Australian Government

Department of Climate Change

Climate Change Risks to Australia's Coast

A FIRST PASS NATIONAL ASSESSMENT

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thinkchange

About this report

Adaptation is one of the three pillars of the Australian Government's climate change strategy.

The first pass national assessment of *Climate Change Risks to Australia's Coast* is one of the key actions identified in the *National Climate Change Adaptation Framework* endorsed by the Council of Australian Governments (COAG) in 2007. The Framework recognised that national assessments are required in key sectors and regions to support informed decisions on adaptation action by policy-makers, business and industry, resource managers and the community.

Scope of the assessment

This Report presents the findings of the first national assessment of the risks of climate change for the whole of Australia's coastal zone. The objectives of the first pass national coastal risk assessment are to:

- Provide an initial assessment of the future implications of climate change for nationally significant aspects of Australia's coast, with a particular focus on coastal settlements and ecosystems.
- Identify areas at high risk to climate change impacts.
- Identify key barriers or impediments that hinder effective responses to minimise the impacts of climate change in the coastal zone.
- Help identify national priorities for adaptation to reduce climate change risk in the coastal zone.

The assessment focuses on risks to settlements and infrastructure, ecosystems and industries in the coastal zone. The spatial and quantitative analysis is restricted to risks to residential buildings at 2100. Analysis of other risks has been through literature review and expert opinion. The scope has not included any analysis of efforts to mitigate climate change impacts through reducing emissions of greenhouse gases and any associated implications for adaptation. The geographic scope of the assessment is the mainland coast and Tasmania; smaller islands and external territories have not been comprehensively considered.

The results from the assessment of residential buildings at risk are useful at a national scale. They will assist in prioritising future coastal adaptation planning needs. However, the available national data is insufficient to answer all questions underpinning decision-making at local and regional scales. The assessment has also highlighted major current data and analytical capacity limitations which can inform future investment in capacity building.

The assessment focuses on impacts and risks at the end of this century. However climate change including sea-level rise will not stop then and impacts beyond 2100 will need to be anticipated in decision-making with long horizons. Nearer term impacts have also not been considered in this assessment as finer scale modelling processes are required for this. Understanding of both the shorter and longer term implications will also be needed to inform adaptation planning. A number of on-ground adaptation options have been identified in the report to support consideration of Australia's adaptation needs.

Community engagement in a discussion on coastal vulnerability is critical. Much of the time spent on this first pass assessment was allocated to building the national tools so that risks could be identified, and so that the assessment can support an informed national consideration on adaptation in the coastal zone. All spheres of government, business, industry and the community will need to be involved in developing an appropriate national response.

Structure of the report

The Report is structured into six chapters. Chapter 1 provides an overview of the geological history of Australia's coastal zone and explores how past variability could inform our understanding of future change. The four broad coastal regions which emerge from this history and the importance of the coastal zone are described.

Chapter 2 discusses the science that supports understanding of climate change risks in the coastal zone. It brings together the science of climate change and geomorphology to understand how coastal risks from inundation and erosion could change in the future.

Chapter 3 describes the investments in national capability that have occurred to enable this first pass national assessment, and the methodology that was applied to identify areas at risk of inundation and coastal instability.

Chapter 4 provides an overview of the implications of climate change for the natural environment. The different responses of the four broad coastal regions (first discussed in Chapter 1) to climate change are identified, as well as key implications for coastal biodiversity and habitats.

Chapter 5 identifies the key risks to built infrastructure with a particular focus on residential buildings at state and local government scales. Risks to infrastructure, services and industries in the coastal zone are also summarised.

Chapter 6 concludes the Report with a discussion on coastal adaptation. It explores whether there is a case for early action and whether there are barriers to adaptation. The Chapter describes emerging areas to enable coastal adaptation which could benefit from national coordination.

One appendix is included; it describes the common elements of an adaptation response particularly for the built environment: planned retreat, accommodating the impacts, and protection through building protective structures.

Technical and scientific terms are used throughout this Report. To assist readers with these terms a glossary is included in the Report.

Acknowledgements

The drafting team would like to extend special thanks to Professor Bruce Thom who generously shared his considerable personal knowledge and expertise.

The technical risk analysis of residential properties relied on the expertise of Geoscience Australia, CSIRO, the University of Tasmania and the GIS Team of the Land Management Branch in the Department of Climate Change.

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In addition, representatives of State and the Northern Territory governments who were consulted in the preparation of the report and provided valuable feedback on aspects of the results and many examples of issues facing coastal communities are acknowledged.

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Contents

Executive Summary

Australia has become a coastal society. Around 85 per cent of the population now live in the coastal region and it is of immense economic, social and environmental importance to the nation. All Australian state capital cities are located within the coastal zone, it is the conduit for our exports and imports, and much of the nation's commercial activities occur in coastal areas. Large numbers of Australians enjoy the recreational benefits the coast provides and it is home to a vast array of treasured environmental values that underpin essential ecosystem services.

The Australian coast is a dynamic place and since initial occupation over 50,000 years ago humans have witnessed major changes in sea level, in habitats and in the shape of the shoreline from great storm events. Over the geological past this dynamism has been even more pronounced, with sea levels up to 4–6 metres higher than today and the shoreline in some places more than 500 kilometres inland.

Over the last 6,000–7,000 years sea level around Australia has been relatively stable, which has generally allowed current landforms and ecosystems to persist without large scale modifications. Since 1788 settlements have been built along our coast in expectation that sea level would remain broadly unchanged. Significant settlement of low-lying areas has occurred, and structures were designed and built to standards defined by a relatively narrow period of experience.

Those conditions are now changing. A new climate era driven by global warming will increase risks to settlements, industries, the delivery of services and natural ecosystems within Australia's coastal zone.

Scientific observations and modelling are pointing to changes in the climate system at the upper end (or above) of projections in the 2007 report of the Intergovernmental Panel on Climate Change (IPCC). The IPCC report estimated global sea-level rise of up to 79 centimetres by 2100, noting the risk that the contribution of ice sheets to sea level this century could be substantially higher.

Recently observed accelerated ice flow and melting in some glaciers in Greenland and Antarctica could substantially increase the contribution from the ice sheets to rates of global sea-level rise. Understanding of the magnitude and timing of ice melt processes is limited and there is currently no consensus on the upper bound of global sea-level rise projections.

There is an increasing recognition that sea-level rise of up to a metre or more this century is plausible, and possibly of several metres within the next few centuries. This timescale is relevant to decisions on the footprint of our major cities. Recent research, presented at the Copenhagen climate congress in March 2009, projected sea-level rise


Photo Credit: William Prince Collection and DEWHA

Erosion along the Gold Coast in 1967.

from 75 centimetres to 190 centimetres relative to 1990, with 110–120 centimetres the mid-range of the projection.

Based on this recent science 1.1 metres was selected as a plausible value for sea-level rise for this risk assessment. It is important to note that the purpose of a risk assessment is to identify areas of risk and therefore plausible worse case scenarios need to be considered. This is a dynamic area of science, and it is expected that sea-level rise projections will change as new research clarifies areas of uncertainty.

Different jurisdictions around Australia have adopted sea-level rise benchmarks for land use planning based on the IPCC's 2007 projections. The intended purpose of these benchmarks for statutory decision-making is different to the approach taken in this national risk assessment, which aims to provide an indication of the magnitude and spread of risk from a plausible 'worse case' scenario over the longer term.

Rising sea levels will bring significant change to Australia's coastal zone in coming decades. Many coastal environments such as beaches, estuaries, coral reefs, wetlands and low-lying islands are closely linked to sea level. There is a lack of knowledge in many cases as to how these environments will respond to sea-level rise, but the risk of beach loss, salinisation of wetlands and inundation of low-lying areas and reefs beyond their capacity to keep pace must be considered in regional decision-making.

With a mid range sea-level rise of 0.5 metres in the 21st century, events that now happen every 10 years would happen about every 10 days in 2100. The current 1-in-100 year event could occur several times a year. For illustration, a current 1-in-100 year event is equivalent to the intensity of storms along the New South Wales central coast in June 2007 when more than 200,000 homes lost power, thousands of people were forced to evacuate their properties, and insured losses exceeded $1.3 billion. An even larger increase in the frequency of high sea level events would occur around Sydney, with smaller increases around Adelaide and along parts of the Western Australian coast. The 1-in-100 year event is used in current planning guidelines as a benchmark for assessing extreme risk.

Extreme weather events are also likely to become more intense with climate change, with larger and more damaging storm surge and the possible extension of cyclones further south along both the east and west coasts. These changes will have implications for the capacity of the built and natural environment to withstand and recover from impacts.

Over recent decades many Australian beaches have been stable or even accreting because the sediment supply has been sufficient. It is expected that sea-level rise will change this dynamic, and an important question is when stable or accreting beaches will flip to receding beaches in the face of rising sea levels. This is a key threshold for coastal management. It is possible that with climate change some beaches could recede hundreds of metres over the course of this century.

This first pass national coastal risk assessment brings together existing and new information to highlight the scale of problem Australia faces as a vulnerable coastal nation. The assessment provides an analysis of residential property at risk from erosion and inundation around the Australian coastline at the end of this century.

There are limitations to the modelling used in this assessment: a 'bucket fill' approach was used to assess inundation. This essentially assumes a calm surface and does not attempt to model local hydrological processes. Inundation risks for a 1-in-100 year event (on top of sea-level rise) were assessed for Victoria, New South Wales and Tasmania based on modelled storm tide data from CSIRO. Where this modelled storm tide data was not available, inundation for a (far more frequently occurring) modelled high water level event, on top of sea-level rise, was assessed for the other states. This means the assessment for New South Wales, Victoria and Tasmania is identifying inundation from a more extreme event than for the other states.

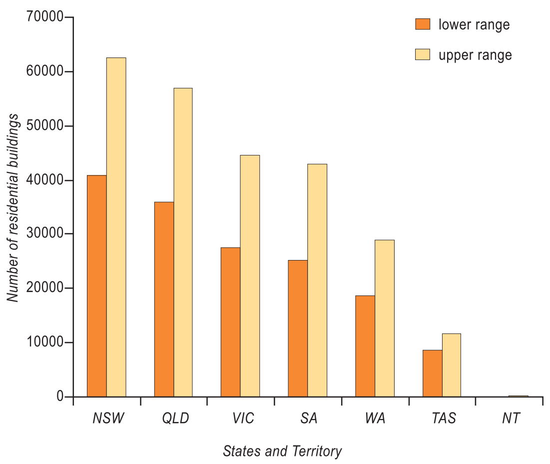

Figure ES.1 Estimated number of existing residential buildings at risk of inundation from a 1.1 metre sea-level rise (incl. 1-in-100 storm tide for NSW, VIC and TAS and high tide event for others).

While these modelling limitations need to be acknowledged, the analysis presented identifies widespread risk – significant stocks of residential housing, and social and economic infrastructure (schools, hospitals, ports, roads, etc) are exposed to risk of inundation and damage.

Up to $63 billion (replacement value) of existing residential buildings are potentially at risk of inundation from a 1.1 metre sea-level rise, with a lower and upper estimate of risk identified for between 157,000 and 247,600 individual buildings. The distribution of these properties across states and the Northern Territory is shown in Figure ES.1.

Coastal communities outside of capital cities generally have less adaptive capacity than capital city communities and may therefore be more adversely affected by climate change impacts. While there is a lack of national information on social vulnerability to climate change, remote Indigenous communities in the north of Australia and communities living on the low-lying Torres Strait Islands are particularly vulnerable to sea-level rise. Some Torres Strait communities are affected under current king tide conditions and even very small levels of sea-level rise are likely to have a major impact on these communities.

With much of Australia's infrastructure concentrated in the coastal zone around centres of population, climate change will bring a number of risks to built environment assets which could have consequences for the delivery of community and essential services, regional economies and possibly the national economy.

Industry reliant on access to or use of the coastal zone will also need to prepare for the impacts of climate change. While coastal industries such as tourism or fisheries as a whole have considerable resilience to climate change impacts, parts of these industries are made up of small to medium sized operators that have less capability to adapt.

Photo Credit: David Hanslow

Inundation from king tide in the Torres Strait.

Terrestrial and aquatic plants and animals that rely on coastal habitat are likely to be adversely affected by sea-level rise, increases in sea surface temperature and ocean acidification. Change in coastal ecosystems is already occurring, with southward migration of some species being observed particularly along the south-east coast of Australia. A major question for several coastal ecosystems is whether they are likely to face a threshold with modest climate change beyond which they will flip into a less desirable state. It is expected that initial responses from ecosystems in response to climate change will be either inland or poleward migration. In southern Australia the effect of 'coastal squeeze', where built infrastructure such as housing development prevents such movement, could constrain this natural adaptation response. The coastal systems most at risk are estuaries and associated wetlands, coral reefs, constrained tidal flat communities and saltmarshes, and beaches where there is a lack of sediment for replenishment.

The assessment provides a case for early action to reduce risk. There is a large legacy risk in the coastal zone from building and other infrastructure constructed in the past without regard to climate change. For 'at-risk' areas, strategies to protect, accommodate or retreat will need to be developed as sea level is projected to continue rising for several centuries. Triggers will be needed to identify when on-ground responses are needed to manage increasing risks.

Where possible, avoidance of future risk is the most cost-effective adaptation response, particularly where development has not yet occurred. While little analysis has been done to date, the application of planning and building regulations to constrain an increase in risk from climate change impacts will deliver considerable savings in damages avoided.

Detailed regional and local assessments under worse case scenarios are needed to inform decision-makers of future risks and enable climate change adaptation to be incorporated into planning approaches. In this context planning approaches need to build resilience of natural ecosystems as they also provide a buffer to communities from changes in sea level. There is also a benefit in aligning disaster risk reduction strategies with adaptation assessments at this scale. Difficult decisions will need to be made in the future on what assets need to be protected and how this should be done; better information is needed to ensure that trade-offs and consequences of decisions are understood.

Engagement of all stakeholders – governments, individuals, and the private sector – is essential if we are to develop and implement a comprehensive, well considered and carefully staged national coastal adaptation agenda. All parties will have a role to play. National issues must be debated and effective collaborative arrangements developed to improve the resilience of Australia's coast in the face of climate change. An effective adaptation agenda will need to include national standards and benchmarks, information and tools for decision-makers, better understanding of risks to critical infrastructure, and enhanced local capacity to manage on-ground impacts. Leadership from governments will be required in a national partnership to maintain the public good assets in the coastal zone for future generations. States, territories, local government, industry and communities will have a primary role in on-ground coastal adaptation action. Where a national response is required, the Council of Australian Governments (COAG) can be an appropriate vehicle to progress reform.

Simulated inundation of Sydney Airport for the first half of next century.

This first pass national assessment of *Climate Change Risks to Australia's Coast* is intended to contribute to that debate. The preparation of the assessment has also identified a range of issues that will need further consideration over the years ahead in order that the Australian community can build on this initial assessment and develop resilient, robust and sustainable responses.

1 CHAPTER

Photo credit: John Baker and DEWHA

AUSTRALIA'S COAST – ITS NATURE AND IMPORTANCE

KEY FINDINGS

- The coastal zone is highly dynamic. Australia's shoreline has shifted greatly in the geological past, and climate change will bring considerable further change to its position.
- Australia's coast has been relatively stable over the past few decades, and planning in a number of areas has not taken into account the extent of observed shoreline instability.
- Australia has four major coastal regions, each with different geomorphology and climate characteristics. Each will be affected by climate change in a different way.
- The coastal zone has immense social and economic value to Australia. It is where most Australians live and work and it is the conduit for our export economy.
- Extensive ecosystems of global and national significance are in the coastal zone, and the diversity of marine plants and animals in southern Australia is among the highest in the temperate regions of the world.
- This risk assessment is intended to inform a national consideration of the adaptation needed to protect our key economic, social and environmental assets in the coastal zone in the face of climate change.

1.1 Coastal dynamics

Australia's 35,000 kilometre coastline is dynamic. The climate and the sea have always been major forces shaping the coast, and over time the position of our shoreline has shifted large distances. Now climate change is driving the evolution of a new coastline for Australia, but the location of that coastline is not yet clear.

1.1.1 Our shifting shoreline – the geological and recent past

The coastline of Australia is continually changing. The level of the sea is regionally variable and moves up and down as a result of changes in ocean currents, ocean temperature, atmospheric pressure and fluctuations in the amount of water held in the great glaciers. The land can also move. Coastal margins can rise or fall because of tectonic forces or changes in glaciation, and the weight of sediment deposited in deltas can cause the coast to subside, as is happening in the USA at the mouth of the Mississippi.

Over tens of millions of years, these processes have driven major fluctuations in the position of Australia's coastline. Palaeontologists and geologists have found evidence that the sea reached as far inland as Norseman and the Kennedy Ranges (some 160 kilometres inland from Carnarvon in Western Australia). The Nullarbor Plain, the Latrobe Valley and the whole of the lower Murray basin to above the Lachlan–Murrumbidgee junction were once inundated by the ocean.

Global glacial (cold) and interglacial (warmer) cycles have been a major driver of changes in sea level over the past 2.5 million years (the Quaternary period). Sea level during the last interglacial period 120,000–130,000 years ago was as much as 4 to 6 metres higher than it is today. In parts of South Australia, sand barriers left by such high interglacial seas on a tectonically rising coast can be found parallel to the current coast and up to 500 kilometres inland.[1] Figure 1.1 shows the extent of sea inundation during the last interglacial near Port Stephens, New South Wales.

At the last glacial maximum (20,000 years ago), sea level was around 120–140 metres lower than today, with water locked up in ice sheets. Considerable areas of the continental shelf were exposed to the atmosphere and to breaking waves, Torres Strait did not exist, and Tasmania and Papua New Guinea were joined to continental Australia (Figure 1.2).

Most of the great glaciers stopped shrinking around 7,000 years ago, and by about 6,500 years ago the sea

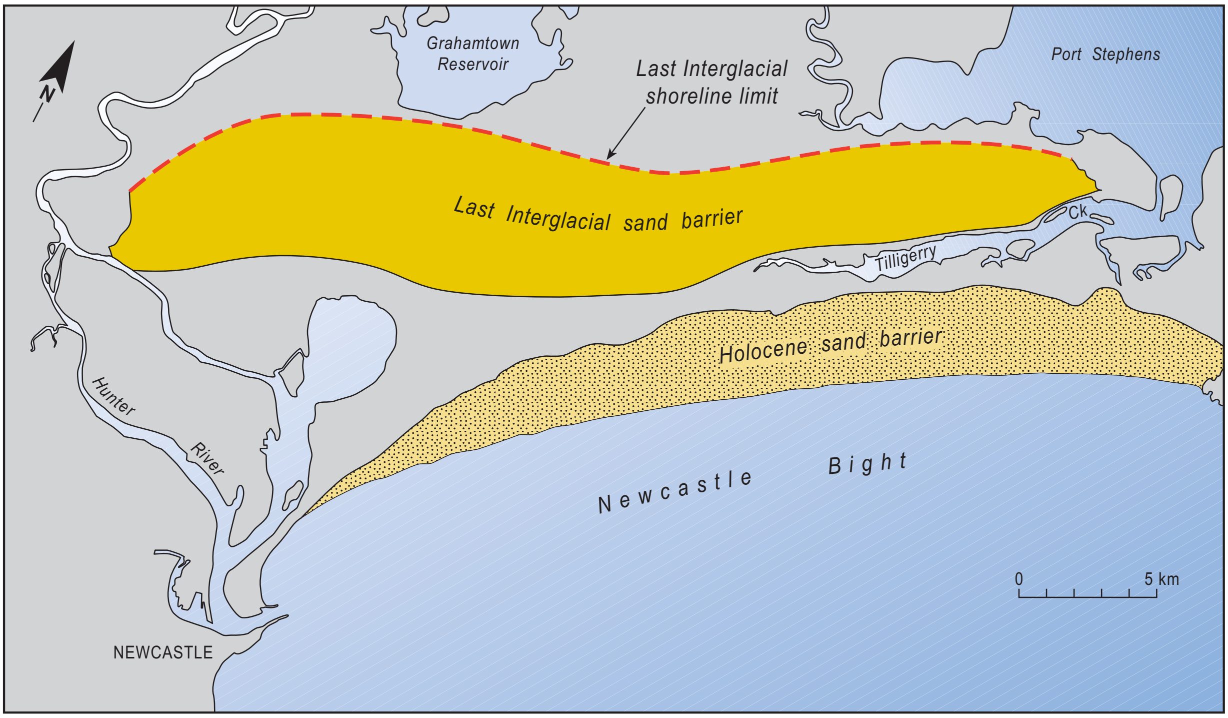

Figure 1.1 Maximum extent of the shoreline in the lower Hunter region, New South Wales, during the Last Interglacial (120,000 to 130,000 years ago) when sea level was approximately 4 metres higher than present in this embayment.

reached close to its current level around the coast of Australia. This coincided with the Holocene interglacial global warm period, which we continue to enjoy.

For the past 6,000 to 7,000 years, the sea level has oscillated within a narrow band of plus or minus 2 metres. This period of relative stability is sometimes referred to as the 'stillstand' period (Box 1.1).

The coast that we recognise today stabilised in this period.[2] Because of the relative stability of the Australian continent over the Pleistocene (2.5 million to 10,000 years ago), the sea returned to a similar local elevation after each major fluctuation. Waves and wind built dune systems, rocky coasts eroded to form sea cliffs, coral reefs developed, and valleys repeatedly flooded to form estuaries.

The relative constancy of sea level over the past 6,000 to 7,000 years in Australia has allowed coastal landforms and ecosystems to adapt in a 'comfort zone' during this interglacial phase. Small oscillations in sea level, where they have occurred, appear to have been slow enough to allow shoreline and estuarine dynamics to accommodate their impacts.

On shorter timescales, parts of the coast can be transformed by extreme weather. While the frequency of tropical cyclones is generally low, the storms they generate can shift large amounts of coastal sediment and deposit it some distance inland. Stranded storm-generated features, such as sand and shell ridges or cheniers, and shingle and boulder ridges, can persist for thousands of years. In northern Australia, the location of detrital coral and shell deposits suggest that even bigger tropical cyclones have occurred in the past than those observed since European settlement. These super-cyclones and the storm surges they generate are likely to pose a major threat to coastal settlement if they recur in the future.[3]

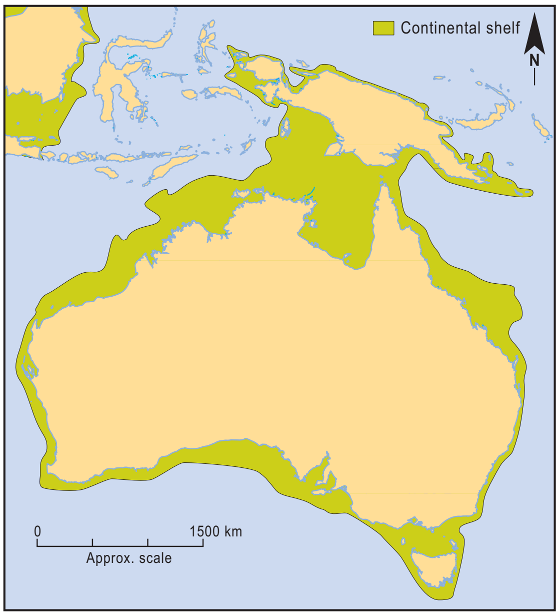

Figure 1.2 Coastline at the last glacial maximum (20,000 years ago).

Box 1.1 Coastal stability over the past 6,000 years – the Australian 'stillstand'

The Australian coast is different from most other continental and island shores, which have not yet reached a relatively stable sea level position after cessation of ice melt following the last glacial maximum. Other countries are still subject to post-glacial rebound (resulting in uplift of land due to the loss of an enormous weight of ice after deglaciation), subsidence due to sediment loading, or uplift where tectonic plates collide.

The Atlantic coast of North America is a case in point. There, the shoreline has been evolving as sea levels have risen over the past 6,000 to 7,000 years. There is no stillstand along these shores (Figure 1.3). Similar conditions occur in southern England and in The Netherlands, making such areas very vulnerable to storm attack. In contrast, parts of northern Europe and eastern Canada are undergoing uplift (due to post-glacial rebound).

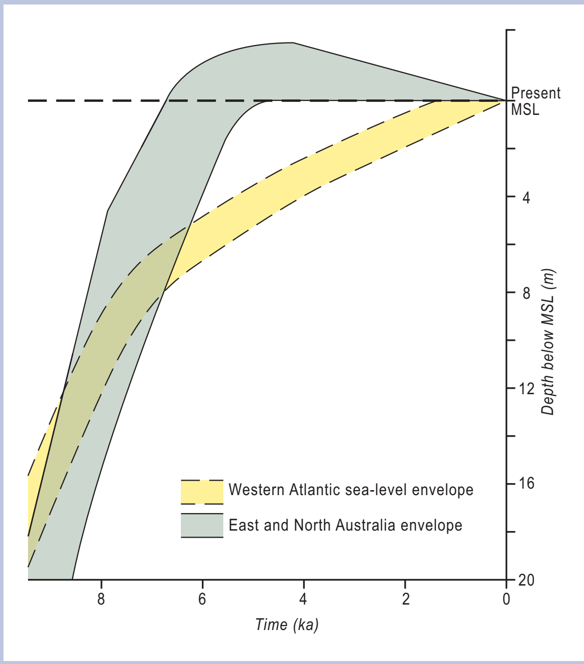

Figure 1.3 Post-glacial rise in sea level as shown by an envelope of the position of rising sea level and subsequent 'stillstand' around the Australian coast commencing between 7,000 and 6,000 years ago compared to a more continuous rate of sea-level rise towards the present along the Atlantic coast of the USA.

1.1.2 Four coastal regions

The dynamic interactions between the sea and the land over time have led to the current Australian coastline. More than 10,000 sandy beaches make up about half of mainland Australia's coast; much of the remainder is rocky shoreline.

