Preparing New Zealand for rising seas:

Certainty and Uncertainty

November 2015

Embargoed until **1pm Thursday 19 November 2015**

Parliamentary Commissioner for the Environment
Te Kaitiaki Taiao a Te Whare Pāremata

Acknowledgements

The Parliamentary Commissioner for the Environment would like to express her gratitude to those who assisted with the research and preparation of this report, with special thanks to her staff who worked so tirelessly to bring it to completion.

Photography

Cover photo: Rock armouring at Cooks Beach, Coromandel.
Source: Parliamentary Commissioner for the Environment archives

This report and other publications by the Parliamentary Commissioner for the Environment are available at: **www.pce.parliament.nz**

Contents

Overview

Sunday 14th June this year was a beautiful windless day in Wellington. On such rare days the sea is usually like glass. But looking down on Lyall Bay, I was surprised to see huge rolling waves washing up the beach and across the road, scattering rocks the size of basketballs across a car park. A great storm in the Southern Ocean had generated giant waves that had travelled, weakening but unimpeded over hundreds of kilometres of sea, to be lifted on top of a king tide as they finally broke on Wellington's south coast.

The sea level rise that has already occurred played only a small part in what happened in Lyall Bay that day, but as the sea continues to rise, there will be more and more such 'flood events' as the scientists call them.

The subtitle of this report is *'Certainty and Uncertainty'*. It is certain that the sea is rising and will continue to do so for centuries to come. But much is uncertain – how rapidly it will rise, how different coastal areas will be affected, and how we should prepare. And we do need to prepare. After all, as an article in the New York Times put it this year: *"Human civilization is built on the premise that the level of the sea is stable, as indeed it has been for several thousand years"*.

The rising sea will lead to flooding on low-lying land near the coast, erosion of many beaches and 'soft' cliffs, and higher and possibly saltier coastal groundwater.

- Flooding of coastal areas will become more frequent, more severe, and more extensive.
- Erosion – a long-familiar problem around some of our coasts – will become more widespread.
- Groundwater linked to the sea will rise and possibly become brackish.

However, care must be taken with generalisations. Local features matter a great deal.

For instance, open unsheltered coasts experience the full force of the sea, so are more vulnerable to flooding than enclosed bays. Beaches regularly replenished with sediment are less prone to erosion. Groundwater problems are most likely to occur in land that has been reclaimed from the sea.

Natural hazards like earthquakes, volcanic eruptions, and river floods can happen at any time. In contrast, sea level rise is incremental and inexorable – its effects on our coast will unfold slowly for a period before accelerating. We must start planning, but there is enough time to plan and do it well.

Certainly the world, including New Zealand, needs to act urgently to reduce carbon dioxide and other greenhouse gas emissions. However, during this investigation, I have realised that the same urgency does not apply to much of the planning we need to do for sea level rise. Indeed, haste can be counter-productive.

Central government has provided some direction and guidance for councils, but it is time for a major review. Councils that have begun to plan for sea level rise have sometimes found themselves between 'a rock and a hard place'.

In a number of locations around the country, the setting of coastal hazard zones based on projections of future flooding and erosion has been challenged by affected homeowners. Receiving a letter saying that your property has been zoned as susceptible to flooding or erosion can come as a shock.

Homes are much more than financial equity. Such zoning and any regulations that follow must be based on a fair process and technical assessments that are both rigorous and transparent.

While these principles should hold for planning for any hazards under the Resource Management Act, planning for sea level rise is outside our experience – it is *terra incognita*.

Part of making such a process fairer is simply to slow it down into a number of steps. It is for this reason that I decided to include the four elevation maps in this report with more available on our website.

This was not an easy decision because I do not want to alarm people unnecessarily. But the first stage in a step by step process should be the provision of information, beginning with accurate elevation maps of coastal land. Note that the coloured areas on these maps in this report are not coastal hazard zones; they simply denote elevation above spring high tide levels.

The analysis used to generate the information for these maps shows that at least nine thousand homes lie less than 50 centimetres above spring high tide levels. This is more than the number of homes that were red zoned after the Christchurch earthquakes.

Also needed is a clear distinction between the role of technical analysts who undertake coastal risk assessments and the role of the decision-makers who sit around council tables.

Because current government policy on sea level rise emphasises the need to take a 'precautionary approach', technical analysts have been embedding 'precaution' into coastal risk assessments to varying degrees. This takes various forms such as assuming 'high end' amounts of sea level rise.

But undertaking a coastal risk assessment is very different from designing a building or a bridge where redundancy and safety factors are intrinsic to the design. Technical assessments of coastal risk should be based on best estimates of all the parameters and assumptions that are fed into the modelling. Decision-makers should then take the modelling outputs including estimates of uncertainty, and then openly and transparently decide how cautious to be in delineating hazard zones.

Clear communication is another vital component of a good process – there is a need to develop a *lingua franca* – a language that will bridge the gap between the experts and the rest of us. In one report, I was amused to discover a heavy downpour described as a 'subdaily precipitation extreme'.

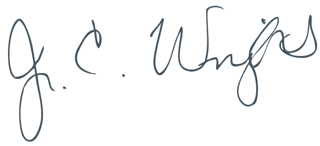
One particular need is to avoid referring to 'one-in-50 year' or 'one-in-100 year' events. Not only is it difficult to understand, it is not a stable measure over time. The 'high water' caused by a storm surge riding on top of a king tide that is now expected to occur once every 100 years will occur more and more often as the sea rises.

There are aspects of planning for sea level rise that should be done with some urgency. One is concerned with the granting of consents for greenfields development. New suburbs and the expensive infrastructure they require should be viewed as long-term investments. We now see building new suburbs on land prone to liquefaction in much of the country as foolish. We should see allowing new subdivisions on vulnerable coastal land as equally foolish.

Another is the need to establish much more extensive monitoring systems. This is required before we can develop better models of shoreline erosion and accretion. Such monitoring is also needed for adaptive management, which will be the appropriate strategy in many cases. Adaptive management involves staging interventions over time as trigger points are reached.

Unusually, one of my recommendations in this report is to the Minister of Finance. It is not too soon to begin to consider the fiscal implications of sea level rise. Both central and local government will face increasing pleas for financial assistance – whether it be for building a seawall, maintaining an eroding coastal road, or, as will eventually happen, moving entire communities further inland.

As I write this, delegates from hundreds of countries are about to meet in Paris to try to hammer out a new agreement to slow the rate of climate change. I remain optimistic. What the world, including our small country, does now will affect how fast and how high the sea rises.



Dr Jan Wright

Parliamentary Commissioner for the Environment

1 Introduction

Over many millennia, the Earth's climate has cycled between ice ages and warm 'interglacial' periods. Over the last seven thousand years the climate has been relatively stable, but this is now changing. Increasing concentrations of carbon dioxide and other greenhouse gases in the atmosphere are trapping heat and the climate has begun to respond. One of the major and certain consequences is rising sea level.

Nowhere in our island nation is far from the sea, and most of us live within a few kilometres of the coast. Houses, roads, wastewater systems, and other infrastructure have been built in coastal areas with an understanding of the reach of the tides and the recognition that storms will occasionally combine with high tides to cause flooding.

However, with rising seas, tides, waves and storm surges will reach further inland than before, resulting in more frequent and extensive flooding. Along some coasts, erosion will increase and shorelines will recede. In some areas, the water table will rise.

The vulnerability of different coastal areas to the rising sea depends on many factors. Elevation – height above the sea – is the first factor that comes to mind when considering the potential impacts of sea level rise, but it is far from the only one. The shape of the coastline, the topography of the land and the seabed, the proximity to the sea, the presence of barriers such as sand dunes, and other local characteristics will affect what happens in different coastal areas.

Other consequences of climate change, such as changing wind and rainfall patterns, will also come into play, increasing or reducing the impacts of rising seas. For instance, more intense rainfall coinciding with storm surges will exacerbate coastal flooding.

Like other countries, New Zealand needs to prepare for rising seas.

Under New Zealand law, the enormously challenging task of planning for sea level rise is the responsibility of local government. It is challenging on many levels. For a start, it is technically complex, and the size and timing of impacts are uncertain. Perhaps the most difficult aspect is the impact on people's homes, which for many are not just their homes, but also their financial security.

1.1 Purpose of this report

The Parliamentary Commissioner for the Environment is an Officer of Parliament, with functions and powers granted by the Environment Act 1986. She provides Members of Parliament with independent advice in their consideration of matters that have impacts on the quality of the environment.

In 2014, the Commissioner released a report titled *'Changing climate and rising seas: Understanding the science'*. This report was written with the intent of making the science of climate change, and specifically sea level rise, accessible and relevant for New Zealanders.

This report follows on from the 2014 report. Its purpose is to:

- increase understanding of how sea level rise will affect New Zealand
- show how low-lying coastal areas around the country can be accurately mapped in a standardised way
- describe how some councils have begun to plan for sea level rise
- identify problems with, and gaps in, the direction and guidance provided by central government.

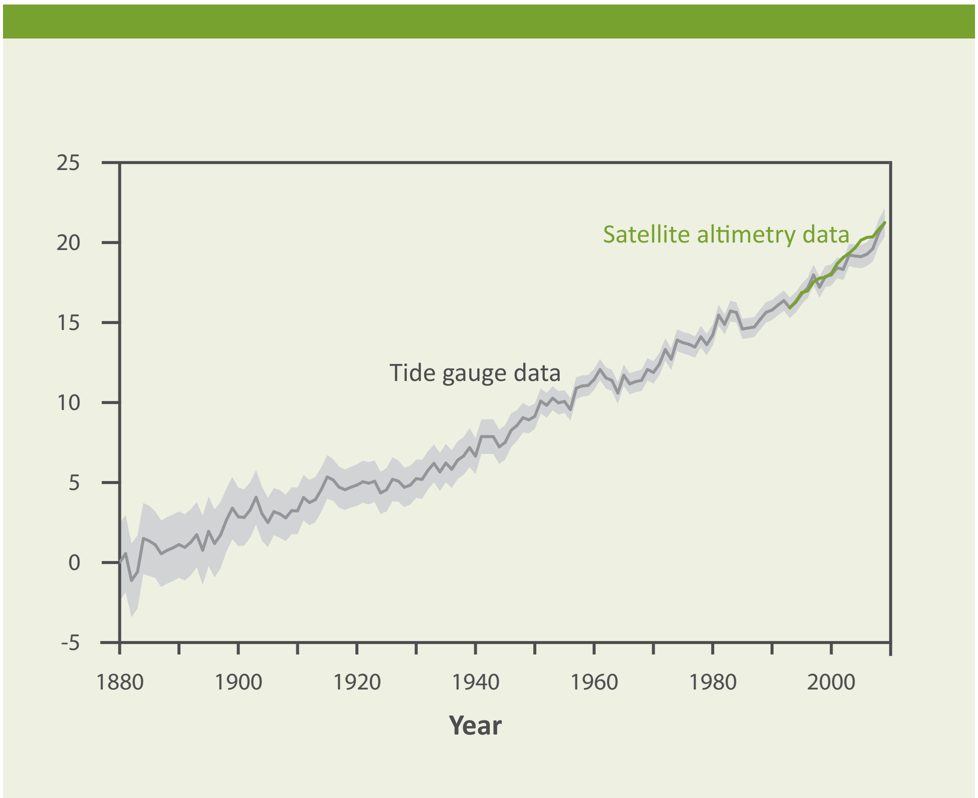
This report has been produced pursuant to s16 of the Environment Act 1986.

1.2 Rising sea level

Global average sea level has risen about 20 centimetres since the beginning of the 20th century.

Records collated from tide gauges at ports around the world show that average sea level began rising around 1900. In the last twenty-five years, satellites have enabled more precise measurement and greater global coverage (Figure 1.1).

This rise in global average sea level does not mean that the sea has risen by the same amount *everywhere* around the world. Changes in sea level at particular locations vary due to a number of factors. So far the seas around New Zealand have risen largely in line with the global average.



Data: Church and White, 2011.

Figure 1.1 Global mean sea level rise relative to 1880.

There are three main ways in which warming air temperatures are causing sea level to rise.

- Water in the sea is becoming warmer and expanding.
- Mountain glaciers are retreating.
- Polar ice sheets on Greenland and Antarctica are shrinking.

1.3 Adapting to sea level rise

Some countries, such as Bangladesh and Kiribati, will be greatly affected by sea level rise. But every country bordered by the sea will be affected in some way, and many are taking actions of various kinds to prepare for higher sea levels.

This section contains two examples of adaptation to sea level rise. The first is concerned with future-proofing an airport development. The second is the development of a strategy to protect a large city from flooding.

Building a new runway in Australia

A new runway at Brisbane Airport is currently under construction. The airport is situated on low-lying land close to the coast. Frequent tropical cyclones and other factors make the Queensland coast very vulnerable to coastal flooding, so in the planning it was critically important that the new runway be protected from flooding as the sea rises.

Several assessments were done to help decide what the height of the new runway should be, beginning with the then state guideline applicable to airports. The first step in such assessments is to use the most recent Intergovernmental Panel on Climate Change (IPCC) projections as the best guide available of future rates of sea level rise. Then other factors enter the calculations of design height – the height of storm surges and waves, the frequency of tropical cyclones, rainfall in the catchment, and so on.

Finally, a judgement must be made about the acceptable level of risk. Should the runway be high enough so that it never floods, or is a flood once a month tolerable? In the end, the decision was made to build the runway at a height described as *"strongly precautionary"*.[1] Airports are critical infrastructure. If a runway floods and aeroplanes cannot land, the financial consequences can be very large.

Source: J Brew, Wikimedia Commons (CC BY-SA 2.0)

Figure 1.2 Brisbane airport is situated on low-lying coastal land.

Protecting London

The Thames Barrier is a series of giant rotating gates spanning the River Thames that began operation in 1984. It is a major part of the system of defences designed to protect the city from flooding.

Flood risk in the Thames Estuary has increased over time. Half of the closures of the barrier have been to protect against tidal flooding and half to protect against river flooding. Both kinds of flood risk are expected to increase as the climate changes – tidal flooding because of sea level rise and river flooding because of more intense rainfall.

In 2002, a project called Thames Estuary 2100 was established to develop a strategy to protect the city through to 2100. Ten years later, the TE2100 Plan was adopted. Because the Thames Barrier was built to a high design standard, it is expected that it will not need to be modified until about 2070.

In the TE2100 Plan, a 'managed adaptive' approach has been adopted. This involves making several interventions over time to manage risk, in contrast with making *"a single, major investment in flood defence infrastructure or activity to achieve a reduction in risk which lasts until the end of the century"*.[2]

Source: James Campbell, Flickr (CC BY-ND 2.0)

Figure 1.3 The Thames Barrier protects London from tidal and river flooding.

In the first example, the elevation of a new runway at Brisbane Airport, a 'strongly precautionary' approach was taken. In the second example, the plan for protecting London against flooding, an 'adaptive management' approach was taken.

Both make sense. In the first case, the consequences of flooding on the runway would be so serious that the extra height was warranted. In the second case, the analysis showed that what was termed a precautionary approach would be expensive and environmentally damaging, and *"… run the risk of creating an expensive 'white elephant' should flood risk rise at a slower level than predicted"*.

These two examples illustrate that adaption to sea level rise needs a 'horses for courses' approach. In particular, different stances on risk will be appropriate for different situations. This, and other aspects of decision-making pertinent to sea level rise, are discussed in this report.

1.4 What this report does not cover

This report does not include any detailed discussion or analysis of the following:

- Climate change mitigation – reducing greenhouse gas emissions
- Other effects of climate change such as changing rainfall patterns, increased river flooding, and acidification of the oceans
- Impacts of sea level rise on coastal ecosystems and landscapes
- Ownership of the foreshore and seabed or any unresolved Treaty of Waitangi claims involving coastal land.

In particular, the report does not contain numerical estimates of the impacts of sea level rise in particular coastal areas around the country. Although some elevation bands are presented in maps, they do not denote coastal hazard zones, so are not suitable for including on Land Information Memoranda (LIMs).

1.5 What comes next?

The remainder of this report is structured as follows:

Chapter 2 contains a general description of some changes that lie ahead, beginning with the latest IPCC projections of sea level rise. It includes an explanation of why natural factors like storms change the level of the sea, and a brief description of how climate change is expected to affect rainfall, winds, and storms in New Zealand.

Chapter 3 is an explanation of how sea level rise will increase the frequency, severity, and extent of coastal flooding. It contains the results of modelling showing how extreme water levels will occur increasingly often. This modelling is based on the longest historic records of sea level in New Zealand, measured at the ports of Auckland, Wellington, Christchurch, and Dunedin.

Chapter 4 is an explanation of how sea level rise will increase the erosion of sandy beaches and 'soft' cliffs.

Chapter 5 is an explanation of the potential impacts of sea level rise on coastal aquifers. In some places the water table will rise as the sea rises. Another consequence may be saltwater intrusion.

Chapter 6 begins by explaining how the elevation of land above sea level can be measured accurately using a system called LiDAR. It contains maps showing low-lying coastal land in Auckland, Wellington, Christchurch, and Dunedin. More maps are available at **www.pce.parliament.nz**. The chapter also contains the results of running a software programme called RiskScape, showing numbers of homes and businesses, and lengths of roads at low elevations.

