of 5% probability; or
- storm sea- surge event of 1% probability with a similar allowance for future sea-level rise.

This was considered to be sufficiently conservative to avoid or mitigate the likelihood of damage.

Lowry Bay Residents Association v Eastern Bays Little Blue Penguin Foundation Inc W45/01 (Environment Court, Judge Kenderdine presiding).

This case involved appeals against consents to establish a facility for the reception, recovery and rehabilitation of wild birds for release back into the wild. The Court said:

"It was the Association's case that the applicants and respondents appear to have studiously ignored the fact that the proposed buildings will be located in an area having an obvious natural hazard. It is not sufficient to say that buildings will be built in accordance with the Building Code. The evidence of the witnesses for the Association demonstrate that location of any buildings on the site proposed is unwise and courting disaster."

The Hutt City Council's witness said that any reference to the potential for the proposed facility to be affected by severe storms, salt deposits and spray drift is not relevant to the consideration of the grant of the consent sought, because the design and construction of the buildings is a matter to be considered under the Building Act 1991.

The Court said: "*We do not understand how a dwelling house, (large enough to hold small children), an educational facility, (which will include small children), and a cafe for 54 visitors could be approved for this site…*

We concluded that the location of all aspects of the proposal and the activities it imports, is not commensurate with the principles of sustainable management. The last word on natural hazard goes to Mr Churchman who submitted it is impossible to say that siting this proposal in an area demonstrably subject to coastal hazards is in accordance with the plan or commonsense – a submission we endorse."

Save the Bay v Canterbury Regional Council C6/2001 (Environment Court, Judge Jackson presiding).

The reference related to provisions of the Proposed Regional Coastal Environment Plan (PRCEP) dealing with coastal hazards as they relate to Taylor's Mistake and Hobson's Bay (Banks Peninsula).

The relevant plan rules

The plan contained:

- Hazard Zone 1 – land at risk from coastal erosion within 50 years (a line approx. parallel to the shoreline); and
- Hazard Zone 2 – Inland from Hazard Zone 1 - land at risk from coastal erosion within 50 to 100 years.

These zones were defined only by reference to coastal erosion. Other natural hazards were not dealt with by the rules but were to be the subject of further plan reviews. These included tsunami events and possible effects of global warming (on sea level, coastal sediment supply and storm generation).

The plan stated:

"There is a need to undertake more investigation on the magnitudes frequencies and possible effects of these events. The results are to be used in future reviews of coastal hazard management policies and methods. In the absence of consensus as to the precise effects of global climate change, the wisest course is to adopt a precautionary approach when considering developments in the coastal area."

Save the Bay was concerned about storm damage by wave action and rockfall.

Court's decision

The Court was concerned that the objectives and policies in the plan only relate to coastal erosion and inundation not to other natural hazards, and in respect of inundation they were not followed through with rules (because the hazard zones only related to coastal erosion risk). Outside the natural hazard zones, the reconstruction of those buildings damaged by the sea was not controlled by the plan at all.

The Court considered there was totally inadequate recognition of catastrophic natural events. 90% of damage to the environment caused by natural hazards occurs in 10% or less of events. *"If resource management has a significant function in relation to natural hazards – and it seems important enough to Parliament to give functions in respect of natural hazards to the regional and territorial authorities – then surely authorities should recognise that inverse relationship in the preparation and wording of their plans".*

The Court heard evidence about the location of the hazard line and said *"In our view drafting a hazard line is not as scientific as ascertaining where the MHWS is (although that too is fraught with difficulty). The task is to draw a line as an administrative boundary which is conveniently ascertainable."*

The Hazard Zone 1 line boundary at Taylor's Mistake was amended.

Conclusions on the case

This case provides guidance on the interpretation and administration of section 30 (prior to its amendment by the RM Amendment Act 2003) and Section 31 RMA:

- regional and territorial authorities need to recognise the significant function of resource management in relation to natural hazards in the preparation and working of their plans;
- councils need to recognise serious, but infrequent events when planning; and
- dealing with only one coastal hazard in the plan rules is not an integrated management approach.

McKinlay v Timaru District Council C24/2001 (Environment Court, Judge Jackson presiding).

The Canterbury Regional Council controlled the use of land in relation to natural hazards through its regional policy statement (RPS). In relation to the site in question, the RPS did not contain any rules relating to natural hazards. There were no rules in the proposed regional coastal plan either. However there *were* rules governing natural hazards at the site in the Timaru Proposed District Plan. Under those rules, construction of a residential building was prohibited at the site (because it was within the “Coastal Inundation Line”).

The Court was asked decide what would happen if an existing residence at the site was destroyed by a natural hazard such as a flood, and whether reconstruction would be prohibited by the proposed district plan. This relates to “existing use rights” (sections 10 and 20 RMA). The Court said that the property-owner would have existing use rights to rebuild provided that the dwelling rebuilt was the same or similar in character, intensity, and scale as the present building (section 10). However if there had been *regional* rules governing the reconstruction, then the situation would be different (sections 10(4) and 20(2)(c)). So, although regional rules can ‘override’ existing use rights, district rules do not. . This is important case law for regional and district councils endeavouring to control building in hazard areas.

Bay of Plenty Regional Council v Western Bay of Plenty District Council A27/02 (Environment Court, Judge Bollard presiding).

This reference related to provisions of Variation No 1 to the Western Bay of Plenty District Council’s proposed plan – development controls affecting coastline areas at Waihi and Pukehina beaches. The referrers were the Regional Council and the Waihi Beach Protection Society.

The plan rules

The plan contained a “Coastal Protection Area” or CPA line, based on a 1993 study. (The Regional Plan also contained a “Areas Sensitive to Coastal Hazards” line which was compatible but not identical to the CPA).

The CPA was split into “high risk” and “low risk” areas. Within “high risk”, new buildings and alterations were a discretionary activity. In “low risk” such activities were permitted subject to conditions. Subdivision was discretionary in both areas. The Regional Council sought discretionary activity status for buildings in both areas. The Society sought permitted activity status for buildings in both the areas.

The District Council pointed out that, for permitted activity status, further conditions on building could be imposed under the Building Act.

The plan Variation was supposed to be an interim solution, providing adequate protection until "future options for coastal management are known". These include coastal protection works, but the Council did not want to proceed with those until other options were investigated.

Court's decision

The Court considered that the planning instruments had recognised properly coastal erosion, inundation, dune stability and sea level rise issues.

The Court considered that the Regional Council's approach should be accepted. It was sound to plan for a 100-year predicted risk period. The District Council argued that only a 50-year risk period should be planned for, but this was rejected, particularly considering the principles in the NZCPS. The areas should be categorised as primary and secondary areas of risk rather than high and low as both areas carry significant risk. Potential adverse effects through changed climate conditions and sea level rise were accepted as existing. In secondary risk areas buildings and extensions should be a limited discretionary activity.

The argument from the Society was rejected as follows:

"… it was argued that the voluntary assumption of risk by private property owners does not abrogate the Council's responsibility of controlling the use of 'at risk' land for the purpose of avoiding or mitigating natural hazards. We accept that submission… Failure to manage known actual and potential effects of natural hazards at Waihi and Pukehina Beaches under the Act's regime would not, in our view, be consistent with the legislative purpose of sustainability."

The Court commented on the evidence and the uncertainty inherent in this area of planning. This together with the NZCPS pointed to a precautionary approach to planning.

Interface with the Building Act

"… the respective means of control under the RMA and the Building Act should not be narrowly construed as merely amounting to alternatives available to a Council to achieve the same ends. Rather they should be viewed in a broader light, both individually and in combination, of assisting to serve the public good. Were the contrary contention sound, Parliament's recognition of the two separate Acts' frameworks of authority and control might be seen as unnecessarily repetitious. Each in fact serves its particular purpose – that under the RMA of promoting the sustainable management of resources in the context of the wide environmental perspective that the Act embraces; and that under the Building Act by focussing on the integrity and safety of buildings wherever they are located. Logically, any relevant controlling provisions that govern a development proposal under the holistic

management regime of the RMA will generally fall to be invoked initially, with the application of controls under the Building Act following as appropriate in terms of that Act."

Conclusions on the case

- Given the uncertainties in this area of planning, a precautionary approach should be taken.
- The Building Act should not be relied on completely – the RMA's purpose of sustainable management should still be fulfilled.

(The final plan provisions for this case were resolved in *Bay of Plenty Regional Council v Western Bay of Plenty District Council* A 141/02).

Skinner v Tauranga District Council A 163/02 (Environment Court, Judge Bollard presiding).

The reference related to provisions of the Tauranga District Council's proposed plan – development controls affecting coastline areas at Papamoa beach. The referrers were residents represented by a Mr Skinner.

The plan rules

The Plan contained a "Coastal Hazard Erosion Policy Area" (the Area or CHEPA). Within this were the following hazard risk zones:

- an extreme risk erosion zone (area immediately susceptible to notable adverse effects from coastal hazards) – any development a prohibited activity;
- a high risk erosion zone (erosion predicted 2050 – 2100 taking into account global warming predictions) – development is limited discretionary;
- a moderate risk erosion zone (erosion predicted 2050 – 2100 taking into account global warming predictions) - development is limited discretionary; and
- a buffer zone – an "at risk" area should parameters used to arrive at the other zones should be too low – has an in-built safety factor of 30%.

The CHEPA had been developed by a coastal hazards expert Mr Gibb. Mr Skinner (resident) sought the CHEPA area to be relocated seaward of the residences. He had already commissioned a report from a Mr Smith. In response the Council had asked a Mr Reinen-Hamill and experts at the Auckland Regional Council (Mr Brookes) to review the Smith report and the Gibb report – concluding that the Gibb report should be preferred.

There was numerous expert evidence on coastal-hazard risk assessment. The Tauranga District Council called as witness Mr Gibb, Mr Reinen-Hamill, and Mr Brookes, supported by Dr Bell (NIWA) and Dr de Lange (Waikato Uni). Some of these witnesses applied the “Bruun rule”.

Mr Skinner called evidence from Mr Smith (NIWA), supported by Dr Abbott, Dr T Lustig and Dr Oldham (NIWA). Mr Smith considered it unlikely that a 1 in 100 year storm cut would cause sufficient damage to endanger beachfront houses, even allowing for future climatic uncertainties and sea level rise. The use of the “Bruun rule” was rejected by these witnesses.

Court’s decision

The Court concluded that the beach was susceptible to erosive cutback when major storm events occur, and to continual dune line change. The 100 year period is reasonable for coastal planning. Predictions were difficult but a lack of field data meant that the CHEPA should not be moved as Mr Skinner wanted: *“In the absence of such data, it would not be prudent to adopt an approach that postulates that the future dynamics of the beach profile will carry no hazard risk to seaward-facing parts of properties immediately proximate to the beach during the next 100 years”*.

On page 22 *“Of major import in arriving at a determination in this instance in the face of the conflicting evidence, is the lack of certainty as to future climate change and how such change will affect the various ‘drivers’ that lead to shoreline movement.”* In this respect, in relation to sea level rise the Court noted the ‘most likely’ mid-range predicted by the IPCC.

Bearing in mind the precautionary element in the NZCPS the Court found in favour of the witnesses who considered the Bruun rule (which applied to ‘closed systems’ – “*we find that the notion of an ‘ample cushion’ of sediment supply cannot be endorsed with [a] degree of confidence…*”).

Economic evidence was put forward on development potential and decrease in property values of beachfront properties. However this was not sufficient to override the need for the council to plan ahead for coastal hazard risk.

The CHEPA was upheld, with the extreme, high and moderate risk zones in it, but the Court considered the safety buffer zone could be removed as it was ultra cautious. *“The effect is to place a zone restriction on the properties affected beyond the extent necessary to ensure sufficient and appropriate recognition of coastal hazard risk to those properties during the 100-year forecasting period.”* However the Council should monitor trends so that the plan could be refined based on continuing experience and additional data input.

Conclusions on the case

- The District Council in this case had appropriately fulfilled its function in relation to natural hazards.
- It was correct to take a precautionary approach, given the uncertainties involved.
- The IPCC predictions on sea level rise were endorsed.
- The case is interesting because of the large number of coastal hazard expert witnesses that were called.