The Australian coast can be classified into four broad regional environments (Figure 1.4):

- **Region 1 – The Muddy North:** highly tidal, cyclone influenced and muddy
- **Region 2 – The Limestone South and West:** small tides, carbonate rocks, high wave and wind energy
- **Region 3 – Eastern Headlands and Bays:** small tides, quartz sands, moderate wave energy, many bays
- **Region 4 – The Barrier Reef:** northern Queensland, including low-lying rocky mainland coasts and the Great Barrier Reef and its islands.

Tasmania and the Bass Strait islands share many of the characteristics of regions 2 and 3.

Each region has distinctive ecosystems and natural assets, and each is vulnerable to a different degree to extreme weather and to the potential impacts of climate change.

Photo credit: Newspix/Troy Bendeich

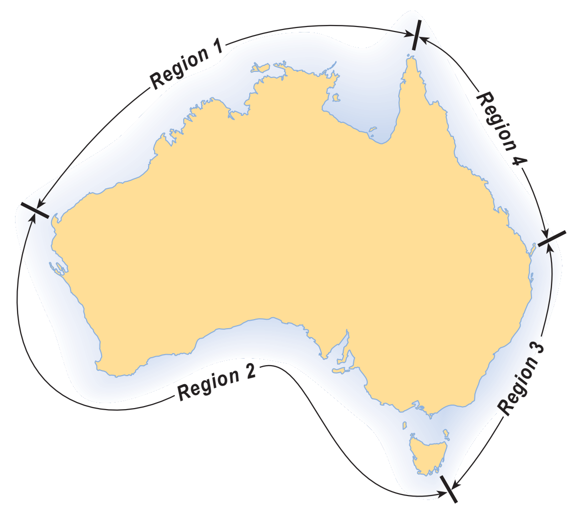

Figure 1.4 Australia can be divided into four broad coastal regions based on geomorphology, sediment type and tide-wave regimes.

1

Region 1 – The Muddy North

The mainly muddy coasts of northern Australia are subject to high tides and the destructive effects of tropical cyclones. Cyclones shape low-relief sand and shell ridges (cheniers) on muddy shorelines fringed by mangroves. Vast tidal flats, often bare of vegetation, extend up many estuaries, where mangrove communities have adjusted to tidal levels and sediment conditions. The region has high seasonal rainfall, so sediments flow out of catchments during the summer wet season. Complex hydrological interactions between tidal flows, river discharge and sediment occur in the estuaries and wide bays and gulfs.

The estuaries and the gulfs are enriched with marine life important to Indigenous communities and commercial fishing. Offshore oil and gas resources in the region have been developed into major export industries.

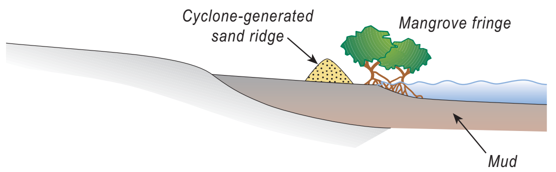

Figure 1.5 Typical geomorphology and sediment type of The Muddy North.

Photo credit: A.D. Short

Region 2 – The Limestone South and West

The coast of the south and south-west is exposed to the world's most energetic waves, generated in the vastness of the Southern and Indian oceans. Sediments are mostly derived from marine carbonates. The traces of previous interglacial high and glacial low sea levels have been preserved locally as calcarenite ridges or platforms, both above and below sea level. Calcareous beach sands can be 'perched' on such surfaces.

Westerly winds effectively mobilise calcareous sands into dunes along stretches from Geraldton to Wilsons Promontory. Elsewhere, limestone forms lengthy stretches of cliff, such as near Shark Bay, the Nullarbor coast of the Great Australian Bight, and in the Port Campbell area of western Victoria. The southern tracks of tropical cyclones also influence coastal conditions along the west coast.

Calcarenite rocky reefs provide buffers to wave attack in some areas and habitat for many organisms, including the rock lobster, an important export. The southern half of Australia also supports the world's most extensive temperate seagrass meadows.

Photo credit: Nick Rains and DEWHA

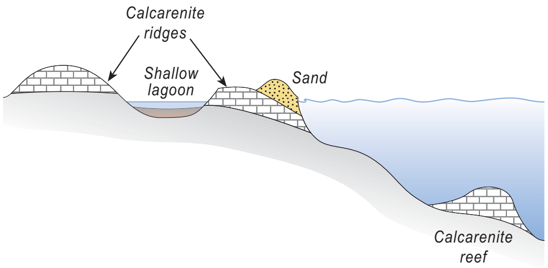

Figure 1.6 Typical geomorphology and sediment type of The Limestone South and West.

Region 3 – Eastern Headlands and Bays

The third region extends from the east side of Wilsons Promontory in Victoria to Fraser Island in Queensland. It has a low tidal range and is exposed to swell and wind waves from the Tasman Sea and Southern Ocean. The region is also subjected to periodic high-energy cyclonic activity, including tropical cyclones to the north and extra-tropical cyclones or ‘east coast lows’. Major storms have occurred in clusters at irregular intervals, for example in 1950, 1967 and 1974.

Rocky headlands separate beach and dune stretches of varying lengths. Towards the north of the region, sands in the littoral system can migrate around the headlands, moving northwards. Drowned river valleys cut into ancient uplands to form intricate estuaries and low-lying deltas, where settlements and farms are clustered.

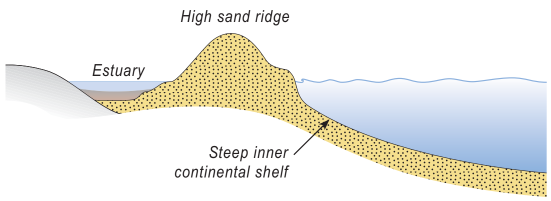

Figure 1.7 Typical geomorphology and sediment type of the Eastern Headlands and Bays.

Photo credit: © Commonwealth of Australia (GBRMPA)

Photo credit: A.D. Short

Region 4 – The Barrier Reef

North of Fraser Island, the Great Barrier Reef (made up of more than 3,600 individual reefs) and islands extend for 2,300 kilometres along the Queensland coast. The modern reef is relatively young and mostly formed in the 6,000 years since the sea level stabilised. It sits on a substrate derived from erosion of the eastern margin of Australia and deposited in previous glacial periods when the sea level was lower, and often forms a veneer over earlier reefs.

Along the mainland coast are low-lying deltas that are periodically inundated during cyclonic floods. In the past, storm surges and high winds have caused enormous personal and economic devastation in these areas. Agriculture, tourism, fishing, ports and transport, as well as ecosystems, have suffered from the impacts of extreme weather. The impacts of land-based activities that generate nutrient and sediment fluxes are a continuing threat to the health of nearshore and reef environments.

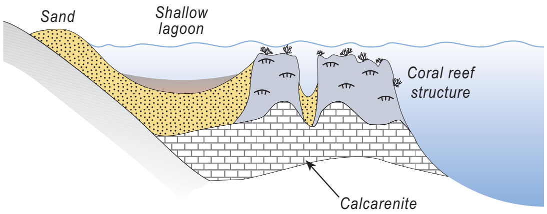

Figure 1.8 Typical geomorphology and sediment type of The Barrier Reef.

1.2 The importance of the coast

All Australian governments have recognised the coastal zone as a vital national asset.[4] The coast plays a critical role in driving the Australian economy and in providing ecosystem services. The cities, industries and ports that provide most of the nation's jobs are in the coastal zone. Its beaches, waterways and coral reefs are also where Australians recreate.

Since European settlement, most Australians have congregated along the thin strip of the coastline. Only a small proportion have inhabited the sparse inland. The proportion of the population living in the country has declined since World War II and will probably continue to do so.[5] Around, 85 per cent of Australians live within 50 kilometres of the coast, and all our state capitals are on the coast.

1.2.1 Economic benefits

The Australian coastal economy is driven by local, national and international demands for goods and services. Financial flows from primary, secondary and tertiary industries are either generated in the coastal zone or pass through it. Coastal industries include transportation; shipbuilding and maintenance; minerals, oil and gas production; fishing; tourism; and construction. The coastal zones are also the site of many essential services, such as health, education, sewerage and wastewater systems, telecommunications, defence and finance.

Australian ports rank among the world's major export ports, and Australia is the world's fifth largest user of shipping. In 2007–08, 789.6 million tonnes of international cargo and 119.3 million tonnes of domestic coastal cargo moved across Australian wharves.[6] International trade continued to expand in 2007–08 and is expected to continue to grow over the next 20 years.[7]

Brisbane, Sydney, Melbourne, Adelaide and Fremantle are Australia's main city ports and account for 89 per cent of total containerised trade. Ports other than the major city ports handle 88 per cent of total non-containerised shipping.[8] Major regional ports and producing centres include Gladstone, Newcastle, Wollongong, Geelong, Launceston, Whyalla and the Pilbara ports.

In 2007–08, bulk-shipped energy exports (uranium, metallurgical and thermal coal, natural gas, LPG, crude and refined oil) were worth $43 billion. Of that, $24 billion was coal; Australia's largest energy export earner[9] (Figure 1.9).

Major infrastructure upgrades valued at many billions of dollars are either underway or being planned for many ports around the Australian coastline. The upgrades include expansions of loading facilities at Dampier, Port Hedland, Newcastle, Hay Point, Gladstone and Abbot Point. It has been estimated that some $2 billion of public investment and $2 billion of private sector investment will be required over the next 30 years in the port of Melbourne alone.[10]

Australia's coastal waters are relatively deficient in nutrients, and do not support a major fishing industry compared to other countries. However, the coastal zone is the base for a range of nearshore and deepwater fisheries that are valuable to local economies and communities and to the national economy. Fishing is Australia's fifth largest food-producing industry; the gross value of fisheries and aquaculture in 2007–08 was $2.19 billion.[11]

Rock lobster is the highest value fishery ($407 million in 2007–08), with production occurring in Western Australia, South Australia, Tasmania and Victoria. It is most important to Western Australia where two-thirds of the catch is taken.[12] In northern waters, the prawn catch is the highest value individual fishery ($74 million in 2007–08).

Wildcatch fisheries are diminishing worldwide. With a growing population, the world increasingly relies on aquaculture to meet the demand for fish. In 2007–08, the gross value of Australian aquaculture was

Photo credit: Arthur Mostead

Photo credit: Bruce Miller

Box 1.2 Australia's ports

Australia's ports vary greatly in type volume and level of activity. Melbourne and Sydney handle the greatest value of throughput each year. Western Australian and Queensland bulk port facilities handle significant volumes of material annually (up to 137 million tonnes).[13]

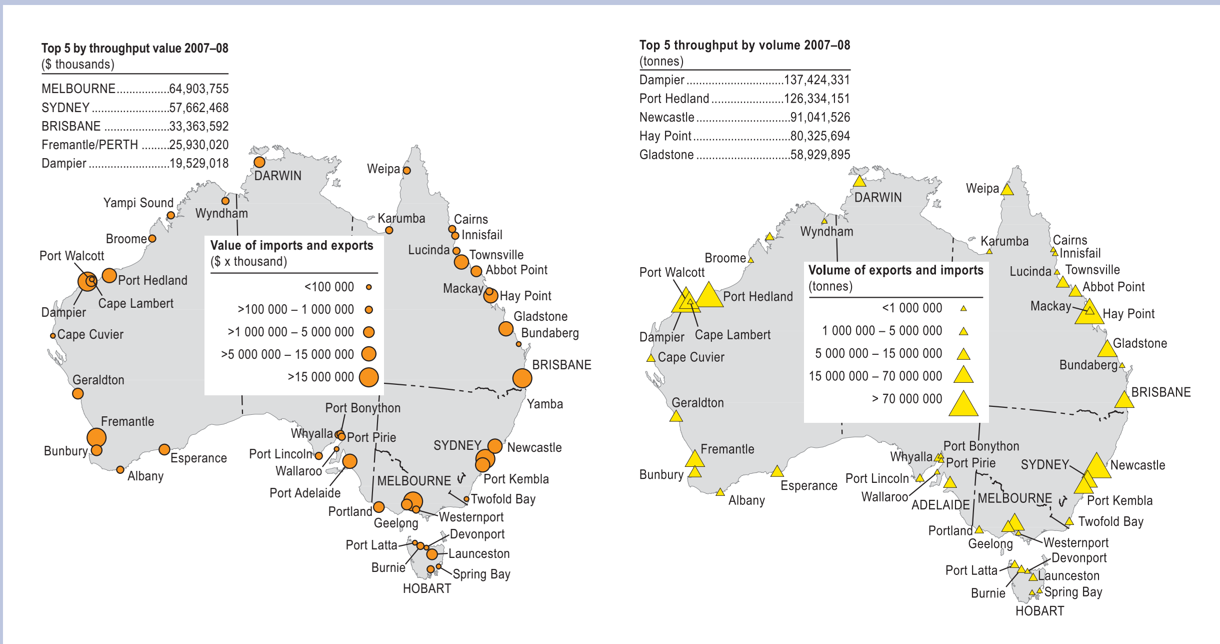

Figure 1.9 Value and volume of throughput at Australian ports 2007–08.
Source: BITRE 2009[14]

$868 million, and the industry is expected to continue to grow in importance.

Tourism and construction, which are related economic activities, are major contributors to coastal centres. Population growth along the coast has fostered local and regional booms in the construction of tourist facilities and housing. Many coastal communities depend on these activities as rural incomes from agriculture and fishing have declined in relative terms since the 1970s.

Tourism is not only dependent on the built environment of the coastal zone but also the natural assets and character of particular regions. Some of Australia's most iconic attractions and World and National Heritage areas are in the coastal zone, including the Great Barrier Reef, Sydney Harbour Bridge and Opera House, Bondi Beach, Kakadu National Park and Shark Bay. Natural attractions include coral reefs, rainforests, national parks, wetlands, mangroves, recreational fishing grounds and beaches.

Tourism creates many jobs and provides a significant contribution to the economy and social fabric of local regions. In 2003–04, an estimated $20 billion was spent on recreation and tourist activities directly involving coastal and ocean ecosystems.[15] Overall, tourism's direct contribution to the Australian economy in 2007–08 was $40.6 billion (up from $34 billion in 2003), 3.6 per cent of the gross domestic product, employment for 497,800 people (up from 461,000 in 2003), and 4.7 per cent of total employment.[16]

Table 1.1 Top five Australian fisheries, by volume and value, 2007–08.

Top five fisheries, by volume (wildcatch and aquaculture)		Top five fisheries, by value (wildcatch and aquaculture)	
Australian sardines	33,600 tonnes	Rock lobster	$407 million
Salmonids	25,500 tonnes	Salmonids	$299 million
Prawns	22,400 tonnes	Prawns	$268 million
Tuna	14,700 tonnes	Tuna	$210 million
Rock lobster	13,800 tonnes	Abalone	$189 million

Source: ABARE 2009[17]

Box 1.3 Great Barrier Reef

Tourism generates the largest economic contribution in the Great Barrier Reef catchment. The Reef has 1.9 million visitors annually.[18]

The Great Barrier Reef Tourism Climate Change Action Strategy 2009–2012 states: 'The health of the tourism industry is inextricably linked with the health of the Reef.'

Tourism's share of GDP in the Great Barrier Reef catchment is 84–87 per cent, and its share of employment is 81–84 per cent. In 2005–06, tourism contributed $6 billion to GDP and employed 55,000 people.[19]


Photo credit: © Commonwealth of Australia (GBRMPA)

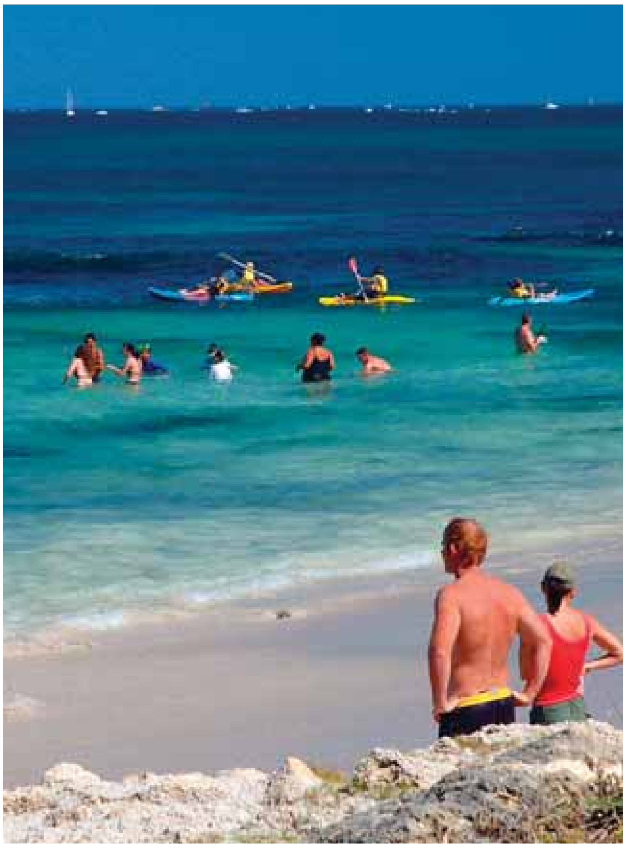
Photo credit: © Suzanne Long/AUSCAPE

Box 1.4 Gold Coast City

The population of the Gold Coast has grown from 110,900 in 1976[20] to 497,848 in 2008[21] and is projected to be 900,000 by 2030. On average the city hosts more than 28,900 visitors every day, 92 per cent of whom come from other places in Australia. Visitors from Japan, New Zealand, Asia and China make up most of the remaining 8 per cent.[22]

Between them, visitors to Gold Coast City spend an average of $4 billion each year. The city's tourism sector employed almost 18,500 people in 2006.[23]


Photo credit: © iStockphoto.com/Jenny Bonner

1.2.2 Social benefits

The beach is an important part of Australian culture and identity. Beaches are public places for all to enjoy and for many Australians beaches provide a sense of place and offer opportunities to participate in activities that stimulate and enhance wellbeing.

Since the early 1900s, there has been a growing recognition that coastal living offered many recreational and aesthetic advantages for city dwellers. It is perhaps no coincidence that the second national park in the world after Yellowstone was the Royal National Park on the coast south of Sydney. Once authorities allowed surf bathing in daylight in 1902 at Manly, the fascination with body surfing and later with board surfing took off. The formation of surf lifesaving clubs as volunteer organisations began a movement, that has deep roots in 20th century coastal life, which continues today.

Photo credit: Dragi Markovic and DEWHA

The sense of place that has attracted so many Australians to the coast was captured by Robert Drewe when he wrote: 'Australians make or break romances at the beach, they marry and take honeymoons at the beach, they go on holidays with their children to the beach, and in vast numbers retire by the sea.'[24]

The interest in coastal living has given rise to the 'sea change' phenomenon, which since the 1970s has driven the demographic and economic revival of non-metropolitan coastal communities. There has been growth in coastal cities such as the Gold Coast and Cairns, as well as an extension of coastal satellite communities within commuter range from capital cities. A number of coastal holiday or lifestyle destination communities, such as Bunbury in Western Australia and Victor Harbour in South Australia, have also grown rapidly in the same period. In many cases the rate of population growth in such coastal local government areas has been about double the national average. This rate of growth has entailed persistent challenges for land use, infrastructure and planning. The 'sea change' phenomenon is expected to continue for the next 20 years, especially as a result of further baby boomer retirement.

The social benefits of the coastline and individual beaches are valued highly by Australians. The value of Adelaide's beaches has been estimated at $46 million per year[27], and the gross value of Gold Coast beaches to tourists alone was estimated at between $106–$319 million in 2006.[28]

Benefits that the coast brings to people, through aesthetics, improved physical and mental health, and culture must be factored into any consideration of the benefits of the coast to the national good.

Box 1.5 Surf Life Saving Australia

Photo credit: Newspix/Elenor Tedenborg

Australia's and the world's first official surf lifesaving clubs were founded in 1906 at Bondi and Bronte. Surf Life Saving Australia now incorporates 305 local surf lifesaving clubs, 17 regional branches in New South Wales and Queensland, and seven state and territory centres.[25] Australian surf lifesavers have rescued more than 500,000 people in the 80 years that records have been kept.[26]

Photo credit: © Steven David Miller/AUSCAPE

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Box 1.6 Population growth

Australia's population is projected to reach 35 million by 2049.[29] All states and territories experienced population growth in 2008. The greatest growth occurred in Queensland, followed by Victoria, then New South Wales.

Outside capital cities, the largest population growth in 2007–08 generally occurred along the Australian coast.[30] Seventy-five per cent of Australia's non-metropolitan population is living in coastal areas.[31]

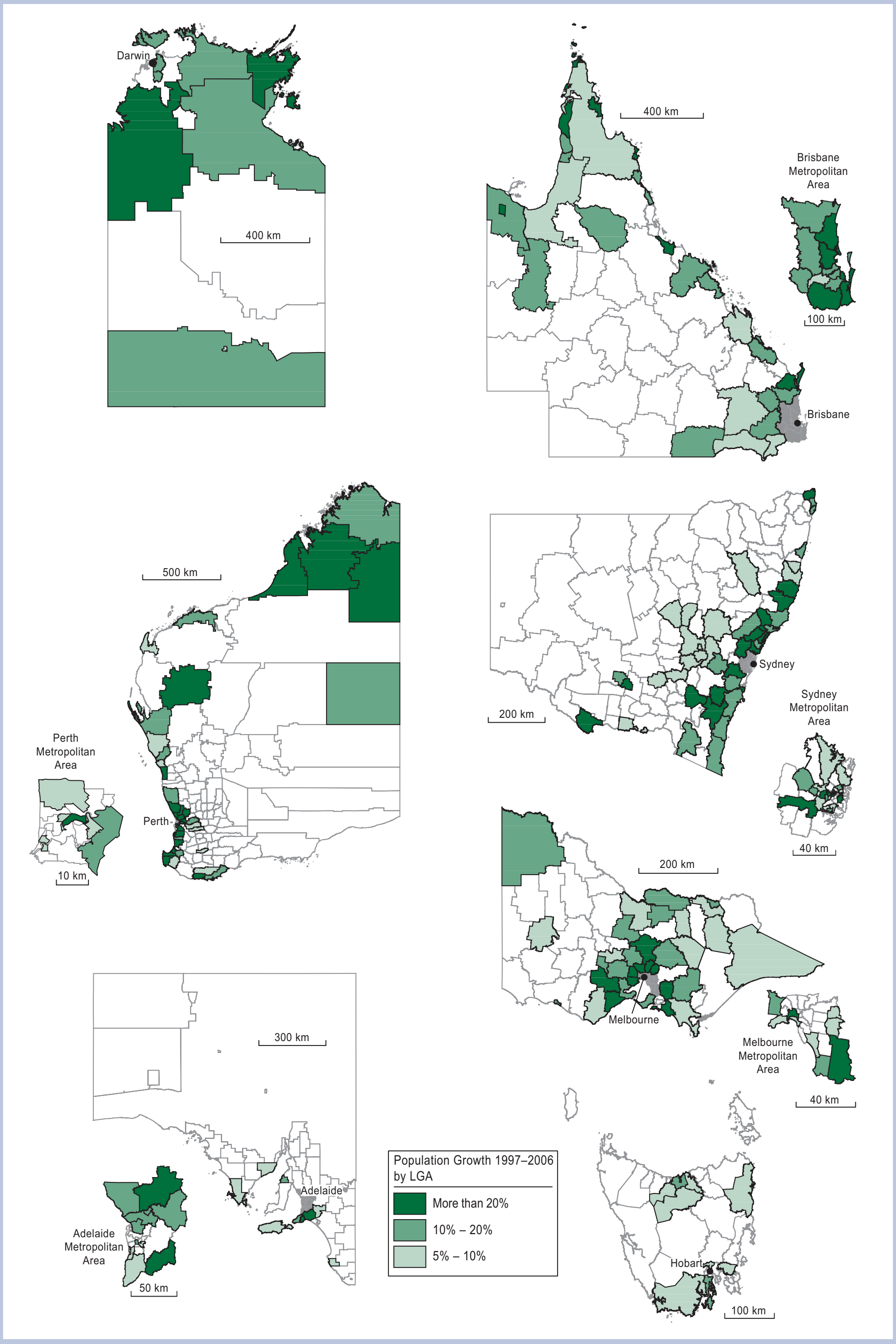

Figure 1.10 Fastest growth local government areas, 1997 to 2006.
Source: DITRDLG 2008[32]

1.2.3 Environmental benefits

Australia has a wide range of coastal environments, with rich and very diverse coastal ecosystems that support a unique biodiversity. Coastal habitats include mangroves, estuaries, saltwater marshes, kelp forests, seagrass beds, rocky shores, beaches, sand dunes, and vegetation communities such as heath and woodland.

Even within a specific ecosystem type there can be a rich diversity of habitats along the Australian coast. For example, the mangrove flora of Australia is one of the world's most diverse, and it covers about 18 per cent of the coastline. Mangroves are important nursery areas for fish and crustacean species, including for many commercial species such as barramundi and prawns.[33] Tropical birds such as the mangrove robin and mangrove fantail are found almost exclusively among mangroves, while other terrestrial birds depend on mangroves at various times of the seasonal or tidal cycle. More broadly, mangroves protect the shoreline and enrich coastal productivity by recycling carbon and nutrients. Nutrient enrichment by mangroves may be particularly important in waters where nutrient concentrations are typically low.