Chapter 7 begins with a look back into the past, describing how governments have dealt with the long-familiar coastal hazard of erosion. It then describes the two government documents that currently guide and direct councils in their planning for sea level rise. This is followed by four sections describing some of the problems that have arisen as some councils have begun to plan for sea level rise.

Chapter 8 contains conclusions and recommendations from the Commissioner.

Three modelling exercises were commissioned to provide information for this investigation – two from the National Institute of Water and Atmospheric Research (NIWA) and one from Dr John Hunter of the University of Tasmania. The methodology and results from this modelling are detailed in technical reports available at **www.pce.parliament.nz**.[3]

2

What lies ahead?

The level of the sea has already risen significantly due to the impact of humans on the climate, and will continue to do so for the foreseeable future.

The first section of this chapter contains the most up-to-date projections of the increase in sea level by the Intergovernmental Panel on Climate Change (IPCC).

While climate change is raising the level of the sea, there are a number of natural factors that influence the level of the sea at any given time. The second section is a brief description of these factors, ranging from exceptionally high tides through to long-term weather patterns.

Climate change is expected to affect the weather in a number of ways – described in the third section. Some of these will have impacts on coastal areas and need to be thought about in conjunction with sea level rise.

The final section introduces the three types of coastal hazards that will be exacerbated by sea level rise – flooding, erosion, and groundwater that rises too high or becomes saline.

2.1 How fast will the sea rise?

As air temperatures have risen around the world, water in the sea has warmed and expanded, and alpine glaciers have retreated. These two processes have driven most of the global sea level rise observed over the last hundred years or so. In the future, a third process – loss of ice from the huge ice sheets that cover Greenland and Antarctica – is expected to become increasingly significant. 'Ice sheet dynamics' is now the focus of much climate change research.

The IPCC undertakes regular assessments of the current state of knowledge about climate change. These include projections of global sea level rise.

In its most recent report in 2013, the projections were based on four scenarios. Each scenario is based on a different Representative Concentration Pathway (RCP) – a trajectory over time of greenhouse gas concentrations in the atmosphere.

The projected rises in sea level that the IPCC assessed as 'likely' under the lowest and highest of these scenarios are shown in the three graphs in Figure 2.1.[4]

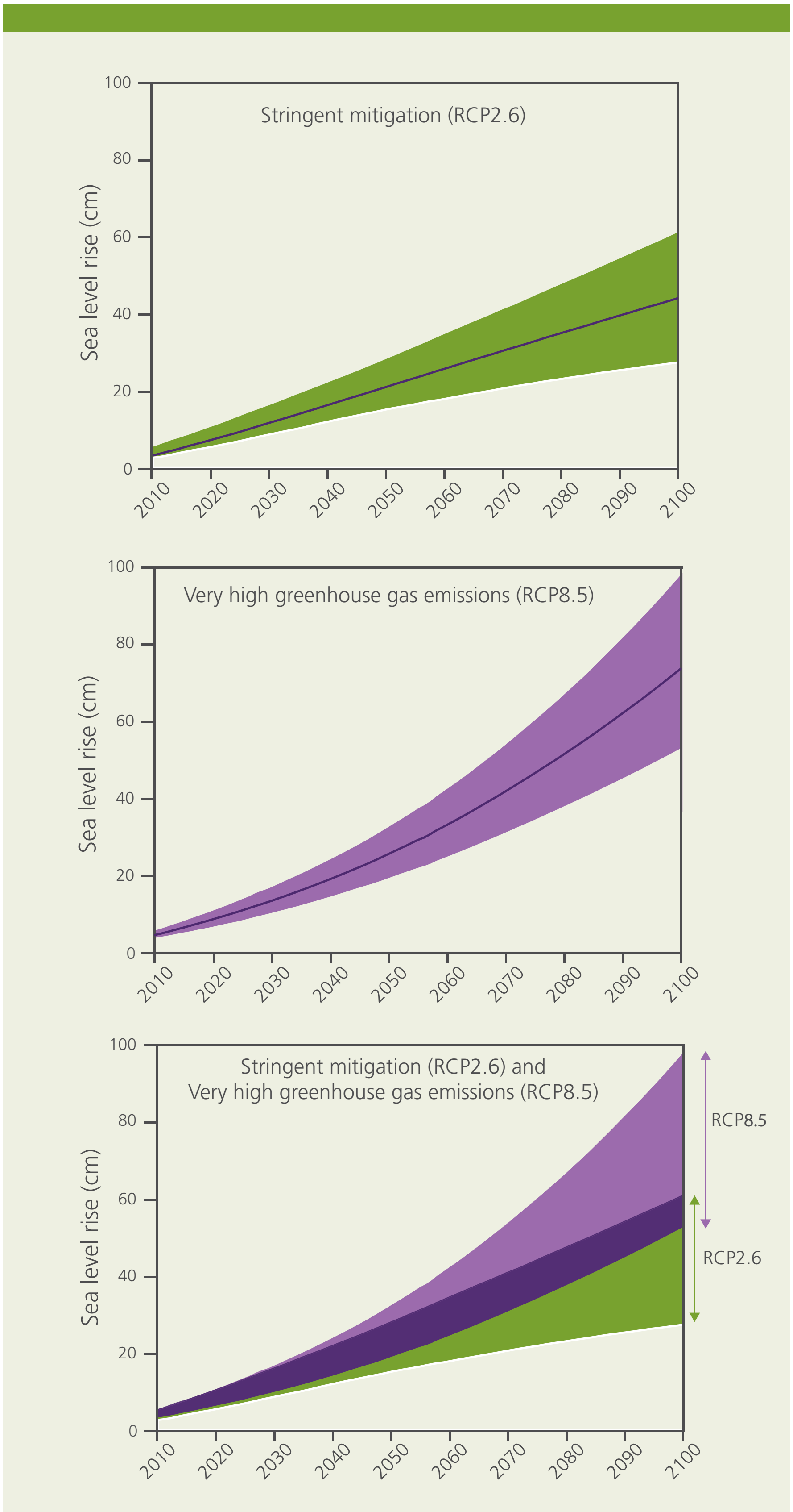
- The first graph shows the projected rise in sea level under the 'Stringent mitigation' scenario (RCP2.6).
- The second graph shows the projected rise in sea level under the 'Very high greenhouse gas emissions' scenario (RCP8.5).
- The third graph shows the projected rise in sea level under both scenarios.[5]

An examination of Figure 2.1 reveals three important aspects of sea level rise.

- The projections for the end of the century are much more uncertain than those for the middle of the century. Uncertainty grows over time.
- Action taken to reduce greenhouse gas emissions will make little difference to the rate of sea level rise for several decades.[6]
- The two scenarios increasingly diverge in the latter half of the century. The sooner emissions are curbed, the greater the effect will be in the longer term.

Around New Zealand, the sea has so far risen at about the same rate as the global average, but may rise a little faster than the global average in the future.[7] How fast the sea will rise in different places around the country also depends on whether the land is rising or falling; this can occur slowly over time or rapidly in an earthquake.

The scenarios in Figure 2.1 are projections of sea level rise up to the year 2100.[8] This does not mean that the sea will stop rising at the end of the century – it will continue to rise for many centuries to come.[9]



Data: IPCC, 2013

Figure 2.1 The most recent projections of global mean sea level rise by the IPCC relative to 1986–2005. The green band represents the range for the RCP2.6 scenario, and the purple band represents the range for the RCP8.5 scenario. In the top two graphs, the lines represent the median of the range.

2.2 Natural variation in the height of the sea

The height of the sea around the coast naturally falls and rises as the tides ebb and flow, and the weather changes.

High astronomical tides

Tides are controlled by the gravitational forces of the Moon and the Sun pulling the Earth's water towards them. How high the tide reaches varies over time, with relatively high 'spring tides' occurring about every two weeks when the Earth, the Sun, and the Moon are aligned.

King tides are particularly high spring tides that occur about twice a year when the Earth, the Sun, and the Moon are aligned, *and* the Moon is closest to the Earth.

Storm surges

During a storm, high winds and low air pressure can combine to create a bulge in the level of the sea that is driven on to the coast. Such storm surges can be thought of as very long, slow waves.

In April 1968, Cyclone *Giselle* formed in the Coral Sea and began tracking toward New Zealand where it was reinforced by a storm from the south. A storm surge of 88 centimetres was measured on the tide gauge in Tauranga Harbour – the largest ever recorded in New Zealand. The waves reached 12 metres in Cook Strait and the *Wahine* sank in Wellington Harbour (Figure 2.3).[10]

Waves

Winds travelling over the surface of the sea create waves. How high waves get depends on the strength and duration of the wind, as well as the depth of the sea and how far the waves have travelled. If unimpeded by land, a wave can travel thousands of kilometres. Wellington's south coast is sometimes pummelled by huge swells that are generated by storms as far away as Antarctica (Figure 2.2).

As waves approach the land, they usually become smaller before they break and run up the shore. During storms, waves can reach several metres above the high tide mark along some coasts.

Long-term weather patterns

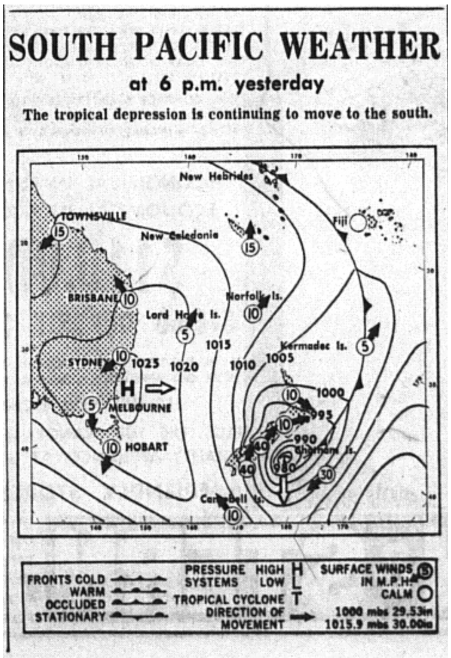
Long-term weather patterns can change the level of the sea over many years or even decades. During an El Niño phase of the Southern Oscillation, the level of the sea around New Zealand falls, and during a La Niña phase, it rises. Over longer timescales, the Interdecadal Pacific Oscillation also affects sea levels around New Zealand.[11]

Combined effect on sea levels

These natural causes of high sea levels can occur together, increasing their impact on coasts. In January 2011, a storm surge and a high astronomical tide overwhelmed stormwater systems and flooded parts of coastal Auckland.

Source: Erik Winquist

Figure 2.2 Waves breaking on the south coast of Wellington near the airport.



Source: New Zealand Herald

Figure 2.3 Air pressures over New Zealand on the day the *Wahine* sank in April 1968.

2.3 Changing rainfall, wind, and storms

In coming decades, weather patterns will continue to alter as the climate changes. Some changes in weather will affect coastal areas and need to be thought about in conjunction with sea level rise.

Rainfall

As the atmosphere warms, it can hold more moisture – about 7% for every 1°C increase in temperature.[12] As the climate changes, both the distribution of rainfall across New Zealand and its intensity are projected to change.

Rainfall is projected to increase in the west of both islands and in the south of the South Island. Northland and eastern regions of both islands are projected to become drier.[13] It is also projected that heavy downpours will become more extreme.[14]

Increases in the amount and intensity of rainfall in some catchments raise the risk of river flooding. Areas close to river mouths can experience the 'double whammy' of river flooding coinciding with the sea pushing its way upriver at high tide. As high tides become higher because of sea level rise, such floods will become more likely.[15]

Winds

The duration and intensity of winds drives the power of waves. As circulation patterns in the atmosphere change, westerly winds are projected to become more prolonged and more intense in New Zealand, especially in winter.[16]

Increased winds would lead to larger waves breaking on the shores of the west coasts of both islands.[17]

Storms

As the atmosphere becomes warmer, storm patterns are likely to change. Storm surges ride on top of the sea and can be driven on to land by wind – their impact will be increased by sea level rise.

It is projected that cyclones that form south of New Zealand in winter will become more intense, leading to stronger winds and larger waves on shores exposed to the south. It is also projected that the intensity of cyclones elsewhere in the country will decrease.[18]

2.4 Three types of coastal hazard

There are three types of coastal hazard in New Zealand that will be directly affected by rising sea level.

Flooding occurs along coasts when the sea flows over low-lying land.

Erosion occurs when waves and currents eat away at 'soft' shorelines.

Groundwater can be affected in two ways – water tables can rise and freshwater can become saline.

The next three chapters deal with each of these in turn.

There is another type of coastal hazard that will be affected by rising sea level – tsunamis. A tsunami is formed when an earthquake or landslide under the sea creates waves. The height of a tsunami when it reaches a shore can range from a few centimetres to tens of metres, and largely depends on the size of the event that caused it and the distance from its origin. Sea level rise will increase the height of tsunamis. Tsunamis are rare and unpredictable. They are not discussed further in this report.

Source: Anne Te Wake

Figure 2.4 Many marae and historical sites are located near the coast on low-lying land. This photo shows Mātihetihe marae on the coast north of Hokianga harbour. The hapū of Te Tao Mauī from Mitimiti are working with NIWA to understand how sea level rise might affect their marae.

3

Coastal flooding

Coastal floods occur when the sea rises above the normal high tide level and flows on to low-lying land.

Such floods range from 'nuisance events' to widespread costly inundation. Seawater may flow on to a waterfront promenade relatively frequently, but only cause traffic delays and inconvenience. Much more rarely, powerful storm surges can flood homes, damage roads, and close businesses.

The first section of this chapter describes the factors that make particular areas of the coastline vulnerable to flooding.

A rising sea will increase the frequency, the duration, and the extent of coastal flooding in New Zealand. The second section contains the results of modelling that shows how the frequency of extreme water levels will increase at four locations around New Zealand.

3.1 Vulnerability to coastal flooding

Different factors affect how vulnerable a coastal area is to being flooded by the sea.[19]

Elevation and distance from the coast

Areas that are low-lying and close to the coast are generally most vulnerable to flooding.

As floodwater spreads inland from the coast, it loses momentum. However, in some situations, storm surges can carry seawater a considerable distance inland.[20]

Shape of the coast

Open unsheltered coasts experience the full force of waves from storms, making them generally more vulnerable to flooding than enclosed bays and estuaries.

However, water carried by a storm surge can be funnelled by the shoreline of a narrowing harbour or estuary. This happened during the January 2011 coastal flood in Auckland, when the sea rose another 30 centimetres as the storm surge flowed through the Waitemata Harbour.[21]

Natural and built defences

Defences against the power of the sea can be natural like sand dunes, gravel banks, wetlands, and cliffs, or built like seawalls, earthen dikes, and tidal barriers. These defences may themselves be undermined by high seas and storms – natural defences can erode and built defences can collapse.

Natural defences can accrete as well as erode. The gravel bank on the beach along Marine Parade in Napier has grown over time as gravel carried down from the hills by the Tukituki River is carried by longshore currents and deposited on the beach.

Stormwater pipes

Stormwater pipes are designed to carry rainwater out to sea. However, if the sea is high enough to cover the pipe outlets, the rainwater can struggle to drain away. In some instances, seawater can run back up the pipes.

Stormwater pipes can be fitted with flap valves to prevent seawater from entering the system. Maintenance is also important – sediment sometimes settles into pipes after storms, and flushing is required to clear them.

Coastal floods often occur during storms, and stormwater systems sometimes cannot cope with both rainwater and seawater.

Source: Craig Thomson

Figure 3.1 In February 2015 a king tide caused minor flooding on boardwalks in Howick, Auckland. As the sea rises such nuisance flooding will occur every high tide in some places.

Source: Sam Gorham

Figure 3.2 Lowry Bay during the June 21st 2013 storm that saw many roads flooded around Wellington Harbour. On this day the tide gauge at the port recorded the highest sea level since records began in 1944.

3.2 A rising sea will increase coastal flooding

The rise in sea level that has already occurred means that king tides, storm surges, and waves now reach higher up shores than they used to. As the sea continues to rise the frequency, duration, and extent of coastal flooding will increase.

In some cases, the rising sea will increase the duration and extent of *river* floods, like the one that occurred in Whanganui in 2015. If such river floods peak at high tide, they will become more damaging as high tides become higher.

Some projections of the increased frequency of extreme water levels were commissioned for this report from NIWA and from an international expert, Dr John Hunter from the Antarctic Climate & Ecosystems Cooperative Research Centre at the University of Tasmania.[22] These projections are based on the longest historic records of sea levels in New Zealand, measured on tide gauges at the ports of Auckland, Wellington, Christchurch (Lyttelton), and Dunedin.[23]

Table 3.1 shows when hourly recording of sea level began at each of the four ports and on which days the sea reached its greatest heights – in relatively recent years. Many Aucklanders will readily recall what happened in January 2011, and many Wellingtonians will readily recall what happened in June 2013.[24]

Table 3.1 Sea level records at four New Zealand ports.

	Year recording began	Date of highest recorded level
Auckland	1903	23 January, 2011
Wellington	1944	21 June, 2013
Christchurch	1924	17 April, 1999
Dunedin	1899	15 June,1999

The results of the modelling are presented in Table 3.2 and Figure 3.3.[25]

For this report, it was decided to express these results in terms of exceedances of high water levels that are *currently* expected to occur only once every hundred years – today's '100 year event'.[26] As time goes on, such extreme levels will occur more and more often.