Glossary and abbreviations

adaptive capacity	is the ability of a human system or ecosystem to adjust or respond to *climate change* (including both variability and extremes); to moderate potential damages; to take advantage of new opportunities arising from climate change; or to cope with and absorb the consequences.
climate	average weather patterns over medium to long timescales of seasons, decades and centuries
climate change	any significant change or trend in climate over time, either the mean state of climate and/or in its variability (e.g., extremes of temperature or rainfall, retreat or advance of glaciers, more intense storms). IPCC include both 'natural' change and that attributable to human activities (e.g., use of fossil fuels).
coastal accretion	a long-term trend of shoreline advance and/or gain of beach sediment volume over several decades. In many cases, accretion is beneficial and creates a buffer against future coastal hazards, but also can be a hazard when too much sediment accumulates in dunes causing blow-outs.
coastal erosion	a long-term trend of shoreline retreat and/or loss of beach sediment volume over several decades. 'Cutback' is a more suitable term to use on a dynamically 'stable' shoreline to describe the temporary loss of beach volume or shoreline retreat during a storm, before it gets replenished over ensuing weeks and months.
coastal margin	aquatic and land environments which are potentially affected by coastal hazards including long-term impacts of climate change, in which the coast and any dune or cliff system is a significant element or part, and includes the coastal marine area.
coastal marine area	(or CMA) means that area of the foreshore and seabed of which the seaward boundary is the outer limits of the territorial sea (12 nautical miles) and the landward boundary is the line of mean high water springs, except that where that line crosses a river, the landward boundary at that point shall be whichever is the lesser of one kilometre upstream from the mouth of the river, or the point upstream that is calculated by multiplying the width of the river mouth by five. [*Resource Management Act (1991)*]
ENSO	El Niño–Southern Oscillation climate cycle of 2–4 years duration that governs year-to-year (interannual) climate variability in the Pacific and Indian Oceans.

hazard	a situation with the potential to cause harm or damage. A hazard does not necessarily lead to harm or damage.
IPCC	Intergovernmental Panel on Climate Change—a group set up by the United Nations Environment Programme and World Meteorological Organization to regularly assess global and regional climate change every 5–6 years.
IPO	Interdecadal Pacific Oscillation—a 20–30 year ‘El Niño-like’ climate cycle in the greater Pacific region that modifies the ENSO system. In the negative IPO phase, New Zealand generally experiences higher sea-levels, and more storm surges and floods in eastern areas.
MHWS	mean high water spring—which traditionally is the level of the average spring tides just after full or new moon. In central-eastern regions, a ‘pragmatical’ MHWS or perigean-spring tide level (MHWPS) is a better hazard measure of upper-level high tides than the traditional MHWS, because the spring-neap effect is weak.
MSL	mean sea level survey datum set down in the 1930s to 1950s. Because of the sea-level rise since then, MSL datum values around New Zealand are usually a few cm below the current mean level of the sea.
natural character	means the qualities of the coastal environment that together give the coast of New Zealand recognisable character. These qualities may be ecological, physical, spiritual, cultural or aesthetic in nature, whether modified or managed or not.
natural hazard	means 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. [*Resource Management Act (1991)*]
risk	relates to both the likelihood and the magnitude of the impact (or consequence). It also has an element of choice by humans.
sea level	the actual level of the sea over a certain averaging period (days, weeks, years, decades) after removing the tides (not to be confused with mean sea level or MSL, which usually refers to a set vertical survey datum).
sea-level rise	trend of annual mean sea level over timescales of at least 3 or more decades. Must be tied to one of the following two types: *global*—overall

	rise in absolute sea level in the world’s oceans; or *relative*—net rise relative to the local landmass (that may be subsiding or being uplifted).
significant wave height	the average height of the highest one-third of waves during a short recording interval (typically 10–20 minutes). Generally considered the height that a trained observer would report for a given sea state.
storm surge	temporary increase in ocean level above the predicted tide height caused during storms by a combination of low barometric pressure and winds that cause a set-up in sea level.
storm tide	the total elevated sea height at the coast above a datum during a storm combining storm surge, wave set-up in the surf zone and the predicted tide height. Note that *wave run-up* needs to be added to the storm-tide level at any locality to get the final storm inundation level, but care is needed to ensure the wave run-up formula doesn’t already include wave set-up”.
vulnerability	susceptibility to potential harm or damage, considering factors such as the ability of a system to cope or absorb stress or impacts and to ‘bounce back’ or recover.
weather	what we see happening or about to happen ‘out the window’, on timescales of hours to weeks
wave run-up	(for storms or tsunami) the ultimate height reached by waves after running up the beach and coastal barrier (see also *wave set-up*)
wave set-up	(for storms) the super-elevation in water level across the surf zone caused by energy expended by breaking waves (see also *wave run-up*)

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Web sites

Tides:

MHWS for Standard Ports: http://www.hydro.linz.govt.nz/tides/info/tideinfo5.asp

MHWS for some Secondary Ports:
http://www.hydro.linz.govt.nz/tides/secports/index.asp

Tide forecasts for Standard Ports:
http://www.hydro.linz.govt.nz/tides/majports/index.asp

Tide predictions for open-coast sites from 1830 to 2006:
http://www.niwa.co.nz/services/tides

Resource Management & Policy:

Resource Management Act 1991:
http://www.legislation.govt.nz/browse_vw.asp?content-set=pal_statutes

Building Act 1991: http://www.legislation.govt.nz/browse_vw.asp?content-set=pal_statutes

Oceans Policy for New Zealand: www.oceans.govt.nz

Natural Hazards & Risks:

Coastal Hazards & Risk Assessment Information: http://coastalhazards.wcu.edu/

California Coastal Erosion Planning & Response:
http://resources.ca.gov/ocean/coastal_erosion_draft2.html

European Union Coastal Guide: http://www.coastalguide.org/

Hazards and Risk Virtual Library: http://life.csu.edu.au/hazards/

Natural Disaster Reference Database: http://ndrd.gsfc.nasa.gov/

NZ Natural Hazards Centre (NIWA/GNS): http://www.naturalhazards.net.nz/

The Tsunami Risks Project: http://www.nerc-bas.ac.uk/tsunami-risks/

Pacific Tsunami– PMEL Tsunami Program, NOAA:
http://www.pmel.noaa.gov/tsunami/

Pacific Tsunami Warning Center (Hawaii):
http://www.prh.noaa.gov/pr/ptwc/bulletins.htm

Climate Change Impacts:

Intergovernmental Panel on Climate Change: http://www.ipcc.ch/

NZ Climate Change Programme: http://www.climatechange.govt.nz/

Appendix 1: Relevant legislation

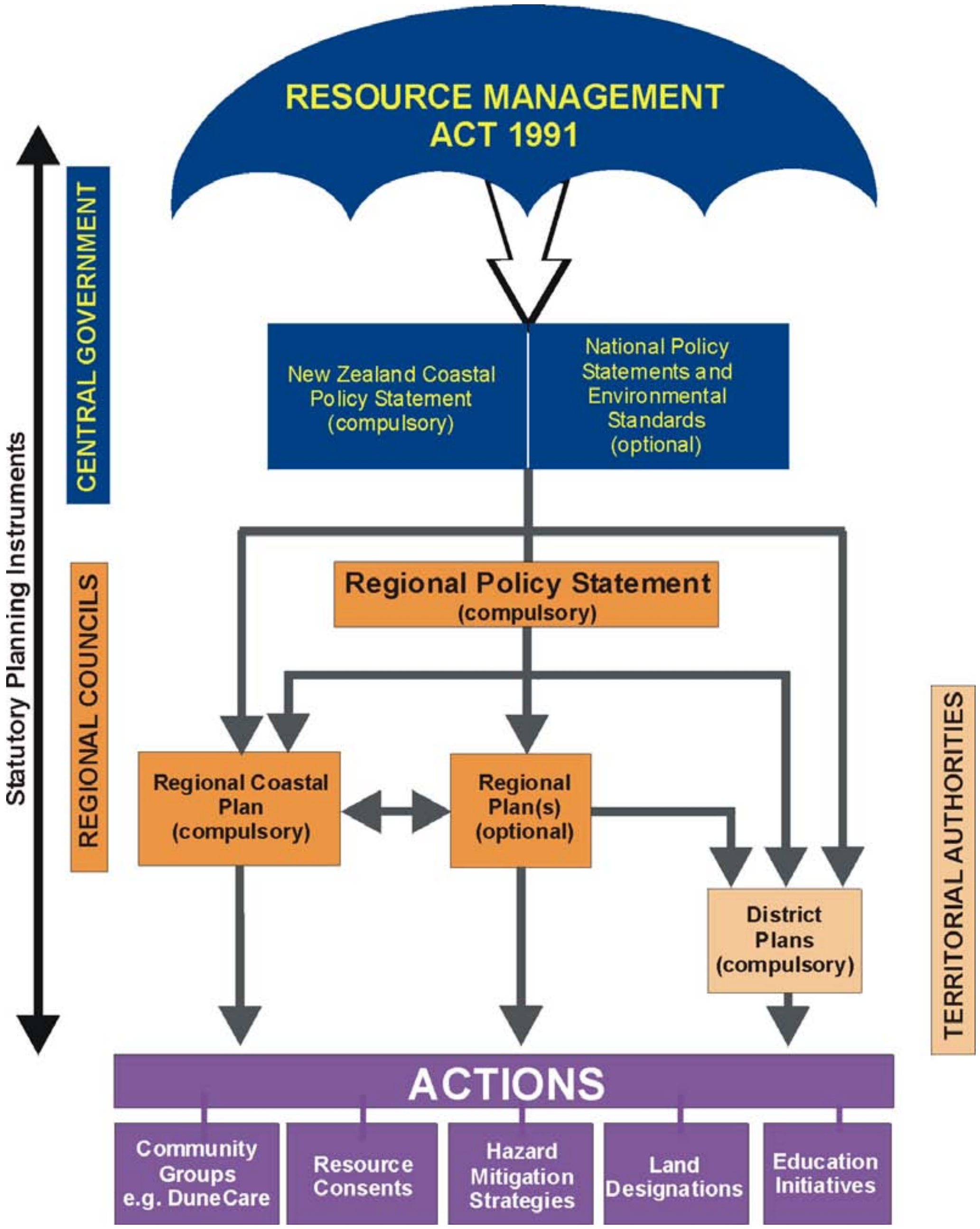

Figure A1.1: Hierarchy of Resource Management Act 1991 provisions.

Resource Management Act

Although coastal management is singled out in the Act, there is no specific part within the Act which deals with it.

Regional coastal plans focus on the sustainable management of natural and physical resources within the coastal marine area (below mean high water springs). Other regional plans can address natural resources, in particular land, (air) and water above mean high water springs, air quality and land management.

District Plans contain management provisions from a district perspective. Under the RMA, District Councils have particular responsibilities for the management of land above mean high water springs, including for subdivision, use and development. District Plans are required to not be inconsistent with the NZCPS, RPS and Regional Coastal Plan.

The issue of hazard management within District and Regional planning documents was considered in the case of Canterbury Regional Council v Banks Peninsula District Council in which McKay J. Court of Appeal noted that

> *It is true, … that natural hazard is not defined as being the consequence of the occurrence, but as the occurrence itself which has or potentially has the adverse consequence. What can be avoided or mitigated, however, is not the occurrence but its effect. Neither in s 30 nor in s 31 are the words "effects of" used in connection with "natural hazards". This is for the simple reason that they would be otiose[20], as the definition of "natural hazard" incorporates a reference to effects. The word "effects" would also be inappropriate in respect of s 30(1)(c)(i)-(iii). It is unnecessary and inappropriate to explain the language by reference to some subtle distinction between the respective functions of regional councils and territorial authorities.*
>
> *It follows that the control of the use of land for the avoidance of (sic) mitigation of natural hazards is within the powers of both regional councils and territorial authorities. There will no doubt be occasions where such matters need to be dealt with on a regional basis, and occasions where this is not necessary, or where interim or additional steps need to be taken by the territorial authority. Any controls imposed can be tested by appeal to the (Environment Court), and inconsistencies are precluded by s 75(2).*

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[20] Functionless.