Australia has the world's most diverse array of tropical and temperate seagrasses. In fact, Australia hosts more than half of the world's 60 species and 11 of the world's 12 genera of seagrasses, with about 51,000 square kilometres of seagrass meadows, with Shark Bay home to the world's largest seagrass bed.[34]

Australia's coral reef ecosystems are unique. The Great Barrier Reef off Queensland and Ningaloo Reef off Western Australia are Australia's coral reef icons, but there are many other coral reef ecosystems with unique species assemblages. There are deepwater corals, low to high latitude transitional reefs in New South Wales and Western Australian waters, and coral atolls in the Indian Ocean and

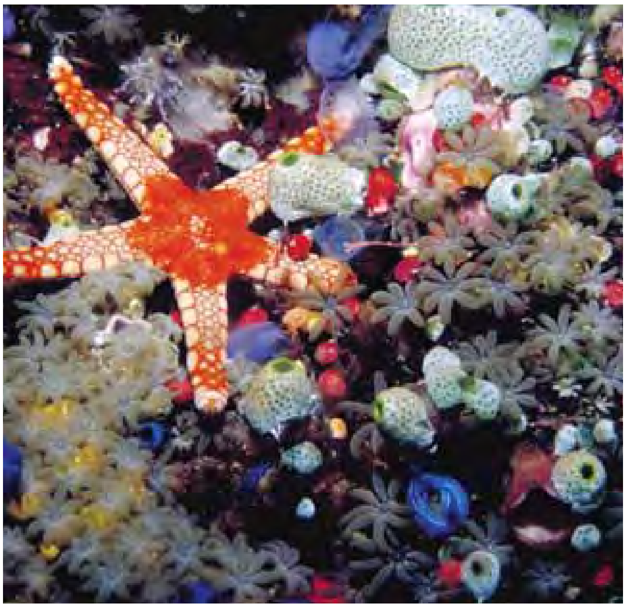

Photo credit: ©Commonwealth of Australia (GBRMPA)

South Pacific Ocean. These coral ecosystems support a broad array of fish and invertebrates, many of which are endemic. They also support a range of species that are important for recreational, commercial and traditional fisheries.[35]

Rocky shores are one of the most easily accessible marine habitats and are a transition zone between the land and sea. The rocky shorelines of southern Australia contain very high numbers of endemic species; it has been estimated that over 90 per cent of mollusc and echinoderm species (such as starfish) and 60 per cent of seaweeds may be endemic.[36]

Coastal wetlands, estuaries and mangroves all perform critical functions, sustaining human activities, assimilating waste and purifying water by removing nitrogen, phosphorus and other pollutants from agricultural or urban runoff.[37] The stabilisation of the shoreline against erosion by sea currents

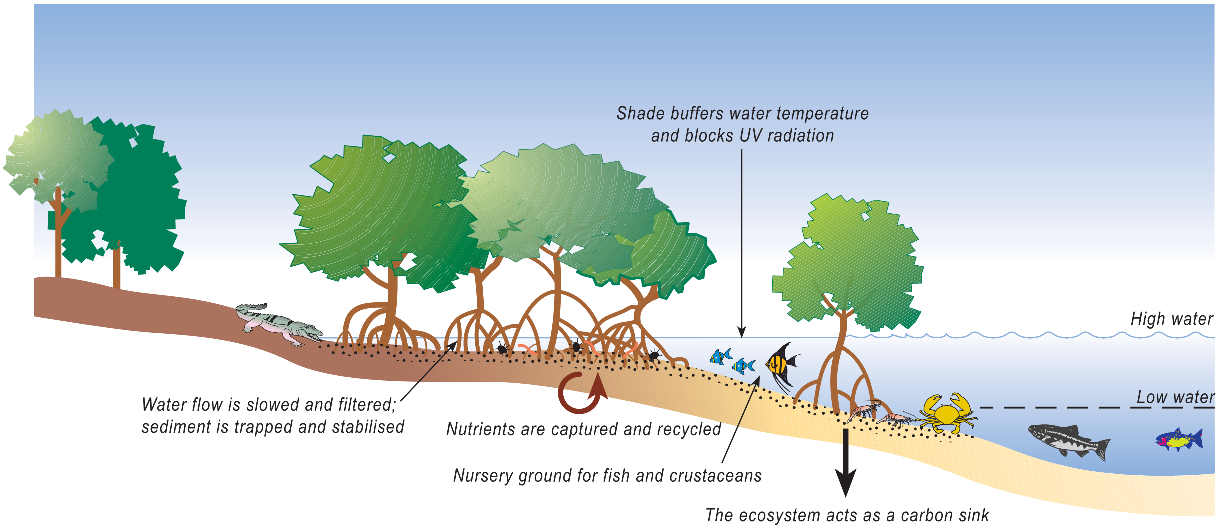

Figure 1.11 A mangrove ecosystem.

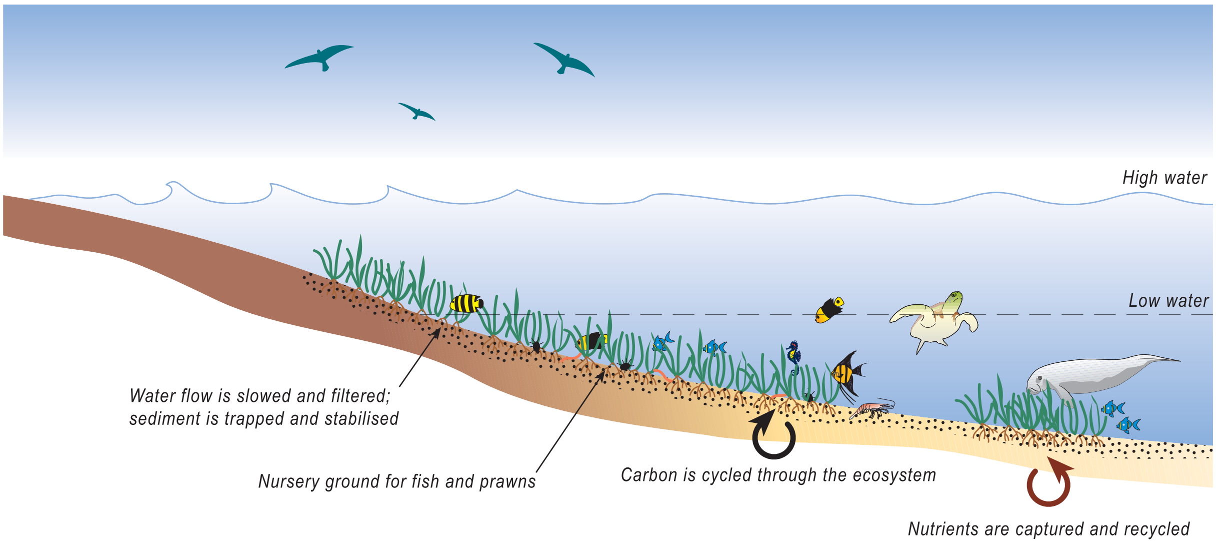

Figure 1.12 A seagrass ecosystem.

and the protection of hinterlands from storms and floods are important ecosystem services that also protect human-made assets, such as infrastructure, agricultural systems and built-up areas.

Many parts of coastal ecosystems heavily used by people are showing signs of stress. Land clearing, soil erosion, pollution of waterways (by industrial effluent, sewage and nutrient runoff from farms), canal construction, overallocation of freshwater supplies, mining of beaches and dunes, use of pesticides and other actions have damaged some coastal ecosystems and reduced their ability to provide ecosystem services.

Photo credit: ©John Lewis/AUSCAPE

1.3 Conclusion

The coastal zone and position of the shoreline is very dynamic. Understanding past variability can help us better appreciate how the coast could change in the future, including as a result of human-induced climate change.

Human settlement has greatly modified the coastal environment over the past 100 years. Australia has become a coastal society: around 85 per cent of the population live within 50 kilometres of the coast. Buildings, utilities, public amenities and transport networks have been constructed in areas that experience periodic flooding, wind damage and shoreline erosion.

The Australian coastal zone has been developed with the expectation that the shoreline will remain stable, extreme events will occur within a range defined by historical experience, and sea level will not change. As the next chapter will show that expectation is no longer tenable.

Climate change and sea-level rise will usher in a period of relative instability in coastal environments, shorelines, storm processes, beach processes, ecological systems and, ultimately, the use of coastal areas. Global warming has the potential to take the Earth's dynamic system out of the 'comfort zone' of past glacial-interglacial cycles and to create disequilibrium. Eventually, sea levels could rise to new equilibrium positions not seen since the Eocene (40 million years ago) if the drivers of climate change are left unchecked.

Understanding and planning for these changes are significant and urgent tasks. The next chapter summarises the latest scientific research and projections for the effects of climate change on the Australian coastal zone.

Chapter 2 describes how the current climatic 'comfort zone' conditions may change at rates not experienced in the historical and geological past. Temperatures and CO_2 are likely to increase beyond levels experienced in the past 6,000 years. Over centuries, sea levels will rise more than a metre beyond existing 'stable' tidal range positions, resulting in new inundation of land and shifts in shorelines.

2

CHAPTER

CLIMATE CHANGE IN THE COAST – THE SCIENCE BASIS

Photo credit: © iStockphoto.com/Jtgray

2

KEY FINDINGS

- Recent science findings suggest the climate system is changing faster than projected and that the impacts of climate change are likely to be more severe.
- Under a high-emissions scenario, a sea-level rise of up to a metre or more by the end of the century is plausible.
- Changes in the frequency and magnitude of extreme sea level events, such as storm surges combined with higher mean sea level, will lead to escalating risks of coastal inundation. Under the highest sea-level rise scenario by mid-century, inundations that previously occurred once every hundred years could happen several times a year.
- Sea-level rise will not stabilise by 2100. Regardless of reductions in greenhouse gas emissions, sea level will continue to rise for centuries; an eventual rise of several metres is possible. This has implications for decisions taken now on the 'footprint' of our cities.
- Evidence suggests that severe and damaging tropical cyclones may occur more often and could track further south along Australia's east and west coasts.
- Rising sea levels are likely to cause accelerated erosion for many beaches around the Australian coastline. The switch from generally accreting beaches to a receding coastline is a key threshold for coastal management and is not well understood.
- Key uncertainties in coastal risks – notably, the magnitude of sea-level rise due to icesheet melt, the regional distribution of sea-level rise and thresholds at which stable or accreting coasts switch to eroding coasts – can be substantially reduced through investment in basic science.

2.1 Overview of climate change in the coastal zone

The coast is a place of energy where air, water and land interact, sometimes with great violence. In addition to the long-term cycles of glaciation described in Chapter 1, a number of short-term tide and weather cycles and episodes of extreme events shape the coastal landscape, building the coastline up and wearing it down.

Humans have introduced another factor into this environment: human-induced climate change. Increases in greenhouse gases in the atmosphere since the industrial revolution, largely from human activity, have contributed to a warming of the atmosphere and the oceans. That warming is driving a range of other changes, some of which are not yet well understood, in the climate system and to coastal processes.

The complexity of interactions in the coastal zone suggests that the impacts of climate change could manifest in many ways (Figure 2.1). Risks of inundation in low-lying areas and accelerated coastal erosion are particular concerns. Changes in sea surface temperatures and ocean acidity can also have large impacts on estuary and marine life (see Chapter 4).

Of particular concern are recent scientific conclusions that climate change could occur more rapidly than previously thought and that the magnitude of change and resulting impacts could be larger. The risks associated with the upper range of climate change projections need to be considered seriously.[1]

Over the next century, human-induced climate change could increase global average temperature by about the same as the rise following the last ice age (around 5°C). If that happens, sea levels could rise up to half of the postglacial rise (roughly 60 metres[2]), although this would take thousands of years.[3]

This chapter describes the current knowledge of climate change in the coastal zone, with a particular focus on sea-level rise and extreme events and on how climate change will affect coastal inundation

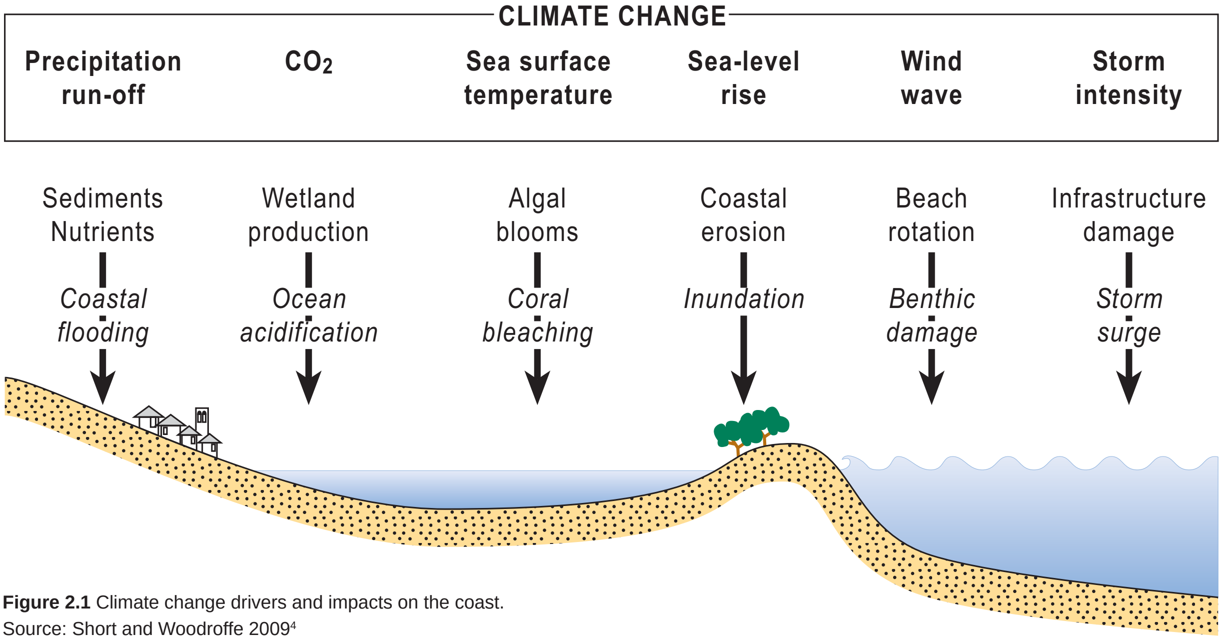

Figure 2.1 Climate change drivers and impacts on the coast.
Source: Short and Woodroffe 2009[4]

and coastal stability risks. Various other global environmental change hazards converge in the coastal zone, including changes to ocean chemistry, sedimentation caused by human land-use, and bushfires on the landward side. While this report is focused on coastal inundation and stability, future work will need to synthesise knowledge of those other sources of risk.

2.2 Sea-level rise

The sea level at any moment is the sum of the mean sea level, plus the state of the tides, wave set-up, responses to air pressure and near shore winds, and may sometimes be affected by additional flows of water from on-shore. It is convenient to group these influences under changes to average conditions and to extreme event hazards. Under climate change both mean conditions and extremes will change over a range of time scales (Figure 2.2).

Mean sea level is a slowly changing variable, combining absolute (or eustatic) sea level with any regional movements of the land surface. The major influences of sea levels are long-term, and there are substantial delays between cause and effect. Relative mean sea-level rise can lead to the permanent inundation of low-lying areas. Increasing sea levels also contribute to an increasing hazard associated with extreme events. Hazards such as extreme short-term inundation events can pose a risk to natural and built structures and move large amounts of sediment, which impacts coastal stability.

Many people imagine that sea level will rise gradually, like water rising in a bathtub. This is unlikely. Coastal waters will continue to be affected by extreme tides, storm surges and storm tides, which may become increasingly severe in many places as a result of climate change. These factors will interact with sediments in coastal systems. The combined effect of rising sea levels and changes in extremes will produce much greater risks in the coastal zone than any single factor.

2.2.1 Drivers of global sea-level rise

Global average sea level is rising mainly because of the expansion of warming and freshening ocean water. Increasing atmospheric temperatures are leading to warmer ocean waters, while the addition of new water from glaciers and icecaps and from the icesheets of Greenland and Antarctica is making the oceans less saline (Figure 2.3).

In contrast to the sea level changes associated with the glacial-interglacial cycles described in Chapter 1, recent sea-level rise has increasingly been driven by human-induced climate change. It is now understood that thermal expansion is responsible for about one-third of the global sea-level rise that occurred in the century to about 1990.[5] Since then, melt water

Photo credit: A.D. Short

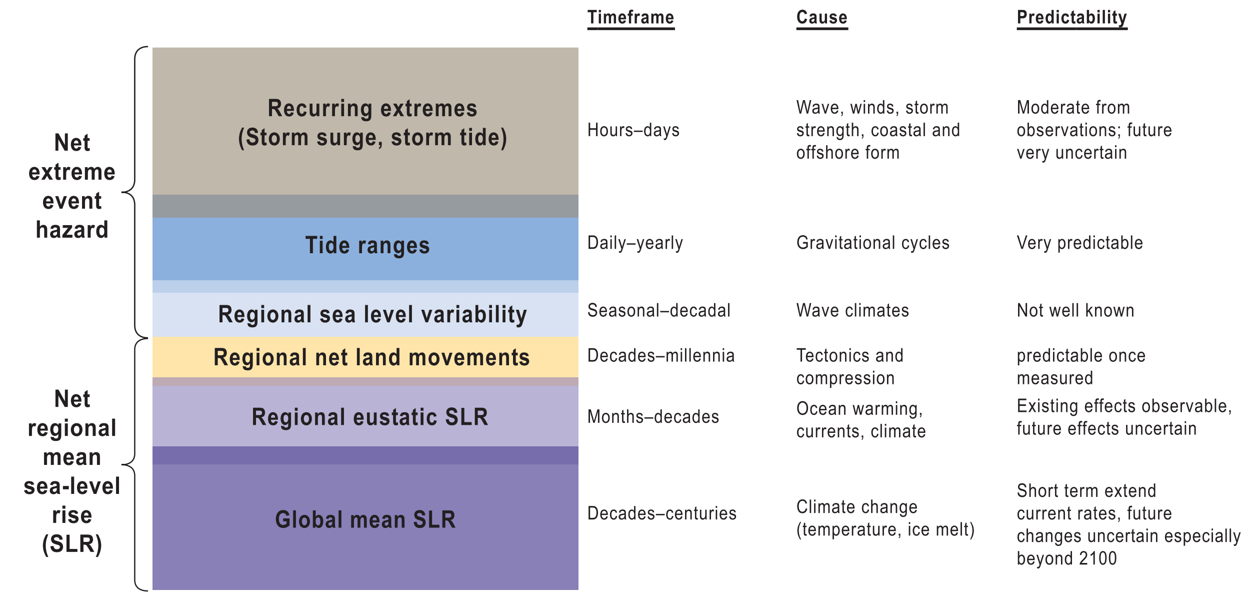

Figure 2.2 Main contributors to net extreme event hazard and regional mean sea-level rise.
Source: Jones et al. 2009[6]

from glaciers, icecaps and ice sheets has become much more important.[7]

Oceans warm much more slowly than the atmosphere, especially the deep oceans, so thermal expansion lags decades behind rising air temperature. Thermal expansion can be predicted with moderate confidence. Estimates of melt water from icecaps and glaciers are similarly robust because the volume of ice and rate of melting are known from global surveys. Contributions to sea levels from ice sheets are more difficult to estimate because of the ice sheets' size, variation in climate across their extent, and data limitations. Water inputs from land (other than ice melt) also contributes to total sea levels, however they are affected by human and natural influences and current trends are negligible; though there may be substantial contributions from anthropogenic extraction of water from aquifers and impounding in reservoirs in the future.[8]

Over timeframes of centuries, the potential contribution of melt from the Greenland and West Antarctic icesheets to global sea-level rise is uncertain. Over the longer term, those icesheets could potentially raise sea level by 6 metres and 3.3 metres, respectively.[9] Past climatic reconstructions and modelling suggest that ice melt from East Antarctica would also add to further sea-level rise if the West Antarctic was to become largely ice free.[10]

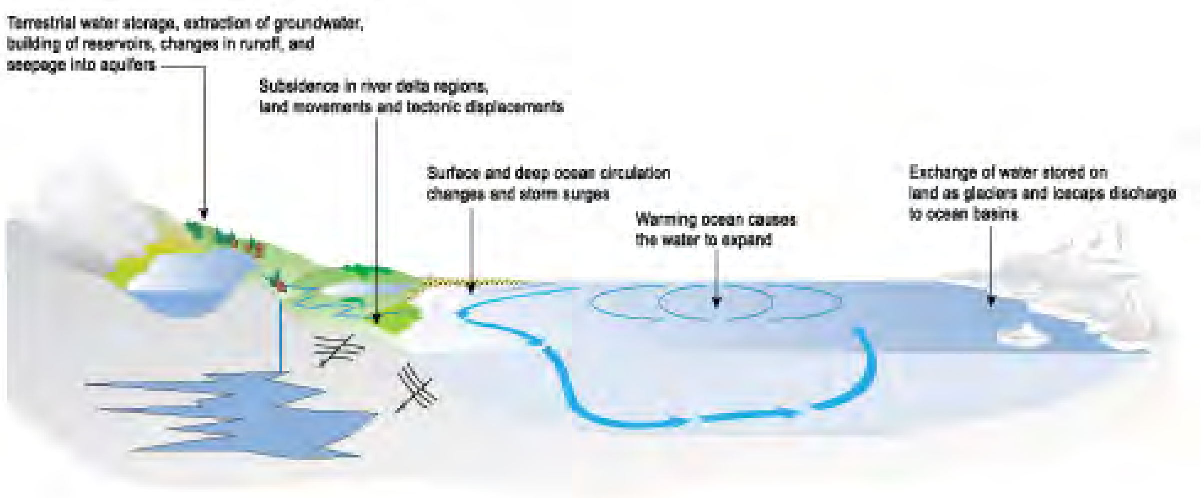

Figure 2.3 What causes sea level to change?
Source: UNEP 2009[11]

Box 2.1 Antarctic ice and the global earth system

Scientists are becoming more concerned that greenhouse gas emissions from human activities will lead to thresholds in the Earth's climate system being exceeded, resulting in very large, abrupt or irreversible consequences.

The Antarctic ice story is complex and regionally variable. Current observations record a small expansion in total extent of sea ice in Antarctica, attributed to increased wind speeds and storm activity associated with the hole in the ozone layer. Global warming has initiated melting of the land based West Antarctic ice sheets, the melt water has contributed to global sea-level rise.[12] The West Antarctic icesheet has been identified as one of a number of components in the earth system vulnerable to abrupt change (Figure 2.4). The icesheet is frozen to land below sea level, so the potential for rapid disintegration as oceans warm is high. This could occur over a period of around 300 years in response to a temperature increase from global warming of 3–5°C.[13]

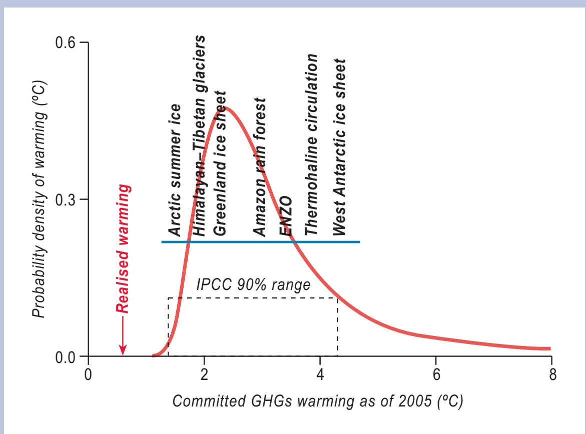

Figure 2.4 Probability distribution for warming by greenhouse gases between 1750 and 2005, showing climate tipping elements and the temperature threshold range.
Source: Ramanathan and Feng 2008[14]

Photo credit: Alison McMorrow and DEWHA

Photo credit: Alison McMorrow and DEWHA

Loss of ice from West Antarctica increased by 60 per cent in the decade to 2006. Ice loss from the Antarctic Peninsula, which extends from West Antarctica towards South America, increased by 140 per cent. Accelerating glacier flows in both areas are caused by warmer air and by high ocean temperatures.

A number of ice shelves along the coasts of West Antarctica and the Antarctic Peninsula, which act as buttresses for the ice sheets, have recently reduced. When they go, the icesheets may move more quickly out into the ocean and add to sea-level rise more rapidly than previously thought.

Icesheet dynamics are in a state of flux in Antarctica. Learning how they are responding to environmental change is one of the most important challenges facing scientists in the coming decade. This research is essential if we are to understand the long-term risks to the coastal zone from sea-level rise.

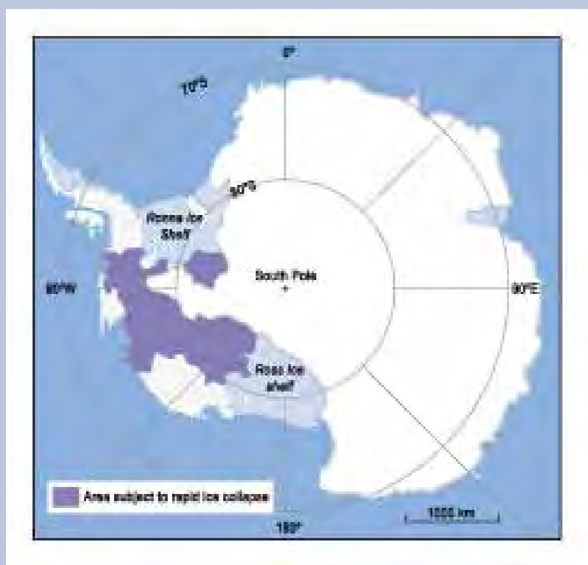

Figure 2.5 West Antarctic icesheet vulnerability to collapse.
Grey: topography above sea level. Brown: topography below sea level and subject to rapid potential collapse.
Source: Bamber et al. 2009[15]

2.2.2 Historical sea-level rise

Global mean sea level has risen about 20 centimetres since pre-industrial times (Figure 2.6), at an average rate of 1.7 millimetres per year during the 20th century.[16]

Since 1993, high-quality satellite observations of sea levels have enabled more accurate modelling of global and regional sea-level change. From 1993 to 2003, global sea level rose by about 3.1 millimetres per year, compared to 1.8 millimetres per year from 1961 to 2003. These rates of increase are an order of magnitude greater than the average rate of sea-level rise over the previous several thousand years.