In New Zealand, sea level is projected to rise by about 30 centimetres between 2015 and 2065.[27]

For a rise in sea level of 30 centimetres, such extreme high water levels would be expected to occur about:

- Every 4 years at the port of Auckland
- Once a year at the port of Wellington
- Once a year at the port of Christchurch
- Every 2 years at the port of Dunedin.

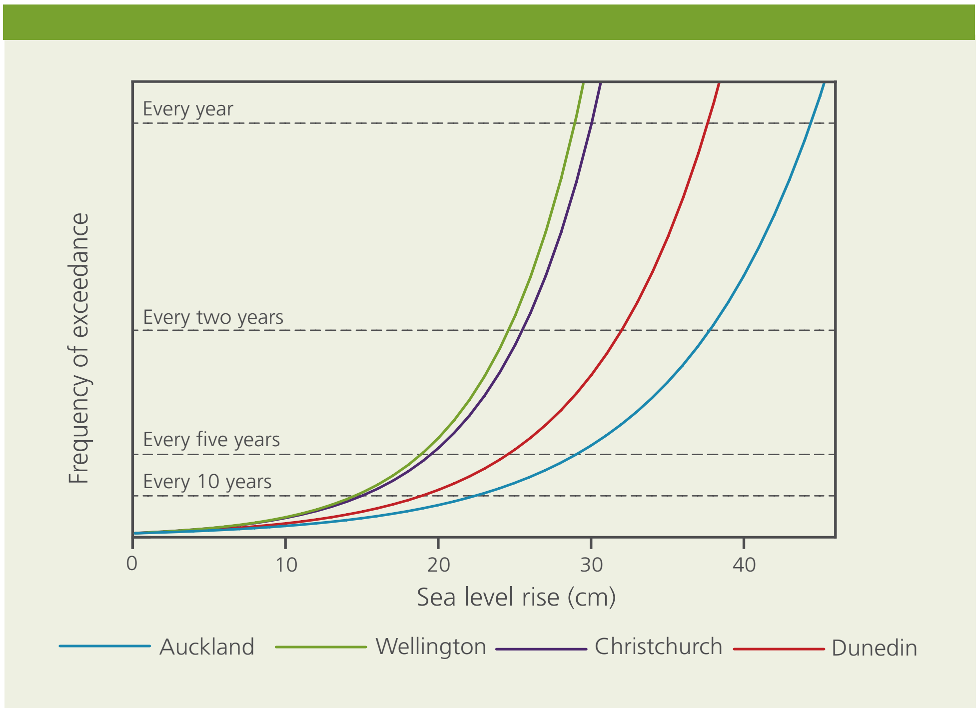
Table 3.2 Exceedances of today's '100 year events' occur more and more often as the sea level rises.

SLR	Auckland
0cm	Every 100 years
10cm	Every 35 years
20cm	Every 12 years
30cm	Every 4 years
40cm	Every 2 years
50cm	Every 6 months
60cm	Every 2 months
70cm	Every month
80cm	Every week
90cm	Twice a week
100cm	Every day

SLR	Wellington
0cm	Every 100 years
10cm	Every 20 years
20cm	Every 4 years
30cm	Once a year
40cm	Every 2 months
50cm	Twice a month
60cm	3 times a week
70cm	Every tide
80cm	Every tide
90cm	Every tide
100cm	Every tide

SLR	Christchurch
0cm	Every 100 years
10cm	Every 22 years
20cm	Every 5 years
30cm	Once a year
40cm	Every 3 months
50cm	Twice a month
60cm	Twice a week
70cm	Every day
80cm	Every tide
90cm	Every tide
100cm	Every tide

SLR	Dunedin
0cm	Every 100 years
10cm	Every 29 years
20cm	Every 9 years
30cm	Every two years
40cm	Every 9 months
50cm	Every 3 months
60cm	Once a month
70cm	Once a week
80cm	4 times a week
90cm	Every tide
100cm	Every tide



Data: Hunter, 2015

Figure 3.3 In the future, the tide gauges at the four ports will record exceedances of today's '100 year events' more and more often.

The shape of all four lines in Figure 3.3 is critically important for understanding how the frequency of coastal flooding will change in the future. All of the lines begin with a relatively flat section and then rise increasingly steeply. There is a period of time for each location before exceedances become common. But after this 'grace period', exceedances rise very rapidly.[28]

As with all modelling, careful interpretation is essential. Some important points include:

- The results show how often exceedances of the '100 year events' are expected to occur with sea level rise. They do not show the duration or extent of any flooding that may occur from these exceedances.
- No change in either the frequency or size of storm surges has been assumed in the modelling.
- Tide gauges do not measure wave height and waves are an important factor in some coastal flooding. Because waves ride on top of the sea, the higher the sea, the higher up the coast the waves will reach.

In assessing flooding risk from particularly high waters, local characteristics are critical. For instance, the records used in the modelling are from tide gauges at ports located in harbours that are more sheltered than coasts exposed to the open sea.

Although the four lines shown in Figure 3.3 have the same shape, they rise at different rates with Wellington at one extreme and Auckland at the other. By the time the sea has risen about 70 centimetres higher than it is now, every high tide at Wellington's port is expected to be higher than today's '100 year event' level. But it is not until the sea has risen over 100 centimetres that every high tide at Auckland's port is expected to be higher than today's '100 year event' level.[29]

This difference is due to the variation in high tide levels. High tide levels at Auckland's port vary over a wide range, so it takes a relatively large rise in sea level to push every high tide over today's '100 year event' level. In contrast, there is little variation in high tide levels at Wellington's port.

3.3 In conclusion

Coastal cities and towns have been developed over time with a stable sea level in mind. Buildings, roads, airports, wastewater systems and other infrastructure have all been built based on an historical understanding of the reach of the tides and occasional flooding during storms.

As the level of the sea continues to rise, areas of low-lying coastal land that currently flood during storms or king tides will experience more frequent and severe flooding. Areas a little higher will also begin to flood over time.

While the modelling results presented in this chapter do have limitations, they provide some useful insights, including the following.

- Each of the lines in the graph in Figure 3.3 begins with a relatively flat section, showing that there is some time for planning for the increased frequency of flooding that will come. How much time depends on the particular location.
- It is certain that the frequency of coastal flooding will increase as sea level rises. But the further ahead we look, the greater is the uncertainty in the modelling results.
- The results of such modelling are best plotted against centimetres of sea level rise. They can then be readily plotted against time for different IPCC scenarios.

4 Coastal erosion

Coastal erosion occurs when waves eat away at the land causing the shoreline to retreat. The sand and gravel stripped from a beach or cliff can be carried away by ocean currents. They can then be deposited out at sea or on another beach, causing it to build up – a process known as accretion.

The first section of this chapter describes the factors that make particular areas of the coastline vulnerable to erosion.

A rising sea can speed up erosion along some parts of the coastline and trigger it in others. This is illustrated with some examples from around the country in the second section.

The third section is a summary of the main points in this chapter.

4.1 Vulnerability to coastal erosion

Different factors affect how vulnerable a shoreline is to being eroded by the sea, whether it be long-term recession of the coastline or short-term cycles of erosion and accretion.

Coastal composition and shape

Sandy beaches are constantly changing. Sand is light and easily suspended in water, allowing it to be readily moved around by waves and currents. In contrast, pebbles from gravel beaches tend to be tossed around by the breakers and dropped back on the beach, sometimes piling up to form steep terraces. In New Zealand, mixed sand and gravel beaches are common.

Unlike beaches, cliffs can only erode – there is no natural process to build them up again. The composition of cliffs is important – cliffs made of silt or soft rock, for instance, are prone to erosion.

As for coastal flooding, erosion is more likely to happen on open coasts that bear the brunt of storm surges and larger waves, than on naturally sheltered coastlines, such as harbours or estuaries.

Size and shape of waves

Episodes of erosion often occur during storms. Storm surges take waves high up beaches, and strong winds generate large steep waves that can remove sand and deposit it on the seabed just offshore.[30] In calm weather, smaller flatter waves tend to deposit sand on to shores, helping beaches to accrete.

For a shoreline to be stable, stormy periods with large eroding waves must be balanced by long periods with smaller accreting waves. Significant erosion often occurs if there is a series of storms over a short period of time.

The balance between erosion and accretion can change over time when the size and direction of waves is influenced by weather cycles. In the upper North Island, beaches on the east coast tend to erode during a La Niña, while west coast beaches tend to erode during an El Niño.[31]

Sediment availability

Sediment – which includes both sand and gravel – naturally moves around the coast. Longshore currents run parallel to the shore and can carry sediment away. But those same currents may also bring sediment into the vicinity of a beach, allowing waves to deposit it on the shore.

Most of this sediment comes from erosion inland and has been carried down rivers to the sea. The supply of sediment varies over time and is influenced by many factors including storms, earthquakes, deforestation, dams, and changes in river flow.

Coastal scientists use the term 'sediment budget' to refer to the balance between the sediment that is removed from and the sediment that is added to different sections of coastlines and rivers.

A deficit will generally lead to net erosion and a surplus will generally lead to net accretion – rather like a bank account.

Built defences

Different kinds of structures, such as seawalls, can be built to prevent or slow coastal erosion.

Piling up large rocks against vulnerable shores is known as 'rock amouring' or 'rip-rap'. The road that runs between Wellington airport and the sea is protected in this way. While this approach may protect the land behind, sand in front of the rocks can be stripped away.

Groynes are barriers running out from the shore that can capture sediment as it is carried along by longshore currents. While groynes can protect a beach from erosion, they can also cut off the sediment supply to neighbouring beaches.

Built structures can also drive localised accretion. Caroline Bay in Timaru has changed markedly since 1878, when a breakwater was constructed to protect the harbour from southerly swells. Thousands of cubic metres of sand have since accumulated on the beach, and the shoreline has advanced hundreds of metres. However, nearby stretches of the coast have experienced accelerated rates of erosion due to the disruption of their sediment supply.[32]

4.2 A rising sea will increase coastal erosion

As the sea rises, erosion will increase in many places around the coast.

High-energy storm waves will rush further up beaches and reach higher up soft cliffs. Thus, beaches and cliffs that are prone to erosion are likely to erode faster.

Stable beaches may also begin to erode, and beaches that are accreting may accrete more slowly or begin to erode.

Waihi Beach on the east coast of the Coromandel, Haumoana in Hawke's Bay, and Beach Road south of Oamaru are three places where coastal erosion is clearly evident, and almost certain to increase as the sea continues to rise.

In places where the shoreline is advancing seaward, it may be many years before the sea rises enough to overcome the processes driving the accretion. The sediment supply is critical. Eastbourne in Wellington has changed from a retreating sandy beach to an advancing gravel beach, although the sea has been rising for a hundred years or so.[33]

Source: Western Bay of Plenty District Council

Figure 4.1 Waihi Beach is subject to episodes of erosion when storms gouge sand out of the dunes.

Source: Parliamentary Commissioner for the Environment archives

Figure 4.2 At Haumoana in Hawke's Bay, the land subsided about 70 centimetres during the 1931 earthquake. The earthquake also altered the sediment supply coming down nearby rivers. Since then the shoreline at Haumoana has moved about 40 metres inland.[34]

Source: Fairfax NZ

Figure 4.3 Beach Road south of Oamaru runs along the top of soft cliffs which have been eroding for thousands of years.[35] Soft cliffs do not undergo periods of erosion and accretion – they only erode.

4.3 In conclusion

Erosion (and accretion) around much of the coastline of New Zealand is a natural process that has been happening for thousands of years.

Councils have long been dealing with some of the consequences of erosion. Carparks, access ramps, and other public amenities have been relocated, and sections of some roads have been lost. Breakwaters and groynes have been built as defences and the odd building has fallen into the sea.

As the sea rises, cycles of erosion and accretion on beaches will change. The net effect of a higher sea will generally be increased erosion because the high-energy waves that strip sediment will reach further up shores.

As with coastal flooding, generalisations can be misleading. But when it comes to soft seaside cliffs that are already eroding, it is possible to generalise with reasonable confidence – the rate of erosion along such shorelines will increase.

5 Coastal groundwater

Groundwater sits in the spaces between soil and sediment particles, and within rock fractures. In many parts of the country, groundwater is used as a key source of water for drinking, industry, and agriculture. Most groundwater extracted in New Zealand is taken from coastal aquifers.[36]

When flooding and erosion occur along the coast, the impact is evident. But groundwater problems are not generally visible and are difficult to measure. Some issues associated with coastal groundwater can be expected to become more significant as the sea rises.

In some places, the groundwater will rise as the sea rises. The first section of this chapter describes the problems caused by high groundwater.

Another consequence of rising sea level will be more seawater moving into coastal aquifers. The second section of this chapter describes why saltwater intrusion occurs and why rising sea level could reduce the availability of freshwater in some places.

5.1 High groundwater

In some coastal areas, the water table is not far below the ground and is connected to the sea. As the level of the sea rises, the water table will rise in these areas.[37]

High groundwater causes a number of problems.

- Boggy ground and surface ponding.
- Damage to infrastructure and buildings.
- Saturated soil raising the risk of liquefaction in earthquakes.

Areas of land reclaimed from the sea are especially likely to experience problems caused by high groundwater.

South Dunedin is an area where such problems were clearly evident when prolonged heavy rainfall in June 2015 led to extensive flooding because the rainwater could not drain away. Much of South Dunedin is built on what was once a low-lying coastal wetland, and the water table is close to the surface, with many direct underground connections to the sea.[38] The water table rises and falls with the tides – in some places, builders know to wait for the tide to go out before excavating.

As the level of the sea rises, the water table in South Dunedin – and in some other coastal areas in New Zealand – will be affected.[39] A rising water table will lead to surface ponding in some places and more extensive flooding after heavy rain. It will also damage roads, pipes, and cables, as well as the foundations of buildings, particularly if the groundwater becomes saline.

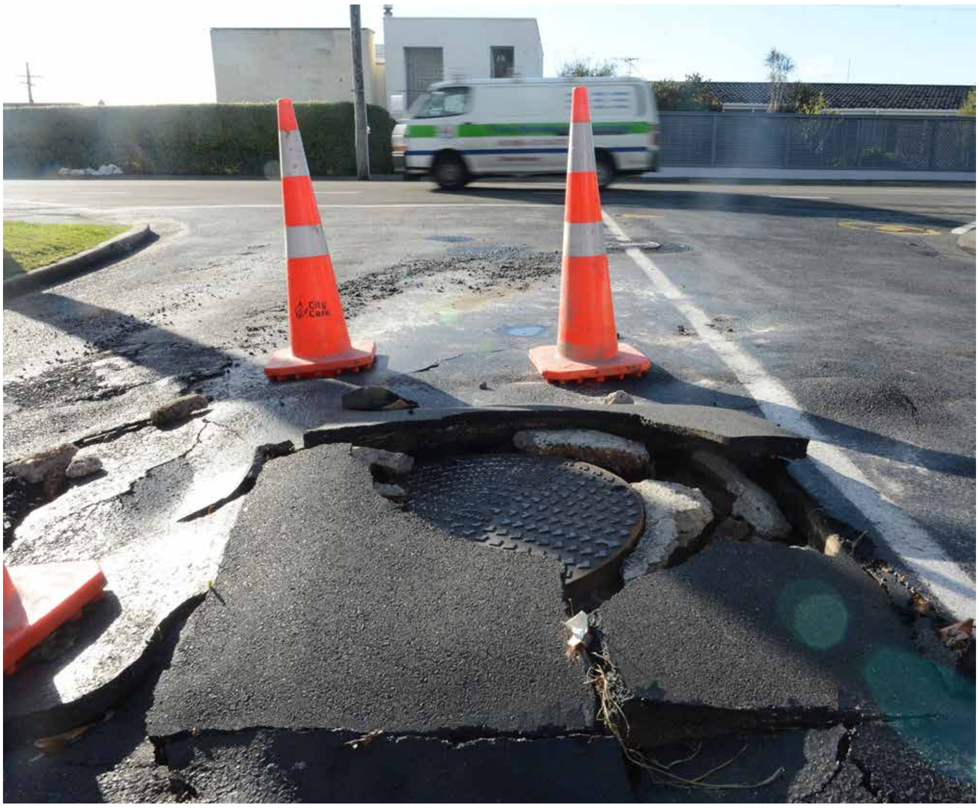
A coastal aquifer does not have to be directly connected to the sea to be influenced by sea level rise. Where an aquifer extends out under the sea, changes in the weight of the water above it can increase the pressure on the aquifer, forcing the water table closer to the surface.

High groundwater can also increase the damage caused by earthquakes. When unconsolidated soils that are saturated with water are shaken in an earthquake, the soil can behave like a liquid. The citizens of Christchurch are all too familiar with the phenomenon of liquefaction.

Areas of reclaimed land are particularly prone to liquefaction. Because rising sea level will generally push up groundwater in these areas, the risk of liquefaction will increase.[40]

Source: Hocken Collection, University of Otago

Figure 5.1 In 1864, artist Andrew Hamilton painted *'Dunedin from the track to Andersons Bay'*. Much of South Dunedin is built on what was once a marshland of lagoons, rushes, and tussock.



Source: Otago Daily Times

Figure 5.2 Heavy rainfall caused flooding and damage in Dunedin in June 2015 when the stormwater system could not cope with the deluge.