Building Act

The relationship between the BA and RMA is considered in sections 68(2A) (regional rules) and 76(2A) (district rules) of the RMA, which states:

> *"Notwithstanding section 7(2) of the Building Act 1991, rules may be made under this section, for the protection of other property (as defined in section 2 of that Act) from the effects of surface water, which require persons undertaking building work to achieve performance criteria additional to or more restrictive than those specified in the building code in force under that Act."*

A corresponding reference is also contained within the Functional Requirement E.1.2, and corresponding Performance Standards of the Building Code. The reference in the Building Code is to 'surface water resulting from an *event*', which ensures that causes of flooding not associated with a storm, such as high tides, are to be taken into account. These events do not specifically refer to climate change events, and instead rely on such events having a 10 percent or 2 percent probability of occurring annually. The provisions will therefore, not protect property from coastal climate change hazards in the future.

Other provisions relevant to coastal hazards are outlined in section 30 and 36 of the Building Act. Section 30 of the BA addresses Land Information Memoranda and enables information to be made available to the purchaser at the time of sale on *potential erosion, avulsion, falling debris, subsidence, slippage, alluvium, or inundation,* that is not otherwise apparent in District Plans. Such provisions could include future coastal hazards likely to result from climate change until such time as more prescriptive criteria (such as through district plan provisions) are able to be established.

Section 36 of the BA notes that a territorial authority is required to refuse to grant a building consent for work on unstable land unless the authority is satisfied that the work will not increase the instability. A building consent granted for such land must be noted on the certificate of title.

In Arkinstall v Wairoa DC [1998] NZRMA 428, noted [1998] BRM Gazette 117, the Court accepted that s 36(2) BA91 was a more appropriate way to deal with concern about erosion, than requiring a covenant under s 108(2)(d) RMA91 to the effect that the only building allowed on the site must be relocatable. The Court adopted the reasoning of Hammond J in Coromandel Peninsula Watchdog Inc v Hauraki DC [1997] 1 NZLR 557, noted [1997] BRM Gazette 53, at p 566.

In many cases it has been argued that controls under the RMA do not need to be applied because the Building Act regulates building in areas subject to natural hazards. This argument has been rejected. In *Bay of Plenty Regional Council v Western Bay of*

Plenty District A27/02 the Court noted that both Acts regulate building in zones subject to natural hazards according to each Act's purpose. The RMA contains a wider environmental perspective than the Building Act ("sustainable management"). Generally the RMA provisions will be invoked initially and the Building Act will follow. In *Lowry Bay Residents Association v Eastern Bays Little Penguin Foundation Inc* W 45/01 (Judge Kenderdine presiding) the Court firmly rejected the argument that the potential of the proposed facility to be affected by severe storms, salt deposits and spray drift was not relevant because design of buildings is a matter dealt with under the Building Act. The Court expressed surprise that the development had been approved for an area demonstrably subject to coastal hazards.

Local Government Act 2002

This Act requires stopped roads along the margins of the coast (along Mean High Water Springs) to be vested in Council as esplanade reserves. The Local Government Act 1974 also establishes the means by which Council may collect financial contributions for funding the acquisition, maintenance and development of reserves.

Section 650A1(i) of the Local Government Amendment (No 2) Act allows for district councils to undertake various works in the coastal environment including the erection and maintenance of: quays, docks, piers, wharves, jetties, launching ramps, and any other works for '*the improvement, protection, management, or utilisation of waters within its district (subject to the controls established by the RMA)*'.

Civil Defence Emergency Management Act 2002

As part of the comprehensive approach to civil defence emergency management (CDEM), all hazards, not only natural hazards, must be taken into consideration.

The CDEMA requires CDEM Groups to form and prepare Civil Defence Emergency Management Plans by June 2005. CDEM Groups are cross-boundary, regional groupings of which all the region's local authorities are represented by their mayors.

The CDEM plans must state and provide for:

- the local authorities that have united to establish the CDEM Group;
- the hazards and risks to be managed by the Group;
- the civil defence emergency management necessary to manage the hazards and risks;
- the objectives of the plan and the relationship of each objective to the National Civil Defence Emergency Management Strategy;

- the apportionment between local authorities of liability for the provision of financial and other resources for the activities of the Group, and the basis for that apportionment;

- the arrangements for declaring a state of emergency in the area of the Group;

- the arrangements for co-operation and co-ordination with other Groups.

Reserves Act

The Reserves Act also enables the formation of esplanade reserves and eplanade strips (in accordance with the purposes outlined in the RMA) where land adjoins the coast. The key difference between these two provisions being that esplanade strips are not fixed in position but maintain their position relative to the coast (or other body of water), even if the coast moves. Unlike esplanade reserves, which can only be created in the circumstances outlined in the RMA, esplanade strips can also be created by voluntary agreement.

While the Reserves Act is based on public use and access, often reserve areas are used to provide buffers of coastal land through managed retreat, or adaptation responses where coastal hazards have been identified. Without explicit reference to buffer functions in a reserve management plan, it is questionable whether reserve areas can be treated in this way by TAs, because their buffering function may impact upon their specified use for reserve or open space recreation reserve.

The eight classifications of reserves differ in their degree of protection and public access rights.

Private Property Rights

RMA case law on property rights has clearly established that property rights are subject to RMA procedures.

The most important case on ‘property rights’ in this context is *Falkner v Gisborne District Council* [1995] 3 NZLR 622 (Barker J, High Court Gisborne). In that case it was held that a common law right to protect ones property from the sea must be subject to the procedures under the RMA.

In *Bay of Plenty Regional Council v Western Bay of Plenty District Council* A 27/02 (Judge Bollard presiding) the Court noted that the even if private property owners are prepared to accept the risk of a hazard, the council still has responsibility to control the use of ‘at risk’ land.

In *Skinner v Tauranga District Council* A 163/02 (Judge Bollard presiding) economic evidence was put forward of the decrease in property values if rules restricting development were included in the plan. However the Court said this was not sufficient to override the need for the council to plan ahead for coastal hazard risks.

In summary, arguments about overriding property rights, and residents who are prepared to accept the risk, have not succeeded.

Appendix 2: Hazard drivers and the effects of climate change

A2.1 Hazard drivers

A2.1.1 Sea-level fluctuations

Fluctuations in the mean level of the sea (after taking out the influence of tides) are an important component to consider when assessing the risk of coastal inundation, and to a lesser extent coastal erosion. The predominant timescales at which sea-level fluctuations occur at are:

- days to weeks (storms and winds);
- seasons (annual heating and cooling cycle by the sun on the ocean surface);
- interannual (3 to 5 year El Niño-Southern Oscillation[21] cycles);
- interdecadal (20 to 30 year Interdecadal Pacific Oscillation[22] cycles).

Besides the general long-term trend in rising sea level under past and future climate-change, climate change will also modify all of the above fluctuations in sea level to a greater or lesser extent.

Presently, the actual mean level of the sea can fluctuate by up to ±0.25 m when all the longer-period sea-level cycles of at least 6 months are included, but without considering storm effects or climate-change trends.

Seasonal variability over a year from thermal heating and cooling can amount to around ±0.04 m on average, but up to ±0.08 m in some years, with the maximum usually occurring between January to April.

ENSO-driven fluctuations in sea level at Mount Maunganui (Figure A2.1) approach ±0.12 m, with the highest sea levels occurring during La Niña episodes. This behaviour pattern is typical of both east and west coasts.

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[21] Cycle of alternate El Niño and La Niña episodes that govern climate and sea-level variations around the Pacific and Indian Oceans—commonly called the El Niño–Southern Oscillation or ENSO system.

[22] Longer "El-Niño–like" 20–30 year cycles of alternate positive and negative phases that effect the wider Pacific Ocean region, abbreviated as IPO. Since 1998 the IPO has been negative.

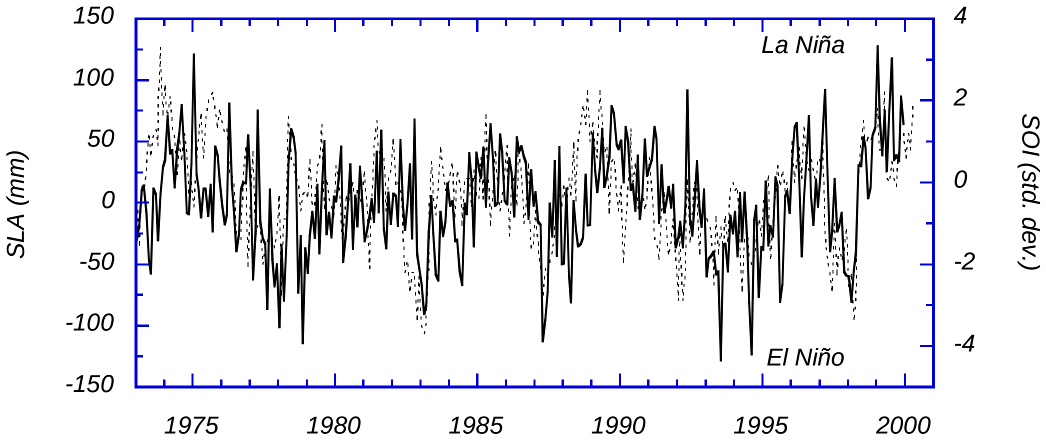

Figure A2.1: Mean sea-level anomaly (SLA) from Mt. Maunganui, after removing tides and the mean annual cycle, compared with the Southern Oscillation Index or SOI (dotted line) over the 27-year period 1973–2000. Positive values of SOI indicate La Niña conditions.

The IPO signal at 20–30 year cycles is clearly seen in New Zealand's longest sea-level record from the Port of Auckland shown in Fig A2.2. The IPO facilitates sea-level fluctuations of up to ±0.05 m, as indicated by the moving-average line, with the higher sea levels being recorded during the negative phase of the IPO.

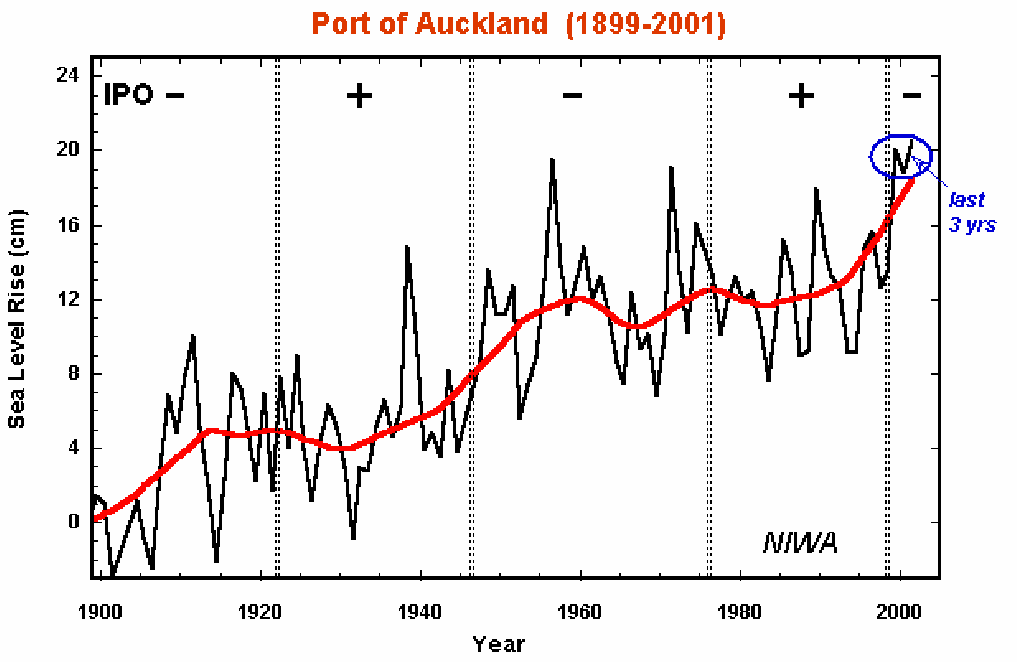

Figure A2.2: Annual fluctuations and the 20-year moving-average (thick red line) for mean-annual sea level from the Port of Auckland, compared with the positive and negative cycles of the IPO. [Note: the overall linear trend in historic sea-level rise is +0.16 m/century.]