Sea level around Australia rose by about 17 centimetres between 1842 and 2002 – a rise in relative sea level of about 1.2 millimetres per year.[17] The rise in sea level has been very variable from decade to decade. The rate of increase was low between the 1970s and early 1990s due to more frequent and severe El Niño events.[18] During neutral conditions, easterly trade winds blow across the tropical Pacific and the sea surface is about 50 centimetres higher and 8°C warmer in the far-western Pacific than in the eastern Pacific. The trade winds relax in the central and western Pacific during El Niño events, resulting in lower sea levels and cooler temperatures than normal in the Australian region. Conversely, La Niña is characterised by higher sea levels in the far-western Pacific, affecting northern and western Australia. Episodes of high sea level on these timescales can affect the severity of extreme events and also accelerate the salinisation of coastal aquifers.

Recent rates of sea-level rise in eastern and southern Australia are similar to the global rate (Figure 2.7). In western and north-western Australia, the current rates are more than double the global rate. These trends are most likely a combination of climate change and shorter term variability.

2.2.3 Projections of sea-level rise to 2100 and beyond

The Intergovernmental Panel on Climate Change (IPCC) provides the most authoritative projections of sea-level rise. The IPCC's climate change projections are based on observations, palaeoclimate analysis and model simulations informed by understanding the climate system. Conclusions about future sea-level rise in the IPCC's Third Assessment Report (TAR, 2001) and Fourth Assessment Report (AR4, 2007) were broadly similar. The IPCC AR4 projections estimated global sea-level rise of up to 79 centimetres by 2100, noting the risk that the contribution of ice sheets to sea level this century could be higher. Figure 2.8 shows sea-level rise projections to 2100 from the TAR and AR4 analysis.

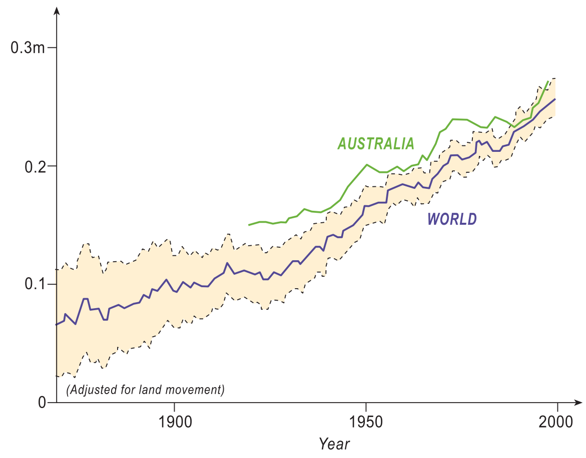

Figure 2.6 Historical sea-level rise from tide gauges and satellite altimeter data.
Source: Church and White 2006[19]

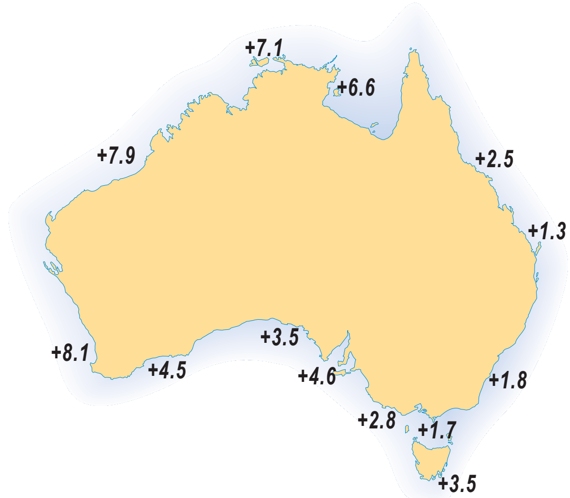

Figure 2.7 Local sea-level rise (mm/year) from the early 1990s to 2008.
Source: NTC 2008[20]

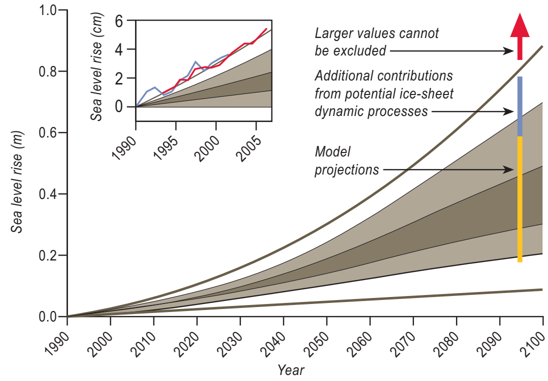

Figure 2.8 Projected sea level for 2100 (IPCC TAR and AR4 projections).
Source: ACE CRC 2008[21]

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Research since AR4 has suggested that dynamic processes, particularly the loss of shelf ice that buttresses outlet glaciers, can lead to more rapid loss of ice than melting of the top surface ice alone. This effect has been observed in the Antarctic Peninsula.

Estimates of total sea-level rise remain uncertain. However, there is growing consensus in the science community that sea-level rise at the upper end of the IPCC estimates is plausible by the end of this century, and that a rise of more than 1.0 metre and as high as 1.5 metres cannot be ruled out.[22]

Sea levels will continue to rise after 2100. The lag between atmospheric and ocean warming and the time required for icesheets to melt could mean that sea levels keep rising for a thousand years after atmospheric greenhouse gas concentrations are limited or stabilised. Figure 2.9 illustrates the relationship between atmospheric concentrations of greenhouse gases and thermal expansion of the ocean.

At the high end, the rate and magnitude of warming projected in AR4 could lead to the complete collapse of the Greenland ice sheet (committing the Earth to a 6 metre sea-level rise), to partial to complete melting of the West Antarctic icesheet (committing the Earth to at least a further 3 metre sea-level rise) and to potential loss from the East Antarctic icesheet. The timing of subsequent rises is highly uncertain – they could perhaps take hundreds to thousands of years, depending on regional climates and icesheet responses that remain poorly understood. Figure 2.10 shows potential sea-level rise beyond 2100 from various studies using simple climate models.

Sea-level rise greater than the global average is projected for south-eastern Australia, while the rise for north-western Australia is less (Figure 2.11). The rise in south-eastern Australia is influenced by a warming East Australian Current moving further south. These estimates are for eustatic, not relative, sea-level rise and they do not consider regional sea-level responses from melting icesheets.

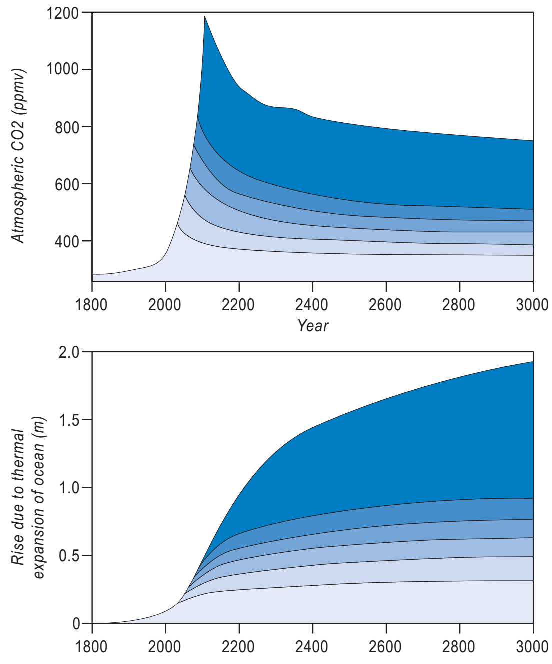


Figure 2.9 Sea-level rise will continue even if greenhouse gas emissions cease (top), as thermal expansion of the oceans will continue (bottom).
Source: Solomon et al. 2009[23]

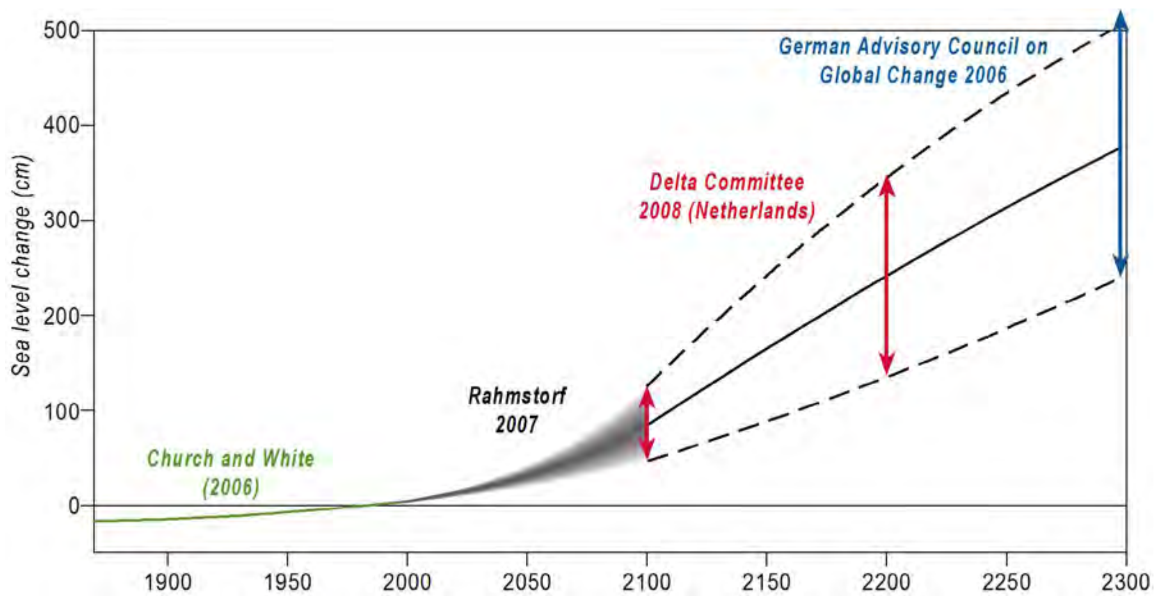


Figure 2.10 Recent estimates of future sea-level rise relative to the 1990s.
Source: German Advisory Council on Global Change 2009[24]

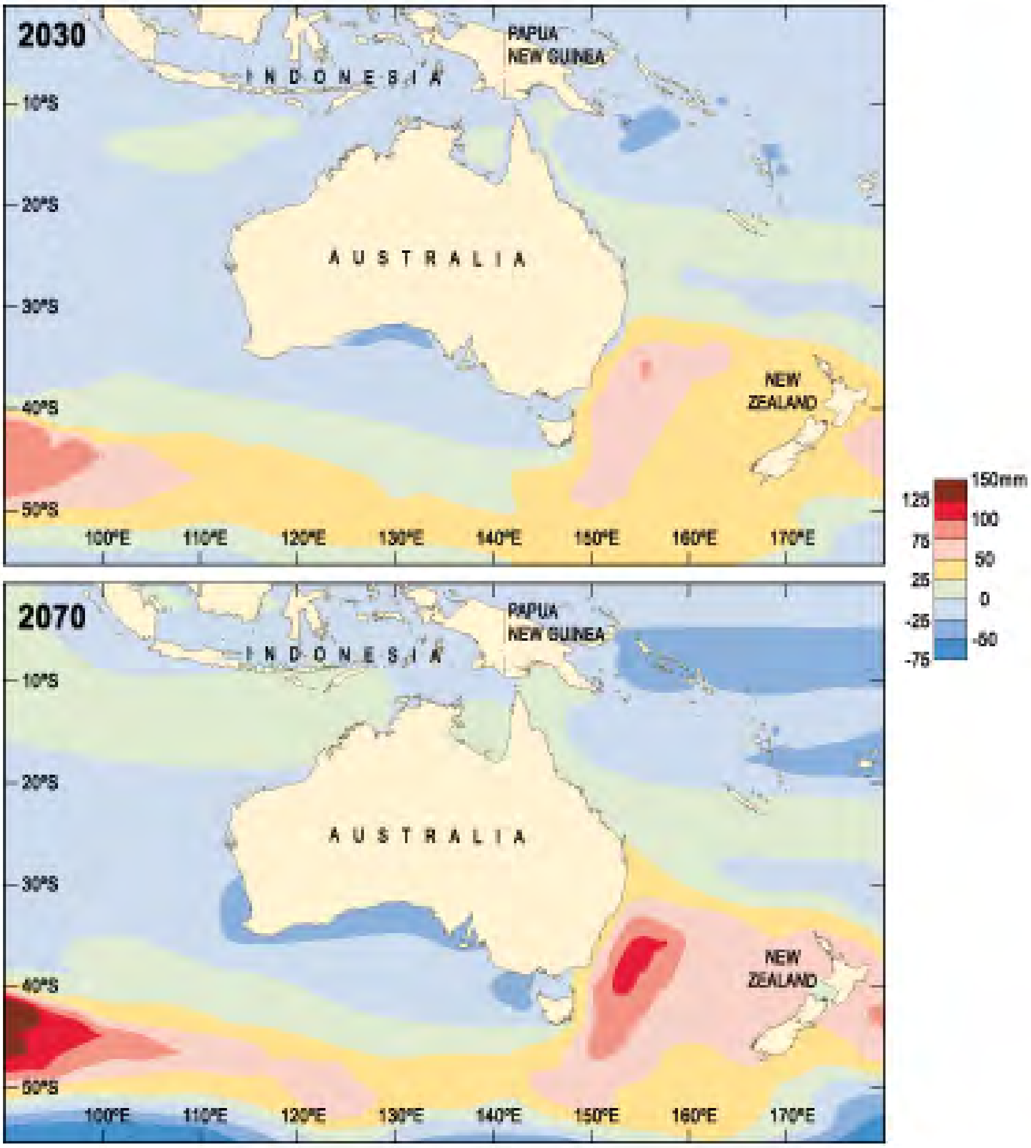


Figure 2.11 Projected sea-level rise for Australia, 2030 and 2070 (departures from the global multi-model mean run for the IPCC A1B scenario). Source: CSIRO and BOM 2007[25]

CSIRO has developed three simple scenarios for sea-level rise (relative to 1990), at three time-steps across the 21st century (Table 2.1):

Scenario 1 (B1) considers sea-level rise in the context of a global agreement that brings about dramatic reductions in global emissions. This scenario represents sea-level rise that is likely to be unavoidable.

Scenario 2 (A1FI) represents the upper end of IPCC AR4 'A1FI' projections and is in line with recent global emissions and observations of sea-level rise.

Scenario 3 (High end) considers the possible high-end risk identified in AR4 and includes some new evidence on icesheet dynamics published since 2006 and after AR4.

Table 2.1 Three sea-level rise scenarios, 2030–2100 (metres).

Year	Scenario 1 (B1)	Scenario 2 (A1FI)	Scenario 3 (High end)
2030	0.132	0.146	0.200
2070	0.333	0.471	0.700
2100	0.496	0.819	1.100

Post AR4 analysis combining thermal expansion and potential rates of ice melt show that the probabilistic distribution is skewed towards the upper end and that using the high-end scenario to inform decision-making is justified. Very recent research also suggests that a 1.1 metre scenario by the end of the century may not reflect the upper end of potential risk, and that risk assessments could be informed by a higher level.

2

Box 2.2 Sea-level rise value used in this assessment

The IPCC's Fourth Assessment Report (AR4) outlined global sea-level rise to 59 centimetres by 2100 based on thermal expansion alone. In the AR4 projections, what could not be modelled was not included. However, the AR4 notes that up to a further 20 centimetres could be added for linear ice melt from glaciers and ice-caps, and that the contribution of ice sheets to sea level this century could be substantially higher.

AR4 findings triggered considerable debate in the science community. More recent analysis finds that sea-level rise of up to a metre or more this century is plausible. Further, nearly all of the uncertainties in sea-level rise projections operate to increase rather than lower estimates of sea-level rise.[26]

Very new research is updating projections of sea-level rise using statistical approaches informed by the observed relationship between temperature and sea level.[27] Sea-level rise projections presented to the March 2009 Climate Change Science Congress in Copenhagen ranged from 0.75 to 1.9 metres by 2100 relative to 1990, with 1.1–1.2 metres the mid-range of the projection.[28]

A sea-level rise value of 1.1 metres by 2100 was selected for this assessment based on the plausible range of sea-level rise values from post IPCC research. This is a dynamic area of science – sea-level rise projections will change and risk assessments and policies will need to be reviewed and amended over time to reflect new research findings.

2.3 Climate change and extreme events

Climate change induced sea-level rise will lead to an increase in the height of extreme sea-level events and to more frequent extremes of a given height. Climate change may also lead to changes in the frequency and intensity of the meteorological drivers of storm surge, such as cyclones and mid-latitude storms, and to riverine flooding. Currently, the baseline of mean sea level is generally considered to be constant in planning terms, but in fact it is already changing. The most important co-events are storm surge occurring on a high tide, and where storm surge occurs during a high rainfall event, which can lead to a combined effect of riverine flooding and storm surge magnifying the spatial exposure.

2.3.1 Wave climates

The 'wave climate' is the long-term direction, frequency, energy and extremes of ocean waves. Waves provide most of the energy that shapes the shoreline and potentially drives coastal erosion. Impacts of changing ocean waves in the coastal zone are:

- coastal inundation during severe storm events through the combined effects of sea-level rise, storm surge and ocean waves
- chronic coastal erosion brought about by large wave events or changes in wave direction that shift coastal sand and sediment
- seabed disturbance affecting sub-tidal habitats.

Australia's wave climate shows high energy across southern Australia and extending up the west coast. It is strongest in winter. Northern Australia is characterised by low-energy waves, except for extremes associated with tropical storms during summer. Years with shorter monsoon seasons also tend to have greater mean wave energy. The east coast experiences high wave energy during periods when east coast low pressure systems are most frequent. A positive trend in the frequency and intensity of large wave events has been identified along Australia's southern margin.[29]

Climate change may slightly increase mean wave climates (both wave height and wave energy) in many regions, in line with slight increases projected in mean wind speed. Variability may also increase with greater variations in air pressure. The dynamic regional analysis required to estimate possible changes in wave direction has not been undertaken for Australia.

Nevertheless, much can be learned from the past. Geological and historical records reveal patterns of extreme storms in the past.[30] They provide a base for comparing projected future changes in the magnitude, frequency and direction of wave attack in extreme wave-driven events.

Decade-scale changes in storm patterns and in the way waves interact with sediment systems to modify beaches, dunes and mudflats are now reasonably well understood for example through the long-term monitoring of Moruya beach on the New South Wales south coast.[31] Severe erosion by mega-storm waves occurred in clusters at Moruya and other places along the east coast such as in 1974 during a La Niña period. Shifts in beach orientation due to La Niña – El Niño oscillations have also been demonstrated.[32] Clustering of storms under a favourable combination of drivers such as La Niña, Interdecadal Pacific Oscillation and other atmospheric systems appears to have strongly influenced extreme wave events in Australia.

Attempts are now being made to develop methods that link future wave climate scenarios to the susceptibility of certain coastal landforms to erode or accrete.[33] This work involves studying the transformation of waves as they propagate from deep to shallow waters and then linking the transformation to coastal sediment budgets and inherited geomorphic conditions.

2.3.2 Cyclones and lows

Tropical cyclones, east coast lows and mid-latitude lows can generate heavy rainfall, very strong winds and big storm surges when they make landfall, leading to considerable damage to coastal environments and built assets.

Tropical cyclones and lows affect northern Australia, and the lows sometimes extend into the mid latitudes on the east and west coasts (Figure 2.14). East coast lows affect eastern Australia and in some years occur as clusters that cause considerable damage. Mid-latitude depressions can drive storm surges into coastal embayments.

Climate change may affect the frequency, severity and positions of cyclones and other storms. While projections of tropical cyclones in the Australian region are uncertain, the available studies suggest that there may be an increase in the number of tropical cyclones in the more intense categories (categories 3–5), but a possible decrease in the total number of cyclones.[34]

Cyclones may also track further south along the east and west coasts. Studies have found a poleward shift of between 0.7 and 2 degrees in latitude of the genesis region of tropical cyclones, and of 3 degrees in the decay location of cyclones on the east coast.[35] Clearly, any increase in the magnitude and poleward extent of tropical cyclones will make shorelines more susceptible to modification by waves and storm surges. This could pose a large risk to cities and communities covered by planning guidelines and building codes which do not require consideration of cyclone risk.

2.3.3 Storm surge and wind

Storm surges are temporary increases in coastal sea levels caused by falling atmospheric pressure and severe winds during storms. The magnitude of a storm surge is determined not only by the size of the pressure fall and the wind speed, but also by the characteristics of the coast. For example, wide and shallow continental shelves (such as across northern Australia and parts of the southern mainland coastline) lead to larger storm surges than the narrow continental shelf off New South Wales.

Extreme winds are more common in the coastal zone than inland because of damaging storm systems coming from seawards. The smoothness of the sea compared to the land means that average wind speeds are higher on the coast. Wind uplift in areas of even modest topography will also increase the intensity of convective systems.

There have been only a few studies of projected changes in wind using climate models, but a number of ‘downscaling’ studies suggest that extreme winds associated with tropical cyclones and mid-latitude lows

Photo credit: Newspix/Bruce Long

Box 2.3 Cyclonic and non-cyclonic wind intensities

A preliminary study on cyclonic and non-cyclonic wind estimated potential changes in wind hazard associated with climate change. For cyclonic winds, the north west coast around Port Hedland, the northern part of Northern Territory, and the north east coast between Cairns and Townsville are the most sensitive regions to changes in intensity and frequency of cyclonic winds (Figure 2.12). For non-cyclonic winds the differences become notable in non-cyclonic dominated regions, but particularly in Perth, Brisbane and Sydney (Figure 2.13).

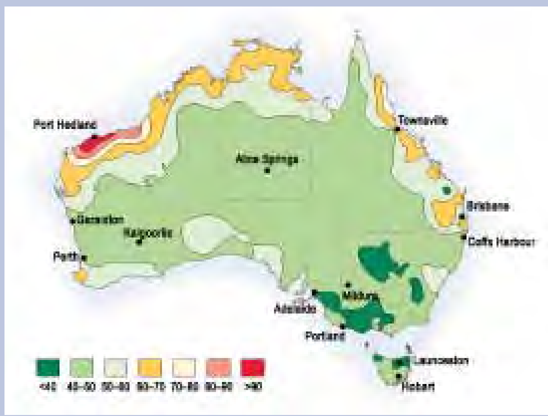


Figure 2.12 Cyclonic wind gust speeds under climate conditions of +20% intensity & +50% frequency for the 500 year return period.

Figure 2.13 The 1000 year return period hazard map for 90th percentile mean wind speed percentage changes.

Source: Wang and Wang 2009[36]

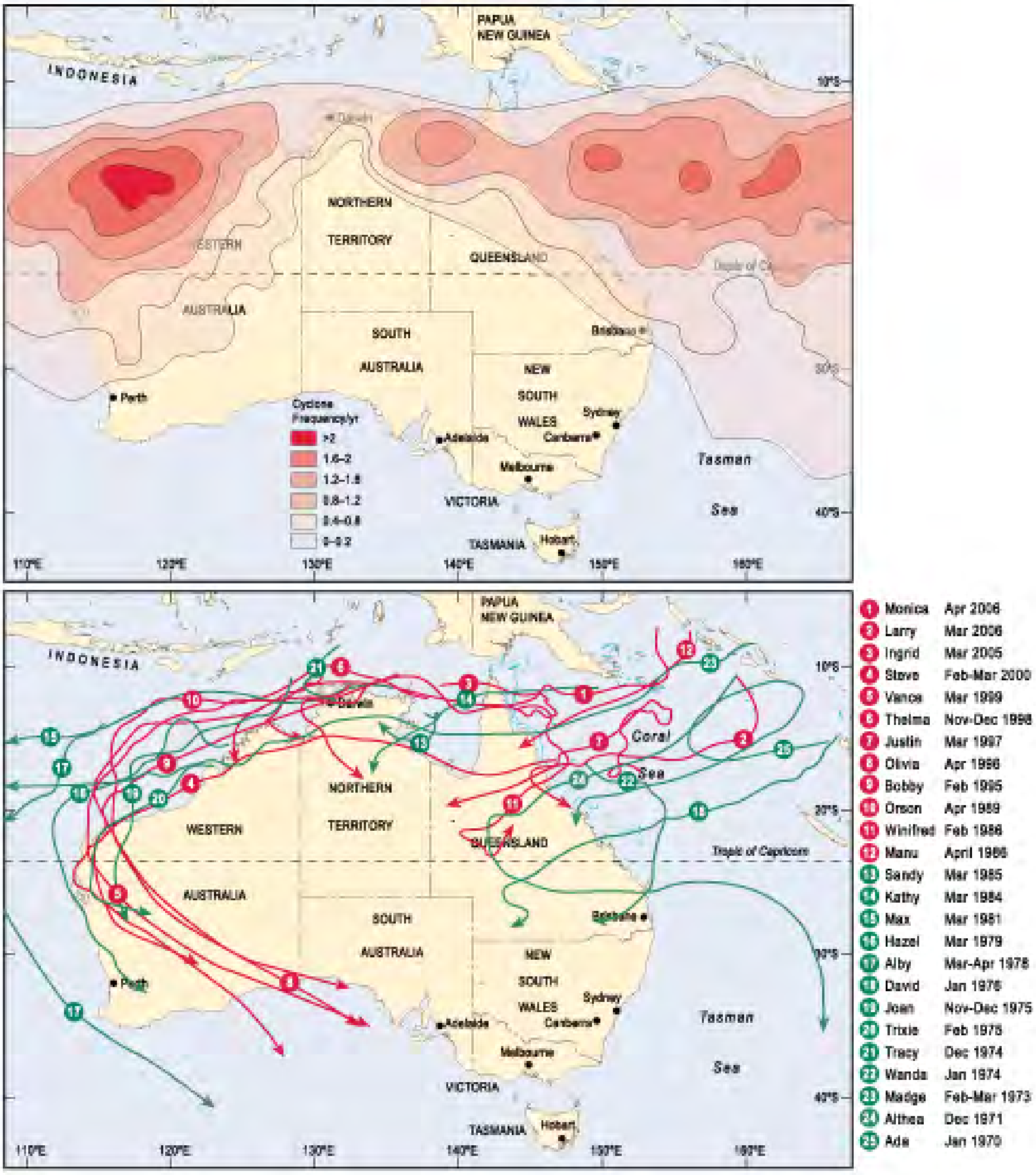


Figure 2.14 Location and frequency of summer tropical cyclone formation across northern Australia, and the trajectory of some of the more damaging tropical cyclones since 1970.
Source: Short and Woodroffe 2009[37]

may increase. Warmer temperatures may also make small-scale convective systems in coastal regions more active, producing micro-bursts of locally high winds and intense rainfall. A southern extension of the warm East Australian Current could also occur with climate change.[38] This could possibly drive an intensification of east coast lows and extreme wave conditions, such as happened in 1950, 1967 and 1974.