5.2 Saltwater intrusion

Sea level rise also increases the potential for saltwater to enter freshwater aquifers.

Coastal aquifers can become contaminated with saltwater when freshwater is extracted at a rate faster than it is replenished. This seems to be a relatively minor problem in New Zealand.

The Waiwhetu Aquifer supplies more than a third of Wellington's water demand. This coastal aquifer extends off the Petone foreshore, and so the risk of saltwater intrusion must be actively managed. Sea level rise is expected to reduce the amount of freshwater that can be extracted from this aquifer.[41]

The Hawke's Bay iwi Ngāti Kahungunu is concerned about the potential for sea level rise to adversely affect the Heretaunga Aquifer. Groundwater scientists from GNS Science are investigating.

Low-lying Pacific atolls are especially vulnerable to flooding and salinisation of groundwater as the sea rises. Such atolls are porous so rainwater seeps directly through to the freshwater layer that floats on the seawater below the ground. On some of these islands, the freshwater has become brackish. One cause of this is waves overtopping and washing over the shores, and this will occur more frequently as the sea rises.[42]

Source: Wikimedia Commons (CC BY-SA 3.0)

Figure 5.3 Giant swamp taro is one of the crops being affected by increasingly saline groundwater.

5.3 In conclusion

Interactions between groundwater and seawater are highly localised and complex, and it is uncertain how groundwater in many places will respond as the sea rises. Predicting impacts on aquifers is made particularly difficult by the 'invisibility' of groundwater and a scarcity of information.

Those places where groundwater is linked directly to the sea are most likely to be affected.

This is particularly the case for groundwater beneath land that has been reclaimed from the sea. After heavy rain in South Dunedin in June this year, the problems that can be caused by a high water table were all too evident with flooded properties and damaged roads. A rising sea will slowly push the water table higher in South Dunedin and some other coastal areas.

Another potential consequence of sea level rise is increasing saltwater intrusion into coastal aquifers that are used as water sources. Saltwater intrusion is already causing serious problems for some of New Zealand's Pacific neighbours.

6 Low-lying and close to the coast

Areas that are both low-lying *and* close to the coast are, in general, most vulnerable to sea level rise. This is certainly the case when it comes to coastal flooding and rising groundwater. Erosion is rather different – a shoreline need not be low-lying to be eroded.

This chapter contains a number of maps showing areas in New Zealand that are both low-lying and close to the coast. Such maps are a necessary early step in assessing what is at risk as the sea rises. But, as has been emphasised in earlier chapters, local characteristics are also vitally important. For instance, a low-lying area close to the coast may be protected by a headland or a natural barrier such as a sand dune. And groundwater will only be a problem if it is connected to the sea.

The first section of this chapter describes how elevation above sea level can be measured accurately using a technology known as Light Detection and Ranging (LiDAR). During this investigation, NIWA was commissioned to convert the available LiDAR data into a standardised form. Once this was done, NIWA used RiskScape software to estimate how much of the built environment is at risk from sea level rise.[43]

The second section contains maps showing low-lying coastal areas in four cities – Auckland, Wellington, Christchurch and Dunedin. These four cities were chosen to provide a link with the modelling results in Chapter 3. Each map is accompanied by a short commentary that contains some RiskScape data. The purpose in this chapter is to give a sense of the information that is now readily available.

The impact of sea level rise will be felt in many other areas outside of these four major cities. Maps of these and other coastal areas have also been prepared in the course of this investigation, and are available at **www.pce.parliament.nz**. The third section contains commentaries on five other cities and towns that have significant areas of low-lying coastal land – Napier, Whakatane, Tauranga, Motueka, and Nelson.

6.1 Elevation maps and RiskScape

Two types of topographic datasets that can be used to map the elevation of coastal areas are available in New Zealand.

The first is the 'national-enhanced Digital Elevation Model'. While the dataset covers the entire country, the measurement of elevation is only accurate to 3 or 4 metres, so it cannot be used as a basis for analysing the impacts of sea level rise.

The second has been created from LiDAR technology. Pulses of light from a laser on an aeroplane are bounced off the ground, and the time taken for the reflected pulse to return is used to measure the elevation of the ground. Topographic surveys using LiDAR are typically accurate to 10 to 15 centimetres, so can be used as a basis for analysing the impacts of sea level rise.[44]

LiDAR elevation data is only available for parts of the country where councils have commissioned it (see Figure 6.1).[45] In the past LiDAR surveying has been very expensive, but is becoming cheaper.

The LiDAR elevation data used in this investigation has been standardised by NIWA to a common baseline – the average spring tide, technically known as 'mean high water springs'.[46,47] Note that the maps show elevation only – low-lying areas that are not directly connected to the sea are included in these maps.

In this chapter, maps of four major coastal cities – Auckland, Wellington, Christchurch, and Dunedin – are presented. Three different elevation bands – less than 50 centimetres, 50 to 100 centimetres, and 100 to 150 centimetres – are shown on the maps.

These maps are not suitable for detailed local level assessments, which must take into account many factors like exposure to storm surges and large waves.

Note also that the local elevation bands shown on the maps are not hazard zones, and should not be interpreted as such.

The RiskScape software programme has been used to find how many buildings, and which roads, railways, and airports are located within the different elevation bands.[48] Underground infrastructure – electricity and gas, telecommunications, drinking water supply, and wastewater and stormwater systems – will also be affected by sea level rise, but were not included in the analysis commissioned from NIWA.

Much of the natural character of the coast will also be affected by sea level rise, but RiskScape only covers the built environment.

Figure 6.1 Areas where LiDAR elevation data has been obtained and made available for use in this report.

6.2 Four coastal cities

Auckland

Compared with other coastal towns and cities in New Zealand, a relatively small proportion of Auckland is low-lying.

Table 6.1 Low-lying homes, businesses and roads in Auckland.[49]

	0–50 cm	50–100 cm	100–150 cm	Total (0–150 cm)
Homes	108	457	795	1,360
Businesses	4	13	43	60
Roads (km)	9	18	29	56

Major low-lying areas shown in Figure 6.2 have not been densely built on. For instance, the large area below 50 centimetres in Devonport is a golf course, another in Northcote is the Onepoto Domain, and a third in Mangere is farmland. These areas are connected to the sea but sheltered from direct wave action.

There are pockets of low-lying land in the city, including parts of the Central Business District, Mission Bay, Kohimarama, St Heliers, Onehunga, Mangere Bridge, and Devonport.

About half of the low-lying homes in Auckland are situated along the coast in the north of the city.

There are also some relatively large areas of low-lying land along the west coast outside the Auckland urban area, which are not shown on the map. These include parts of the towns of Parakai and Helensville that lie close to the Kaipara River. Further south, the beach at Muriwai, though not as low-lying, has been eroding at a rate of about a metre a year since the 1960s.[50]

Vulnerable transport links include the Northern Motorway just north of the Harbour Bridge and the causeway on the Northwestern Motorway where it crosses the mud flats at Waterview. The latter is currently being raised by 1.5 metres and widened, partly to allow for gradual sinking into the soft marine mud and partly to allow for sea level rise.

Tamaki Drive, an important arterial road that provides access to the eastern suburbs, is also subject to flooding, most frequently where it crosses Hobson Bay.

Part of the western end of Auckland Airport lies less than 150 centimetres above the spring high tide mark, with 180 hectares built on reclaimed land and protected by sea walls.[51]

Figure 6.2 Low-lying coastal land in Auckland.

Wellington

Like Auckland, Wellington has about 100 houses that are lower than 50 centimetres above the spring high tide mark, but there are many more at slightly higher elevations.

Table 6.2 Low-lying homes, businesses, and roads in Wellington.[52]

	0–50 cm	50–100 cm	100–150 cm	Total (0–150 cm)
Homes	103	1,920	2,985	5,008
Businesses	1	20	139	160
Roads (km)	2	21	35	58

Figure 6.3 shows that most low-lying areas in Wellington are on the floodplain of the Hutt River – in Petone, Seaview, and Waiwhetū. The more pressing issue for this area is river and stream flooding. However, rising sea level will exacerbate such river floods by reducing the fall to the sea.

There are also small pockets of low-lying land in the Wellington Central Business District, Kilbirnie, Eastbourne, and around Porirua Harbour. Some of these areas have been reclaimed from the sea, so are generally more vulnerable to sea level rise.

Sections of State Highway 1 near Porirua Harbour, Cobham Drive (the main road to the airport), and Marine Drive (the only road to Eastbourne) are low-lying. An upgraded sea wall that reflects waves back out to sea has been proposed for Marine Drive.[53] The Esplanade that runs around the south coast of Wellington is generally higher, but is often pummelled by huge storm waves.

The rail line that runs around the top of the harbour is 2 to 3 metres above the spring high tide mark, but has nonetheless been damaged by high seas in the past. Trains do not have alternative routes, and when a storm washed out the seawall protecting the track in June 2013, it took almost a week to restore the service.[54]

Wellington's airport has been built on reclaimed land that is more than 3 metres above the spring high tide mark.

Figure 6.3 Low-lying coastal land in Wellington.

Christchurch

A relatively large proportion of land in Christchurch is low-lying.

Table 6.3 Low-lying homes, businesses, and roads in Christchurch.

	0–50 cm	50–100 cm	100–150 cm	Total (0–150 cm)
Homes	901	3,629	5,427	9,957
Businesses	5	58	130	193
Roads (km)	40	77	84	201

A map showing low-lying land in Christchurch prior to the 2010 and 2011 earthquakes would look rather different from Figure 6.4. In parts of Christchurch, land sank by as much as a metre or more, particularly along the lower reaches of the Avon River. Where land has sunk, water tables lie closer to the surface – this along with other changes has made these areas more prone to flooding.[55]

A considerable amount of low-lying land shown on the map is in the Residential Red Zone and so has been largely cleared of buildings. The numbers of homes and businesses listed in Table 6.3 do not include any in the Residential Red Zone.

Despite this, there are many more low-lying homes in Christchurch than in Auckland or Wellington – around the rivers and in the coastal suburbs.

Sand dunes run the length of the New Brighton coastline and provide some protection from the open coast to the low-lying areas behind. On Southshore, located on a spit between the open coast and the estuary, the lowest-lying land is on the estuary side.

Main Road that leads round the coast to Sumner is particularly low-lying, although somewhat protected by a seawall. This is currently the only access road to Sumner, since the other road in has been closed since the earthquakes.

As in Auckland, some large areas that are less than 50 centimetres above the spring high tide mark are not built up. For instance, the large area in Burwood is the Travis Wetland.

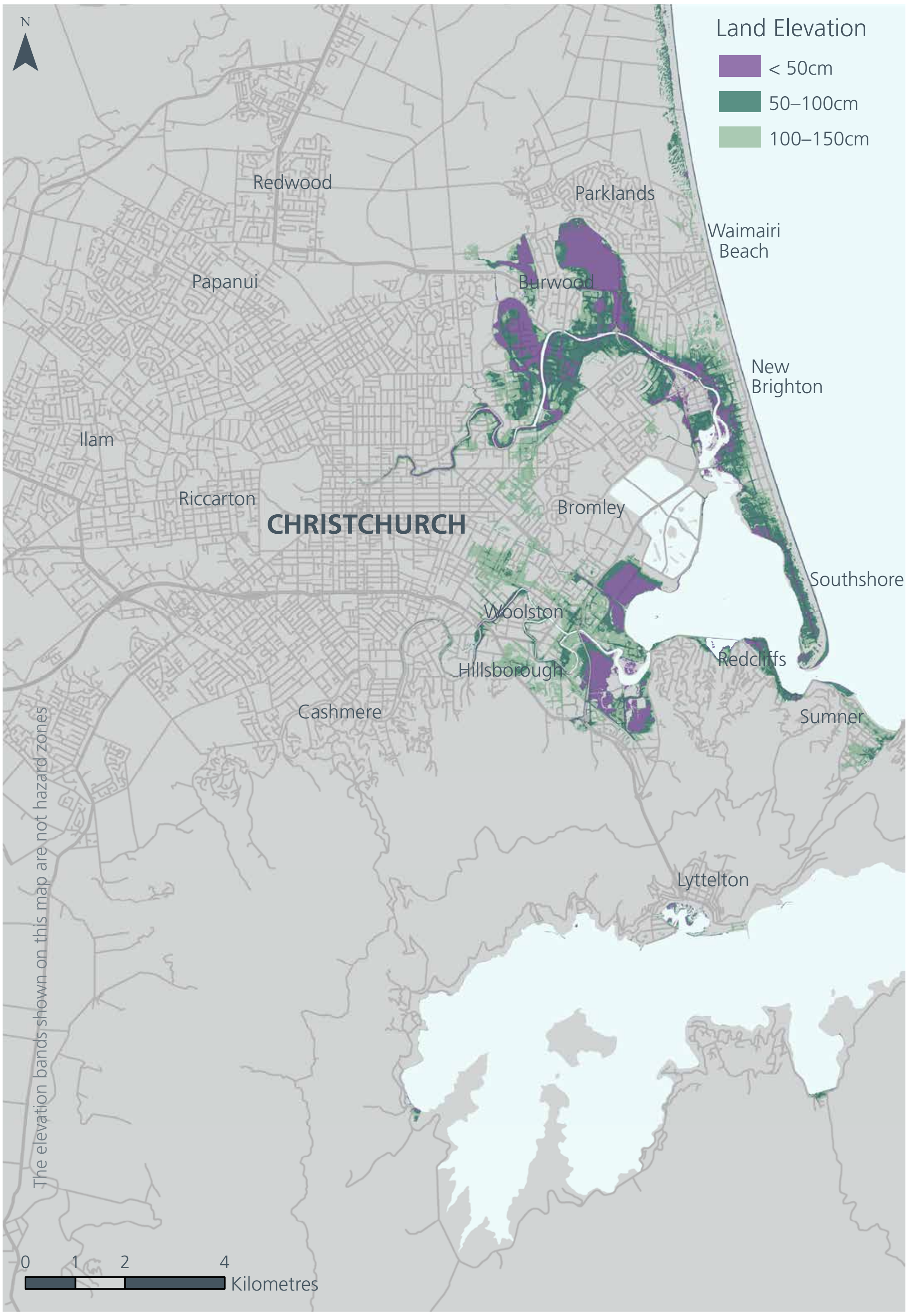


Figure 6.4 Low-lying coastal land in Christchurch.

Dunedin

Dunedin is notable for the large built-up area in the city's south that is very low-lying (Figure 6.5).

Table 6.4 Low-lying homes, businesses, and roads in Dunedin.

	0–50 cm	50–100 cm	100–150 cm	Total (0–150 cm)
Homes	2,683	604	317	3,604
Businesses	116	29	40	185
Roads (km)	35	17	20	72

As discussed in Chapter 5, South Dunedin was built on land reclaimed from a coastal wetland. Of the nearly 2,700 homes that lie less than 50 centimetres above the spring high tide mark, over 70% are lower than half that elevation.

The low elevation of South Dunedin along with its high water table makes it prone to flooding after heavy rain. The water table also rises and falls with the tides, so these problems will increase as high tides become higher.

The seawall protecting the St Clair esplanade in South Dunedin has required considerable maintenance and reinforcement in the wake of heavy seas over the last two years.[56]

Beyond South Dunedin, some areas of the waterfront and Central Business District are low-lying. These include sections of State Highway 1 and Portsmouth Drive. Portobello Road and Aramoana Road that run along either side of the harbour also have low-lying sections, with some places less than 100 centimetres above the spring high tide mark.

The rail line to Port Chalmers is an important link in the region's transport infrastructure. Much of it lies less than 150 centimetres above the spring high tide mark.