A2.1.2 Tides

Timing and height of the tide is an important determinant for whether coastal or river-flood inundation from a storm will occur in a particular coastal area. Tidal currents are also an important process in shifting supplies of sediment via sandbars or deltas into and out of estuary and river entrances, feeding or starving the adjacent coastal beach systems. Consequently, tides are part of the coastal hazard equation (along with river sediment exports, coastal wave climate, and alongshore sediment drift) as to why the end of sand spits such as Ohiwa, Mokau, and South Brighton are vulnerable to excessive erosion or accretion. The delicate balance between these hazard drivers at river and estuary entrances has major implications for managing coastal erosion, increasingly so as climate change effects increase.

Tides are generated by gravitational forces exerted by both the Sun and Moon on the Earth's oceans. Ocean tide waves then propagate onto the continental shelf and into estuaries and harbours, being modified by wave refraction (where the tidal wave slows down and increases in tide range as the water becomes shallower), friction from the seabed, and constrictions such as estuary entrances, river mouths and straits.

As tide height is a critical component of any coastal inundation event, an upper-limit tide level is needed for a risk assessment (see inset box on assessing inundation levels in Section 4.4.2). One such upper level that is widely available is mean high water spring (MHWS)[23]. MHWS traditionally is computed as the long-term average of the highest high tide that occurs just after every New and Full Moon, called spring tides. Normally only around 10–12% of high tides would exceed the MHWS mark.

While MHWS is a simple concept and widely available, New Zealand tides along the central-eastern coasts don't easily fit with the traditional MHWS definition. For example, at Kaikoura over 50% of high tides exceed the MHWS level. The reason is there is little difference between the fortnightly neap and spring tides along the central-eastern region. Instead, the highest tides occur once a month (27.5 days), when the Moon's elliptical orbit takes it closest to the Earth (i.e., when the Moon is in its perigee). Therefore in estuaries and open coast locations from Christchurch to East Cape, a better 'hazard' definition of the peak monthly tides is to use a 'pragmatical' MHWS, such that only 10–12% of local high tides exceed it, or use the perigean-spring tide level. These different types of MHWS level may be able to be obtained from NIWA or the regional council.

Knowledge of the frequency distribution of high-tide heights (Figure A2.3) can also provide a useful context in assessing the coastal inundation risk over several decades and also to calculate a 'pragmatical' MHWS level for central-eastern coasts.

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[23] MHWS for Standard Ports is at: http://www.hydro.linz.govt.nz/tides/info/tideinfo5.asp and for some Secondary Ports at: http://www.hydro.linz.govt.nz/tides/secports/index.asp

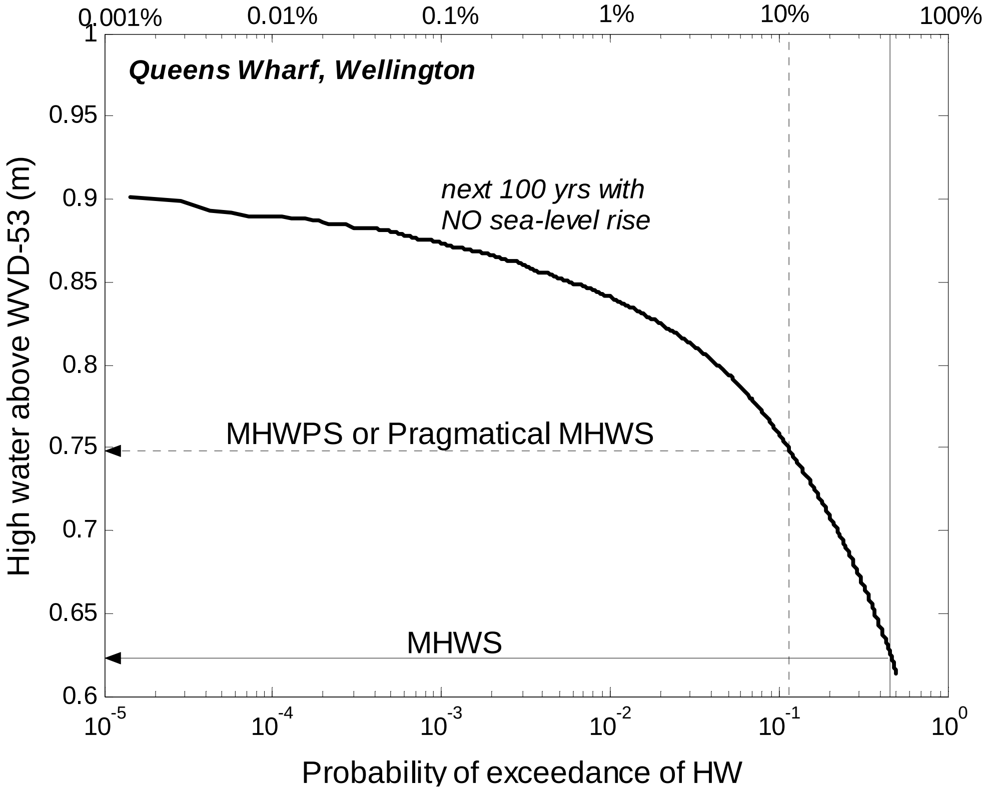


Figure A2.3: Example probability-of-exceedance plot of predicted high water (HW) heights over the next 100 years for Queens Wharf (Wellington), excluding storm and global-warming effects. The traditional MHWS level in Wellington is 0.62 m, but it is exceeded by 46% of all high waters. A ‘pragmatical’ or the mean high water perigean-spring (MHWPS) level, which is 0.13 m higher than MHWS, is only exceeded by 11% of all high waters. The peak predicted tide height for the next 100 years is another 0.15 m above the ‘pragmatical’ MHWS.

A2.1.3 Storms and adverse-weather patterns

Storms or sustained adverse weather patterns are the most well-known cause of coastal hazards. The effects can be sub-divided into:

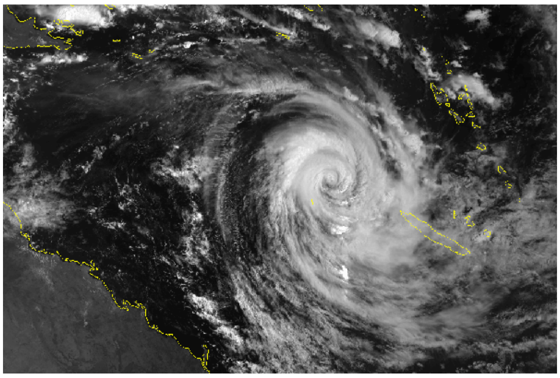
- weather-related causes that directly impact the coast:

  - ► severe meteorological events, such as extra-tropical cyclones (see Case Study below) or mid-latitude depressions, where strong winds cause damaging waves, strong currents and storm tides, and low barometric pressure further intensifies storm tides;
  - ► adverse-wind patterns over extended periods that contribute to chronic coastal erosion (or at the other end of the spectrum, chronic accretion) through movement of sediment up- or down-coast or offshore/onshore;

- weather-related causes that operate in the hinterland, but indirectly affect the coast:
    - ► severe storms producing heavy rainfall that cause rivers to flood, ultimately inundating low-lying coastal areas near river mouths and in estuaries, particularly during high tides, or changing geomorphological conditions at river mouths or along beach fronts that make coastal areas more susceptible to erosion/inundation;
    - ► storm events can deliver fresh sediment sources to coastal and estuarine systems via rivers;
    - ► adverse weather patterns, such as drought periods or El Niño episodes that produce westerly winds, when sediment supply to east-coast areas reduces, and vice-versa in La Niña conditions.

Waves and storm tides are discussed separately below, with inputs needed for the risk assessment process.

CASE STUDY: Ex-tropical cyclones—Cyclone *Drena* passed New Caledonia on 7 January 1997 en-route to New Zealand (see photo). Nearer New Zealand it re-intensified as an ex-tropical cyclone.



Cyclone *Drena* off New Caledonia on 7 January 1997. [*Photo: courtesy of NOAA]*

The storm hit both North and South Islands from 9 to 12 January with heavy rain, gale force winds, low pressure (990 hPa) and coincided with large tides that exceeded mean high water perigean-spring tides. *Drena* caused large ‘storm tides’ that lead to coastal inundation of properties in Moanataiari suburb of Thames (30 houses), New Plymouth and Nelson (Ruby Bay). On average, northern New Zealand is affected by one extra-tropical cyclone per year.

Waves and swell

New Zealand’s location in the open ocean between the strong westerly wind or ‘roaring forties’ belt (45–60°S) and the mid-latitude high pressure belt (30°S) means that the coast is exposed to one of the highest energy wave regimes in the world. The wind-generated waves observed at the coast represent the combination of locally generated (wind-sea) and distantly generated (swell) waves. In most northern and central regions, the local wind generated component tends to dominate, particularly during extreme storm conditions. However, there have been occurrences on otherwise fair-weather days of swell riding on the back of high tides causing coastal inundation through coastal barrier overtopping (Figure A2.4).

Figure A2.4: Coastal inundation at East Clive, south of Napier, in August 1974 caused by swell (right) on the back of very high tides overtopping the gravel coastal barrier and causing coastal inundation (left).

A consistent New Zealand-wide wave climate for the 20-year period 1979 to 1998 has been developed by NIWA.[24] The results are summarised in Figure A2.5 in terms of the 20-year average of the significant wave height H_{av}. (Note: *significant wave height* is a term used by engineers and scientists to embrace the higher bracket of all individual wave heights that occur over a period—usually over a 15 to 20 minute period—being the average height of the highest 33% of wave heights). The pattern of the 20-year average for significant wave height in Fig. A2.5 is only a general guide to open-coast wave exposure in assessing the coastal hazards, as many coastal localities have a degree of sheltering from deepwater waves in particular directions due to headlands or islands.

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[24] Gorman, R.M.; Bryan, K.R.; Laing, A.K. (2003). A wave hindcast for the New Zealand region–Deep water wave climate. *NZ Journal of Marine and Freshwater Research Vol. 37(3)*, in press.

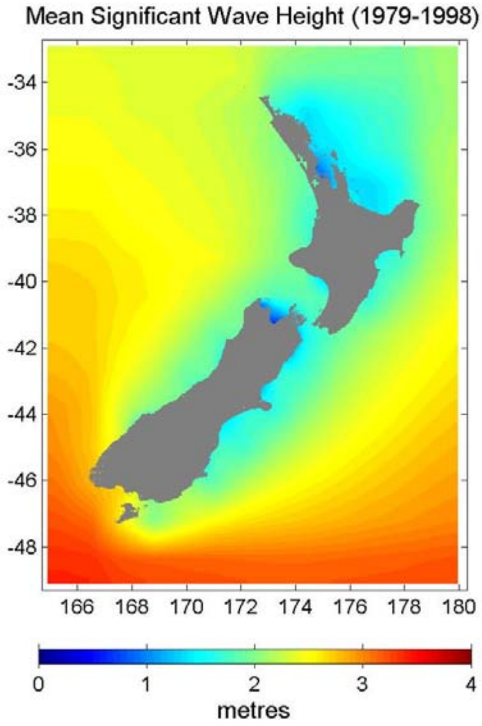

Figure A2.5: 20-year average of the significant wave height (H_{av}) around New Zealand, based on a deep-water wave model. Note: results are only approximate in coastal areas.