Box 2.3 shows that the densely populated regions of Brisbane and Sydney could face increased impact from wind as a result of climate change.

The effect of climate change on storm surge has been investigated in a number of studies around Australia. In north Queensland, an increase in the intensity of tropical cyclones increased the 1-in-100 year storm surge by around 0.3 metres.[39]

An example of detailed storm surge modelling for the south coast of eastern Australia is shown in Figure 2.15. Storm tide includes a storm surge component and a tidal component.

As Figure 2.15 shows, storm tide height can increase significantly with climate change (bottom panel) compared to current climate (second panel). Changes in wind speed have a much smaller effect on storm tide height than sea-level rise (10–20 centimetre and 82 centimetre increases in sea level respectively, at 2100), although there is greater uncertainty about how winds will be affected by climate change.

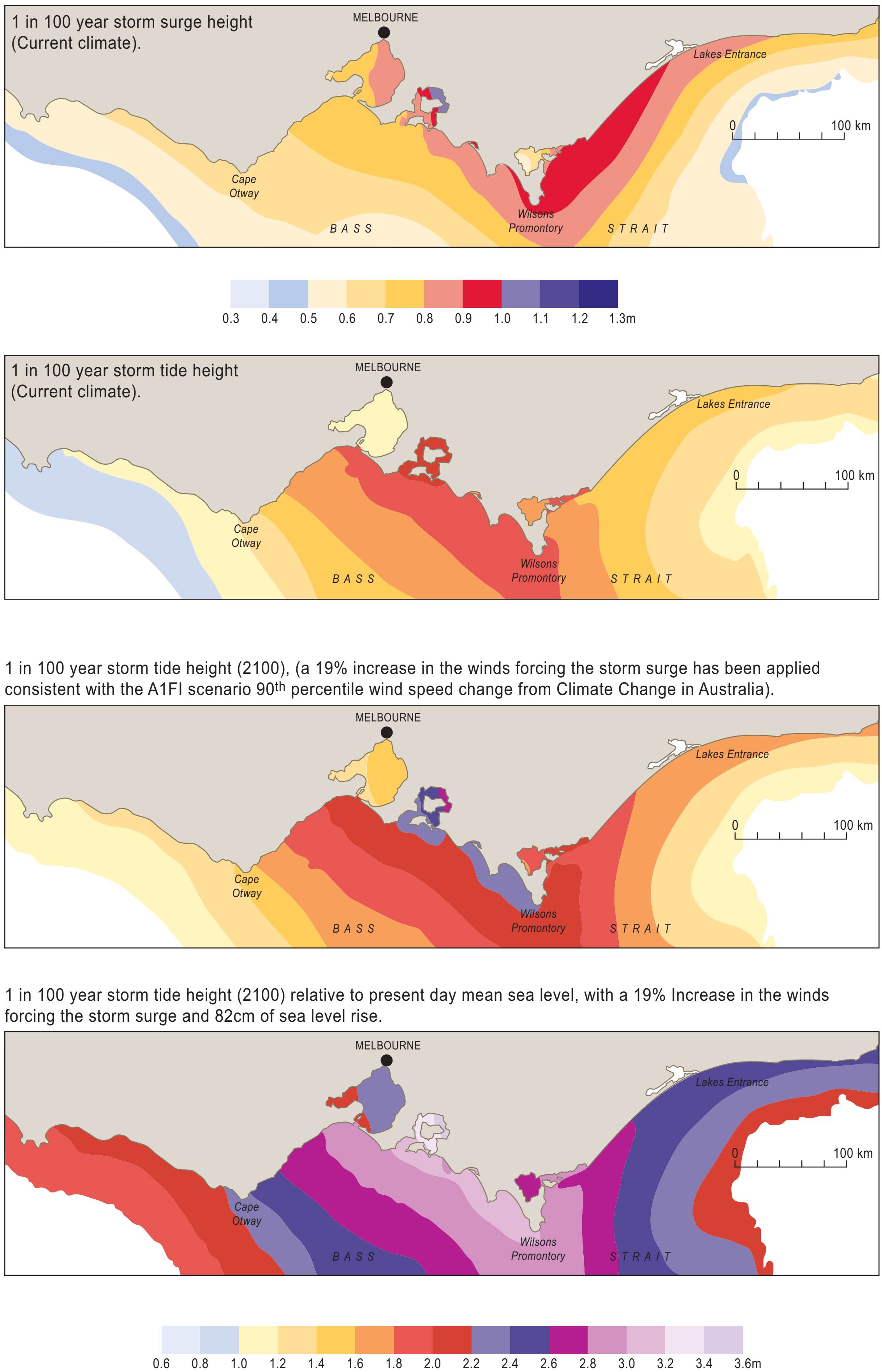


Figure 2.15 Current and projected 1-in-100 year storm surge and tide heights along the Victorian coast (metres).
Source: Top figure McInnes et al. 2009a[40]; and lower 3 figures McInnes et al. 2009b[41]

2.3.4 Riverine flooding

Riverine and/or flash flooding can exacerbate coastal inundation and sedimentation in river deltas and estuaries. Where outflow is restricted, riverine floodwaters can back up behind coastal surges, increasing the height and duration of the flood and the impact on those specific areas. Most river mouths are settled because they supply fresh water and natural harbours.

Although much of Australia is expected to dry because of climate change, increases in extreme rainfall are still expected in many regions. The most extreme events could increase in magnitude even where mean rainfall decreases. Increases in the frequency and magnitude of extreme rainfall can also be expected where seasonal rainfall increases (most likely along the east coast and in northern Australia). Seasonality of rainfall is also important: annual mean rainfall may decrease, but seasonal increases could drive up extremes in a given season.

Photo credit: Newspix/Patrick Hamilton

Photo credit: Newspix/John Grainger

2.4 Inundation and erosion risk

The combination of rising sea levels and changes in extreme events gives rise to two basic risks on the coasts: inundation and coastal erosion. The severity of the risks in a particular location is affected by a range of factors related to climate, geomorphology and the way low-lying areas have been modified by construction or drainage.

2.4.1 Inundation risk

Inundation risk is best expressed as the likelihood of exceeding a given level of tide, surge and flood height over a particular time horizon. Inundation events vary in frequency and magnitude. Frequency is measured as average recurrence intervals of events. For example, a 1-in-100 year storm tide is the storm tide height that is expected to be exceeded on average once every 100 years. Magnitude refers to a given level of tide, surge and flood height. The less frequent the event generally the larger in size it is.

Coastal risks have traditionally been assessed with an assumption that mean sea level will remain constant. By combining hazards over a given planning horizon, the level of risk to any existing or proposed asset can be estimated (if the relevant data are available). Under current conditions, if the climate and location are well enough described coastal risks can be analysed to inform zoning and planning approvals. Additionally, when setting a benchmark for planning purposes, a certain amount of 'headroom' is commonly allowed for error or for an unexpectedly large event.

A changing sea level means that the baseline upon which current inundation risk is being calculated is moving. For example, in Figure 2.16 the average recurrence interval for sea-level extremes at Fremantle

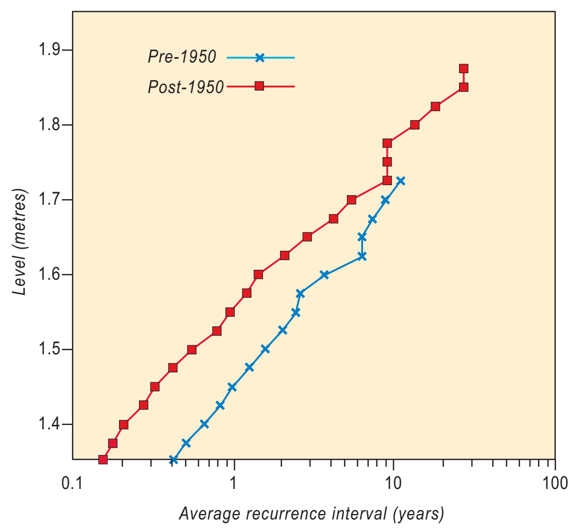


Figure 2.16 Changes in the average recurrence intervals of extreme sea levels, Fremantle, 1897–2004.
Source: Church et al. 2006[42]

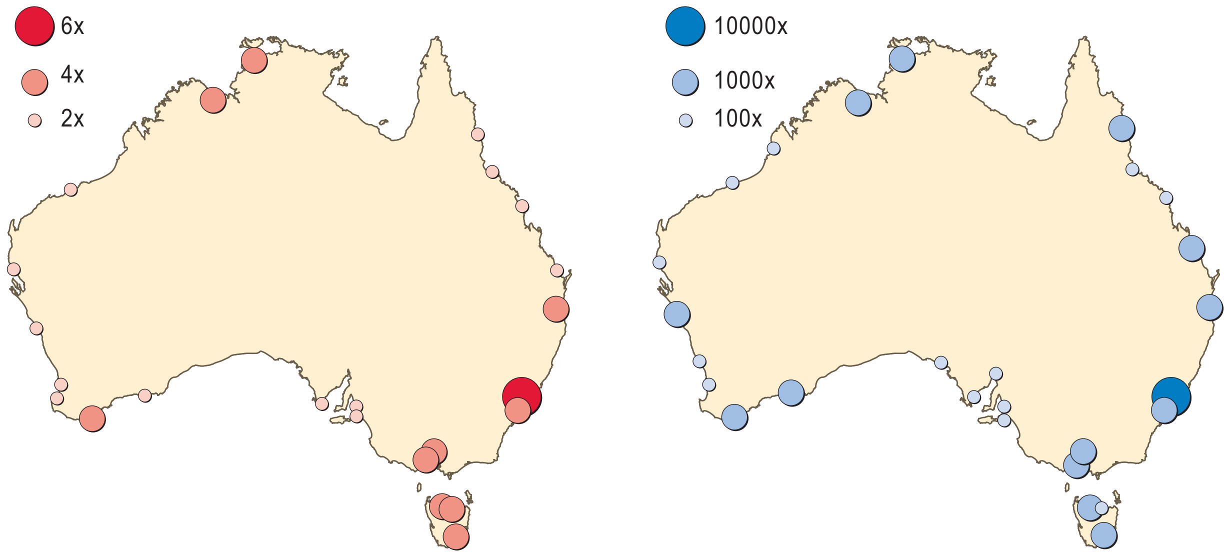


Figure 2.17 Estimated increases in the frequency of high sea-level events (indicated by the diameters of the circles), caused by sea-level rises of 0.1 metres (left) and 0.5 metres (right) showing the increasing frequency of events for rising sea levels is not linear.
Source: ACE CRC 2008[43]

shifted markedly after 1950. The post 1950 curve has moved upwards by about 0.1 metres (representing the sea-level rise between the two sets of data). On annual and decadal timescales, the frequency of extremes increased by a factor of about three. The problem of planning with a moving baseline becomes more difficult when considering longer planning horizons and accelerating sea-level rise.

By increasing mean sea level, climate change will increase the frequency of extreme sea level events. Figure 2.17 shows estimated increases in the frequency of high sea level events around Australia (expressed as multiplying factors) for sea-level rises of 0.1 metres and 0.5 metres. The factors are calculated by adding sea-level rise to current variability, and show that significant increases are possible. If changes in storm intensity driven by atmospheric changes occur, even higher values are possible.

With a mid-range sea-level rise of 0.5 metres in the 21st century, events that now happen every 10 years would happen about every 10 days in 2100. An even larger increase in the frequency of extremes would occur around Sydney, with smaller increases around Adelaide and along parts of the Western Australian coast.

A common strategy is to assess the risk of changing inundation events under sea-level rise projections. Figure 2.18 shows a return period curve for simulated storm tide events at Stony Point, Victoria, at 2030, 2070 and 2100.

For Stony Point, the 1-in-100 year storm-tide height in 2070 (yellow dashed line, Figure 2.18) is around 0.7 metres higher than the control value. Of that increase, around 75 to 80 per cent is due to sea-level rise, while the remainder is due to wind speed increase.[44] The frequency of extreme events also increases in the scenarios shown: the control 1-in-100 year event is exceeded on average once every 30 years in 2030 and once every 5 years in 2070.

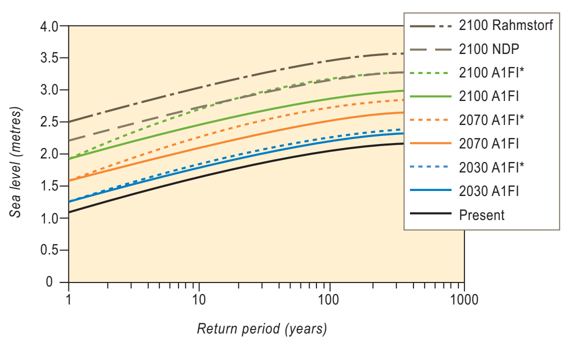


Figure 2.18 Storm-tide return-period curves for Stony Point under the high climate change scenarios for 2030, 2070 and 2100. The A1FI scenarios are from AR4, and those with an asterisk include an allowance for increasing wind-speed. The NDP scenario is based on the upper sea-level rise developed for the Netherlands Delta Committee, Rahmstorf is the upper estimate from Rahmstorf (2007) also see Figure 2.10.
Source: adapted from McInnes et al. 2009 and personal communication K McInnes[45]

2.4.2 Erosion risk

Australia's coastline has been remarkably stable over the historical period, given that sea levels have risen by 17 centimetres over that time. Generally in Australia, beaches appear not to be receding on a large scale, except in some localised places where natural recession is occurring, such as on the 90 Mile Beach in Victoria. In many places where vegetation removal had made dunes unstable, revegetation and better coastal management have reversed erosive processes. On Fraser Island, revegetation of shifting sands has occurred naturally since the early 1980s in a period dominated by El Niño conditions.[46] There are also some erosion hot spots that are the result of localised hard engineering structures or when development has occurred on the foredunes, which prevents sediment movement along the shoreline or displaces sediment from the lower shore face.

Coasts will tend to erode (or accrete) depending on the combined effect of four factors:

- change in mean sea level
- changes in the frequency and magnitude of transient storm erosion events
- extent of supply and loss of sediments from nearby sources and sinks
- realignment of shorelines due to changes in wave direction.

Under equilibrium conditions, the shape of the shore face is governed by a balance between onshore and offshore transport of sediment by surface waves. The shore profile is generally related to a given level of wave activity, inherited topography and sediment grain size.

If sea-level rises (assuming no change in the wave climate and sediment supplies), the balance between onshore and offshore sediment transport will change until the shoreline moves upward and encroaches landward. The wave climate may also change, affecting the movement of coastal sediment. This will modify the shore profile, forcing changes from the upper limit of sediment movement at high water level all the way to the limit of sediment movement offshore.

Over recent decades, many Australian beaches have continued to accrete because sediment supply has been sufficient. Adequate sand supply from the lower shore face is typical of most shores with concave profiles, enabling them to keep up with recent sea-level rise.

An important threshold of change is when accreting or stable shorelines begin to recede as a result of sea-level rise and larger surge events; the erosive capacity of accelerated sea-level rise and the increasing frequency of high water level events will at some point outstrip the capacity of natural processes to replenish beaches. This is a key threshold for coastal management.

It is likely that the change from stable to receding beaches may first become apparent on narrow beaches exposed to low to medium wave energy. The persistent erosion of beaches of Redcliffe near Brisbane for example is consistent with the present day increase in sea level. Such a change may also result from a decrease in sediment supply.[47]

Local disturbances and changing wave conditions have been the main cause of detectable, systematic coastal erosion to date. However, it is expected that sea-level rise and changes in storms will begin to dominate coastal processes over the next few decades, particularly if the rate of sea-level change continues at the upper range of projections. Current erosion hotspots would be expected to increase in size and magnitude and new localised areas will emerge.

The most vulnerable coasts are those made up of unconsolidated sediments, such as beaches, dunes and sand cliffs on the open coast of leaky embayments and on the shores of coastal lakes and lagoons. Most hard coasts will continue to erode at about the same rate as current sea levels, but soft sedimentary and weathered cliffs, especially those formed in calcarenite, may erode more quickly as more of the coastal face is exposed to wave action.

Coastal recession due to sea-level rise will also be affected by systematic patterns of seabed erosion and sedimentation. These geomorphic effects can be expected in all shoreline environments, including wave-dominated and protected oceanic settings, as well as in estuaries, coastal lakes and wetlands. However, further work is needed to identify where those impacts may occur and how they will play out.

Photo credit: Victorian Government Department of Sustainability and Environment

Potential rates of recession due to sea-level rise are highly uncertain. The rate of shoreline retreat is a function of the rate of sea-level rise, the shoreface profile, the height of the dune or friable cliff, the shoreward or alongshore sediment flux (if any) and any local sediment source, such as a river or estuary.[48] In the absence of full information on these factors the Bruun Rule may be used to provide a generalised indication of the amount of recession accompanying sea-level rise.

The Bruun Rule is expressed as a ratio between a rise in sea level and the extent of recession (erosion) on a sandy shoreline with no cliff or platform. This ratio is expected to remain constant when sea level and shoreline are in equilibrium, and is in the range of 50–100 metre recession for every one metre rise in sea level. When localised factors are taken into consideration the range can be greater or smaller.

In Figure 2.19 the erosion potential for two New South Wales beaches are compared with an increased sea level of 0.28–0.79 metres by 2100. It highlights that beaches will respond individually depending on local sediment processes. The main influence at Manly Beach is sea-level rise and modelling suggests a 50 per cent probability of 50 metres of erosion at Manly Beach by 2100. Modelling for the Bundjalung Beach, which is on the New South Wales north coast, demonstrates the beach is sensitive to changes in alongshore sediment supply (loss), as well as sea-level rise, and has a 50 per cent probability of 150 metres of erosion by 2100. Simulation modelling such as was undertaken for Manly and Bundjalung, provides a more detailed projection of coastal erosion and highlights the relative contributions of various components of coastal recession. Wave direction, longshore transport and sea-level rise are clearly able to drive recession and have the potential to alter the coastline dramatically.

As noted in Section 2.3.1, there are still major knowledge gaps on the implications of future wave climates for coastal sediment budgets and erosion risk. Some swash-dominated beaches (those that receive their sediment from the lower shore face) may initially accrete rather than recede despite sea-level rise, although this becomes less likely with increased rates of rise. They are less vulnerable than beaches that depend on longshore transport of sand. While there has been little research to date, the deepening of estuaries with sea-level rise can increase their role as sinks for sands, reducing supply to adjacent beaches.

Over the very long-term, coastal recession in at-risk areas as a result of climate change could be considerable. Figure 2.20 illustrates potential recession for Lake Macquarie Beach in New South Wales out to 2300 and indicates a 50 per cent probability of potential erosion of more than 300 metres.

Box 2.4 Factors influencing shoreline recession

Embayment geometry and sediment budget dynamics are highlighted by simulation of the impacts of four factors influencing recession: mean-trend recession due to accelerated sea-level rise (note small probability of accretion); increased storm erosion demand; imbalance in the alongshore sand transport budget (Bundjalung only); and rock reefs and seawall (Manly only). Manly Beach represents a closed sediment beach whereas Bundjalung experiences alongshore sediment transport with potential loss or leakage from the beach. The modelling undertaken for the two beaches highlight the different rates of recession for sea-level rise alone, and when local processes are also considered.

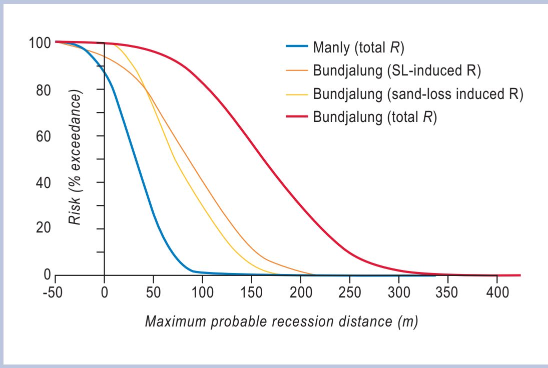


Figure 2.19 Maximum probable recession to 2100 for Manly Beach, Sydney and Bundjalung Beach on the New South Wales north coast between Iluka and Evans Head.
Source: P Cowell et al. 2006 and P Cowell personal communication[49]

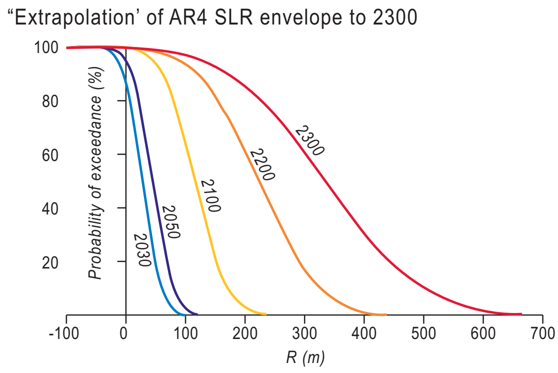


Figure 2.20 Potential long-term coastal recession in Lake Macquarie Beach, New South Wales.
Source: M Kinsela 2007 and P Cowell personal communication[50]

2.5 Changes in ocean waters

Both increasing temperature and the acidification of ocean waters will have profound effects on near coastal ecosystems, affecting the biota and potentially in the long-term, the generation of calcareous sediment supply by marine organisms.

The greater thermal mass of the oceans means that in general they will warm more slowly than the atmosphere. Areas of highest warming tend to be near the coast, especially in areas of poor circulation, and in the south Tasman Sea where the East Australian Current is projected to move further south.

About twenty five percent of the carbon dioxide emitted each year by human activities is absorbed by the ocean. Dissolved CO_2 increases the acidity by forming carbonic acid. This chemical process, which is driven by increasing levels of CO_2 in the oceans, reduces the availability of carbonate ions (CO_3^{2-}). Many marine organisms use the dissolved carbonate ion to build solid carbonate shells and skeletons. As carbonate ion concentrations decline with increasing atmospheric CO_2 (see Figure 2.21), the rate of formation of calcium carbonate in species like corals will decline.

The acidity of the oceans has already increased because of anthropogenic carbon dioxide (Figure 2.22). With continued emissions of carbon dioxide, and continued absorption by the oceans, acidification of the oceans' waters will also increase.

Ocean acidification can have serious ecological and economic consequences. Most research has focused on the reduced calcifying rates of organisms such as corals, which is a threat to ecosystems such as the Great Barrier Reef. Other impacts may arise through effects on the respiration of fish and the larval development of marine organisms and through changed solubility of nutrients and toxins. Recent research is also investigating the implications of ocean acidification for concrete structures in the coastal zone, such as wharves and piers. Further information on the impacts on marine ecosystems and infrastructure is in Chapter 4 and Chapter 5.

Changes in sea surface temperatures can also have large impacts on marine life. In the southern hemisphere, tropical and temperate species are likely to migrate southward, potentially changing the structure of marine and coastal ecosystems. Coral bleaching episodes will become more frequent, and there are risks to kelp forests off eastern Tasmania.