Dunedin Airport lies on the floodplain of the Taieri River and floods from time to time. The level of the water in the river fluctuates with the tides, and will be affected by sea level rise.[57]

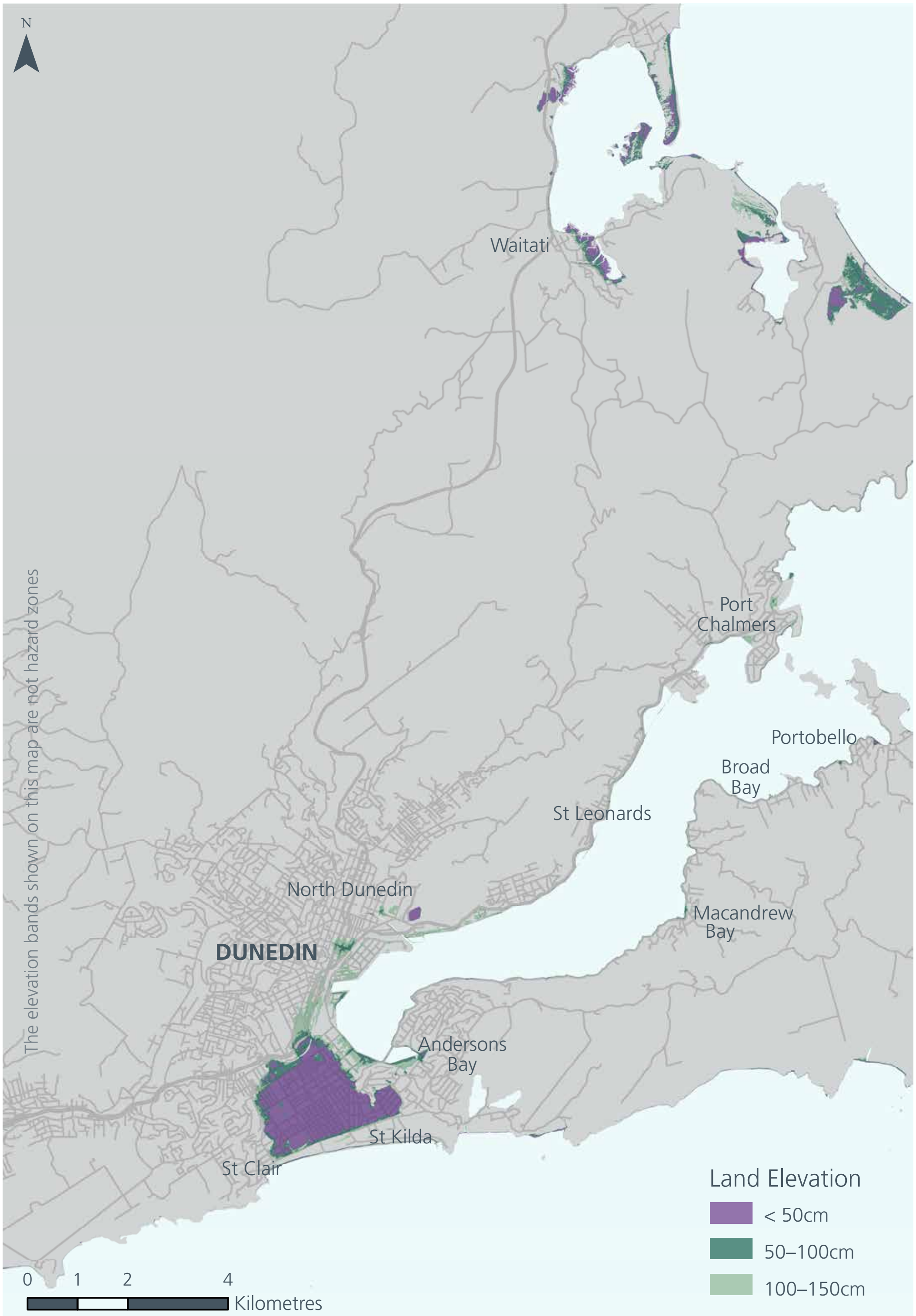


Figure 6.5 Low-lying coastal land in Dunedin.

6.3 Other coastal towns and cities

It is not just the four main cities in New Zealand that will be affected by rising seas. Many smaller towns and coastal settlements have also been built on the coast.

Running the RiskScape programme shows that there are five more cities and towns with more than a thousand homes lying less than 150 centimetres above the spring high tide mark – Napier, Whakatāne, Tauranga, Motueka, and Nelson.[58]

Table 6.5 Low-lying homes, businesses, and roads in Napier.

	0–50 cm	50–100 cm	100–150 cm	Total (0–150 cm)
Homes	1,321	2,958	3,694	7,973
Businesses	12	32	32	76
Roads (km)	37	59	49	145

Table 6.6 Low-lying homes, businesses, and roads in Whakatāne.

	0–50 cm	50–100 cm	100–150 cm	Total (0–150 cm)
Homes	276	563	470	1,309
Businesses	4	48	54	106
Roads (km)	9	15	14	38

Table 6.7 Low-lying homes, businesses, and roads in Tauranga

	0–50 cm	50–100 cm	100–150 cm	Total (0–150 cm)
Homes	77	419	735	1,231
Businesses	4	22	81	107
Roads (km)	3	14	18	35

Table 6.8 Low-lying homes, businesses, and roads in Motueka.

	0–50 cm	50–100 cm	100–150 cm	Total (0–150 cm)
Homes	45	390	618	1,053
Businesses	0	3	0	3
Roads (km)	4	7	8	19

Table 6.9 Low-lying homes, businesses, and roads in Nelson.

	0–50 cm	50–100 cm	100–150 cm	Total (0–150 cm)
Homes	64	351	628	1,043
Businesses	4	22	91	117
Roads (km)	6	12	23	41

Much of *Napier* has been built on land that rose out of the sea during the 1931 earthquake or has been reclaimed since that time. Nearly 8,000 homes are less than 150 centimetres above the spring high tide mark, and a considerable area of the city, including the airport, is less than 50 centimetres above the spring high tide mark.

Most of the city's low-lying areas are protected by the gravel banks along the beach on Marine Parade. These gravel banks are replenished mainly by sediment washed up north from the mouth of the Tukituki River. However, further north, the beach along Westshore has been eroding for some time.

Whakatāne is vulnerable to river flooding, and will become increasingly vulnerable to high seas. A large area of farmland to the west of Whakatāne and a part of the town centre lie less than 50 centimetres above the spring high tide mark. Much of the town and the surrounding areas are protected by stopbanks along the river, and water levels on the farmland are managed by pumping.

In *Tauranga*, there are many pockets of low-lying land around the harbour. Most of the low-lying homes are in Mount Maunganui and the suburbs of Otumoetai and Matua. Most of the low-lying businesses are near the airport. The harbour provides some protection from the full force of the sea.

In *Motueka*, about a third of the homes lie less than 150 centimetres above the spring high tide mark. A long sandbar currently protects the town from big waves during storms.

In *Nelson*, the industrial area around the port, the airport, and the suburbs of The Wood, Tahunanui, and Monaco are all low-lying. Minor ponding occurs in parts of the central city when king tides cause seawater to flow back up stormwater pipes. At times, waves crash over the seawall along Rocks Road.[59]

6.4 In conclusion

Accurate measurement of land elevation above sea level is an essential first step in considering the potential impacts of sea level rise. This is especially so for coastal flooding, which will be particularly visible and widespread.

The choice of which elevation contours to map is much more than a technical decision. How far ahead into the future should we look? Which of the IPCC scenarios should we use as a guide? How risk-averse should we be?

These elevation maps are only a first step. Assessment of the vulnerability of a particular area generally requires information about a range of local characteristics. These include the size and likelihood of storm surges hitting different parts of the coast. Storm surges ride on top of the sea, and so temporarily raise sea level.

Many of the cities and towns on New Zealand's coasts are located at river mouths. In such cases, sea level rise will exacerbate river floods by reducing the fall to the sea.

As discussed later in the report, elevation maps like those in this chapter provide a starting point for councils beginning to engage with their communities on this challenging issue.

7 Dealing with coastal hazards in New Zealand

As the climate changes and sea levels continue to rise, coastal hazards will also change. Not only will erosion speed up in places and become more widespread, coastal floods will become more frequent and extensive, and in places there will be groundwater problems.

There are seven sections in this chapter.

The first section looks back into the past and describes how the New Zealand government at both central and local level has dealt with erosion – the long-familiar coastal hazard.

Councils are required to plan for sea level rise.[60] The second section describes the direction and guidance provided to councils by central government.

The next four sections describe how councils have begun to plan for sea level rise, using examples from and near the four major coastal cities of Auckland, Wellington, Christchurch, and Dunedin. These examples illustrate problems with, and gaps in, the direction and guidance provided by central government.

The seventh section is a brief summary of the chapter.

7.1 Erosion – a long-familiar coastal hazard

The people of New Zealand have known about the dangers of living by the coast for a long time. Māori oral histories and traditions record the impacts from great waves, flooding, and erosion caused by storms.[61]

In the 19th century European settlement occurred along many parts of New Zealand's coast, particularly in places providing a safe port. Buildings, roads, and railways were constructed along the coast. In some places, large areas of land were reclaimed from the sea.

An early warning of the economic cost of coastal erosion occurred in 1879 when a storm knocked out part of a railway viaduct in Timaru.[62] In Oamaru in the 1930s, old locomotives were dumped on the beach to protect the railway yard from being washed away by the sea.[63]

Increasingly, seawalls were installed by public agencies and private landowners.

In the 1950s and 1960s, the Department of Lands and Survey actively encouraged sub-division of coastal property, without considering the impact on the landscape or coastal hazards.[64] In many places sand dunes were bulldozed.

In at least one case, the Department of Lands and Survey sold sections on Ohiwa Spit in the Bay of Plenty, where an entire town had been previously abandoned because of erosion. After several destructive storms in the 1960s and 1970s, the residents of Ohiwa Spit tried unsuccessfully to win compensation from the Government. The then Minister of Lands responded *"The principle is quite clearly 'caveat emptor' and I know of no fact which could establish any liability on the Crown"*.[65]

In contrast, compensation had earlier been paid to residents of Mokau who had lost their homes to the sea. The Department of Lands and Survey had subdivided this coastal area in Taranaki against the recommendation of the local council.[66]

By the 1970s erosion had become a major issue at many coastal settlements, especially in Northland, Coromandel and the Bay of Plenty. But erosion was not the only issue facing coastal settlements at this time. The loss of the natural character of the coast due to largely unconstrained development had become a major concern of the Government and the public. This was reflected in new policy and legislation.[67]

The concept of mapping parts of the coast considered more hazardous than others emerged at this time. Coastal survey programmes were established to collect data and methods for estimating coastal hazard zones developed.[68] The coastal hazard setback at a subdivision at Onaero Beach in Taranaki in 1978 may have been the first to be included in a district scheme.[69]

In the 1980s, councils began to restrict development using their powers under the Local Government Act 1974. Under s 641, councils could not grant building permits for sites subject to erosion or inundation by the sea, unless provision had been made for protection of the land. In 1981, an amendment allowed councils to grant permits for relocatable buildings in such areas.[70]

7.2 Sea level rise – amplifying coastal hazards

The passage of the Resource Management Act (RMA) in 1991 coincided with the growing recognition that sea level rise would increase coastal hazards.

In the previous year, the Intergovernmental Panel on Climate Change (IPCC) had published its first assessment which included projections of sea level rise. In 1992, New Zealand was one of 156 countries that signed up to the United Nations Framework Convention on Climate Change created at the Earth Summit in Rio de Janeiro.

In 1994, the first New Zealand Coastal Policy Statement (NZCPS) was published by the Minister of Conservation, as required under the RMA. This document directed councils to *"recognise the possibility of sea level rise"* in managing coastal hazards.[71]

In 2004, this was further reinforced in an amendment to the RMA that required councils to have *"particular regard to … the effects of climate change"*.[72] In the same year, the Ministry for the Environment (MfE) published guidance to assist councils in planning for sea level rise. This guidance was updated in 2008.

In 2010, the second NZCPS was published, and sea level rise was given much more prominence than in the earlier version.

Since then, there have been calls for more central government direction on sea level rise. The Ministry for the Environment began work on a national environmental standard in 2009. However, this work has now stopped. The Minister for the Environment's view is that there is *"too much uncertainty for a rigid standard to be applied"*.[73] The Ministry is now working on an update of its guidance document.[74]

Thus, current central government policy for planning for sea level rise is contained in two documents:

- The 2008 Ministry for the Environment Guidance Manual on Coastal Hazards and Climate Change
- The 2010 New Zealand Coastal Policy Statement.

2008 Ministry for the Environment Guidance Manual

This document provides two kinds of high level guidance, as well as a great deal of technical information.

The first kind of guidance is concerned with the amount of sea level rise that should be incorporated into planning decisions. It is recommended that a base amount of 50 centimetres from 1990 to 2100 be used, but that the consequences of an 80 centimetre rise (or more) be considered. Beyond 2100, an allowance of one centimetre each year is also recommended for planning purposes.

These sea level rise projections are taken from the IPCC's Fourth Assessment in 2007.[75]

Coastal hazards are to be assessed over *"a lengthy planning horizon such as 100 years"*.[76]

The second kind of guidance is expressed in terms of four general principles that councils should incorporate into their decision-making.

- A precautionary approach
- Progressive reduction of risk over time
- The importance of coastal margins
- An integrated, sustainable approach.

2010 New Zealand Coastal Policy Statement

The purpose of the NZCPS is to state policies in order to achieve sustainable management in relation to the coastal environment. Councils are required to follow the NZCPS when planning.[77]

This document begins with a list of seven coastal policy objectives. The fifth is concerned with coastal hazard risks which are to be managed taking account of climate change. There are three parts to the objective (slightly paraphrased).

- Locating new development away from areas prone to coastal hazards
- Considering responses, including managed retreat, for existing development prone to coastal hazards
- Protecting or restoring natural defences to coastal hazards.

The New Zealand Coastal Policy Statement requires councils to:

- Identify areas 'potentially' affected by coastal hazards over 100 years or more
- manage such areas using a 'precautionary' approach.

The New Zealand Coastal Policy Statement is largely focused on the protection of the natural coastal environment. It contains a preference for strategies that reduce the need for 'hard' protective structures like seawalls.

Around New Zealand, councils are responding to Government policy on sea level rise in various ways. The next four sections of this chapter explore some of the planning for sea level rise that has been undertaken in and near the four major cities featured in Chapter 3 and Chapter 6. The purpose is to illustrate some of the issues that have arisen.

7.3 Auckland and Coromandel

Erosion has long been a problem in places along Auckland's coasts.

An example is the southern end of Muriwai Beach on the west coast, which has been eroding since the 1960s. In just three years (2005 to 2007), several storms caused the shoreline to retreat around eight metres inland. Since then the council has decided to allow a section of the beach to move inland. Sand dunes have been built up and planted, and a car park and the surf club moved many metres inland.[78]

On the east coast, erosion is a problem at the developed beachside town of Orewa. The Auckland Council is currently piloting an approach to manage the beachfront by dividing it into different sections – some sections are being armoured with large boulders, and dunes are being planted to stabilise them in others. At the southern end of the beach, where there is a reserve, the shoreline is being left to move naturally.[79]

The decision to allow part of the shore at Muriwai to retreat and the mixed approach being taken at Orewa are examples of strategic thinking at a beach level. Strategies for whole coasts are being developed and used overseas. In the United Kingdom, Shoreline Management Plans for the entire coastline of England and Wales have been developed, specifying which areas are to be defended from the sea and which are not.[80] Auckland Council is aiming to develop similar plans for their coasts.[81]

Although the Coromandel Peninsula is part of the Waikato Region, it is often called 'Auckland's playground'. Holiday homes have proliferated along its beachfronts *"creating an extensive and growing urban footprint along the coast"*.[82]

The beauty and wildness of Coromandel's beaches is what has made them so appealing to holidaymakers. 'Hard' engineered protection changes the natural character of the coast and leads to the loss of beaches by preventing them from migrating inland. Moreover, defending one part of a coast can make other parts more vulnerable.

However, in some places the only way to protect homes and roads will be by building 'hard' defences. In the Coromandel's Mercury Bay, a mixed approach is being taken to dealing with areas affected by coastal erosion.

The question as to whether coastal defences are funded by councils or by those directly affected will need to be considered as erosion (and flooding) worsens.

In Whitianga, the district council and community board have agreed that owners should pay for the protection of their own properties. Homeowners at Cooks Beach have paid for a seawall to be built, whereas the extension of the seawall at Buffalo Beach has been funded by the council in order to protect a road and beachfront reserve.[83]

The Auckland Council has notified its first Unitary Plan and an independent panel is currently considering the concerns of thousands of submitters.

In its proposed plan, the Council distinguished between 'greenfield' areas and 'other' areas in considering the potential for coastal flooding.[84]

- *Greenfield* areas with an annual 1% chance (or more) of being flooded after two metres of sea level rise were deemed to be 'coastal inundation areas'.
- *Other* areas with an annual 1% chance (or more) of being flooded after one metre of sea level rise were deemed to be 'coastal inundation areas'.

The proposal in the plan is that *greenfield* coastal inundation areas would be out of bounds for development. However, new buildings can be constructed in other coastal inundation areas, provided floors are raised at least 50 centimetres.[85]

The Independent Hearings Panel questioned the need to plan for a two metre rise in sea level, and consequently the restriction on greenfield development.[86]

Distinguishing between greenfield development and development in other areas makes sense. In evidence presented to the hearings panel, a council planner rightly pointed out: *"Urban growth and subdivision of land creates a land use expectation for an indefinite future period"*.[87]

The 2008 Ministry for the Environment Guidance Manual does not provide specific advice on time frames (and amounts of sea level rise) to use in planning for different kinds of development.

The Auckland Council now proposes to replace reference to a two metre rise with *"broader references to 'long term'"*.[88] In essence, this leaves the problem with the Environment Court – developing policy through case law. Yet the judgements on two recent cases dealing with this issue are very different. Both judgements were consistent with the law; the inconsistency lies in the different ways in which coastal hazards were dealt with in the relevant council plans and policies.[89]

7.4 Wellington and Kapiti

Much of Wellington city's shoreline is protected by concrete seawalls and/or rock armouring.

Such hard defences will require increasingly expensive maintenance as the sea rises. The seawall at Paekakariki is soon to be replaced at a cost of $11 million.[90]

At Island Bay on the south coast, a large section of a seawall that had stood for decades was destroyed in the June 2013 storm. It too is soon to be repaired. A proposed longer term option was to move part of the road inland and allow the beach to expand and merge with a park. Wellington City Council is planning to develop a resilience strategy for the south coast.[91]

Such coastal strategies are essential to avoid costly *ad hoc* responses to increasing erosion and flooding. In particular, councils need clear direction on when they can make the 'hard call' to stop maintaining a coastal road or seawall.

Just north of Wellington city is the Kapiti Coast where the district council's planning for coastal erosion went awry. Some useful scientific and policy insights can be gleaned from examining what happened.