New Zealand can been subdivided into 4 major zones in terms of open-coast wave exposure for a broadly-based risk assessment. These zones are categorized by the range of the long-term mean for significant wave height (H_{av}), the average wave period between wave crests (T_{av}), and prevailing compass directions from where waves approach:

a) South-facing coasts, Fiordland to Catlins, South Island—an extremely high-energy wave zone (mean H_{av} =3–4 m; T_{av}=10–12 sec; SW–W). Waves are typically steep, indicating a zone of active wave generation, but also contain a sizable swell component from the Southern Ocean.

b) Western New Zealand coasts—a fairly high energy wave zone (mean H_{av} =2–3 m; T_{av}=6–8 sec; SW–W). The waves are steep and respond to the regular passage of weather systems across the Tasman Sea.

c) Eastern New Zealand up to East Cape—a moderate-energy wave zone (mean H_{av} =1.5–3 m; T_{av}=6–9 sec; S), due to sheltering from prevailing westerly winds by the New Zealand landmass. Wave steepness is variable, indicating a mixed swell and local sea environment.

d) North-eastern North Island (East Cape to North Cape)—a low-energy lee shore (mean H_{av} =1–2 m; T_{av}=5–7 sec, N–E). Wave steepness is variable. Highest waves occur during extra-tropical cyclones, or as swell that is generated by Pacific cyclones well out to the north-east of the North Island.

In all areas, waves are about 50% higher in the winter season compared with the summer.

During severe storms, waves can reach much higher levels than these long-term average wave heights, and therefore contribute to coastal inundation and/or coastal erosion. One example of extreme waves occurred during the *Wahine* storm on the 10 April 1968, when the significant wave height (H) exceeded 8 m and maximum wave heights reached 13 m off the south Wellington coast. Similar wave conditions also occurred along the south Wellington coast on Waitangi Day in 2002. The Wahine Storm also generated significant wave heights of up to 9.9m in the Bay of Plenty, and significant wave heights of 9.0m with a maximum wave height of 10.5m were recorded off Tauranga during Cyclone Fergus (1996) when average wind speeds reached 30 knots and gusts reached 64 knots.

At present there is no reliable set of extreme wave height statistics around the entire New Zealand coast. A consistent set of wave height statistics for different open-coast regions is currently being developed by NIWA from the 20-year wave climate study. Waves change in character from deep water to the nearshore due to wave breaking, refraction, defraction and shoaling. The processes are complex and site- specific, requiring consideration by an experienced coastal engineer or scientist.

In estuaries and harbours, waves are mostly generated by local winds and the crest height they can reach is limited by the wind fetch. Fetch is the distance downwind of continuous open water, with long fetches allowing the wind to build up larger waves. Wind waves in estuaries and harbours can still cause erosion and inundations hazards, particularly during very high tides or concurrent with a high storm-surge level from the open sea.

Waves contribute to coastal inundation hazards by three consecutive processes:

► wave set-up—after incoming waves break, the average level of the water inside the surf zone to the beach is set-up higher than the sea level offshore from the breaker zone;

► wave run-up—extra height elevation is reached as the broken waves run up the beach and adjacent coastal barrier (natural or artificial) until the wave energy is finally expended by friction and gravity; and

► overtopping—if wave run-up reaches the crest of the coastal barrier or defence structure, then seawater will spill over and flood land and properties behind the barrier. Also if the depth and velocity of overtopping wave-flow across the top of the coastal barrier are sufficiently high, the momentum of the flow can inflict considerable damage to coastal properties and cause injuries to people.

The factors that affect wave set-up are essentially the offshore wave height and wave period, together with the nearshore seabed slope. These factors may be similar over large stretches of coast in the district, which is why wave set-up is often included in the storm-tide level. In contrast, wave run-up at any coastal locality is usually quite site specific—factors such as beach slope, roughness (sand, gravel or large rocks), wave height, exposure to ocean swell, how close inshore waves can penetrate before breaking, and whether the shoreline is bounded by dunes, seawalls, or low cliffs, or worse, unbounded. In most cases, wave run-up calculations require assistance from coastal specialists, but for the purpose of a screening risk-assessment process, an indicative formula is given for typical natural sandy or estuary beaches (but not modified shorelines).

Wave set-up, run-up and overtopping can be assessed using various formulae and nomographs for wave set-up and run-up in the *Shore Protection Manual* (US Army Corps of Engineers 1984), or the recently completed Coastal Engineering Manual (US Army Corps of Engineers, 2003).

For coastlines with coastal protection works or cliffs terminating in ocean water with no intertidal buffer, wave run-up will be higher than for beach areas which assist dissipation, as large waves can approach much closer to the shoreline before breaking.

Waves also play a major role in causing coastal erosion, by de-stabilising and moving large quantities of sediment back and forth between the beach and nearshore bars, or moving sediments along the coast in the down-drift direction. Run-up/run-down, overtopping and cliff toe-attack by waves are other mechanisms for erosion. Waves approaching the coast at an angle to the shoreline will generate sediment drift down-coast of the approaching waves. Erosion can occur in this situation, especially if the drift is predominantly in one direction when any structure or natural feature traps sediment behind it, ‘starving’ the down-drift coast. Gentle swell and more quiescent waves following a storm usually assist in ‘re-stocking’ a beach by slowly combing sediment back onto the beach, helping it to recover. Sequencing of moderate to severe storms that generate high wave activity is also an important factor in the susceptibility of a beach or cliff to severe coastal erosion.

Storm surge and storm tides

Storm surges are temporary increases in coastal and estuary water levels associated with severe storms. Storm surge is a combination of two processes:

- strong persistent winds that ‘pile up’ water against the coast; and
- low barometric pressure allows sea level in a region to rise above the pre-storm sea level, known as the ‘inverted-barometer’ effect. (Cause: low atmospheric

pressure means the weight of air above the sea is reduced, allowing the sea level to temporarily rise above normal levels).

The mix of both the wind and inverted-barometer contributions can vary widely, but typically would be around 50:50 for extreme events. A storm surge can last from several hours to a few days, and can extend along at least 100 km of coast. In New Zealand, the most severe storms could generate storm-surge heights to just over 1 m above the predicted tide level. A New-Zealand wide default storm-surge height of 0.9 m can be used for the risk assessment process if local upper-limit values are not known.

The storm-surge hazard for a local coastal community depends on the total level reached by the sea at any shoreline location at any time. Therefore it is important to account for the normal ocean tide and the wave conditions at the time of the storm surge. The combined total sea level (storm surge + high tide + wave set-up) that could impact the coast is called the '**storm tide**', and is the term used in this Guidance Manual as the storm driver for coastal inundation hazards. As discussed in the previous section, wave run-up must be added to the storm-tide to estimate the total storm-driven elevation of the sea that could impact coastal properties or infrastructure.

The likelihood of coastal inundation relates to the joint probability of a storm response (random chance) coinciding with reasonably high tides. Though tides are well described, storm-surge measurements around New Zealand are limited, which makes it difficult to carry out a rigorous return-period analysis of the likelihood of coastal inundation from storm tides around the New Zealand coast. In the interim, the combination of an equivalent MHWS or MWHPS high tide level and a default value of a 0.9 m storm surge, along with estimates of wave set-up and wave run-up will provide a realistic severe storm-tide 'event'.

A high storm tide in isolation does not necessarily imply that coastal erosion will take place, but the potential for erosion increases as waves are able to mobilise sediments further up towards the back-beach or the toe of coastal cliffs or dunes.

CASE STUDY: Worst North Island storm-tide events of last century—The impact of the *Wahine* storm (ex-tropical cyclone *Giselle*) on the Bay of Plenty produced a storm tide of around a 75-year return period. Barometric pressure fell to 963 hPa accompanied by winds gusting to 90 knots, producing a 0.9 m storm surge at the Port of Tauranga (inside Tauranga Harbour). Fortunately it coincided with neap tides.

Large seas of up to 10 m whipped up by ex-tropical cyclone *Giselle* (Wahine storm) off Mt Maunganui on 10 April 1968. [*Photo: Tauranga Harbour Board engineer*]

The biggest storm-tide events last century occurred close together in 1936. The Great Cyclone of 1–2 Feb 1936, with barometric pressures down to 970 hPa and ferocious winds, on the back of a very high perigean-spring tide, caused widespread coastal inundation damage along the east coast of the North Island. Coastal roads were washed away, a house fell into the sea at Te Kaha, while the sea swamped houses 100 metres inland at Castlepoint when the sea broached the coastal dunes.[25] A month later on 25–26 March 1936, an easterly gale produced by a low depression combined with extremely high 100-year high tides. This event caused extensive sea-flooding of the Hauraki Plains and some low-lying areas of Auckland.

A2.1.4 Earthquakes and undersea landslides and volcanoes (tsunami)

Geological processes operating on or within the seafloor can cause coastal hazards in the form of a tsunami. *Tsunami* is a Japanese word meaning ‘harbour wave or waves’, because these long waves only amplify and become obvious in coastal waters. Tsunami are generated by large earthquakes (generally Magnitude >7) that rupture the seafloor, submarine landslides (which may or may not be caused by earthquake shaking), undersea volcanic eruptions, or from large coastal cliff slides into the sea. In terms of risk and emergency management, tsunami exceeding 1 m in height at the coast are considered to be a significant hazard requiring a Civil Defence response, while a tsunami exceeding 10 m height would be catastrophic. Considering all historic and known prehistoric tsunami events recorded anywhere in New Zealand, the average return periods for 1, 5, and 10 m wave heights occuring somewhere on the New Zealand coast are approximately 8, 18 and 53 years.[26] For example, tsunami of approximately 10 m height are believed to have occurred in 1947 (north of Gisborne) and 1868 (Chatham Islands).

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[25] Brenstrum, E. (1998). *The New Zealand Weather Book*. Craig Potton Publishing, Nelson.

[26] de Lange, W.P.; Fraser, R. (1999). Overview of tsunami hazard in New Zealand. *Tephra Vol. 17*, p. 3–9.

It is helpful to categorise tsunami into two types according to their source region because their characteristics and risk profiles differ:

- *local* tsunami—generated on New Zealand’s continental shelf, where active offshore faults, undersea volcanoes or steep/unstable continental slopes or large coastal bluffs are present. Local tsunami are characterised by short periods between wave crests, could reach large heights (>10 m) over short stretches of coast, but die away reasonably quickly. [NZ risk areas ☞ *East-coast North Island (Northland to Wairarapa), Kaikoura, Southland, Fiordland/Westland, Greater Cook Strait*[27]];

- *remote* tsunami—generated beyond New Zealand’s continental shelf, with the predominant risk from South America. Remote tsunami waves have longer periods, more limited in maximum wave height at the coast than local tsunami (e.g., up to 5–10 m), impact wide stretches of coast and can persist for several days. [NZ risk areas ☞ *entire east coast, Southland, Greater Cook Strait*].

The best available source of information on tsunami risk in the New Zealand context is the October 1999 issue of *Tephra* published by the Ministry of Civil Defence and Emergency Management. This information is about to be updated in Goff et al. (2003). However, much further work is needed to build in the risk of local tsunami in different parts of New Zealand, and the knowledge that tsunami comprising different wave periods will resonate or amplify in different parts of our coastline. In the interim, approximate return periods for different magnitudes of maximum vertical tsunami height (to be superimposed on the local tide and sea level) are listed in Table A2.1 and shown in Figure A2.6. Dr Willem de Lange is currently revising this information.

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[27] Includes Cook Strait, Marlborough, South Taranaki Bight and Tasman/Golden Bays.

Table A2.1: Return periods (years) for specified tsunami heights determined for a selection of New Zealand major and minor ports. These results should be treated with caution as the data used to derive the distributions are of limited quality. The results are based mainly on remote tsunami data. [*Source*: de Lange & Fraser (1999)].