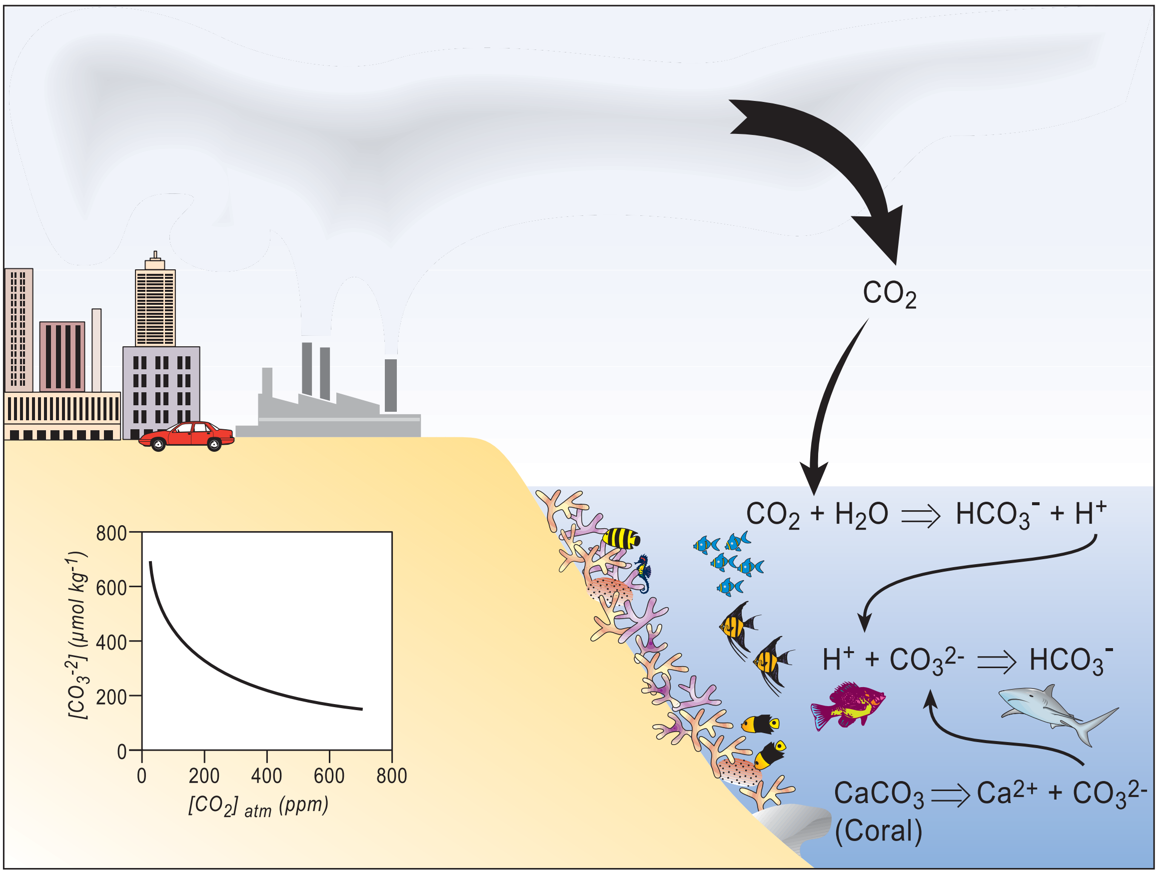


Figure 2.21 Chemical pathways showing the relationship between increasing atmospheric CO_2 and ocean acidification.
Source: Hoegh-Guldberg et al. 2007[51]

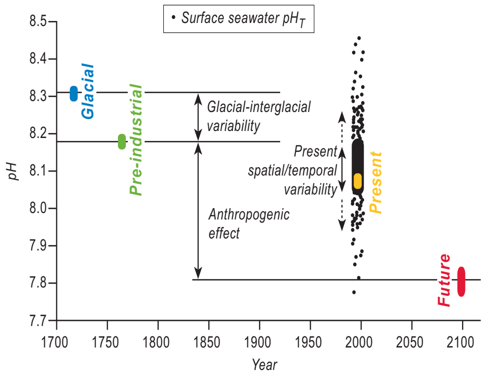


Figure 2.22 Observed and possible future levels of ocean acidity.
Source: W Steffen 2006[52]

Photo credit: © Commonwealth of Australia (GBRMPA)

Sea surface temperatures will rise more slowly than air temperatures, but possible changes over the course of 21st century are still substantial. CSIRO and the Bureau of Meteorology suggest, as a best estimate, warming of 0.3–0.6°C by 2030 for most Australian waters, with faster warming (0.6–0.9°C) in the southern Tasman Sea and off the north-west shelf of Western Australia. By the end of the century, sea surface temperatures could rise by as much as 2°C along the south coast and 2.5°C elsewhere (see Figure 2.23).

Marine and coastal ecosystems will also be affected by changes in ocean currents, but those changes are more difficult to project. However, most models suggest that the East Australian Current will strengthen, bringing warmer waters further south.

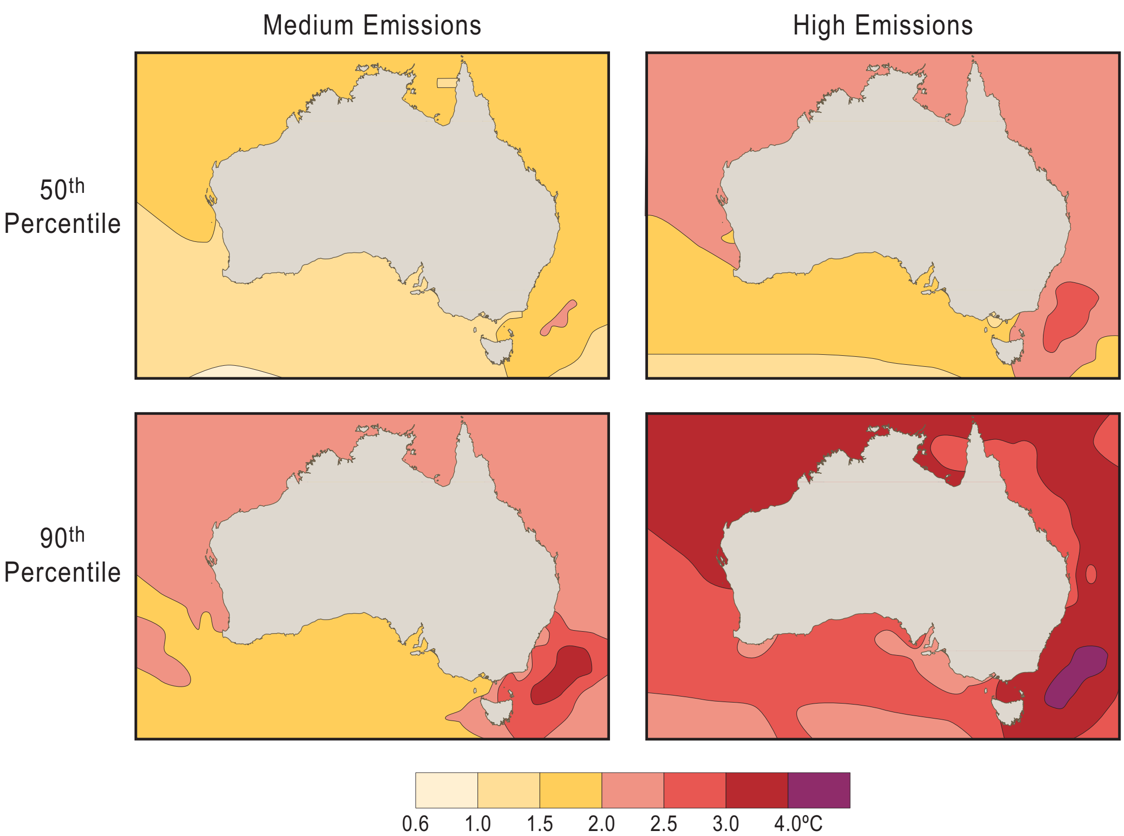


Figure 2.23 National sea surface temperature change projections for 2070.
Source: CSIRO and BOM 2007[53]

2

2.6 Conclusion

Recent science findings suggest that the climate system is changing faster and to a greater extent than previously thought in response to human-induced greenhouse gas emissions. These changes suggest that many parts of Australia's coastline could face considerable risks from inundation, erosion and changing conditions of coastal waters.

The most severe risks will be from coincident events of several hazards. For example, sea-level rise on top of an extreme storm tide and a severe riverine flood from the same weather event. In a highly urbanised area this combined series of events has the potential to cause large economic impacts. The breaching of a key coastal barrier during an extreme event, exposing coastal lakes or estuaries to increased wave and tidal energy could also have severe consequences. Climate change will drive changes in many of the processes associated with inundation or erosion of the coastline and will increase the frequency of individual high water level events. With increasing frequency the likelihood of events occurring simultaneously increases and what were once seen as rare and independent events will increasingly become more common.

Australia has a strong science capability to assess climate change risks. In particular, we have developed world-class climate change science expertise and made important contributions to global knowledge in such areas as sea-level rise and ocean dynamics. However, there are areas of relative weakness in our national science capability. One of these is in the interactions between geomorphology, wave climate and climate change, where little work has been done.

This national assessment of the risks to the coastal zone from climate change has also been constrained as a result of major gaps in knowledge, including:

- the likely future contribution of icesheet dynamics to sea-level rise, which will ultimately determine the magnitude of the adaptation challenge
- the regional distribution of sea-level rise
- the future frequency and magnitude of cyclones, including their relationship to the El Niño – Southern Oscillation and La Niña systems

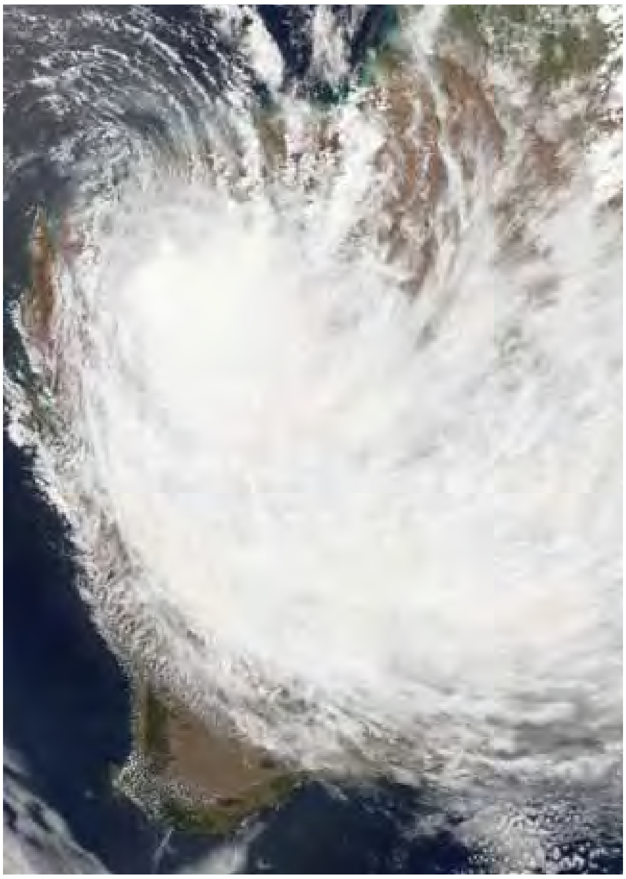


Photo credit: NASA/Wikimedia Commons

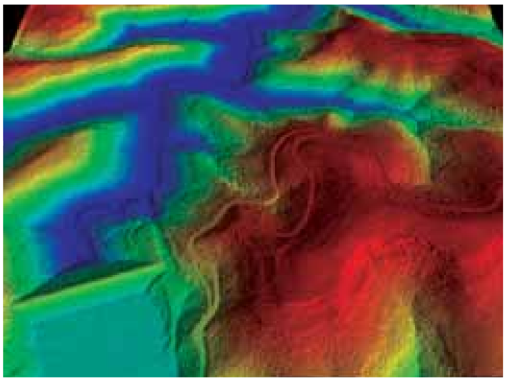
Tropical Cyclone Emma, 28 February 2008, Pilbara region, northwest Western Australia.

- the implications of climate change for onshore wave climate and the longshore transport of coastal sediments, which is critical to understanding the risk of coastal erosion
- where and when the thresholds of coastal erosion will be exceeded as a result of sea-level rise
- where other thresholds or tipping points to irreversible or wholesale change may exist.

The uncertainty in these priority areas of knowledge, which are important in assessing national risk, can be substantially reduced with targeted investment in research. More information on the role of research in a national approach to coastal adaptation is in Chapter 6.

3

CHAPTER



APPROACH TO THE FIRST PASS NATIONAL COASTAL RISK ASSESSMENT

Photo credit: AAMHatch

KEY FINDINGS

- This assessment is the first national assessment of the extent and magnitude of climate change risks to Australia's coastal zone.
- A significant investment in national capacity has underpinned the assessment – a consistent, detailed national coastal geomorphology map and a medium resolution digital elevation model covering the Australian coast are now available. Investment in high resolution elevation modelling is also occurring in many jurisdictions.
- A 'bucket fill' method was used to assess coastal inundation hazard. It combined sea-level rise of 1.1 metres, tidal range and storm surge (where available) with a medium resolution digital elevation model to identify locations likely to be flooded. Soft, erodible shorelines around the Australian coast were also identified.
- The number of existing residential buildings exposed to inundation risk was quantified using Geoscience Australia's National Exposure Information System (NEXIS) infrastructure database for each state, the Northern Territory and for key local government areas.
- Comparison with small areas where high resolution elevation data was available provided some verification of the method and indicated that the first pass outputs are generally robust. Further analysis using high resolution data will likely alter the estimated number of properties at risk.
- There are a number of limitations to the approach used which influenced the results. Storm tide modelling for a 1-in-100 year event was used where available (Victoria, Tasmania and New South Wales), a lack of modelled storm tide datasets for the other states has meant that modelled high water level was used (Queensland, Western Australia, South Australia, and Northern Territory). Similarly there is a current lack of national capacity to effectively assess climate change impacts on estuaries, where a large proportion of residential communities are clustered; and from the combined risk of catchment flooding and storm surge.
- Spatial and quantitative analysis of assets at risk has also been limited to residential buildings in this first pass assessment – further work is needed to assess the impacts on infrastructure and other assets.

3.1 Assessment objectives

While the coastal zone has been consistently identified as highly vulnerable to the impacts of climate change, assessments of risk to date have generally been at local or regional scales. With a growing focus on the need for adaptation action and a call for governments to provide further guidance to assist communities manage likely impacts, there is a need for a clearer picture of the nature and geographic spread of risks from climate change.

The National Climate Change Adaptation Framework endorsed by the Council of Australian Governments (COAG) in 2007 identified the need for a first pass national coastal vulnerability assessment.

The Framework notes that the absence of a national elevation model and nationally consistent mapping in the coastal zone has limited the analysis of coastal vulnerability to date. The need for a national assessment of risks from climate change to the coastal zone was reinforced by the COAG Working Group on Climate Change and Water in 2008.

The objectives of the National Coastal Risk Assessment are to:

- Provide an initial assessment of the climate change implications for Australia's coastal regions, with a particular focus on coastal settlements and ecosystems
- Identify areas of high risk to climate change impacts

- Identify key barriers or impediments to developing effective coastal adaptation responses
- Help identify national priorities for adaptation to reduce climate change risk in the coastal zone.

This assessment was initiated under the auspices of the Natural Resource Management Ministerial Council.

The focus of this chapter is largely on the approach used to identify the national risk to residential properties from sea-level rise as a result of climate change. The results of this analysis are described in Chapter 5. Risks to coastal ecosystems and industries are covered in this national assessment, but are based on a review of recent literature.

3.2 Building national capability

At the commencement of the assessment the available data and tools were not of sufficient resolution to underpin the national identification of areas at risk around the coastline. The Australian Government undertook a review of the methods and knowledge available for a national coastal risk assessment including identification of key gaps.[1] Consideration was also given to whether international studies or projects in other countries could inform an Australian risk assessment.[2]

Two key requirements emerged from this review and were supported by expert advice – the need for higher resolution national coastal elevation data and for more consistent geomorphology data. In response to this review the Australian Government has invested in building national datasets and capability, and the capacity to undertake a national risk assessment has also been enhanced. The following parts of this section describe these capabilities.

3.2.1 Digital elevation data and modelling

An accurate picture of coastal elevation is critical to assessing risk from inundation as water will obviously move to lower lying areas first where accessible.

The creation of a national digital elevation model (DEM) was the highest priority task identified by the Australian Government for the national risk assessment. DEMs have become widely used in the last 20 years for catchment and natural resource management and risk analysis. They provide a three dimensional model of the ground surface topography and can be constructed using a range of remote sensing technologies such as photogrammetry, airborne radar and satellite imagery (Figure 3.1).

Prior to commencing this assessment the best DEM available with national coverage was that derived from the 3 second arc resolution Shuttle Radar Topography Mission (SRTM), which had a horizontal resolution of approximately 90 metres. The SRTM DEM was used by the insurance industry in an assessment of addresses at risk from climate change which was briefly reported in the IPCC's Fourth Assessment Report.[3]

Elevation data and modelling options were assessed by the Spatial Information Council and the Cooperative Research Centre for Spatial Information (CRCSI). The Australian Government made a decision to invest in a mid resolution DEM covering the entire coast and derived from *High Resolution Stereoscopic Reference3D* (SPOT) satellite imagery. The decision was based on the better resolution available through SPOT data (with a one second arc, 9 SPOT grid cells fit within one SRTM cell), and the fact that the data had been tried and tested and was available for the whole continent (except Cape York).

The SPOT DEM has a horizontal resolution of approximately 30 metres and a vertical height resolution of 1 metre (that is, the elevation of the surface is in steps of 1 metre intervals). It has absolute elevation accuracy (90 per cent confidence) of around 10 metres and a standard deviation value of approximately 6 metres. However, it should be noted that errors in the SPOT DEM are generally not geographically distributed on a random basis (i.e. single points in the data layer) but rather, errors will be distributed over an area in the DEM. This means that

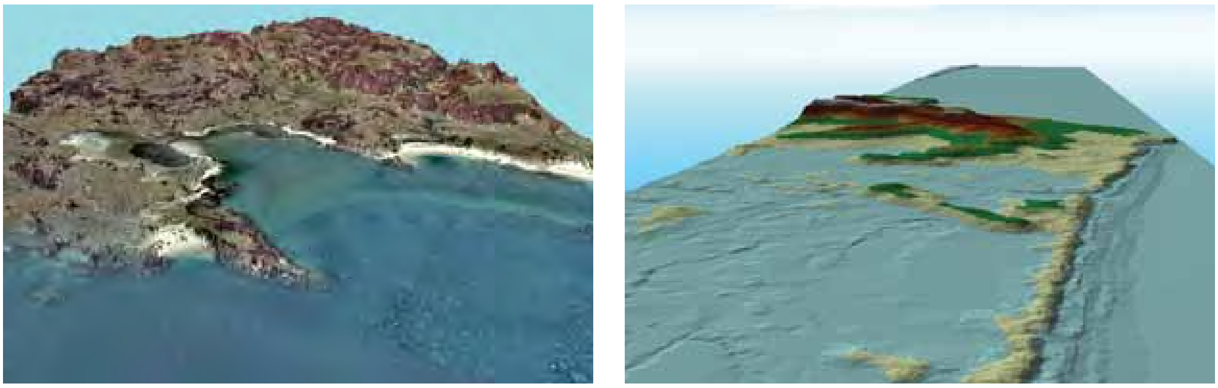


Figure 3.1 Image examples of digital elevation models for the Burrup Peninsula, Western Australia (left); and a coral reef and island of the Queensland coast (right).
Source: Fugro Spatial (left) and AAMHatch (right).

the general shape of the land tends to be adequately represented, even if the heights are not exactly correct, and relative patterns of inundation are able to be obtained. For a whole of continent first pass national analysis the SPOT data was assessed as fit-for-purpose.

The Australian Government is also interested in ensuring that access arrangements are put in place for the DEM data that maximise its public good use. The majority of DEMs built in Australia over the past 15 years have been built by the private sector, often with government funding, but using contractor models. This has resulted in a fragmented and uncoordinated network of DEMs with varying accuracies and specifications. To help constrain this problem the Spatial Information Council is coordinating a National Elevation Data Framework to:

- improve the quality of elevation data and derived products, such as DEMs
- optimise investment in existing and future data collections
- provide access to a wide range of digital elevation data and derived products to those who need them.

The Spatial Information Council organised a national workshop at the Australian Academy of Science in March 2008 to facilitate the development of the science case, business plan and governance approach for the National Elevation Data Framework. The workshop was preceded by nation-wide consultation with the geospatial community and a data audit and user-needs analysis.

State governments and the Australian Government have also invested in high resolution elevation data for key urban centres. The acquisition of high resolution elevation data (around 10–15 centimetres vertical accuracy) will pilot the quality assurance process of the National Elevation Data Framework. Existing, high resolution data will be accessed in the first instance, with new LiDAR (Light Detection and Ranging) data expected to be acquired in a few small areas to fill gaps. The Australian Government has committed to providing access to the generated DEMs for public good purposes and work is progressing on developing the required infrastructure to deliver online access to the DEMs.

3.2.2 Coastal geomorphology

One of the expected impacts from climate change is accelerated coastal erosion due to rising sea levels, although rates and location of erosion are highly dependent on several factors including:

- the inherent susceptibility of differing coastal landform types
- regional variations in the processes driving erosion or instability (for example, sea-level rise and wave climate)
- local factors such as topography and sediment budgets.

Figure 3.2 Illustration of the coastal attributes captured in the National Coastal Geomorphology Mapping tool.
Source: Sharples et al. 2009[4]

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The inherent susceptibility of landform types is of first-order importance in assessing coastal vulnerability. The creation of a detailed map of coastal landform types – the coastal geomorphology, was essential to provide an understanding of the potential extent of risk from erosion or other types of instability, for example, cliff slumping. Further work on understanding regional variations and local factors would provide significantly improved estimates of the magnitude of risk of unstable shorelines.

Prior to this national assessment the most detailed nationally consistent map available was an early geographic information system (GIS) map produced by CSIRO in the 1980s. This map was constructed by dividing the coast into 10 kilometre segments, sampling the landform types within each segment and recording the proportion of various types in each segment. While useful for broad national purposes, the resolution of this earlier mapping was not considered adequate for a national coastal risk assessment.

Following an expert meeting in early 2007 it was decided that the coastal geomorphic and vulnerability mapping approach that had been undertaken for Tasmania would be used as the basis for compiling a map for the entire Australian coastline. This approach uses a line map format to rapidly compile geomorphic data and then through analysis, identify potentially unstable shores.[5] Such an approach was considered to be the only method capable of being prepared for the whole country in the timeframe.

The development of a national geomorphology map of continental Australia and most adjacent islands (excluding the Great Barrier Reef) was a major step forward in building national capability. The mapping captures the enormous geodiversity of Australian coastal landforms within a simple, nationally-consistent geomorphic classification (see Figure 3.2). As a 'geomorphic' map, the topography of the coast (the platform, elevation and shape of the coastal landforms) is captured as simple categories, and it also indicates what the differing coastal landforms are made of – varying rock types, coral, sand, mud, laterite, boulders, and beachrock.

The data for the geomorphology mapping was derived from over 200 pre-existing maps and datasets, many compiled at different times, at different scales for different purposes, across different jurisdictions and using different classification systems. Landform data was obtained from many sources and reclassified into a single nationally-consistent format.
The geomorphology mapping represents the first dataset to provide coastal landform information in a consistent format for the entire national coast, and at a level of detail that allows features down to 50 metres or less in size (such as small pocket beaches or short cliff-lines) to be individually distinguished (Figure 3.3).

Figure 3.3 Example of extracting a particular type of landform (seacliffs) around the Australian coast viewed at a national scale, from the National Coastal Geomorphology Mapping tool.
Source: Sharples et al. 2009[6]

The mapping captures the geomorphology information in a single GIS polyline representing the shore (usually a nominal mean high water mark line). The line is split into segments wherever the coastal landform types change and each distinctive segment is assigned with multiple attribute fields (data records) that describe the landform types of that segment of the coast. Landform attributes of the coastal zone are captured both inland and offshore up to 500 metres from the high water level.

The example in Figure 3.5 shows simplified examples of four of the 'basic' geomorphic attribute fields, each displayed as individual line maps. The fifth line map in the series shows how coastal types, having specified combinations of these multiple attributes, can be represented in a single line. In this example coastal landform stability classes are displayed.

The National Coastal Geomorphology mapping has been peer reviewed in a national workshop at the University of Tasmania and is available on the OzCoasts website (www.ozcoasts.org.au) where it can be queried and interrogated through the web browser.

While the mapping was prepared from data sources with differing scales and resolutions, it is possible to extract information on the lengths of coastline in each state and territory which are potentially unstable (refer to Box 3.2).

Box 3.1 Why use a line map approach?

The dataset of coastal geomorphology was compiled in a line format because of the ease with which each of the different landform attribute fields can be displayed or analysed, individually or as specific combinations of attributes. A line map is able to segment the coast at every point where any of the landform attributes change, as illustrated in Figure 3.4.

Because of the essentially linear nature of coasts a line map is a useful and efficient map format for many coast-related purposes, but there are some applications for which polygon or topographic mapping is required. For example, while the coastal geomorphology mapping could indicate potentially flood-prone coastal segments (using the Backshore profile attribute), a contour map or DEM is necessary to map the actual areas likely to be inundated.

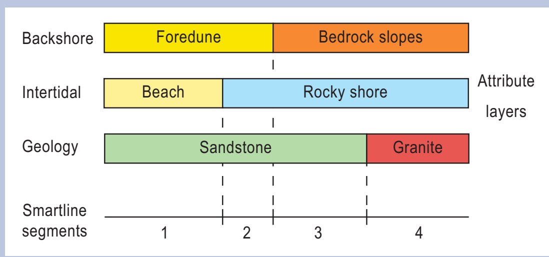

Figure 3.4 The 'line mapping' representing the coastline, is segmented wherever any one or more coastal attributes change, allowing the full alongshore extent of all attributes to be recorded. Source: Sharples et al. 2009[7]

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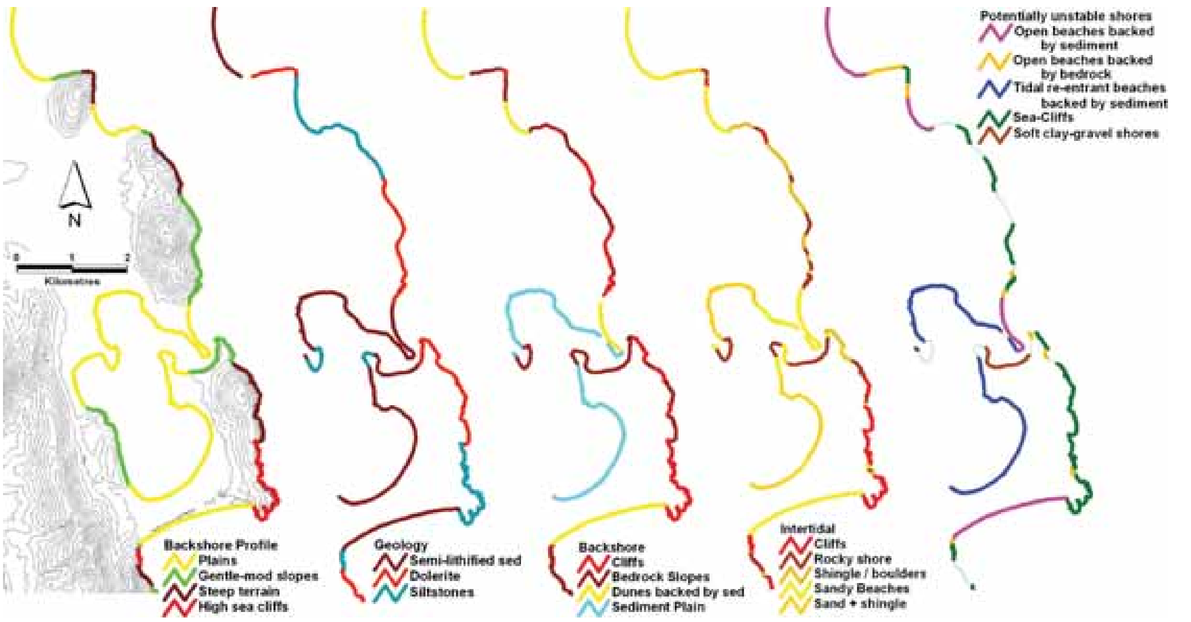

Figure 3.5 Simplified examples of information provided by four of the basic geomorphic attribute fields contained in the geomorphology line map (LH four line maps), and an example of a coastal landform stability class that has been derived by analysing these geomorphic attributes (RH line map). Source: Sharples et al. 2009[8]

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Box 3.2 Coastline lengths for coastal stability classes

The lengths of the Australian coastline occupied by each major coastal landform stability class have been measured from the National Coastal Geomorphology Mapping tool (Smartline). Table 3.1 identifies the length of each landform stability type, essentially for open coasts but including a few major coastal re-entrants (estuaries or bays) as noted in the Table 3.1.