Some parts of the Kapiti shoreline are eroding and other parts are accreting. In August 2012, the Kapiti Coast District Council released a report on coastal erosion that included projections of where the shoreline could be in 50 and in 100 years' time.[92] These projections were used to create 'erosion hazard zones' that included 1,800 coastal properties along the Kapiti coast.[93] On the day the report was released, the Council sent letters to affected coastal property owners informing them that the 'erosion hazard zones' would now appear on Land Information Memorandum (LIM) reports.

Three months later, the Council notified the new Proposed District Plan, placing restrictions on building and subdivision within the 50 year hazard zone. In response a Waikanae couple, Mike and Veronica Weir, challenged the Council in the High Court. They were supported by Coastal Ratepayers United, a group of affected property owners.

In an interim judgement, the High Court found that while placing the erosion risk on LIMs was required by the law, the way in which it was done was inadequate and misleading.[94]

In April 2013, the Council appointed an independent scientific panel to review the methodology used in the assessment. In December 2013, the Council decided that the 'erosion hazard zones' would no longer appear on LIM reports.

In its June 2014 report, the independent panel concluded that the 2012 coastal erosion assessment was *"not sufficiently robust for incorporation into the Proposed District Plan"*.[95] The Council is no longer considering coastal erosion zones in its current review of the District Plan, but is planning further research.

The Kapiti experience is instructive in a number of ways.

Importantly, the process was hasty. On a single day, the report was released, the hazard zones were put on LIMs, and letters were sent to property owners. In his judgement, Justice Joe Williams commented that it *"would be a callous Council indeed that was unmindful of [the] potential impact"* on the value and marketability of coastal properties.[96]

Both the New Zealand Coastal Policy Statement and the MfE Guidance Manual require councils to take a 'precautionary approach' to planning for coastal hazards. In the Kapiti assessment of erosion hazard, 'precaution' was embedded into the scientific modelling in a number of places. This included double-counting part of the predicted sea level rise, and assuming accreting parts of the beach would not continue to accrete.[97]

Box 7.1 Putting hazard information on LIMs

Justice Joe Williams began his judgment on the Kapiti case thus:

"The site of this debate is the humble LIM: the local authority's land information memorandum familiar to every purchaser of property in New Zealand."

Local councils are required to provide up-to-date information on properties within their districts either by putting it on LIMs or by including it in a district plan.

The information must identify special features and characteristics of the land *"… including but not limited to potential erosion, avulsion, falling debris, subsidence, slippage, alluvion, or inundation, or likely presence of hazardous contaminants…"*.[98]

Councils could be found negligent if they hold relevant information and fail to provide it clearly, fairly, and accurately.[99]

7.5 Christchurch

Planning for sea level rise is currently a topic of debate in Christchurch. In July this year, information on coastal hazard risks was placed on the LIMs of nearly 18,000 properties in the city. With ten times the number of properties involved, this is the Kapiti situation writ large.

A year earlier, the Government had directed the Christchurch City Council to complete a new district plan by March 2016. This direction, made under the Canterbury Earthquake Recovery Act, specified a fast-tracked process that shortened consultation periods and allowed appeals only on points of law.[100]

When a district plan is developed, consideration of how natural hazards are to be managed and planned for is required. The Council commissioned a report to identify areas that will be vulnerable to coastal flooding and coastal erosion within the next 50 and 100 years.[101] This resulted in a series of maps that showed four hazard zones – 50 year and 100 year zones for flooding and for erosion.

The report was released on 3 July 2015, and on the same day the new information was placed on the LIMs of the affected properties. Public meetings were held by the Council to explain the information. Three weeks later, new rules restricting subdivision and development in these zones were notified.[102]

In response, as in Kapiti, some affected residents formed a group called Christchurch Coastal Residents United (CCRU). An important difference from the Kapiti situation is that some of the areas denoted as coastal hazard zones were badly damaged in the 2010 and 2011 earthquakes. It is not surprising that meetings organised by CCRU were attended by hundreds of people. Residents expressed concern that the process was rushed and lacked transparency, and that the Council's public meetings were held too late.[103]

At the end of September, the Government decided to remove coastal hazards from the fast-tracked process. At a joint press conference with Government Ministers, the Mayor of Christchurch stated:

"The fast-tracking of the District Plan Review was always intended to be about earthquake recovery. We do not need to move with the same speed with respect to these longer term issues".[104]

Currently, the Council is legally obliged to keep the hazard zone information on the LIMs of affected properties. However, the residents group has raised concerns about the coastal risk assessment used to identify the hazard zones.

"This assessment is considered to be based on speculative predictions which are overly precautionary and which do not look at what is likely to occur but instead take a worst case scenario viewpoint of what maybe is possible".[105]

As noted in the previous section, both the 2010 New Zealand Coastal Policy Statement and the 2008 MfE Guidance Manual require councils to take a precautionary approach.

As in the Kapiti situation, 'precaution' has been embedded into parts of the Christchurch coastal risk assessment. This is particularly notable in the identification of 100 year erosion hazard zones.

The New Zealand Coastal Policy Statement refers to protecting *existing* development *likely* to be affected by sea level rise and *new* development *potentially* affected by sea level rise. In the Christchurch coastal risk assessment, *likely* was interpreted to mean a chance of being affected by erosion of at least 66%, and *potentially* to mean a chance of being affected by erosion of at least 5%.[106]

The result is that a property estimated to have only a 5% chance of eroding in 100 years time is deemed to be within an erosion hazard zone.[107]

The modelling of future erosion relies on the Bruun Rule. This rule was first proposed in 1954. It applies to sandy beaches that are in a stable state – not actively accreting or eroding – and where there is little sediment movement along the shore. In other situations the Bruun Rule is only useful as a first approximation.[108]

The Brighton shoreline has been accreting since at least 1941 due to longshore currents carrying sediment from the Waimakariri and other North Canterbury rivers.[109] Although the Christchurch coastal risk assessment does add in an accretion component, the modelling projects a reversal of this long-term trend. Certainly, as the sea rises, accreting shores are likely to begin to erode, but there is great uncertainty about when this will happen in any particular case.[110]

Finally, when hazard information is put on a LIM, it must be clear. The wording that has been placed on the LIMs of properties in the 50 year flood hazard zone reads: *"This property is located in an area susceptible to coastal inundation (flooding by the sea) in a 1-in-50 year storm event"*.

What does this mean? It seems to say that the property is likely to be flooded once in the next fifty years.

But what it actually means is something much more complicated, namely that in the year 2065 (after 40 centimetres of sea level rise), there is at least a 2% chance that the property will be flooded. The chance that the property will be flooded now is significantly lower.

7.6 Dunedin

The part of Dunedin that is most at risk from sea level rise is the area of Harbourside and South City. Built on land reclaimed from the harbour, it is very low-lying and the water table is close to the surface in places.

This area is bound by the dunes that rise many metres above St Clair and St Kilda beaches, so a wall of sand currently protects the flat suburbs from southerly swells that pound the beaches. The flats have been flooded by high seas in the past. In the late nineteenth century, the sea flooded in through breaches in the sand dunes, caused at least in part by the Government mining the sand.[111]

St Clair Beach has a long history of erosion – the readily visible piles in the sand are remnants of failed groynes installed in the early 1900s.[112]

In June this year, large areas of these suburbs were swamped when heavy rainfall overwhelmed drains. The drainage system could not cope with both a high water table and little fall to the sea.

The water table in these suburbs has a 'tidal signal' – it rises and falls with the tides. The closer to the sea, the more marked this effect is. As the sea rises, it will lift the water table higher.

In 2014, the Dunedin City Council commissioned an assessment of a range of options for defending these suburbs from the effects of sea level rise.[113]

One option canvassed was to build an underground seawall, designed to stop seawater pushing up the groundwater from below. This was not recommended – not only would it be very expensive, it could not be guaranteed to work.

The other options all involve various dewatering schemes – pumping water out of the ground. The recommended option is to sink dewatering wells along the coastal fringes, including along the harbour. The effectiveness of such a scheme depends on the Middle Beach dune remaining intact. Also, dewatering can lead to ground slumping.[114]

The Council is continuing to investigate measures to protect these suburbs, but is also investigating non-protection measures – that is, forms of managed retreat.

However, how to go about managed retreat is far from clear. In its 2014 report on managing natural hazard risk, one of the research priorities identified by Local Government New Zealand was *"When does retreat become the most viable option and how can this be given effect to?"*

The situation in this part of Dunedin could become analogous to the red zoning in Christchurch after the 2011 earthquake, although over a longer time frame. Local Government New Zealand has raised the possibility of creating a fund similar to that of the Earthquake Commission (EQC).

"While the legal tools exist, it is difficult to see how it can be implemented effectively without some form of (probably nationally funded) financial assistance mechanism similar perhaps to an EQC fund that might operate before an event rather than after an event. Such a mechanism does not currently exist and its design and implementation would raise many vexed public policy issues".[115]

7.7 In conclusion

While central government has provided some direction and guidance, the responsibility for planning for the effects of a rising sea has largely been devolved to local and regional councils. The difficulty and complexity of this task is considerable and councils that have tackled it should be commended. However, when councils have acted they have sometimes been challenged by those affected.

Better direction and guidance is needed in three broad areas:

- Scientific assessment of the impact of a rising sea on coastal hazards
- The process of engaging with the community
- The planning and management decisions that follow.

Methodologies that are used in coastal risk assessments need to be fit-for-purpose and consistent, with assumptions clearly stated. Further, they need to be written in a way that can be readily understood, or else they will not be trusted.

Affected communities have expressed concerns about various aspects of the process that follows the undertaking of coastal risk assessments. One of these is the speed of the process; another is the lack of transparency.

The decisions being made by councils planning for sea level rise can be far-reaching and affect many people, so should be made carefully. Current policy is geared toward risk aversion – in some situations, this will be appropriate, in other situations not.

The concluding chapter contains eight recommendations from the Commissioner to the Government.

8 Conclusions and recommendations

The world must grapple with two aspects of climate change – mitigation and adaptation.

- Mitigation – reducing emissions of carbon dioxide and other greenhouse gases to slow down climate change.
- Adaptation – dealing with the consequences of climate change.

This report is about adaptation to one of the consequences – the rising level of the sea.

There is an urgency to mitigation – greenhouse gas emissions should be reduced as quickly as possible.

But this sense of urgency need not spill over into adaptation planning. During this investigation, it has become clear that there is some time to develop good policy and planning for sea level rise. Because so many will be affected, whether it be by flooding, erosion, or changes to groundwater, councils must engage with coastal communities in a measured and empathetic way. The focus should be on preparing well rather than rushing.

The level of the sea around New Zealand is rising and will continue to rise for the foreseeable future. This much is certain. What is uncertain is the rate of rise, especially later this century and beyond.

New Zealanders are familiar with the power of the sea. Living with risks of flooding and erosion are part and parcel of living near the coast. However, these risks are changing. As the sea rises, coastal floods will become more common, erosion will increase, and groundwater will rise.

There will be far-reaching impacts on coastal towns and cities. Mapping undertaken to support this investigation shows significant areas only a metre or so above today's spring high tide mark.

The actual impacts on such areas will vary from place to place. A range of local physical factors determine just how vulnerable a low-lying coastal area is to sea level rise. Thus, the maps of land elevation in this report are just that – they are not maps of hazard zones.

Both the uncertain rate of sea level rise and the range of local factors make anticipating the nature – and timing – of the impacts of a rising sea very difficult.

The sea is gradually but inexorably rising, and the risks therefore incrementally worsen. In a few places the effects are already tangible or are imminent, but in most places will unfold slowly over time.

Councils and communities across the country face the difficult task of assessing the risks and deciding what to do in response. Planning in the face of uncertainty is never easy, but is particularly difficult when choices will affect people's homes.

Coastal residents will bear the brunt of a rising sea, but did not cause it and were not warned of it before choosing where to live. Yet failing to inform those considering living on the coast is not an option.

So plan we must, and plan carefully. However, in all but a few situations, haste is not necessary or desirable. Councils need to take some time to develop strategies and make fair decisions that are based on assessments that are both robust and transparent.

Where should protective seawalls be built? Who will pay for them? Where should beaches be left to retreat inland? When is abandoning maintenance of a coastal road justified? And when does the retreat of a whole community become inevitable?

This chapter contains eight recommendations from the Commissioner to the Government. The first seven are aimed at improving the direction and guidance provided by central government to councils. The last is focused on the fiscal implications of sea level rise.

8.1 National direction and guidance

Currently, there are two central government documents – the 2010 New Zealand Coastal Policy Statement (NZCPS) and the 2008 MfE Guidance Manual – that provide direction and guidance to councils on how they should deal with sea level rise.

A number of problems with how councils are planning for sea level rise have emerged during this investigation – problems with science assessments, with the process of engaging with the community, and with the planning and management decisions that follow.

In seeking to improve central government direction and guidance, the question of the form it would best take arises. For instance, should the two documents simply be revised? Or should a National Policy Statement (NPS) on sea level rise be created, as some have suggested?

The New Zealand Coastal Policy Statement is the only NPS to be prepared by the Department of Conservation and signed by the Minister of Conservation. This came about because the natural character and beauty of the coast and access to the sea are greatly valued by New Zealanders, and seen to be of national importance.

However, because the NZCPS is largely focused on protecting the natural coastal environment, it does not address all the dimensions of sea level rise. Objective 5, which is concerned with the management of coastal hazard risks taking account of climate change, is just one of seven objectives. If Objective 5 were to be removed from the NZCPS, some of the policies would still need to refer to sea level rise. This is because sea level rise will affect ecosystems, natural character, and public access.

The Minister for the Environment has indicated an intent to add natural hazards to the list of national priorities in the RMA and to develop an NPS on natural hazards. Sea level rise could be included in such an NPS.

Whatever form it takes, direction and guidance needs to reflect the particular nature of sea level rise. It is incremental and relentless; it is outside human experience, so seems unreal.

The 2008 MfE Guidance Manual is soon to be revised, providing an opportunity to address matters that emerged during this investigation. The revised guidance should be a 'living document', so it can be readily updated.

Recommendation to the Minister for the Environment and the Minister of Conservation:

a. Take direction on planning for sea level rise out of the New Zealand Coastal Policy Statement and put it into another National Policy Statement, such as that envisaged for dealing with natural hazards.

b. Direct officials to address the matters raised in this investigation in the revision of the 2008 MfE Guidance Manual.

8.2 Measuring land elevation

Every centimetre of sea level rise will have an impact. Thus, measuring the elevation of coastal land above the sea as accurately as possible is essential for planning.

The technology for accurate measurement of elevation is LiDAR. Pulses of light from a laser on an aeroplane are bounced off the ground, and the time taken for the reflected pulse to return is used to measure the elevation of the ground.

Three councils have mapped their entire regions with LiDAR, and others have mapped selected parts. However, the mapping has been done with varying levels of accuracy and different baselines have been used.

The work commissioned from NIWA for this report standardised all the available data to a baseline or 'zero level' of MWHS-10 – the mean of the highest 10% of high tides.

Such national consistency is essential. There is no good reason for a 50 centimetre contour to mean one thing in one part of the country and something else in another. It also ensures that science assessments and planning decisions are comparable.

To attain national consistency, protocols for procurement of LiDAR data must be developed. Further, the elevation datasets should all be put into a national repository.

It is also important to map the elevation of floodplains where there is the potential for incoming tides to exacerbate river flooding.

Recommendation to the Minister for the Environment:

In revising central government direction and guidance on sea level rise, include protocols for the procurement of elevation data, and work with Land Information New Zealand and other relevant agencies to create a national repository for LiDAR elevation data.

8.3 Projections of sea level rise

In its latest report, the Intergovernmental Panel on Climate Change (IPCC) presented projections of sea level rise under four different scenarios of greenhouse gas emissions. Each projection is presented as a trajectory with a best estimate, a lower and an upper limit out to 2100. The projections are relatively consistent for several decades, but then increasingly diverge.

How should such projections of sea level rise be incorporated into direction and guidance for councils?

There are a number of aspects to this, including the following.

First, the base year must be clear. In its 2013 report, the IPCC averaged mean global sea levels between 1986 and 2005 for use as a baseline.

Second, adjustments may need to be made for particular regions or localities where the land is known to be rising or falling.

Third, the IPCC produces its reports every five or six years. A 'living' guidance manual could be quickly updated after each IPCC report.

Finally, the range in projections under different scenarios of sea level rise should be recognised in sensitivity analysis of coastal assessments.

Recommendation to the Minister for the Environment:

In revising central government direction and guidance on sea level rise, set standards for the use of IPCC projections of sea level rise to ensure they are used clearly and consistently across the country.

8.4 Time horizons – how far ahead to look?

The 2010 New Zealand Coastal Policy Statement set a time horizon for planning of at least 100 years. But what is needed is a variety of planning horizons which depend on the nature of the decisions to be made.

In practice, however, planning for sea level rise has become focused on 50 and 100 year time horizons.

The 2010 New Zealand Coastal Policy Statement has one policy that covers *'Subdivision, use, and development in areas of coastal hazard risk'*. Yet there is a big difference between subdivision of a quarter acre section in an urban area and subdivision of farmland to create a new suburb.

In the former case, 100 years seems excessive, given that the Building Act only requires a new building to have a life of 50 years.