Tsunami return periods (yrs)				
	Tsunami height (m)			
Location	**1.0**	**2.5**	**5.0**	**10.0**
Whangarei	179	930	14,500	3,510,000
Auckland	85	427	6,280	1,360,000
Tauranga	80	322	3,300	345,000
Gisborne	44	67	135	556
Napier	56	97	243	1,540
Wanganui	79	147	414	3,260
Wellington	40	119	728	27,200
Lyttelton	35	52	101	376
Timaru	63	130	439	5,010
Dunedin	125	1075	39,000	51,000,000

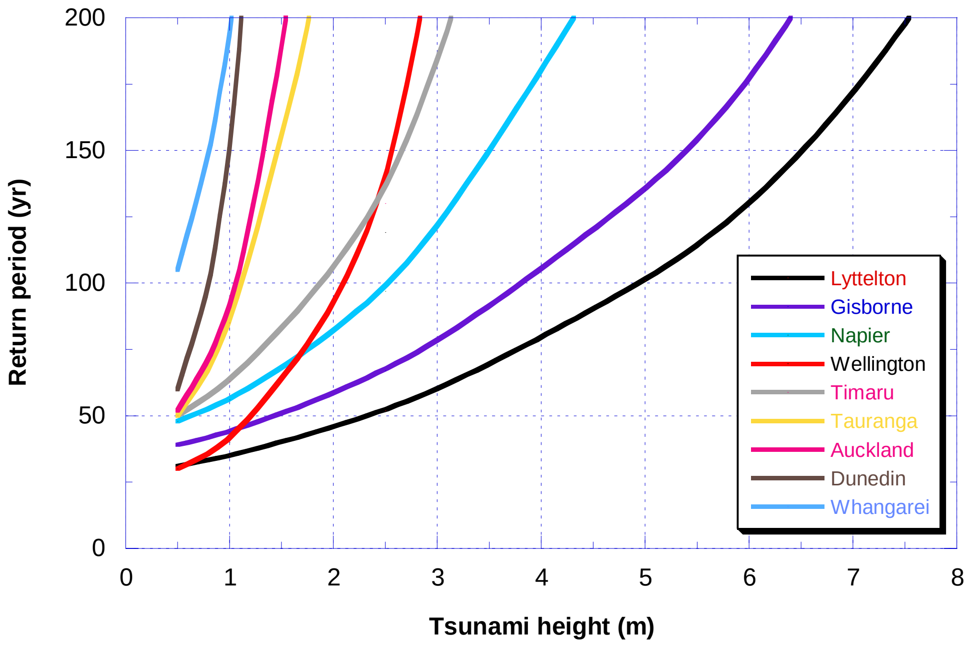

Figure A2.6: Return-period distributions for major ports around New Zealand, based on the data in Table A2.1. Clearly Lyttelton and Gisborne areas have the highest likelihood. [*Source*: de Lange & Fraser (1999)].

A2.2 Impacts of climate change on coastal hazard drivers

Climate change due to global warming will have a profound effect on coastal communities and environments. However, climate change won't introduce any 'new' coastal hazards—instead it will impact on existing coastal hazards through changes to hazard drivers. In very general terms, localities that are currently subject to occasional coastal hazards, are likely to suffer increased risks with a warming climate, while areas that are currently in a delicate balance may begin to experience more damaging coastal hazards in future.

A2.2.1 Climate change effects on sea level

There is no doubt that future sea-level rise due to increased global warming will contribute to a worsening situation with respect to coastal hazards. As shown by the overall trend in Figure A2.3 for sea-level data from the Port of Auckland (and similarly for our other main ports), sea level has been steadily rising around the New Zealand coastline at a national average of about +0.16 m/century, with a ±0.04 m/century variation between the four main ports (Auckland, Wellington, Lyttelton, Dunedin)[28]. (This rise is also evidenced by the fact that older MSL survey datums established in the 1940-50's around New Zealand are now several cm's below the current mean level of the sea.) The variations between the main ports in the linear trend in sea level are mainly accounted for by different rates of land subsidence or uplift and the quality of the historic data.

The long historic records from New Zealand ports demonstrate clearly that sea level is rising–so far in a linear fashion. However, as global warming becomes established and the oceans begin to warm, the rise in sea level is projected to accelerate in the near future. Global sea-level rise projections for the rest of this century have been issued by the Intergovernmental Panel on Climate Change (IPCC) in their Third Assessment Report.[29]

Although there are variations in sea-level rise around the world, mainly due to differences in vertical land movement (uplift or subsidence), research in the New Zealand region indicates that, at this stage, the IPCC (2001) global projections for sea-level rise are reasonable estimates to use for New Zealand. One exception may be Canterbury, where the historic relative sea-level rise is a little higher, around 0.2 m per century (based on Port of Lyttelton records), indicating a small degree of subsidence is occurring. However, until further land-movement assessments are complete, the NZ-

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[28] Prof J. Hannah (Univ. of Otago, pers. com.-publication pending).

[29] IPCC (2001). Climate Change 2001: The scientific basis. Technical Summary of the Working Group I report, contributing to the Third Assessment Report of IPCC. Available at: http://www.grida.no/climate/ipcc_tar/wg1/index.htm

wide average should be used. Further research continues on sea-level variability in our regional oceans, as well as GPS[30] measurements on vertical land movements.

Figure A2.7 combines the historic relative sea-level rise of 0.16 m per century at Auckland over the past 100 years (which is close to the global-average of around 0.18 m per century) with the projected accelerating sea-level rise to 2100 due to global warming from IPCC(2001). The uncertainty bands increase towards the end of this century due to uncertainties in the science and modelling, and also the uncertainty about what the world's socio-economic systems (including use of fossil fuels) will look like in 100 years time. The historic annual mean sea-level fluctuations from Figure A2.2 are also plotted in Figure A2.7, illustrating the extent to which sea level can fluctuate from year-to-year about the long-term trend (see Section A2.1.2).

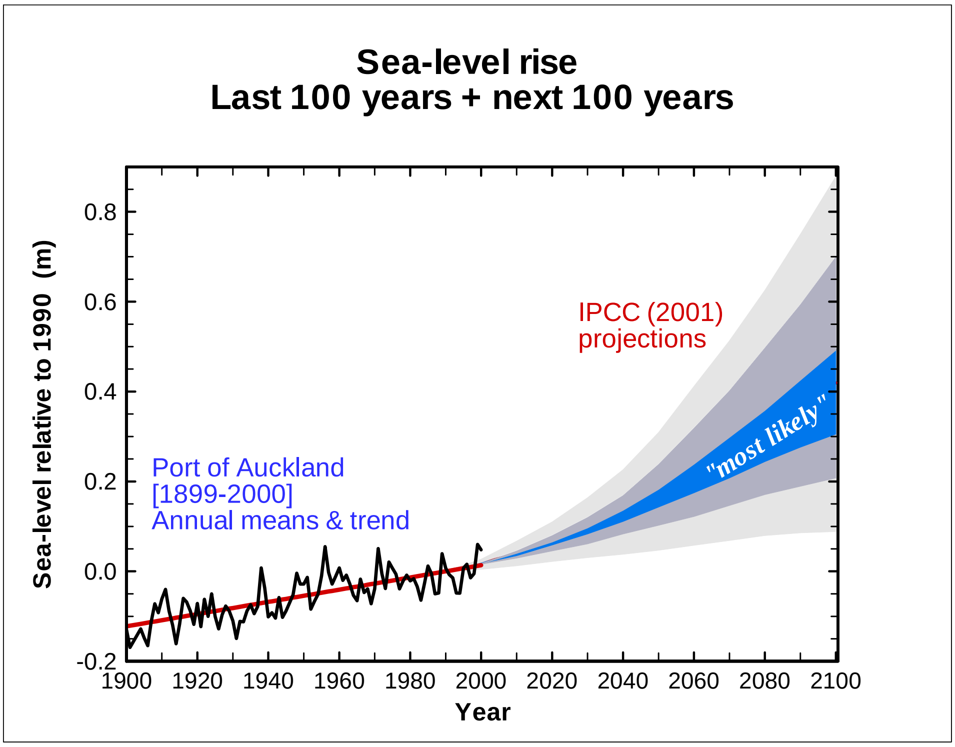

Figure A2.7: Relative sea-level trend (linear) for Auckland since 1899 (red), superimposed on the annual variability in the mean level of the sea (black), spliced with the predicted IPCC (2001) projections for global sea-level rise from 1990 up to 2100. The middle 'most likely' (blue) zone spans the range of average estimates produced by a range of climate-ocean models. The least likely estimates (high and low) are the lightest-coloured zones. (Note: sea level has been plotted relative to the 1990 sea level, which for Auckland was 1.840 m above gauge datum.)

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[30] Global Positioning System: a few NZ coastal sites have a GPS mounted permanently recording height and horizontal movement. http://www.gns.cri.nz/what/earthact/crustal/contgps.html

Recommended sea-level rises to use in the risk assessment process are listed in Table A2.2, along with the various uncertainty ranges.

IPCC have only issued formal projections on sea-level rise to the year 2100. However, for long-term planning in coastal areas it is important to note that IPCC expect sea level will continue to rise for several centuries, even if greenhouse gas emissions are stabilised. This is due to the long lag times needed for the deep oceans to respond to ocean surface heating and the expected contributions from the massive Antarctica and Greenland ice sheets after 2100.

Table A2.2: Projections of future sea-level rise (SLR) for New Zealand above 1990 mean sea level. Values in blue-shaded row are recommended for use in the risk assessment process.

Scenario	Climate factors	SLR by 2050 (m)	SLR by 2100 (m)
Recommended NZ sea-level rise magnitudes		0.2	0.5
IPCC–2001 'Most-likely' mid-range [Figure A2.7]	Averages of climate models & socio-economic scenarios	0.14–0.18	0.31–0.49
IPCC–2001 Outer ranges [Figure A2.7]	Intermediate zones	0.10–0.24	0.21–0.70
	Upper & lower extreme zones	0.05–0.31	0.09–0.88
Average historic NZ trend continues (0.16 m/century)	No change in sea-level trend over the 1900's	0.08	0.16

Note: 'Most-likely' projections and uncertainty ranges (Figure A2.7) for future global sea-level rise (SLR) by 2050 and 2100 from IPCC (2001), compared with a continuance of the NZ-average rise in relative sea level from 1900's with no acceleration. Suggested 'most-likely' SLR projections to work with are shaded in blue.

***CASE STUDY: Interaction of tides and sea-level rise at Wellington*—**The effect of a rising sea level can be illustrated by Figure A2.8, using the present exceedance curve for high tides in Wellington (Figure A2.3). At present, the maximum high-water level is 0.9 m above datum at Wellington (lower curve). With a projected 0.2 m rise in sea level by 2050, this present maximum high-water mark will be exceeded by 22% of all high tides (follow arrows on Fig A2.8). After a projected 0.5 m rise in sea level by 2100, that same present-day mark will be exceeded by 99.9% of all high tides. This illustrates the rapid rise in the likelihood of extreme high tides exceeding a given level, which in turn will increase the likelihood of storm tides or tsunami exceeding a specified datum level.

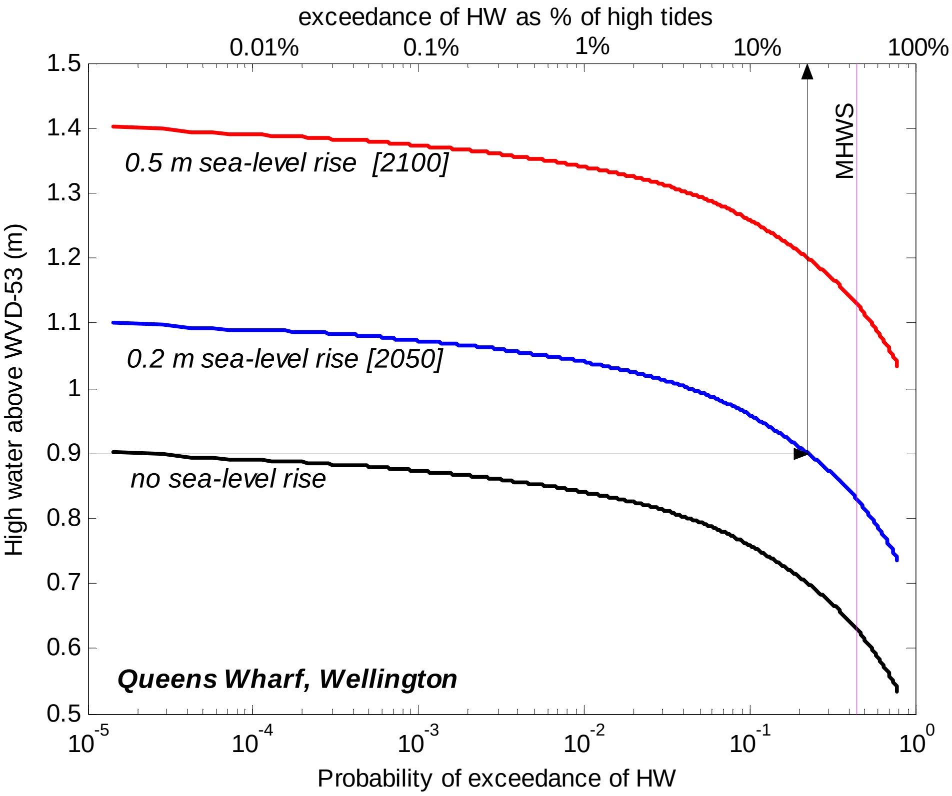

Figure A2.8: Example probability-of-exceedance curves for High Water (HW) based on 100-years of tidal predictions at Queens Wharf (Wellington), illustrating the effect of sea-level rise on the increased frequency of the present-day maximum high water level being exceeded (in this case 0.9 m above datum).