Approximately 63 per cent of the Australian coast is classed as either sandy or muddy. The remainder is composed of 'soft' or 'hard' rock shores. Sandy and muddy shores are to a large degree quite mobile especially where backed by soft sediments rather than bedrock (47 per cent). This is a significant statistic as it encompasses shores which are unimpeded by human structures and are quite free to move under conditions of climate change and those in more built-up areas where migration of 'soft' shorelines generate planning and management issues for local and regional communities. Sandy shores make up 30 percentage points of the 47 per cent of 'free-moving' unimpeded shores while 17 percentage points are muddy shores. Given the methodology used, muddy shores are potentially underestimated in Queensland where sandy shores are likely to be overestimated.

The high proportion of sandy shores not backed by bedrock in New South Wales (37 per cent) is significant as this is the most urbanised state along its entire length. However, sandy sediment backed beaches also occur over long stretches in other states such as Queensland, South Australia and Victoria.

Territory shores are distinctly different to the other states in that while hard rock and sandy shores are present, the tide-dominated Northern Territory coasts are strongly characterised by significant stretches of highly mobile muddy shores (especially tidal mudflats), and also by erodible lateritic soft rock shores.

Roughly half of the Western Australian coast is rocky. This is mainly in the Kimberley and south coast regions, with the remainder of the coast being dominantly sandy with significant muddy tidal flats north of Exmouth. The proportion of rocky coast that is calcarenite in Western Australia was not able to be identified as it was not included in the source data used to compile the National Coastal Geomorphology mapping (see Notes on Table).

Considerable sections of most states have hard rock shores although the proportion is less in Western Australia and the Northern Territory. This general class includes both sloping (resilient) or cliffed (potentially unstable) rocky shores. A high proportion of soft rock shores occur in the Northern Territory and Victoria. As noted the proportion for Western Australia may be an underestimate of both hard and soft rock classes.

Source: Sharples 2009[9]

Notes on Table:

Coastal lengths have been measured on the Smartline map, which has been compiled from data of varying base map scales. The lengths have been normalised to an equivalent 1:100,000 scale to provide nationally-comparable coastal lengths for each stability class. The total length for each state and Northern Territory, and for Australia, includes measurements of mainland and major island lengths. The measured length using Smartline of 59,311 kilometres compares quite closely with 59,736 kilometres derived from the Geoscience Australia GEODATA coast 100 kilometres 2004 data base. That database shows mainland coast length of 35,877 kilometres and island length of 23,859 kilometres.

Coastline lengths and percentages summed over all stability classes may add up to over 100 per cent of the total coastal length for some states because some stability classes overlap. For example, 'sandy shores backed by bedrock' and 'hard rocky cliffs' may occur on the same coastal segments, as may 'sandy shores' and 'muddy tidal flats'. While total distances and percentages for Australia sum to less than 100 per cent because 'unclassified stability classes' are not included, and these are significant in a few regions including northern Western Australia, as well as in the numerous small islets with unclassified shores that are included in coastal length distance in each state.

'Hard Rock' shores have been combined with 'Undifferentiated hardness Rock' shores. The latter are rocky shores which were not assigned to a hardness category in the Smartline classification, either because it was unclear how hard the rock type is, or because the rock type making up the rocky shore is not recorded in the source data. Although some of these are likely to be soft rock types, for the purposes of this breakdown they are classed together with hard rock types.

A high proportion (27 per cent or 5,616 kilometres at 1:100,000 scale) of Western Australian shores are not classified into a coastal landform stability class, owing to gaps in the source data. These gaps are most extensive in the northern half of Western Australia, especially the Kimberley region.

Miscellaneous minor coastal stability types and unclassified shores are not included in these stability class figures, but are included in the total coast lengths.

Table 3.1 Coastal Lengths for Selected Coastal Landform Stability Classes.

OPEN COAST LENGTHS – including islands; km, at 100,000 scale)	Embayments, estuaries and islands included in analysis	Total open coast length	Sandy shores undifferentiated (undiff)	Sandy shores backed by soft sediment	Sandy shores backed by bedrock	Muddy & undiff sed. shores (commonly tidal flats) undiff	Muddy & undiff sed. shores (commonly tidal flats) backed by soft sediments	Muddy & undiff sed. shores (commonly tidal flats) backed by bedrock	Soft rock shores – undiff and low profile	Soft rock shores – mod. to steeply sloping	Soft rock shores – Very steep to cliffed	Hard (& undiff hardness) rock shores – undiff and gently to moderately sloping	Hard (& undiff hardness) rock shores – cliffed
Vic	Port Phillip Bay, Western Port, Corner Inlet	**2,395**	**261** (11%)	**689** (29%)	**487** (20%)	**193** (8%)	**497** (21%)	**106** (4%)	**101** (4%)	**27** (1%)	**147** (6%)	**78** (3%)	**510**
NSW	Botany Bay, Sydney Harbour (to harbour bridge), Hawkesbury estuary (to 18km), Port Stephens (to 22km), Jervis Bay	**2,109**	**94** (4%)	**695** (33%)	**161** (8%)	**16** (1%)	**22** (1%)	**11** (0.5%)	**5** (0.2%)	**7** (0.3%)	**0**	**533** (25%)	**166** (8%)
Qld	Western Side of Fraser Island, Southern end of Moreton Bay	**12,276**	**1,510** (12%)	**5,563** (45%)	**1,989** (16%)	**217** (2%)	**37** (0.3%)	**81** (0.7%)	**155** (1.3%)	**30** (0.2%)	**39**	**700** (6%)	**1,241** (10%)
NT		**11,147**	**170** (1.5%)	**869** (8%)	**2,022** (18%)	**624** (6%)	**3,419** (31%)	**781** (7%)	**1,681** (15%)	**186** (1.7%)	**41**	**382** (3%)	**315** (3%)
WA*	Albany Harbour, Major estuary mouths (only) in Kimberly – Bonaparte Gulf region	**20,513**	**2,154** (10.5%)	**1,780** (9%)	**1,383** (7%)	**2,263** (11%)	**1,932** (9%)	**1,261** (6%)	**26** (0.1%)	**53** (0.3%)	**29**	**1,815** (9%)	**3,990** (19%)
SA	Several moderate-size re-entrants on Eyre Peninsula, Kangaroo Island	**5,876**	**362** (6%)	**1,521** (26%)	**885** (15%)	**264** (4%)	**402** (7%)	**113** (2%)	**322** (5%)	**46** (1%)	**129**	**224** (4%)	**1,785** (30%)
Tas	Blackmans Bay (Forestier Peninsula), Pittwater, Lower Derwent estuary (only), Lower Huon estuary (only), Cloudy Lagoon, Macquarie Harbour (excludes Birches Inlet), as well as King, Flinders, Bruny, Maria and adjacent islands	**4,995**	**1,053**	**1,081** (22%)	**509** (10%)	**7** (0.1%)	**53** (1%)	**103** (2%)	**69** (1.4%)	**48** (1%)	**25**	**1,443** (29%)	**1,210** (24%)
Total Aust#		**59,311**	**5,604**	**12,198** (21%)	**7,436** (12.5%)	**3,584** (6%)	**6,362** (11%)	**2,456** (4%)	**2,359** (4%)	**397** (0.7%)	**410**	**5,175** (9%)	**9,217** (15.5%)

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3.3 Assessment approach

The national mapping of areas of coastal inundation was carried out at the Spatial Science Group, School of Geography and Environmental Studies, University of Tasmania. Counts of the number of residential buildings affected in inundated areas were provided by Geoscience Australia. The counts were derived by intersecting the areas of inundation with the National Exposure Information System (NEXIS) database which contains data on the location and type of infrastructure.

Building counts were assessed at local government area for a lower and upper end estimate of residential exposure. The inundation mapping was based on a 1.1 metre sea-level rise, and included an allowance for tidal influence (modelled high water level) or storm tide values, where they were available for the whole of the state coastline. No provision was made for the potential impacts of inland flooding converging with coastal (from the ocean) inundation. Convergence of inland flooding and coastal inundation could greatly increase the areas inundated.

The high and low estimates are derived from the treatment of the uncertainty in the data inputs to the model. For example there are uncertainties around the elevation data used to describe the landform (height relative to sea level). To express the uncertainties, the model generates a probability of inundation occurring for each 30 metre by 30 metre grid cell. The probability thresholds for the high and low estimates of inundation bounded select areas that were mapped using very high resolution data. This provides greater certainty in the method for identifying likely areas of inundation.

Table 3.2 Source of 'tide' data used in analysis.

State	Tide data
Tasmania	1-in-100 storm tide modelling (McInnes 2008[10])
Victoria	1-in-100 storm tide modelling (McInnes 2008[11])
New South Wales	1-in-100 storm tide modelling, however no wave setup used in this modelling; this is likely to contribute to under representation of the values along this part of the coast (McInnes 2008[12])
Queensland	Modelled high water level (NTC 2008[13])
Western Australia	Modelled high water level (NTC 2008[14])
South Australia	Modelled high water level (NTC 2008[15])
Northern Territory	Modelled high water level (NTC 2008[16])

The core elements of the mapping were the inundation analysis and the data inputs. These are each described in more detail below.

3.3.1 Key input data

Digital elevation model

The digital elevation model (DEM) was a key dataset for the national assessment of potential coastal inundation. The DEM identifies the height above sea level of each grid cell (in this case 30 metres by 30 metres) in the national map. The landform described by the DEM also allows for understanding of the geographic patterns of potential inundation, and in particular, whether there is low-lying connectivity to the coast, or a continuous raised landform that provides protection from inundation.

The DEM is derived from satellite data and provides a nationally consistent basis for the assessment.

Sea-level rise

A sea-level rise value of 1.1 metres for 2100 was informed by research since the AR4 and expert advice.

Modelled high water level and storm tide

Storm tide is calculated from models using observations from tide gauges, global tide data and wind models. Modelled storm tide data for a 1-in-100 year event was used for Victoria, Tasmania and New South Wales (Table 3.2). Storm tide values are a 1-in-100 year storm surge, with an allowance for a tidal component included. Storm tide values were used where there was a consistent modelled dataset that could provide storm tide values for the entire state coastline.

For other areas, tidal heights were obtained from continent-wide high tidal height predictions (essentially modelled high water level values) from the National Tidal Centre within the Bureau of Meteorology. There will clearly be some difference in the interpretation of results between the states for which storm tide values were used (representing inundation risk using a current 1-in-100 event) than for those states for which high tide data was used.

The storm tide and high tide values provide a more realistic scenario of flooding as rises in sea level will act on top of existing tidal values. Figure 3.6 provides an indication of the storm tide or high tide values used in the analysis. It should be noted that higher sea level events are possible and have occurred on a regional basis. These events are generally associated with either tropical cyclone storm surge and/or estuarine flooding events from either intense east coast low pressure systems or severe winter storms.

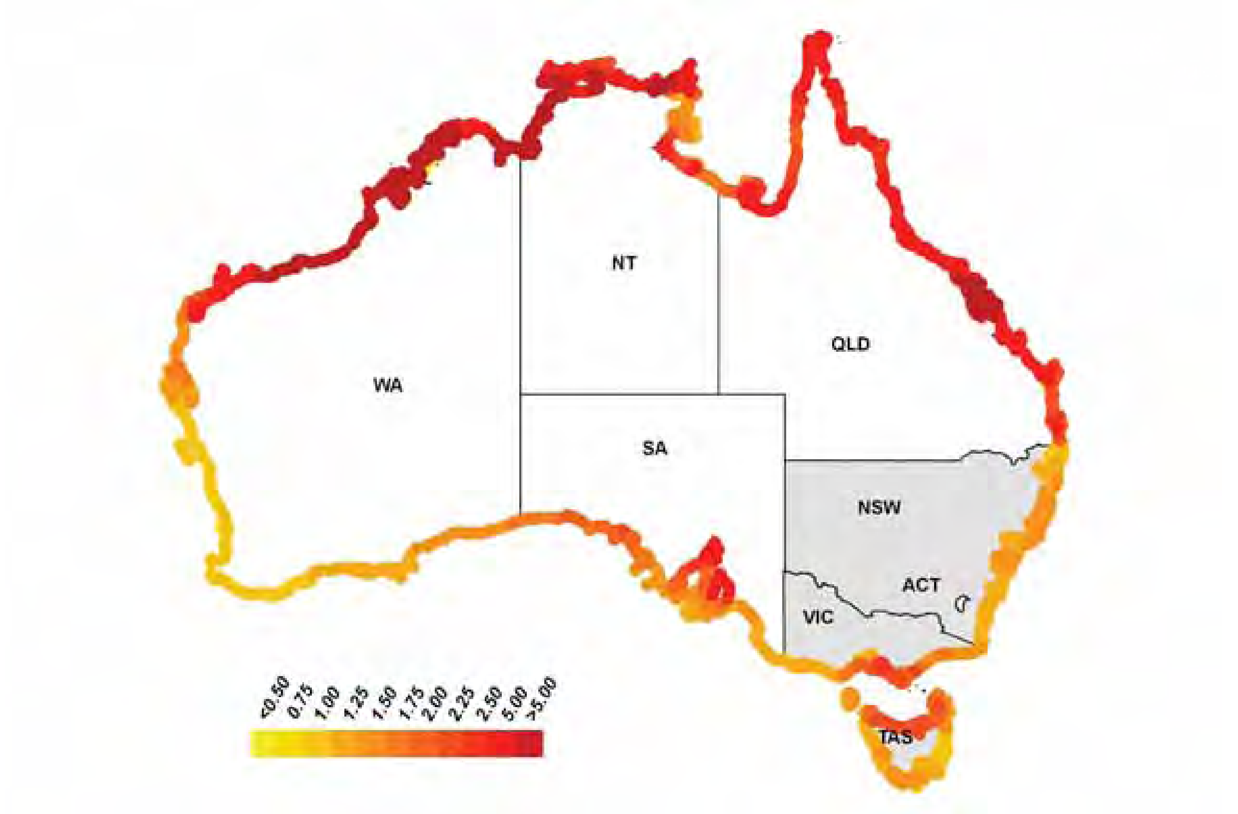

Figure 3.6 The range of modelled high water level and storm tide values applied in the analysis. States for which 1-in-100 storm tide estimates were applied are in grey, the modelled high water level values are shown elsewhere.
Source: Geoscience Australia 2009[17]

Additionally, the intensity of the 1-in-100 year storm tide event may also be impacted by climate change, for example through increased wind speeds (see Figure 2.15), but this has not been modelled in this analysis.

No allowance for the potential impact of riverine flooding was included in this analysis. Areas that are currently prone to flooding from catchment based sources (as opposed to sea-level rise) would be at much greater risk than is identified through this analysis. Investigation of the hazard of coincident events – storm surge with a high rainfall event leading to riverine flooding, for flood prone areas should be an immediate priority.

Coastal geomorphology

Areas of 'soft', potentially erodible coastline were mapped as these areas are more vulnerable to rising sea levels. Increased erosion of soft coastlines would result in a future shoreline that is further inland than it is today. It may also mean that tides and storm surges are able to penetrate further inland than is currently the case. Where 'soft' coastlines are identified, the inundation model 'considered' a new shoreline position that was 110 metres inland, and then applied the inundation modelling rules – i.e. is the land low enough to be flooded and what areas of inundation are close enough to each other to be considered connected.

3.3.2 Inundation modelling

The inundation modelling used a relatively simple 'bucket fill' approach to determine areas that would be inundated at certain sea-level rise and tidal conditions. This form of modelling projects the water height inland and inundates all land areas at an elevation below this level; it therefore does not take into account the hydraulic processes, such as the width and depth of channels for flooding, which can be important when assessing inundation from storm events on top of a given sea-level rise. However, for the analysis of inundation from sea-level rise and modelled high water level, a bucket fill approach is likely to be quite robust within areas of reasonable proximity to the coast; as rising sea levels will essentially flow into low-lying lands.

To determine the extent of coastal flooding, the potential sea-level rise was combined with the modelled high water level and, for areas where data was available, storm tide values. These two components were assessed around the coast approximately every 10 kilometres and combined to provide a potential high water level at a distance approximately 50–100 metres from the coast. This predicted high water level was then projected onto the coastal topography (provided by the medium resolution SPOT DEM) to estimate areas that might be flooded.

The modelling approach has several features that also reduce the potential overestimation that can occur from a bucket fill approach:

- Rules for connectivity to the coast were applied so that the area would be inundated under the sea-level rise scenario, and the area had to be within 145 metres of low elevation coastline (Figure 3.7)
- The presence of soft, erodible shorelines informed the potential for a 'new' shoreline position by 2100; wherever soft shoreline areas were also of low elevation a greater connectivity to the sea was assumed, for example, seawater was assumed to find a pathway within an extra 110 metres (utilising the Bruun Rule[18] for soil erosion, that is, 100 times the sea-level rise height)
- An uncertainty analysis was applied to recognise possible data limitations. The model outputs gave a likelihood rating of inundation to each 30 metre by 30 metre grid cell potentially subject to inundation.

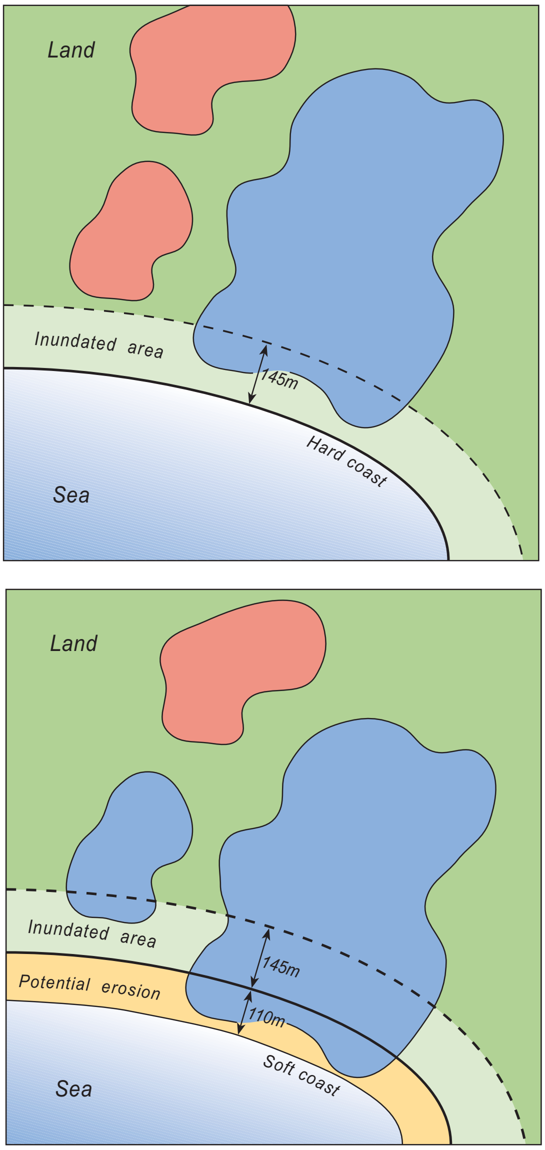

Figure 3.7 Example showing the connectivity rules applied to the inundation modelling. Within 145 metres of the coast it was assumed there would be a pathway for rising sea waters to flow into low elevation areas; where there was also a 'soft', potentially erodible, coast a new future shoreline 110 metres inland was assumed from which the 145 metre connectivity rule was then applied. In the Figure, red polygons are low-lying areas but a connection to the sea cannot be established. The blue polygons are low areas and the connectivity rules mean they are counted as inundated.

The bucket fill approach is useful because it is a simple, fast method that indicates potential areas at risk with a level of spatial resolution that can, if used carefully and with other lines of evidence, assist in prioritising further activity. For a national assessment, it was considered to be a cost effective approach that would provide an estimate of extent and magnitude of risk and assist in identifying areas of further attention.

3.3.3 Integration with NEXIS

The National Exposure Information System (NEXIS) infrastructure database, being developed by Geoscience Australia, has been designed to provide nationally consistent exposure information for regional or national impact analyses. The information is categorised into residential, business (commercial and industrial), institutions and infrastructure components. In its current form NEXIS is not intended to provide national precinct-level analysis involving one or two buildings. This would require more specific information than is currently contained within NEXIS, although this is available for some major cities.

The NEXIS database used in the analysis provides 'nationally consistent' information to identify the extent of residential buildings exposed to an inundation hazard.

NEXIS utilises the best available national address dataset from the Geocoded National Address File (GNAF) sourced from Pitney Bowes Business Intelligence and PSMA (Public Sector Mapping Agency Australia Ltd) along with specific building data sourced from state and local agencies.

Caveats associated with NEXIS include:

- Building locations are represented as single points rather than the area of the building footprint. This may have lead to an under estimation of risk as some buildings that may actually be within the area identified as subject to inundation (and therefore potentially impacted) may not have been captured in the analysis.
- The June 2008 version of the NEXIS information was used in this analysis. As building numbers will have increased in the past year this may have resulted in an under estimation of buildings at risk.
- Potential error (between what NEXIS holds for physical infrastructure and what is actually present) is expected to be larger in rural areas that have not

Figure 3.8 Example of overlay of NEXIS with an inundation footprint. Source: Geoscience Australia 2009

been surveyed as frequently or extensively. This error may have under estimated risk, for example the Tiwi Islands and East Arnhem LGAs do not contain any residential building information.

- Due to the lag time between the release of an address and the time a building is constructed on that address, proposed buildings may be represented in NEXIS. This may have slightly over estimated the total number of buildings at risk.

In addition, NEXIS was used to calculate the number of buildings within 55 and 110 metres of ‘soft’ and potentially erodible shorelines. These buildings could be at risk over the coming century from accelerated coastal erosion.

The approximate total replacement value of the residential properties was also calculated based on information held in NEXIS. The values have been based on average replacement values per state or local government area (where available). These figures represent the total value of assets at risk though it should be noted that the extent of damage due to flooding would not always, or often, result in a total replacement of all infrastructure affected.

3.4 Emerging priorities for methods development and assessment

Undertaking the first pass assessment has led to the identification of a number of areas where national datasets and methods need to be developed or enhanced in order to better assess risk of inundation or erosion.

The timing limits of this report constrained the breadth of sectors considered in the risk assessment. An early priority would be to extend this assessment to the transport, energy, water and waste sectors, and to industrial and commercial infrastructure in the coastal zone. The development of accessible datasets on the location of important infrastructure is required to underpin this work.

A key issue which emerged was the need for an improved consideration of estuaries – for both inundation and erosion hazards as well as consideration of coincident events (i.e. riverine flooding with storm surge events). Estuaries are where many people live, where most infrastructure is located, and they have complex hydrological characteristics making them challenging to model.

Given the diversity of estuaries, analysis needs to be at a regional or catchment scale using finer resolution data. To support this, the shoreline geomorphology of most estuaries and tidal lagoons needs to be better incorporated into the national geomorphic map. Tidal re-entrants such as estuaries and tidal lagoons are likely to be sensitive to erosion resulting from sea-level rise, and they often include more soft erodible muddy and clayey shoreline types than do open coasts. Additionally estuaries tend to behave individually in relation to storm surge and tidal processes and hydrodynamic modelling is necessary to capture this variation in hazard extent.

More generally regional and local influences on coastal instability need to be better understood to improve the understanding of the magnitude of risk associated with coastal instability. While the mapping of coastal geomorphology provides an indication of vulnerable areas of the coast, it cannot identify potential rates of erosion. Further development of detailed site-specific case studies of representative coastal geomorphology types would improve our understanding of regional and local processes, such as wave energy and direction, which can influence the rate of erosion.

For highly populated areas with shallow elevation gradients, an analysis using high resolution DEMs (based on LiDAR) would increase the accuracy of the inundation modelling and hence the estimation of risk to physical infrastructure. Similarly, bathymetric data or elevation data for the seabed for near shore areas would enable a more informed assessment of how sea-level rise may affect inundation patterns through changing wave directions and energy. This will be important in understanding how risk to physical and natural assets will change at regional scales.

In addition, adequate national data was not available in some areas to assess the risks from storm tide which is known to lead to flooding of assets in low-lying areas. The science of combined hazards analysis is also improving and should be able to inform a future assessment of coastal inundation risk.

Key gaps were also identified in the areas of economic data and socio economic information, for example a valuation of damage to infrastructure, which is needed to inform cost-benefit analysis, was not possible. An analysis of socio economic implications will also be needed to identify vulnerable communities and to understand local and regional population projections and associated implications for potential infrastructure stock into the future. Figure 3.9 presents a concept of risk assessments at different scales and the data/ research needed to underpin the assessments.

Further information on research priorities to underpin refined assessments of risk and to support informed decision-making on adaptation is provided in Chapter 6.