In the latter case, 100 years seems too little, given that new suburbs are expected to exist into the indefinite future. New suburbs also require expensive infrastructure where the investment is only recouped over many decades.

Further, the current prominence given to 100 years can give the impression that the sea will stop rising then, which is extremely unlikely because of the inertia in the climate system. Centuries of 'committed sea level rise' almost certainly lie before us.

Recommendation to the Minister for the Environment:

In revising central government direction and guidance on sea level rise, specify planning horizons that are appropriate for different types of development.

8.5 Separating scientific assessment and decision-making

Both the 2008 MfE Guidance Manual and the 2010 New Zealand Coastal Policy Statement require a 'precautionary' approach to planning for sea level rise.

Taking a precautionary approach to making decisions concerned with protecting the environment has been made a requirement in a number of New Zealand laws and international agreements such as the Rio Declaration.

Sir Peter Gluckman has noted that the precautionary principle *"… has long been a target for confusion and controversy. … The problem is in the multiple and, at times, conflicting interpretations…"*.[116] Regardless of the various definitions that are used, the precautionary approach was originally intended to be used in protecting the natural environment, not the built environment.

During this investigation, it has become clear that precaution is being embedded into scientific assessments of coastal hazards, sometimes to an extreme extent. In the Kapiti situation, Justice Williams concluded that there was *"a good argument"* for describing the result of the coastal assessment as the *"very worst case scenario"*.[117]

Judgements, such as those involved in adding safety margins or setting restrictions on development, should be made transparently by decision-makers, not rolled into technical assessments.

The standard results of running a coastal hazard model should instead be probability distributions with most likely values and ranges of potential values expressed with a level of confidence.

Recommendation to the Minister for the Environment:

In revising central government direction and guidance on sea level rise, specify that 'best estimates' with uncertainty ranges for all parameters be used in technical assessments of coastal hazards.

8.6 Engaging with communities

The standard way in which councils deal with planning for natural hazards like earthquakes, land slips, and river floods is to first commission a technical report that identifies the properties at risk. Once the council has accepted the report, the hazard information is immediately put on the Land Information Memoranda (LIMs) of affected properties. Any regulations that restrict the use and development of the properties are notified at the same time or soon after.

It is difficult to believe the sea is rising because it is outside human experience. For many, receiving a letter advising of susceptibility to flooding or erosion will come as a shock. It is not surprising that a condensed process and a lack of transparency is meeting with community opposition and legal challenges.

What is needed is a much slower process that actively engages with affected communities *before* decisions are made. Sometimes difficult decisions will need to be made that will disadvantage some, but they must be made carefully and with empathy.

The first stage of such a process should be the gathering and provision of information, beginning with accurate maps of elevation in coastal areas. Where there are 'soft' shores, all historical aerial photographs that can be found should be provided.

In many situations there will be time to build and share understanding of the risks. Locals know their beaches well so there is value in including local knowledge into coastal assessments.

Coastal communities can also be involved in deciding what the trigger points for a change in management should be.[118] There is a need for openness to considering a range of options.

Clear communication is vital. One particular problem is the need for describing 'high waters' other than a 'one in a 20/50/100 year flood event'. Not only is this terminology difficult to understand, it is not a stable measure over time. As is shown in Chapter 3, a 'one in a 100 year flood event' will become a 'one in a 50 year flood event', then a 'one in a 20 year flood event', and so on.

The placing of hazard information on LIMs is required under s 44A of the Local Government Official Information and Meetings Act 1987. There is certainly a need for informing property buyers, but it should be done in a way that is fair and does not come as a complete surprise to coastal residents.

Recommendation to the Minister for the Environment:

In revising central government direction and guidance on sea level rise, include a standard process for council engagement with coastal communities.

8.7 Strategies for coastlines

Developing strategies for coastlines requires thinking far into the future, and will not be easy because of competing priorities.

In places around the country, seawalls are being built or strengthened, and beaches are being 'armoured' with banks of large rocks. While each of these hard defences may not cost a lot, collectively the costs will mount. A piecemeal reactive response will become increasingly expensive and, as the sea continues to rise, maintenance and replacement will be needed. At some point, most hard defences will be abandoned.

The cumulative cost of building and maintaining hard defences is one issue. Another is the loss of the natural character of the shoreline. Many settlements have grown up by the coast because of access to sandy beaches, *kai moana*, and the beauty and wildness of the coast. Preserving some natural shorelines – or rather allowing them to freely move slowly inland – is vital. For this reason, soft defences – replenishing and planting dunes – should be preferred wherever feasible.

It is encouraging to see strategic thinking for Auckland beaches like Orewa and Muriwai and the intention to extend such thinking to whole coastlines. Decisions about, for example, where to defend or when to retreat, need to be made strategically with consideration of costs and trade-offs. Current central government direction and guidance requires strategic planning for coastlines, but further guidance is needed on how to do it.

Without strategic planning, difficult negotiations over the funding of hard defences and coastal infrastructure lie ahead. How is the cost of a seawall to be split between a council and the community it will protect? When will a council be justified in ceasing to maintain a vulnerable coastal road?

The Shoreline Management Plans developed in the United Kingdom provide one model. In each plan, the shoreline is divided into units. Policies developed for the units include variations of 'active defence', 'managed realignment', and 'no intervention'.

Strategies for coastlines must be able to deal with the uncertainty in the rate of sea level rise and the uncertainty in the impacts on different parts of the coast. In many places, an adaptive management approach will be needed. For this, monitoring of coastal parameters is vital for identifying when trigger points have been reached. Such monitoring is also required if we are to develop better models of erosion and accretion.

Recommendation to the Minister for the Environment:

In revising central government direction and guidance on sea level rise, specify that councils develop whole coast plans for dealing with sea level rise, and expand coastal monitoring systems to enable adaptive management

8.8 Fiscal risk associated with sea level rise

Continued sea level rise is not something that might happen – it is already happening, will accelerate, and will continue for the indefinite future. Unlike earthquakes and volcanic eruptions, it is foreseeable.

Adapting to sea level rise will be costly. Homes, businesses, and infrastructure worth billions of dollars have been built on low-lying land close to the coast.[119]

Some may argue that individuals should be allowed to make their own choices and bear the consequences. It may be possible to do this in some situations, but this should be done at no cost to the public.

There are also risks with council planning. Restrictions on development that are premature or overly precautionary will incur significant opportunity costs.

It is inevitable that both central and local government will begin to face pleas for increasing financial assistance. The highest costs will come from large scale managed retreat.

Both the 2008 MfE Guidance Manual and the 2010 NZCPS encourage managed retreat – moving homes and infrastructure to higher ground away from the coast – in preference to building bigger and bigger hard defences.

However, little thinking has been done on how to implement a managed retreat strategy. The critical factor is scale – with scale will come the uprooting of entire communities and the associated financial cost. But the alternative to managing an inevitable retreat will be leaving people living in homes that become uninsurable and then uninhabitable.

New Zealanders have an expectation that central government will provide financial assistance for those affected by natural disasters. Local Government New Zealand has suggested that a financial mechanism similar to the Earthquake Commission fund could be created to assist with managed retreat.

It is not too soon to consider the economic and fiscal risks of sea level rise, and include the forward liability into planning and investment decisions. This will require input from representatives of a range of interests – local government, coastal residents and landowners, the insurance and banking industries, and infrastructure providers.

Recommendation to the Minister of Finance:

Establish a working group to assess and prepare for the economic and fiscal implications of sea level rise.

Notes

[1] National Climate Change Adaptation Research Facility, 2013.

[2] United Kingdom Environment Agency, 2012, pp. 5, 34-35.

[3] The technical reports commissioned from NIWA are entitled: *'The effect of sea-level rise on the frequency of extreme sea levels in New Zealand.'* (NIWA, 2015a), and *'National and regional risk-exposure in low-lying coastal areas: Areal extent, population, buildings and infrastructure.'* (NIWA, 2015b). And from Dr John Hunter: '*Sea-Level Extremes at Four New Zealand Tide Gauge Locations And The Impact Of Future Sea-Level Rise'* (Hunter, 2015). Professor John Hannah at the University of Otago performed the initial standardisation of the tide guage data used in NIWA, 2015a and Hunter, 2015. A report detailing this standardisation also commissioned, entitled: *'The Derivation of New Zealand's Monthly and Annual Mean Sea Level Data Sets'* (Hannah, 2015).

[4] IPCC, 2013, Working Group 1, Chapter 13, pp.1181-1182. The four scenarios are RCP2.6, RCP4.5, RCP6.0, and RCP8.5. For simplicity, only the lowest (RCP2.6) and highest (RCP8.5) scenarios are shown in the figure. The projections of sea level rise under the middle two scenarios are very similar.

[5] Although the global mean sea level is generally rising, it does vary somewhat from year to year. Accordingly, the IPCC took the average of a 20 year period as its baseline in its 2013 report – the period from 1986 to 2005. This is why the projected sea level rises shown in Figure 2.1 are above zero in 2010.

[6] The sea level rise that will happen over the next several decades will occur largely as a result of past greenhouse gas emissions because of inertia in the climate system. IPCC, 2013, Working Group 1, Chapter 12, pp.1106-1107; IPCC, 2013, Working Group 1, Chapter 13, p.1143.

[7] *"New Zealand: Offshore regional sea level rise may be up to 10% more than global SLR."* IPCC, 2014, Working Group 2, Chapter 25, p.1381; Hannah and Bell, 2012, para.32.

[8] *"Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the likely range during the 21st century. However, there is medium confidence that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century."* IPCC, 2013, Working Group 1, Summary for Policymakers, p.25.

[9] IPCC, 2013, Working Group 1, Chapter 13, p.1140.

[10] Bell *et al.*, 2000, p.7; NIWA website, Coastal storm inundation.

[11] NIWA, 2015b, p.31. The El Niño Southern Oscillation can raise or lower the level of the sea around New Zealand by as much as 12 centimetres. The Interdecadal Pacific Oscillation can raise or lower the level of the sea around New Zealand by as much as 5 centimetres.

[12] A 7% increase in moisture in the atmosphere for every degree Celsius of warming is derived directly from the Clausius-Clapeyron equation. For more information, see IPCC, 2013, Working Group 1, Chapter 3, p.269.

[13] IPCC, 2014, Working Group 2, Chapter 25, p.1380. The IPCC has made this projection with a 'medium' level of confidence. Changes in rainfall are expected to be more pronounced in winter. See also Reisinger *et al.*, 2010, p.34.

[14] IPCC, 2014, Working Group 2, Chapter 25, p.1380. The IPCC states with a 'medium' level of confidence that most regions of Australasia are likely to experience an increase in: *"the intensity of rare daily rainfall extremes … and in short duration (sub-daily) extremes"*.

[15] Changes in rainfall will also affect the amount of sediment washed down rivers. This will change the amount of sediment carried by longshore currents and, in turn, affect erosion and accretion along coastlines (see Chapter 4). In some coastal areas, the water table will be pushed upward by the rising sea, increasing the risk of flooding from heavy rainfall (see Chapter 5).

[16] IPCC, 2014, Working Group 2, Chapter 25, p.1381. The IPCC has made this projection with a 'medium' level of confidence.

[17] McGlone *et al.*, 2010, p.89.

[18] IPCC, 2014, Working Group 2, Chapter 25, p.1381. The IPCC has made this projection with a 'medium' level of confidence.

[19] The vulnerability factors described in this chapter and the next are physical in nature. Vulnerability in the context of climate change adaptation is defined in various ways, including the scale of exposure, sensitivity, and the ability of communities to adapt.

[20] In 1938, a storm surge funnelled by the Firth of Thames caused tidal bores to rush up rivers. The storm surge and the accompanying heavy rainfall led to water overtopping the stopbanks resulting in flooding of at least 8,000 hectares of the Hauraki Plains. Dryson, 1938; Ray and Palmer, 1993, p.496.

[21] NIWA, 2013, p.34.

[22] Hunter, 2015; NIWA, 2015a. Such modelling is complex and sensitive to assumptions, for example, the choice of probability distributions. The results from both analyses were similar, though the methodologies differed somewhat. For simplicity, only the results from Hunter, 2015 are presented in this chapter. Both technical reports are available at **www.pce.parliament.nz**.

[23] The dataset has been corrected for shifts in the location of the tide gauges and tectonic changes in the height of the chart datum at each port (Hannah, 2015).

[24] On *23 January 2011 in Auckland*, a very high tide coincided with a very large storm surge of 41 centimetres. Homes, businesses and roads, including two motorways, were flooded, and stormwater systems backed up. On *21 June 2013 in Wellington*, a very strong southerly swept over the country, with heavy rain and swells of up to 10 metres reported in Cook Strait. Parts of the seawalls at Petone and Island Bay were smashed, and logs and driftwood scattered along Marine Parade and The Esplanade (NIWA, 2015a, Appendix A).

[25] The modelling results were provided with 68% confidence intervals that increasingly widen as the sea rises. How fast the sea will rise also becomes increasingly uncertain through time, as shown in Figure 2.1.

[26] In the modelling, the high water levels in these '100 year events' are higher than the highest levels on record by:

- 3 centimetres in Auckland
- 9 centimetres in Wellington
- 16 centimetres in Christchurch
- 11 centimetres in Dunedin

[27] The average of the midpoints of the four IPCC scenarios for global mean sea level rise projections from 2015 to 2065 is about 26 centimetres. The additional 10% rise projected by the IPCC for New Zealand gives a figure of about 28.6 centimetres. This has been rounded to one significant figure giving a value of 30 centimetres.

[28] The results from the NIWA modelling showed the same pattern. See NIWA, 2015a, p.32.

[29] This cannot be seen in Figure 3.3 because only increases in sea level up to 45 cm are shown.

[30] Most gravel beaches are 'reflective', meaning they are relatively steep, with waves surging up the shore rather than forming the classic breakers associated with wide, sandy 'dissipative' beaches. When gravel beaches erode, the gravel tends to migrate along the shore laterally rather than being carried out to sea (Hawkes Bay Regional Council, 2005, chapter 5, p.3.).

[31] Northland Regional Council, 2007, p.109; Thames Coromandel District Council website, The costs of protecting our coastlines.

[32] Hart *et al.*, 2008.

[33] Olson, 2010, p.123.

[34] Hastings District Council, 2013, p.10.

[35] Forsyth, 2009, p.1.

[36] Ingham *et al.*, 2006.

[37] The water table is the boundary between groundwater and the dry earth above it. It can be thought of as the upper surface of the groundwater.

[38] *"The water table lies close to the surface, typically 0.3 m to 0.7 m under the urban area."* (Rekker, 2012, p.ii.).

[39] *"It has been suggested that … every 0.1 m rise in sea level will result in an additional 0.09 m rise in ground water level over and above the rise in sea level itself."* (BECA, 2014, p.3.). See also Rekker, 2012.

[40] *"Liquefaction is an existing hazard in the Wellington region that may be exacerbated in some areas by higher groundwater levels resulting from sea level rise."* (Tonkin and Taylor, 2013, pp.8-9.).

[41] *"The [model] predicts that the sustainable yield from the Waiwhetu Aquifer will decline as sea level rises. … a 15% reduction in yield for a 0.75m sea level rise, and a 31% reduction for a 1.5m sea level rise."* (Gyopari, 2014, p.3.).

[42] IPCC, 2014, Working Group 2, Chapter 29, p.1623.

[43] NIWA, 2015b. The RiskScape GIS database was developed by NIWA and GNS Science to assist with the management of natural hazards.

[44] NIWA, 2015b, pp.10-12, 39-51.

[45] LiDAR elevation data is available for the entire Auckland, Bay of Plenty, and Wellington regions. In other regions, LiDAR data is available for some areas. In general, where LiDAR was available it was included in NIWA, 2015b.

[46] Councils have collected LiDAR data using different baselines. There are a number of definitions of Mean High Water Springs (MHWS). The definition used in the NIWA report is MHWS-10. This level is exceeded by 10% of high tides.

[47] Maps typically show coastlines at 'mean sea level' – the level halfway between high and low tides. The vertical difference in high and low tides around New Zealand varies considerably – it is less than 2 metres in Wellington and greater than 3.5 metres on the west coast of Auckland (Land Information New Zealand website, Tides around New Zealand).

[48] The RiskScape results shown in the tables in this chapter are for the entire urban areas of the four cities, but the accompanying maps have been necessarily truncated. The four maps have all been drawn to the same scale.

[49] The data in this table is for the Auckland urban area as defined by Statistics New Zealand. It extends as far north as Orewa, west beyond Massey and Henderson, and as far south as Papakura. It does not include some areas within the region with low-lying land such as Waiheke Island and Helensville.

[50] Blackett *et al.*, 2010.

[51] Auckland International Airport, 2006, p.17.

[52] The data in this table is for the Wellington urban area as defined by Statistics New Zealand – Wellington City, Porirua, Lower Hutt, and Upper Hutt.

[53] Pers. comm., Hutt City Council, 28 April 2015.

[54] KiwiRail media release, 24 June 2013, *'24 hour a day effort by KiwiRail to repair storm damage'*.

[55] Hughes *et al.*, 2015.

[56] Dunedin City Council website, St Clair Seawall Updates.

[57] Otago Regional Council, 2013, p.47.

[58] A further 30 urban areas collectively have over 5,000 homes that are less than 150 centimetres above the spring high tide mark.