A2.2.2 Climate change effects on storms

New Zealand is subject to storms that originate from either the tropics (ex-tropical cyclones) or mid-latitudes (mid-Tasman depressions, southerly gales and fronts).[31]

The IPCC Third Assessment indicates that by 2100 it is likely that in some regions the peak wind intensities in tropical cyclones may increase by 5–10%. Tropical cyclones change their characteristics by the time they reach New Zealand, evolving into ex-tropical cyclones, and tend to affect mainly northern and eastern coastlines of the North Island and central eastern regions (Wellington, North Canterbury). During La Niña episodes, ex-tropical cyclones tend to track more directly southwards towards New Zealand, while during El Niño episodes, they tend to track more south-easterly. However, during both ENSO episodes, the frequency of occurrence is still about 1 severe ex-tropical cyclone per year that reaches New Zealand. Climate models discussed in the Overview Guidance Note show an El Niño-like change in the overall mean state of the tropical Pacific over the next 50 years. Whether or not this decreases

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[31] Revell, M. (2003). Weather systems that produce floods and gales. *Tephra*, *Vol. 20*, p. 2–6. Ministry of Civil Defence & Emergency Management, Wellington.

the likelihood of severe ex-tropical cyclones reaching central New Zealand is not clear, but northern regions will likely continue being impacted with a similar frequency of about 1 severe event per year. With warmer air and sea temperatures, the moist processes that govern the development and associated winds of an ex-tropical cyclone may lead to an increase in wind intensity during severe events.

Mid-latitude storms are discussed in detail in the Overview Guidance Note. “Storminess” is likely to increase in the Southern Hemisphere this century, but it is not yet possible to say whether this would mean more intense storms or a higher frequency of passing cold fronts, or a combination of these. Also regional changes over New Zealand may vary considerably from this projection for the Southern Hemisphere.

A2.2.3 Climate change effects on ocean currents, winds, and waves

Global ocean-atmosphere climate models do not include enough detail to show the narrow ocean currents that flow over the continental shelf around New Zealand. At a broad scale, there may be little change to the northern warm-water currents that flow down the eastern North Island, but increased westerlies to the south of New Zealand may accelerate the cold Antarctic Circumpolar Current, as discussed by the Overview Guidance Note.

With global warming, the average westerly wind component across New Zealand is suggested to increase by approximately 10% of its current mean value in the next 50 years.[32] However, changes to the average state of winds doesn’t easily translate into what changes we might experience in extreme winds. Strong winds are associated with intense convection (expected to increase in a warmer atmosphere) and with intense low-pressure systems (see above section), so an increase in severe wind hazards could occur, as discussed in the companion guidance manual to this document “Climate Change Effects and Impacts Assessment”.

Due to the short length and paucity of historic wave measurements around New Zealand, changes in wave patterns associated with global warming are not easily discerned. Increased westerlies (as described above) would affect the ocean wave climate around New Zealand, especially in southern and western coastlines. Coastal regions exposed to prevailing westerly and south-westerly winds would be subject to an increase in the frequency of heavy seas and swell that would add to the effects of higher sea levels. Waves generated by extreme storms could also increase if storm intensity increases with climate change.

A2.2.4 Climate change effects on sediment supply to the coast

Sediment is “food” to open-coast systems, so the effects of climate change on factors that affect the supply of sediment to the coastal/estuarine regions is critical to the

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[32] Mullan, B.; Bowen, M.; Chiswell, S. (2001). The crystal ball: model predictions of future climate. *NIWA Water & Atmosphere Vol. 9*: p. 10–11.

assessment of future coastal erosion hazards. Important factors that affect coastal sediment budgets are: the availability of offshore sediments to be moved onshore; changes in wave and wind climate; foredune and cliff stability; changes in river and catchment supply of sediment, abrasion; and carbonate production from ground-down shells.

Possible climate-change outlooks for wind and wave patterns (described in the previous section) will also affect different erosion and deposition processes along the coast, such as increased erosion of foredunes, gravel barriers and cliffs during extreme events, and loss or gain of sediments from the shoreline by wind blow or higher waves reaching the deeper seabed sediments more often.

Increasing sea levels will increase the tidal prism (volume of water that comes in and out each tide) in estuaries bordered by low-lying land areas, where the higher seas can encroach onto a wider area (if not bounded). This change in tidal prism is likely to alter the tidal current patterns at estuary and harbour entrances, including higher current speeds, which could alter the formation and movement of sand bars. Such changes induced at tidal entrances and estuary/river mouths may well cause further detrimental erosion on the adjacent shorelines either side of these entrances, given that these areas, such as the end of sand spits, have always been highly dynamic with marked shoreline shifts (e.g., see Ohiwa Spit photo in Fig. 1.1, where the shoreline has fluctuated within a range of around 200 m).

Changes to run-off from rivers and catchments could also markedly affect sediment delivery to the coast, provided the rivers are not already constrained by dams. A warmer atmosphere can hold more moisture, so the potential for heavier extreme rainfall (and hence higher river/sediment flows) certainly exists. The Overview Guidance Note indicates that a particular storm scenario, under a 2°C change in temperature and a 10% increase in wind speed, could result in a 16% increase in both maximum and catchment-averaged rainfall. Various modelling studies suggest that heavy rainfall events will occur more frequently in New Zealand over this century, but the likely size of this change is not yet very certain. Even less certain is how sediment delivery to the coast for different regions will respond to not only heavier, more intense rainfall events, but also greater frequencies and persistence of drought events in eastern areas, or growing urbanisation (hardening) of catchments.

A2.2.5 Climate change effects on coastal erosion

The previous section described the various perturbations from climate change that could individually impact on the supply of sediment to coastal and estuary shorelines—some may deliver more sediment to the coast, while others will reduce supply. Adding together the effects of these perturbations (pluses and minuses) plus the potential future changes in dynamics of shoreline behaviour, whether they be sandy shores, cliffs or estuarine shores, poses a real challenge in trying to produce credible predictions of trends in coastal erosion for the next 50+ years.

On sandy shores, it is generally anticipated that future sea level rise is likely to bring an increase in rates of shoreline erosion for eroding beaches, while stable to slightly-accreting beaches may begin to erode. This expectation is behind the intuitive reasoning that lies behind the so-called 'Bruun Rule' (Bruun, 1962, 1988), which was developed as a simple predictor of shoreline retreat. Bruun's model balances sediment in the beach with that in the nearshore seabed profile in response to sea-level rise. The model predicts that, as sea level rises, there will be an adjustment in the shape of the seabed and beach profile, resulting in (Fig. A2.9): (a) a shoreward displacement of a beach as the backshore is eroded; (b) movement of this eroded sediment being equal in volume to sediment deposited on the near offshore seabed; and (c) a rise of the near offshore seabed as a result of this deposition, equal in height to the sea-level rise.

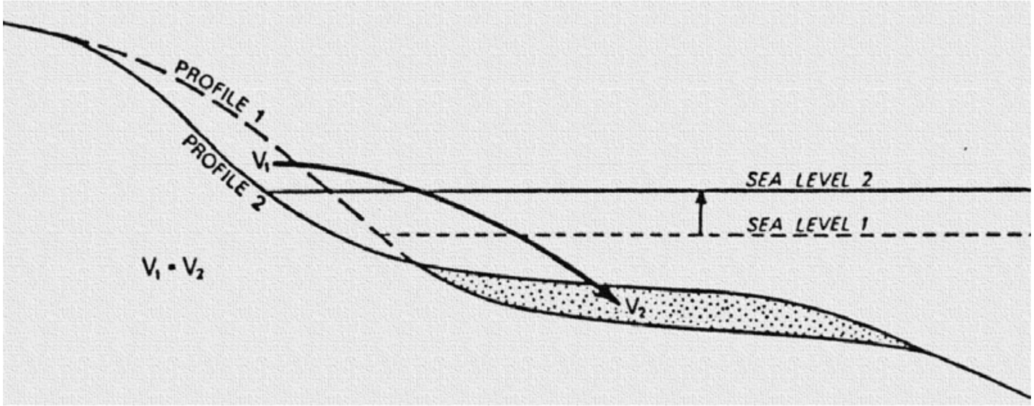

Fig. A2.9: Schematic of the Bruun Rule: response of the beach/nearshore profile to a relative sea-level rise, based on a shift from one state of *equilibrium* profile to another, where the volume V_1 of sediment lost from the backshore is conserved in the two-dimensional profile by being deposited offshore (V_2), but results in a retreat of the backshore.

Because of its simplicity, the Bruun Rule is often used in the management and long-term planning for coastal margins under a rising sea-level scenario. For typical beach profiles in New Zealand, the Bruun Rule predicts horizontal shoreline retreat rates at between 10 to 100 times the vertical sea-level rise rate. Details of how to use the Bruun Rule can be found in Bruun (1962, 1988), most coastal textbooks (e.g., Komar, 1997; Douglas et al., 2001), or refer to the ARC Coastal Erosion Handbook (ARC, 2000) for various methods of estimating coastal erosion hazard zones. However, before applying this method, it is important to understand the assumptions and limitations of the Bruun Rule. In particular, the model:

- describes the general overall shape (an equilibrium or statistical average profile), which will vary with storm events;

- applies to a two-dimensional *equilibrium* profile, wherein there is no longshore drift and the sediment volume is conserved within the cross-shore profile;
- is sensitive to selecting the distance offshore, and hence water depth, particularly the outer boundary of the active beach-nearshore profile (sometimes called the profile *closure depth*);
- can not be applied where site-specific factors for long-term erosion or accretion exist, such as in the vicinity of port breakwaters, groynes, channel dredging and dammed rivers, or to beaches near the entrance to rivers and estuaries;
- does not imply the sea-level rise itself actually causes erosion; rather, increased sea level enables high-energy storm waves to attack further up the beach and transport sand offshore. By inference, such a situation does not apply to flat intertidal beaches in estuaries, where shoreline retreat can be dominated by *inundation* from a higher sea level, not just erosion (loss of sediment), and waves can only impact the beach at high spring tides;
- was developed for sandy beaches (Bruun, 1988). It does not readily describe the response of mixed shingle/sand beaches, muddy coasts and cliffs.

Recent articles and papers continue to debate the relative merits and applicability of the Bruun Rule, especially if applied locally at a site rather than regionally or near tidal inlets (e.g., Pilkey and Cooper, 2004; Zhang et al., 2004; Stive, 2004).

For coastal cliffs, coastal retreat accompanying sea level rise depends on factors that are not directly related to the actions of the sea, such as rock types, hydro-geological processes and slope stability. Coastal cliffs can be categorised according to their composition on a scale from hard to soft. Erosion of *hard* rock or *semi-hard* cliffs (e.g. Waitemata Group cliffs in North Shore City) is mainly by way of weathering, mass slumping or slab failure, with undercutting of the toe by wave action only a secondary factor (Moon and de Lange, 2003). Any future alteration in erosion rates of these types of cliffs is more likely to be impacted by climate-change effects on hydrological “drivers” (e.g., soil moisture, heavy rainfall, droughts, groundwater) rather than sea-level rise, except where cliffs are quite low. On the other hand, *soft* coastal cliffs comprising clays or unconsolidated gravels are more likely to undergo massive slope failure that is more directly linked to undercutting at the toe by wave action. In these cases, future sea-level rise is likely to facilitate higher wave energy at the toe of the cliff, provided the shore platform is narrow[33], thereby potentially accelerating cliff erosion in tandem with climate-change impacts on hydrological processes. Further guidance on coastal cliff processes and hazard management are available in ARC (2000), Moon & de Lange (2003) and Glassey et al. (2003).