[59] See Nelson Mail, 14 August 2010, *'Stormy waves force road closure' and Nelson Mail, 6 March 2015, 'Roads re-open after wild weather'*.

[60] Refer to the New Zealand Coastal Policy Statement 2010, prepared pursuant to the Resource Management Act (RMA) 1991. See also ss 7(i), 30, and 31 of the RMA 1991.

[61] King and Goff, 2006, p.13.

[62] Extract from the Report of the Railway Commission, Appendix to the Journals of the House of Representatives, 1880 Session 1, E-03, from question 3485.

63 Otago Daily Times, 18 February 2009, *'Offers sought for remains of locomotive'*.

64 See Peart, 2009, Chapters 11 and 12 for a history of coastal management in New Zealand.

65 Hon. Duncan MacIntyre, Minister of Lands and Minister in Charge of the Valuation Department letter to Hon. P.B. Allan, 30 June 1972. See also Richmond *et al.*, 1984, p.470, and Memo from the Secretary of Transport to the Minister of Transport, 29 January 1976.

66 Blackett et al., 2010.

67 In 1974, New Zealand's first national coastal policy included: *"Recognition that the stability of a large proportion of the coastal land depends on the efficiency of sand dune fixation …"*. Minister of Works and Development, 1974. New legislation required regional and district schemes to recognise and provide for the preservation of the natural character of the coast and its protection from *"unnecessary subdivision and development"*. Town and Country Planning Amendment Act 1973, s 2.

68 Hume *et al.*, 1992, pp.8-9.

69 Taranaki Regional Council, 2009, p.24.

70 Local Government Act 1974, ss 641 and 641A. Both sections were repealed by the Building Act 1991. The equivalent sections in today's Building Act 2004 are contained in ss 71-74.

71 RMA 1991, ss 28, 62, 67, and 75; NZCPS 1994, Policy 3.4.2.

72 RMA 1991, s 7(i).

73 Local Government and Environment Select Committee, July 2015. 2015/16 Estimates for Vote Environment, p.5.

74 In New Zealand, much environmental management is devolved to councils. There are two 'RMA instruments' that the Government can use when consistent environmental management across the country is sought. National Policy Statements (NPSs) are used to prescribe objectives and policies that must be 'given effect' in council plans. National Environmental Standards (NESs) are regulations that prescribe technical standards and methods. The New Zealand Coastal Policy Statement is an NPS.

75 Note that these projections are not directly comparable with those in section 2.1 in this report. Not only do the scenarios in the Fourth Assessment differ from those in the Fifth Assessment, but the 20 year baseline period is 1980 to 1999 instead of 1986 to 2005.

76 Ministry for the Environment, 2008, p.67.

77 The RMA requires councils to give effect to the NZCPS in policy statements and plans and have regard to it in decisions on resource consents. For a summary of the requirements of the RMA in relation to the New Zealand Coastal Policy Statement, see New Zealand Coastal Policy Statement, p.7.

78 Carpenter and Klinac, 2015.

79 Auckland Council is developing Coastal Compartment Management plans, the beginnings of a strategy for managing the coast. See, for example, Orewa Beach Esplanade Enhancement Programme 2014 Revision.

[80] There are 22 Shoreline Management Plans in place for England and Wales. These can be found on the United Kingdom Environment Agency website. Each plan breaks the coast down into a number of smaller 'policy units'. Within each unit, decisions are taken about whether the coast will be defended or not over the short, medium and long term. Active defensive policies include 'advancing the line', where defences are built further seaward than the current shoreline to reclaim land, or 'holding the line' where existing defences are upgraded or maintained. However, due to the costs involved in active defence, policies such as 'managed realignment' or 'no active intervention' are becoming more common. A policy of 'managed realignment' allows the shoreline to move, but under relatively controlled circumstances, whereas a 'no active intervention' policy effectively signals a need to retreat from the coast.

[81] Pers. comm., Auckland Council, 3 November 2015.

[82] Peart, 2009, p.95.

[83] Pers. comm., Thames-Coromandel District Council, 27 October 2015; Thames-Coromandel District Council website, Coastal Management Areas – Mercury Bay.

[84] The Proposed Auckland Unitary Plan, 2013. Natural Hazards and Regional and District Objectives and Policies 5.12, policies 14-16. The plan defines 'greenfield' as 'land identified for future urban development that has not been previously developed'. The Proposed Unitary Plan, 2013, Part 4 Definititions.

[85] The Proposed Auckland Unitary Plan, 2013. Regional and District Rules 4.11, Natural Hazards, and Regional and District Objectives and Policies, 5.12.

[86] Independent Hearings Panel, 2015. Interim Guidance Text for Topic 022 Natural Hazards and Flooding. The provisions are being finalised through mediation.

[87] Statement of Primary Evidence of Larissa Blair Clark, 14 March 2015, p.54.

[88] Memorandum of Counsel for Auckland Council, 12 June, 2015, p.4.

[89] *Mahanga E Tu Incorporated v Hawkes Bay Regional Council* [2014] NZEnvC 83 and *Gallagher v Tasman District Council* [2014] NZEnvC 245. The first case was concerned with an application to build houses on coastal land prone to erosion in Mahia, Hawke's Bay. The Court approved the application subject to certain conditions, including the houses being built so they were relocatable and a bond being provided to cover the cost of removal. The second case was concerned with an appeal by a landowner against a change the Council proposed to its plan, which would have prohibited further subdivision on land in Ruby Bay, Mapua, at risk to coastal hazards. The Court declined the application despite the landowner proposing to mitigate the risk by building relocatable houses on elevated building platforms.

[90] Kapiti Coast District Council website, Paekakariki seawall upgrade gets green light.

[91] Wellington City Council website, Island Bay Seawall Project; Wellington City Council, Environment Committee Minutes, 16 December 2014.

[92] CSL, 2012.

[93] Up to 1,000 properties were in the 50 year zone and 1,800 properties were in the 100 year zone (Kapiti Coast District Council, September 2012 presentation. Coastal hazards on the Kapiti Coast).

[94] *Weir v Kapiti Coast District Council* [2013] NZHC 3522.

[95] Carley *et al.*, 2014, p.53.

[96] *Weir v Kapiti Coast District Council* [2013] NZHC 3522.

[97] *"A range of other factors (precautionary measures used in data processing) serve to increase the overall safety margin."* (CSL, 2012, p.19). In the report, CSL noted that the general precautionary approach may have resulted in some hazard distances being *"overly cautious"* (p.63), and that other factors need to be considered when the results of a scientific assessment are converted into management zones (p.65).

[98] Local Government Official Information and Meetings Act 1987- s 44A(2)(a). For those mystified by the language in this section, 'avulsion' is the sudden removal of land by the change in a river's course or by flooding to another person's land, and 'alluvion' is the deposit of earth, sand etc., left during a flood.

[99] See, for example, *Marlborough District Council v Altimarloch Joint Venture Ltd and Ors* [2012] NZSC at para. 234. In this case, the Supreme Court considered the Marlborough District Council had breached its duty of care as the LIM contained misstatements. The Court found the Council liable for losses to a purchaser who relied on the accuracy of the contents of a negligently prepared LIM.

[100] Canterbury Earthquake (Christchurch Replacement District Plan) Order 2014, cls 6 and 19. Under the normal RMA process, submitters unhappy with decisions made by a council can appeal to the Environment Court. The Court then undertakes a full review of the evidence – the science as well as the law.

[101] Tonkin and Taylor, 2015.

[102] Proposed Christchurch Replacement District Plan, Christchurch City Council. Rule 5.11.4.

[103] Pers. comm., CCRU, 2 November 2015.

[104] The Press, 29 September 2015, *'Controversial coastal hazards zonings dropped'*; Hon Gerry Brownlee, Hon Nick Smith, Hon Nicky Wagner, media release, 29 September, 2015, *'Coastal hazard issue to be uncoupled from fast-track Earthquake Recovery Plan process'*.

[105] Christchurch Coastal Residents United, Proposed Christchurch Replacement District Plan – Stage 3 Submission Form.

[106] NZCPS 2010, Policies 25 and 27; Tonkin and Taylor, 2015, p.42.

[107] Since all the properties in the 100 year erosion zone are also in the 100 year flood zone, some might ask why this matters. It matters because of what seems to be becoming standard practice in coastal risk assessments – quantifying 'potentially' with a subjectively chosen number and thereby embedding 'precaution' into the assessment.

[108] *"Approaches that adopt the Bruun Rule will be conservative and should be considered a first order approach, even within the probabilistic framework outlined above"* (Ramsay et al., 2012, p.73.). The probabilistic framework referred to was used in Tonkin and Taylor, 2015.

[109] About 14 cm of sea level rise has occurred in Christchurch over the last 70 years (Ministry for the Environment and Statistics New Zealand, 2015, Figure 39).

[110] With enough excess sediment, beaches can continue to accrete despite a rising sea. Whether or not the Christchurch beaches will continue to accrete into the future depends on the interaction between many factors, including sediment supply, future sea level rise, and any changes in wave strength and direction. One study of beach behaviour that included sediment budgets predicted that the Christchurch beaches were likely to continue to accrete with 50 cm of sea level rise (Hicks, 1993). In comparison, the modelling exercises carried out to support planning in Christchurch have predicted that the beaches will all switch to significant erosion over the next 50 years. These predictions should be thought of as 'highly precautionary.'

[111] The Dunedin Amenities Society, 16 July 2015, *'Armed for the Fray, The Mining of St Kilda'*.

[112] Otago Daily Times, 11 October 2015, *'Groynes buffeted by failure, opposition'*.

[113] BECA, 2014.

[114] Dunedin City Council, Report to Planning and Regulatory Committee, Climate change adaptation – Harbourside and South City Update, 24 July 2014.

[115] Local Government New Zealand, 2014, pp.43, 57.

[116] 2015 RMLA Salmon Lecture, Sir Peter Gluckman, p.5.

[117] *Weir v Kapiti Coast District Council* [2013] NZHC 3522, at para 71.

[118] See, for instance, Barnett *et al.*, 2014.

[119] The RiskScape analysis in NIWA, 2015b shows that the replacement value of buildings within 50 centimetres of the spring high tide mark is $3 billion and that of buildings within 150 centimetres of the spring high tide mark is $20 billion.

References

Auckland International Airport, 2006. Valuation of Reclaimed Land & Seawalls, Runway, Taxiways & Aprons and Infrastructure Assets. Final Valuation Report.

BECA, 2014. Assessment of Options for Protecting Harbourside and South City from Direct Impacts of Sea Level Rise. Report prepared for Dunedin City Council.

Bell, 2010. Tidal exceedances, storm tides and the effect of sea-level rise. Proceedings of the 17th Congress of the Asia and Pacific Division of the IAHR, Auckland, New Zealand.

Bell, Goring, and de Lange, 2000. Sea-level change and storm surges in the context of climate change. *IPENZ Transactions*, 27:1-10.

Blackett, Hume, and Dahm, 2010. Exploring the social context of coastal erosion management in New Zealand: What factors drive particular environmental outcomes? *The Australasian Journal of Disaster and Trauma Studies*.

Carley, Komar, Kench, and Davies, 2014. Coastal Erosion Hazard Assessment for the Kapiti Coast: Review of the Science and Assessments Undertaken for the Proposed Kapiti Coast District Plan 2012.

Carpenter and Klinac, 2015. Adapting shorelines – a reflection of managed realignment at Muriwai. *Coastal News*, 59:6-7.

CSL, 2012. Kapiti Coast Erosion Hazard Assessment – 2012 Update. A report prepared for the Kapiti Coast District Council.

Dryson, 1938. Hauraki Plains – Drainage and flooding. Memorandum from District Engineer to Permanent Head, Public Works Department, Wellington.

Forsyth, 2009. Planning on a retreating coastline: Oamaru, North Otago, New Zealand. GNS Science Report.

Goff, Nichol, and Rouse (eds.), 2003. The New Zealand Coast. Dunmore Press.

Gyopari, 2014, Lower Hutt Aquifer Model Revision (HAM3): Sustainable Management of the Waiwhetu Aquifer. Greater Wellington Regional Council.

Hannah, 2015. The Derivation of New Zealand's Monthly and Annual Mean Sea Level Data Sets. Prepared for Parliamentary Commissioner for the Environment.

Hannah and Bell, 2012. Regional sea level trends in New Zealand. *Journal of Geophysical Research*, 117:1-7.

Hart, Marsden, and Francis, 2008. Chapter 20: Coastal Systems. In: Winterbourn, Knox, Burrows and Marsden (eds.). *The Natural History of Canterbury*. Canterbury University Press, Christchurch.

Hastings District Council, 2013. Statement of Proposal – Sustainable long term solutions to coastal hazards at Haumoana.

Hawkes Bay Regional Council, 2005. Environmental Change, Shoreline Erosion and Management Issues. Asset Management Technical Report.

Hicks, 1993. Modelling long-term change of the Pegasus Bay shoreline. NIWA, Christchurch.

Hughes, Quigley, van Ballegooy, Deam, Bradley, Hart, and Measures, 2015. The sinking city: Earthquakes increase flood hazard in Christchurch, New Zealand. *GSA Today*, 25:4-10.

Hume, Bell, de Lange, Healy, Hicks, and Kirk, 1992. Coastal oceanography and sedimentology in New Zealand, 1967-91. *New Zealand Journal of Marine and Freshwater Research*, 26:1-36.

Hunter, 2015. Sea-Level Extremes at Four New Zealand Tide Gauge Locations And The Impact Of Future Sea-Level Rise. Research conducted for Office of the Parliamentary Commissioner for the Environment.

Ingham, McConchie, Wilson, and Cozens, 2006. Measuring and monitoring saltwater intrusion in shallow unconfined coastal aquifers using direct current resistivity traverses. *Journal of Hydrology* (NZ), 45:69-82.

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, Qin, Plattner, Tignor, Allen, Boschung, Nauels, Xia, Bex, and Midgley (eds.)]. Cambridge University Press.

IPCC, 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, Field, Dokken, Mastrandrea, Mach, Bilir, Chatterjee, Ebi, Estrada, Genova, Girma, Kissel, Levy, MacCracken, Mastrandrea, and White (eds.)]. Cambridge University Press.

King and Goff, 2006. Maori environmental knowledge in natural hazards management and mitigation. NIWA Client Report. Prepared for GNS Science.

Local Government New Zealand, 2014. Managing natural hazard risk in New Zealand – towards more resilient communities. A think piece for local and central government and others with a role in managing natural hazards.

McGlone, Walker, Hay, and Christie. 2010. Climate change, natural systems and their conservation in New Zealand. In: Nottage, Wratt, Bornman and Jones (eds). *Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives*. New Zealand Climate Change Centre, Wellington.

Minister of Works and Development, 1974, *Coastal Planning & Development*.

Ministry for the Environment, 2008. Coastal Hazards and Climate Change: Guidance Manual for Local Government in New Zealand.

Ministry for the Environment and Statistics New Zealand, 2015. New Zealand's Environment Reporting Series: Environment Aotearoa 2015.

National Climate Change Adaptation Research Facility, 2013, Brisbane Airport - New Parallel Runway Project.

NIWA, 2015a. The effect of sea-level rise on the frequency of extreme sea levels in New Zealand. Prepared for Parliamentary Commissioner for the Environment.

NIWA, 2015b. National and regional risk-exposure in low-lying coastal areas: Areal extent, population, buildings and infrastructure. Prepared for Parliamentary Commissioner for the Environment.

NIWA, 2013. Coastal inundation by storm-tides and waves in the Auckland region. Prepared for Auckland Council.

Northland Regional Council, 2007, State of the Environment Report.

Olson, 2010. Decadal Shoreline Stability in Eastbourne, Wellington Harbour. Masters Thesis.

Otago Regional Council, 2013. Natural hazards on the Taieri Plains.

Peart, 2009. Castles in the Sand: What's happening to the New Zealand coast? Craig Potton Publishing, Nelson.

Ramsay, Gibberd, Dahm, and Bell, 2012. Defining coastal hazard zones for setback lines: A guide to good practice.

Ray and Palmer, 1993. Managing of Coastal Flood Hazards in the Waikato Region, New Zealand.11th Australasian Conference on Coastal and Ocean Engineering: Coastal Engineering.

Reisinger, Mullan, Manning, Wratt, and Nottage, 2010. Global & local climate change scenarios to support adaptation in New Zealand. Paper in: Climate Change Adaptation in New Zealand: Future scenarios and some sectoral perspectives.

Rekker, 2012. The South Dunedin Coastal Aquifer & Effect of Sea Level Fluctuations. Otago Regional Council.

Richmond, Nelson, and Healy, 1984. Sedimentology and evolution of Ohiwa Harbour, a barrier-impounded estuarine lagoon in Bay of Plenty. *New Zealand Journal of Marine and Freshwater Research*, 18:461-478.

Taranaki Regional Council, 2009. Coastal Erosion Information: Inventory and recommendations for state of environment monitoring.

Tonkin and Taylor, 2015. Christchurch City Council – Coastal Hazard Assessment – Stage Two. Prepared for Christchurch City Council.

Tonkin and Taylor, 2013. Sea Level Rise Options Analysis Report. Report prepared for Wellington City Council.

United Kingdom Environment Agency, 2012, Thames Estuary 2100, managing flood risk through London and the Thames estuary, London.

Embargoed

until

1pm Thursday
19 November 2015