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[33] Note: wide, shallow shore platforms at the base of cliffs provide a dissipative environment for incoming waves, considerably reducing the energy of waves impacting on the cliff face, even with moderate rises in sea level.

Appendix 3: The response of different coastline types to coastal hazards

A3.1 Open-coast sand beaches

A sand beach system generally comprises compartments such as dunes, the backshore (normally not reached by tide), the intertidal beach (foreshore) and sand in the shallow nearshore, including the nearshore bar (where most of the wave breaking occurs). Sand is exchanged between these compartments by the wind and waves. Sand exchange between the dunes and the beach is retarded by the growth of vegetation, which traps material. Sand can also be delivered to the beaches by rivers and streams, from cliff erosion, from neighbouring coastal areas by wave-driven littoral drift, from the breakdown of shells, and reworked ashore from offshore seabed sediments.

Prior to human intervention, sand dunes on beaches provided good buffers against both coastal inundation and erosion hazards. Where dunes have been removed by development there is little natural defence (or ‘buffer’) against coastal erosion and inundation. Developments behind the foredune also prevent the dune from migrating landward (even temporarily); hence on a beach experiencing long-term erosion, the size of the natural buffer is continually reducing.

Removing vegetation leaves bare sand, which is prone to wind erosion. Removing native sand-binding species and replacing them with introduced sand binders, predominantly marram, produces a higher and steeper ‘dunescape’ which can cause ‘blowouts’.

In some open coast locations, the foredune has been removed completely. These ‘foreshore only’ systems have little natural protection against erosion and inundation. As a consequence, coastal protection measures are often installed, including seawalls or rock revetments. These structures often do not dissipate the energy of wave run up. Instead they cause increased turbulence at the toe of the structure, which in turn causes increased scour and beach lowering. They also prevent the foreshore migrating landward to capture additional sediment, and in some locations have resulted in the total loss of the beach (e.g., Sumner, Christchurch).

Sand spits and sand barriers warrant special consideration from a coastal hazards perspective, particularly when they are narrow. New Zealand has many examples e.g., Ohope/Ohiwa, Omaha, and South Brighton. The end of the sand spit or barrier is very transient, even under normal tidal conditions, but particularly during storms and at times of river floods. Sand spits are among the most dynamic and changeable landforms found on the planet.

Beach and dune erosion is exacerbated locally at stream mouths or stormwater outlets due to both direct erosion as the stream meanders with time, and indirectly because the high water table in the beach sediments makes them more susceptible to erosion.

Long term and storm-induced erosion (sandy beaches)

At longer time scales, slow rates of shoreline change (0 to 1 m/yr) are most common. Rates of long-term erosion greater than 2 m/yr are less common, and long-term rates greater than 5 m/yr are rare (except for sand spits). Although over the long term there may be little change in shoreline position, movements over medium-term timescales (e.g., a couple of years up to decades) can be large and rapid. The most noticeable place where this occurs is on sand spits, where movements of hundreds of metres can occur in a matter of years. For example, the end of the Brighton Spit in Christchurch retreated 500 m in 9 years between 1940 and 1949. Coastal erosion of sandy beaches is also often serious with ‘foreshore only’ beaches that are tightly squeezed or ‘bounded’ by development or coastal protection works.

Short-term erosion occurs as a result of individual storm events, or multiple storm events over periods of weeks or a few months. These short-term responses need to be added to the long-term changes to assess total susceptibility to erosion.

Inundation caused by storms

Sand beach foreshores tend to be very flat, with slopes of 1:20 to 1:50 being common. Depending whether the beach has recently been in an erosional or accretion phase, the upper limit of these foreshores tend to be in the order of 2 to 4 m above MSL. Even in an accreted state, moderate storm run-up will run over the foreshore to the sand dunes or what ever lies behind the foreshore. Therefore ‘foreshore only’ shorelines are very vulnerable to coastal inundation.

Sand dunes are much steeper than the foreshore, so run-up onto dunes is generally less than on the foreshore. Nevertheless, run-up on dunes can reach more than 6 m above MSL. It is also important to determine whether ‘blowouts’ are present along the dune, since wave run-up can surge through these gaps and flood low-lying areas behind the dunes.

Figure A3.1: Waves overtopping the shingle/sand barrier at East Clive, south of Napier, during a storm in August 1974. [*Source*: Ministry of Works and Development collection, Napier.]

In situations where beaches are bounded by hard artificial structures, protection from coastal inundation is dependent on the height, slope and type of structure. In general, the lack of dissipation of energy from these structures results in higher wave run-up than would occur on natural beach materials.

Inundation and erosion caused by tsunami

Our understanding of the effects of tsunami is less than that for storm effects, simply because we have had less modern experience with moderate to strong tsunami. Note: small tsunami are relatively frequent (see Appendix 2). However, the greatest impact of tsunami inundation and erosion will be felt on low-lying margins behind sand beaches, gravel ridges and around estuaries and inlets. For sand beaches and gravel ridges, tsunami will run-up the beach to elevations well in excess of the offshore tsunami wave height. Also for a tsunami event with wave heights over 2 to 5 m, the sheer volume in each wave crest and the speed with which the water moves (up to 35–40 km/h) will cause erosion of dunes and beach ridges that will be more extreme than in storm events. Hence the greatest vulnerability is to low lying hinterlands behind narrow coastal barriers of less than 10 m in elevation.

A3.2 Open coast gravel beaches

There are two types of gravel beaches, one where a distinct upper-beach ridge separates the foreshore and the backshore, and the other where the beach consists of only a foreshore slope. The material on gravel beaches is transported only by wave run-up processes, hence these beaches tend to be narrower and lower than sand beaches (where wind processes are also important for beach building). As a consequence, the height of the gravel ridge is limited by the magnitude of past storm wave run-up and the supply of sediment available to build the ridge.

In many locations, there is insufficient material to build a ridge to the full height reached by storm run-up. In these circumstances, storm waves overtop the barrier, resulting in inundation of the low-lying hinterland. Overtopping also results in gravel being 'rolled over' the ridge crest, resulting in the landward retreat of the whole beach profile. In this erosion process, beach volumes are retained, but beach heights are lowered, resulting in the potential for the process to be repeated more frequently.

In locations where stopbanks have been constructed, these have often been buried by the retreating beach ridge, rendering them ineffective. This results in greater offshore sediment losses and increased run-up, accelerating beach retreat and further increasing the risk of inundation. Along the Seadown coast, north of Timaru, three rows of stopbanks have been buried by the retreating gravel barrier over the last 70 years.

Because of the high permeability of gravel beach ridges, flow directly through the beach face can also occur, often causing the crest to 'blow out' as the landward face of the crest is undermined.

Figure A3.2: Attempted armouring of the gravel/sand beach at the mouth of the Orari River, South Canterbury (late 1950s). (*Source*: D. Todd).

'Foreshore only' gravel beaches occur where the beach has insufficient width for the development of a ridge profile. Where there is insufficient width or elevation to provide the required level of protection, artificial barriers such as seawalls or rock revetments are often constructed at the back of the beach. An example of this is the protection works on State Highway One along parts of the Kaikoura coast. This artificial ‘bounding’ of the beach often results in decreased dissipation of storm wave run-up and increased turbulence at the toe of the structure, which in turn causes increased scour and beach lowering in front of the structure, further reducing the effective width of the nature buffer system. Ultimately, protection of the shoreline against erosion and inundation becomes totally dependent on the artificial structure.

Gravelly spits enclose shallow elongated lagoons at the mouths of rivers in some locations (e.g., Ashburton River). These low narrow spits are built by wave-driven up-coast drift and are very unstable. They are overtopped in large seas, and during floods the river will burst through the spit (barrier) and straight out to sea.

Because gravel beaches are steeper and coarser than sand beaches, run-up should theoretically be less than for sand beaches. However, there are many examples of gravel ridges up to 6 m high being overtopped by storm wave run-up. The reduction in ridge crest elevation as a result of these failures results in large areas of hinterland being exposed to greater inundation hazards. A storm in South Canterbury in July 2001 resulted in over 1100 hectares of land being inundated by a combination of overtopping and beach failure.

Figure A3.3: Damage caused to a coastal property at Haumoana (Hawke’s Bay) by waves overtopping the gravel barrier in the Easter storm of 3–4 April 2002, assisted by high perigean-spring tides. [*Source*: Hawkes Bay Regional Council].

A3.3 Cliffed coastline

Where the rocks of cliffs are hard and strong, such as the metamorphic cliffs of Fiordland or the hard volcanic rocks of the Banks Peninsula and parts of the Auckland coast, the susceptibility to erosion at management timescales is very low. However, with softer sedimentary rocks the rates of cliff retreat are often up to 1 m/yr, and where the rocks are poorly compacted, badly weathered, closely jointed, sheared, or faulted, long-term retreat can be 2 m/yr.

Erosion generally occurs during storms when elevated sea levels and large waves attack the base of the cliff, resulting in undermining and failure. Cliffs also erode slowly under wetting and drying processes.

Many sea cliffs, particularly those formed in harder rocks, have either inter-tidal wave cut shore platforms at the base of the cliff or nearshore reefs. These platforms can modify vulnerability to erosion by either reducing wave heights at the shore, or possibility focusing wave energy to one spot. Soft coast cliffs, particularly alluvial outwash fans, may have beach deposits at the base of the cliff, which can reduce the frequency and intensity of wave run-up attacking the cliff face, hence reducing their vulnerability to erosion.

Other processes that can affect the stability of cliffs are vegetation cover (positively or negatively), rainfall runoff, stormwater discharges and seismic instability.

A3.4 Estuaries

In many situations, rural and urban development has occurred right up to the edges of estuaries, and the shore have been bunded, removing the important transitional area at the margin of the estuary. As a result, coastal hazards exist around many estuaries.

In estuaries where processes are driven largely by the tides and river inflows, the hazards of flooding and erosion will be greatest at the mouth and in the headwaters. Inundation is maximised when the estuary is surrounded by low-lying land and extreme tides combine with river floods. While wave energy is inhibited inside most estuaries, erosion of estuary banks still occurs, particularly in the soft sediments often found around the margins of low-lying estuaries. Changes in the location of channels can also result in significant erosion of estuary banks. In many cases, urban and farming development of the margins of these shallow estuaries has resulted in artificial barriers being placed around the edges of estuaries, to provide protection against both inundation and erosion. Large estuaries (e.g., Manukau Harbour) have fetches great enough that winds generate sizeable waves that attack the shoreline. Ocean swell can enter the mouths of large estuaries at high tide and erode the shore (e.g., Kaipara Harbour).

Erosion

The long-term movements of estuary shorelines are generally poorly recorded and difficult to quantify. However, estuary shorelines are generally less vulnerable to erosion than open coast shorelines, due to the low energy of the erosion drivers present. Also, in general, sedimentation rates in the main basins of estuaries have been keeping pace, or surpassing, the contemporary rates of sea level rise of about 2 mm/yr. As a consequence, estuaries do not have sediment deficit. Therefore significant long-term erosion of estuary shorelines is mainly limited to changes in channel patterns in the estuary, the causes of which are complex.

Inundation

Flooding of low-lying coastal land about the shores of estuaries is common, particularly where wetlands have been reclaimed for farmland and the ability to accommodate additional water in the shallow basins is limited. Although wave heights inside estuaries are often limited due to the shallow water depths and short fetch lengths, waves can make a significant contribution to inundation when strong winds combine with extreme water levels. Ocean waves overtopping narrow sand or gravel barriers can also significantly increase water levels in lagoons.

Tsunami

For large inlets, the topography may increase the amplitude of the incoming tsunami waves, due to resonance. For example, it is believed that amplification in Lyttelton Harbour during a 1960 tsunami resulted in higher tsunami elevations that on the open coast. Tsunami can also scour the entrances of tidal inlets, causing long-term changes in the tidal compartment.