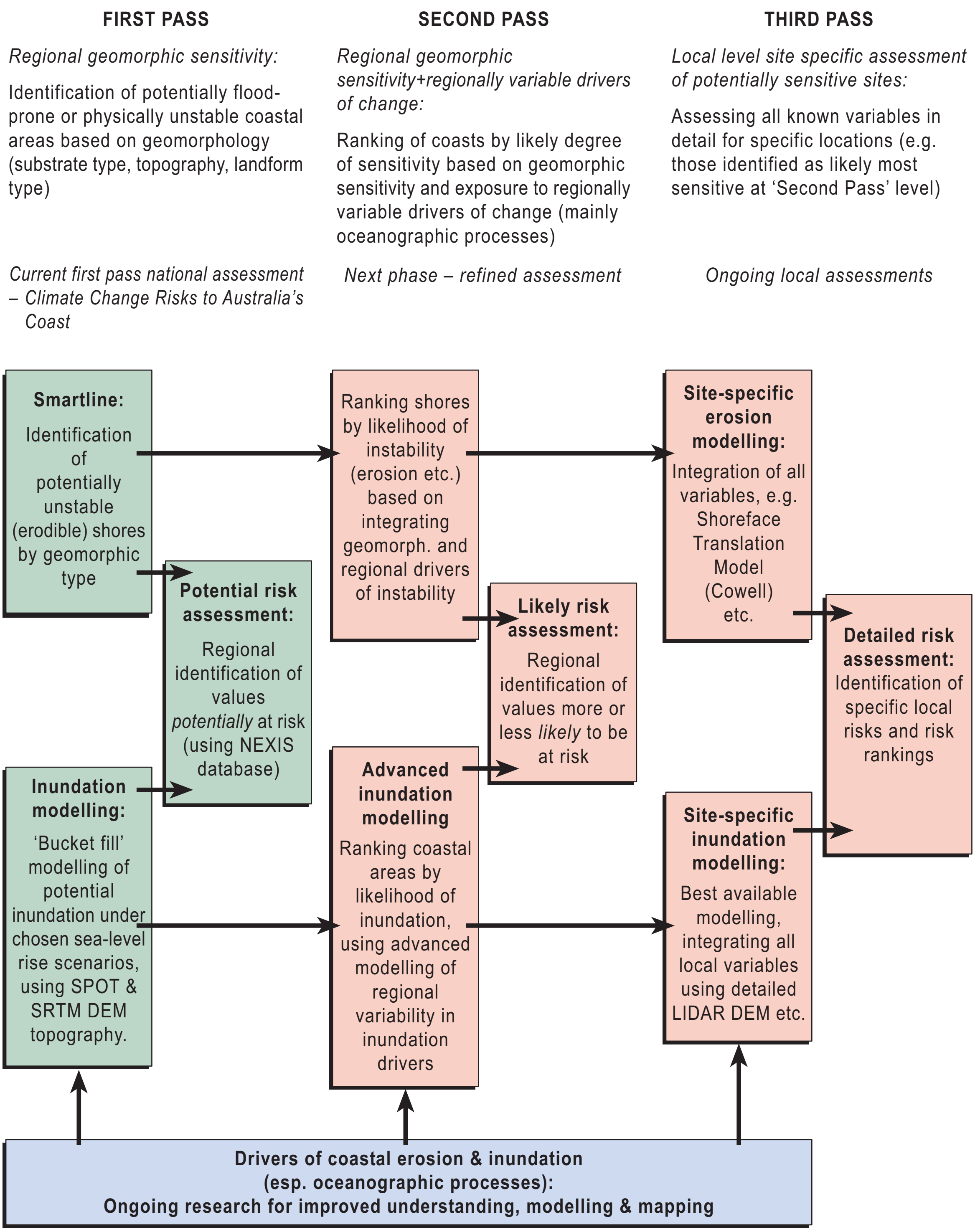

Figure 3.9 Concept of risk assessments at different scales.
Source: Sharples 2008[19]

4

CHAPTER

CLIMATE CHANGE RISKS TO THE COASTAL ENVIRONMENT

Photo credit: T King

KEY FINDINGS

- The responses of Australian coastal ecosystems and landforms to climate change will vary but are expected to involve shoreline recession, vertical accretion, increased saline inundation of wetlands, and the modification and southward shift of habitat.
- 'Coastal squeeze' could occur in southern Australia where obstacles such as roads or settlements prevent the landward migration of some ecosystems such as saltmarshes.
- There are a number of nationally and globally significant coastal environments at risk from climate change and habitats for some migratory bird species could be reduced.
- The coastal systems most at risk are estuaries and associated wetlands, coral reefs, constrained tidal flat communities and beaches where there is a lack of sediment replenishment.
- Climate change impacts, particularly coming on top of other stresses, could shift coastal systems past thresholds or tipping points beyond which the landforms or ecosystem no longer function in the same way.
- Changes to ecosystems can already be observed, some of which, such as the southward migration of a species of sea urchin on the east coast, may be a response to climate change to date.
- The reduction of non-climate stresses on coastal ecosystems can play an important role in increasing resilience to the impacts of climate change.

4.1 National overview

Chapter 2 outlines the range of climate changes which will affect the coast. Because the phenology and behaviour of many species are linked to climate variables such as temperature, climate change will potentially lead to wide-ranging impacts on coastal ecosystems. Sea-level rise will lead to inundation of parts of the coastal zone, accelerated erosion and saline intrusion into coastal waterways and wetlands. Low-elevation coastal deltas, floodplains and estuaries will be affected, and seagrasses, mangroves and saltmarshes are particularly vulnerable to sea-level rise. Changes in ocean currents may also affect the productivity of some tropical systems through changes in dispersal processes or nutrient upwellings, and increased acidity will affect corals and other species with calcium carbonate structures.

Coastal environments of national and global significance will be affected by climate change. Kakadu National Park, the Great Barrier Reef, Shark Bay and Fraser Island are all World Heritage properties in or partially in the coastal zone. Many beaches have iconic status such as Bondi and the Gold Coast. There are as many as 20 wetlands of international significance in the coastal zone.

Coastal ecosystems are already under substantial pressure from a range of non-climate stressors related to urban development and housing and the economic and recreational uses of coastal resources notably for agriculture, fisheries and transport. This can involve direct loss or modification of habitat or more indirect impacts such as pollution or the encroachment of pests and weeds. Pollution, sedimentation and nutrient exports to coastal habitats may be either point source (for example, sewerage outlets) or diffuse such as run-off of nutrients and sediment from agricultural operations in coastal catchments. There is clearly wide regional variability in the distribution of these pressures, with large parts of the Australian coast remote from high levels of human impacts.

Climate change will add to these existing pressures, compounding their impacts in possibly complex and diverse ways which may be difficult to predict, track and manage.

4.1.1 Key responses of coastal ecosystems to climate change

The responses of Australian coastal ecosystems, habitats and dependent species to climate change

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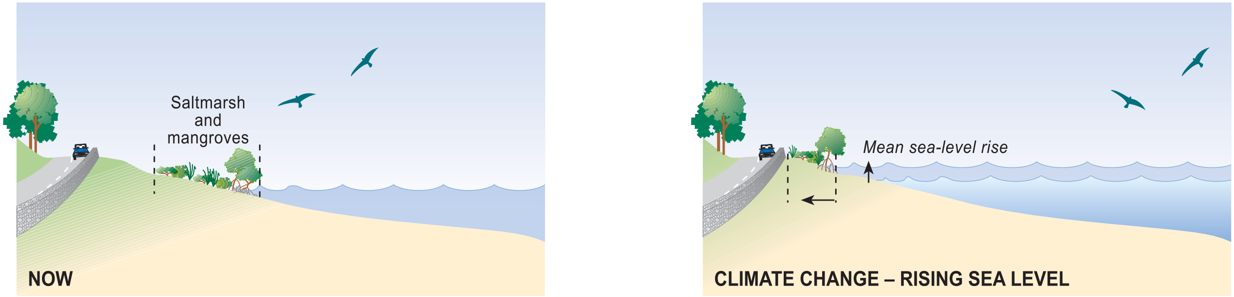

Figure 4.1 'Coastal squeeze' under sea-level rise: impact of development.

impacts will vary but can be expected to involve landward shift, vertical accretion or growth, and southward migration where possible.

Sea-level rise will result in the gradual inundation of ecosystems for about half of the Australian coast. The response of ecosystems to sea-level rise will be variable. For example, in estuarine environments the response will depend on the existing topography and sediment budgets (ie the balance between sediment added to and removed from the coastal system). If the land is uninhabited, there is an opportunity for landward migration of many intertidal and shallow subtidal communities such as seagrasses, mangroves and saltmarshes as sea level rises.

However, if there are built structures that prevent this migration landward (as in much of south-eastern Australia and parts of south-western Australia), these ecosystems are likely to be reduced by a process called 'coastal squeeze' (Figure 4.1). Even where there may be limited opportunity for migration inland of an intertidal ecosystem such as mangroves, this is likely to be at the expense of other higher terrain ecosystems such as saltmarsh habitat.

The story of the vertical response of coastal ecosystems to sea-level rise is a similarly complex and varied one. Wetland vertical accretion is a function of multiple, dynamic and complex factors, including the elevation of the wetland, flooding and run-off regimes, soil organic matter, and the type and quality of local and regional sediment supply.

Research and modelling suggest that mangrove ecosystems on the northern Australian coastline may be able to accrete vertically at a sufficient rate to keep up with projected rising sea levels. This largely reflects the usually high amounts of sediment supply on this part of the coastline for use in the accretion process. With extensive areas of flat and low-lying hinterland, these mangroves may also be able to migrate landward as necessary.[1]

Increasing ocean temperatures may result in a southward movement of some ecosystems; for example, a southward shift in the latitudinal limit of some species of seaweed has already been observed in New South Wales, and there has been a reduction of kelp in north-eastern Tasmania.

Higher temperatures, together with higher concentrations of nutrients triggered by human activities, are also likely to result in more frequent appearances of harmful algal blooms in coastal waters. It is also possible that higher temperatures may induce more upwelling of nutrients from the ocean floor, with possible food chain impacts on coastal and marine species.

High temperatures can also lead to reproductive failure and adult mortality in seabirds. Elevated sea surface temperatures associated with El Niño events already correlate with significant decreases in seabird nesting success, slowed chick development and reduced breeding incidence[2], and climate change will probably increase the incidence of such temperatures. In some reptile species, such as turtles and estuarine crocodiles, warmer temperatures can affect the sex ratios of embryos and reduce incubation success.

Warming temperatures are likely to have particularly serious impacts on coral reefs, including mass coral bleachings. It has been suggested that a 2°C rise in sea surface temperatures is likely be a threshold level that could threaten the viability of some coral reefs.

Climate change impacts, particularly coming on top of other stresses, could shift coastal ecosystems beyond thresholds or tipping points such that the ecosystem no longer functions in the same way. This change into an alternative state or regime can happen abruptly in a discontinuous, non-linear form when a threshold is crossed.[3] This issue of 'flipping' to alternative systems is illustrated further in *Thresholds and flips to alternative ecosystem states* opposite.

A generally warming and drying climate is likely to have other consequences for Australian coastal ecosystems. For example, reduced rainfall and increased evaporation in southern and eastern Australia will significantly reduce run-off to coastal rivers and streams. This will result in higher salinity concentrations in estuaries, and impacts on species can be expected. Concurrent with the drying and salinisation of the Coorong coastal estuarine system in South Australia have been reports of dramatic declines in waterbird numbers. Monitoring has shown that 23 of the 27 most common species of waterbird have declined in the Coorong by at least 30 per cent since 1985.[4]

Box 4.1 Thresholds and flips to alternative ecosystem states

Human stresses can rapidly flip ecosystems to an alternative state, which may be permanent. For example, the combined effects of eutrophication, (i.e. nutrient enrichment of water which reduces dissolved oxygen and may stimulate algal blooms), removal of grazing fish and global warming can reach a threshold beyond which corals rapidly decline and algae growth accelerates. Algae can then smother corals, preventing photosynthesis by their symbiotic zooxanthellae (the small organisms that live within the coral).

The temperate Chesapeake Bay estuary system (United States) is now dominated by bacteria and large phytoplankton blooms following over-exploitation of its extensive oyster beds which filter the waters of the bay. Benthic seaweeds and algae have virtually disappeared because of shading by phytoplankton.[5]

Recent evidence suggests that other coastal and open-water systems can rapidly flip from being dominated by fish (that keep jellyfish in check through competition or predation) to a less desirable 'gelatinous' state.[6] This new ecosystem state is resistant to returning to its original state because jellyfish are voracious predators of fish eggs and larvae, and effectively prevent fish from returning. This flip to a jellyfish-dominated system once a critical threshold is reached has been termed 'the jellyfish joyride'. Figure 4.2 shows a natural ecosystem on the left, but one that is slowly degraded by the combination of continued overfishing, eutrophication and climate change. In this state, the number of low-oxygen zones ('dead zones') where there are few fish, marine mammals and seabirds increases. This is consistent with the 'rise of slime' – a term coined by Jeremy Jackson.[7]

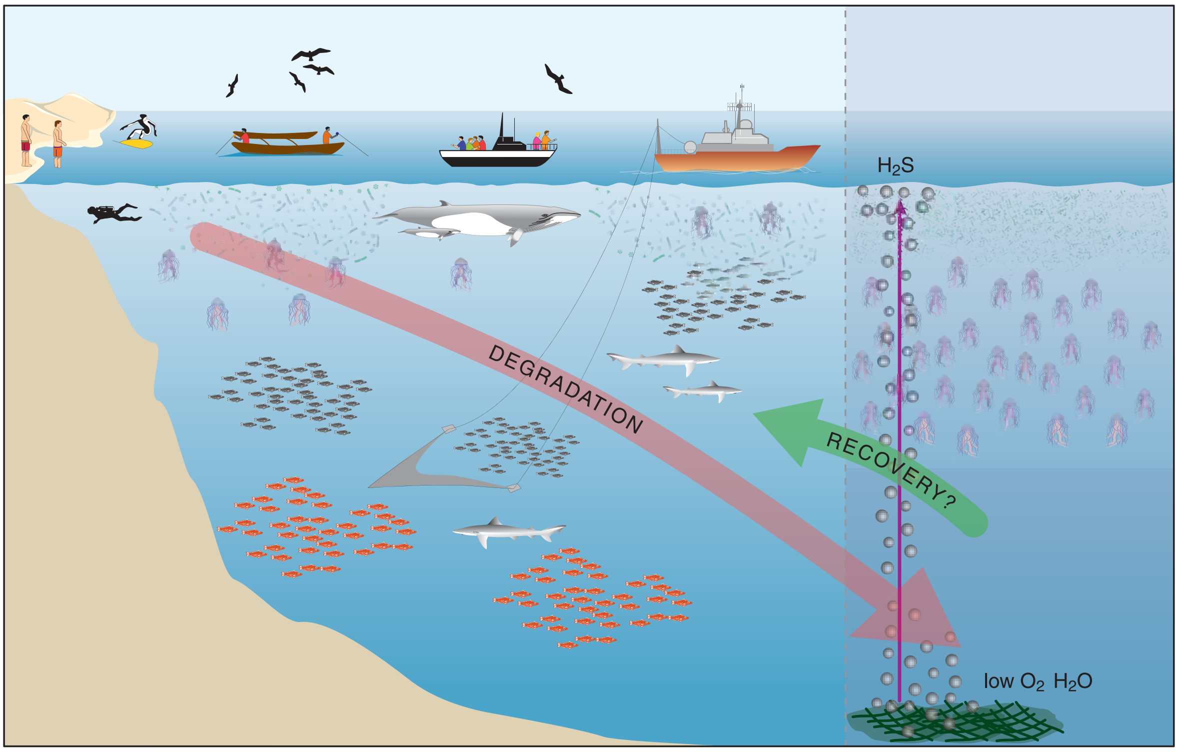

Figure 4.2 Coastal and open water systems can rapidly flip from being dominated by one species to another through the impact of human stresses.

4

Box 4.2 Migratory and nomadic shorebirds

Australian coastal regions are part of the East Asian – Australasian Flyway, an important intercontinental migratory bird route. Many species using this flyway are already threatened.

The migratory shorebirds rely on a range of coastal ecosystems for roosting and staging, feeding (often including wading), breeding and rearing young. Climate change impacts expected on coastal bird habitats include:

- conversion of coastal freshwater habitats to saline habitats following inundation
- increased mortality and decreased breeding success due to heat stress
- alteration to the synchronised timing of migration of shorebirds and the abundance of food species on which they depend. A significant shift in migration timing has already been observed for some but not all shorebirds visiting Australia[8]
- warming temperatures may induce a southward shift in the range of many shorebird species.[9]

Photo credit: John Manger/CSIRO

Bar-tailed Godwits arrive in Australia each year in August from breeding grounds in the northern hemisphere.

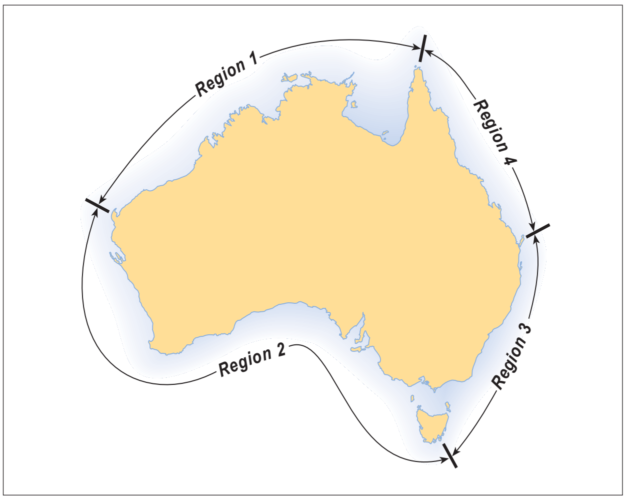

Figure 4.3 Australian coastal regions.

To the extent that increasing temperatures, changing rainfall patterns and other climate change phenomena place stress on flora and fauna of coastal ecosystems, it is possible that invasive plant and animal species will increasingly occupy niches once held by the stressed species.

4.2 Vulnerability of coastal landforms

Chapter 1 describes the four coastal regions: 1 The Muddy North; 2 The Limestone South and West; 3 Eastern Headlands and Bays; and 4 The Barrier Reef (Figure 4.3). Each will be affected by climate change differently.

Region 1 is dominated by a high tidal range which provides the main driving force in coastal landform and habitat development. Global warming is most likely to be felt by changes in tidal extent and more extreme weather events, particularly tropical cyclones.

Tropical cyclones are a major climate driver in this coastal region. As described in Chapter 1, geomorphological studies show that there have been considerable natural variations in the magnitude and frequency of cyclones in the past. If a storm strikes the coast coincident with the higher sea levels during high astronomical tide, surge impacts will be much greater than experienced over the past 400 or so years. Coarse (sand and shell) material will be washed considerable distances inland, forming new ridges or cheniers.

On a smaller scale in northern Australia, there is a possibility of faster local erosion of soft rock shores under rising sea levels and storm events such as around Darwin, and possible changes in wind strengths and direction on the small dune areas in the region.

Region 2 covers much of the southern and western Australian coastline; it is a vast stretch of coast with a range of features and processes. Within the region there exist large bays, estuaries and gulfs (including Shark Bay, the Swan River estuary, St Vincent and Spencer gulfs and Port Philip Bay) where tidal processes and flats are more significant. Impacts of water extraction for irrigation and rainfall decline in the Murray–Darling Basin are influencing landform and habitat conditions at the Murray estuary mouth and the Coorong lagoon.

Extensive stretches of limestone and calcarenite cliffs occur in this region and are known to periodically collapse under wave attack. Whether cliff erosion will be more severe under climate change in this region is unknown, but it is possible, given that climate change may slightly increase mean wave climate. Undercutting of very fragile and friable aeolianites (i.e. sediment deposited by wind) as a result of more erosive waves poses real threats to lives and property in urban and recreational areas as sea level rises.

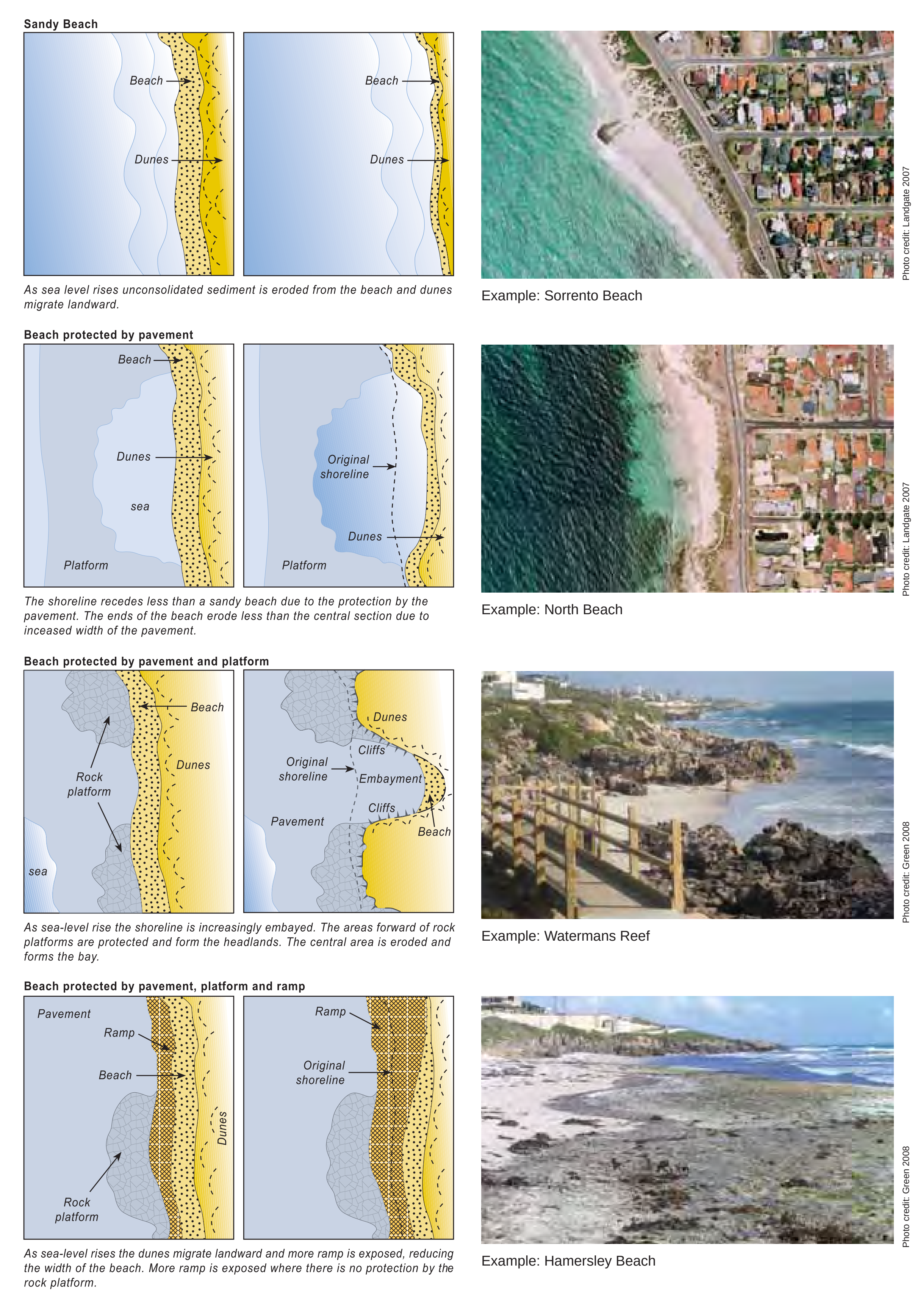

Figure 4.4 Change to beaches from sea-level rise. The four conceptual models above show beaches on a rocky calcarenite, embayed coast, typical of the Perth region. The models show the different types of response to sea-level rise.
Source: Green 2008[10]

This southern region is typified by the occurrence of shoreline and nearshore reefs of calcarenite flanked by 'perched' beaches. Cemented beach and dune limestone provide a degree of shoreline stability along many shorelines facing the open ocean. However, swell waves and storm waves generated by travelling low pressure systems should continue to abrade these surfaces and redistribute calcareous sand both alongshore and into embayments.[11]

Where nearshore reefs exist, they will continue to dampen the impact of waves, potentially reducing the effect of surges. It is unclear at that stage what impact changes in the position of the Southern Annular Mode under climate change may have on storm wave parameters that affect the western and southern coast. There is similar uncertainty about long-term changes in the intensity and southward penetration of tropical cyclones along the west coast.

As in other regions, there is the strong likelihood that there will be increased inundation over areas never before flooded as global sea-levels rise. Whether the low tidal ranges typical of this region will be amplified or conversely be more attenuated than at present will depend on the size and geometry of the bay or estuary, the size and depth of the entrance, and any changes in sediment flux that may affect those factors. Artificial opening or expansion of entrances may have adverse effects on ecosystems of semi-enclosed coastal water bodies, such as the Peel–Harvey Lagoon in Western Australia.

The highly populated eastern seaboard or **Region 3**, is a coastal region where several major climate change drivers, including storm events, could have a range of impacts on the geomorphology, depending upon how they interact with local sediment supplies, bay and shelf geometry. Tasmania has many of the characteristics of Region 3, although calcareous sediments occur in places in common with Region 2, and the west coast in particular is dominated by the wave–wind regime of the Southern Ocean.

There is uncertainty as to what changes will occur in the character of tropical cyclones, as well as east coast lows, in this region under climate change. Historical records show that such storm types have occurred in clusters at irregular intervals in Region 3 and that, when they do, they have a dramatic impact on shoreline conditions by causing extensive foredune erosion and flow of water over topographical structures.

Different sand barrier and nearshore shelf sand body types have been identified between Gippsland and Fraser Island. They are composed of mostly siliceous sand and have been developed during the 'stillstand' period as a result of onshore transport by waves and winds. Over longer periods of high and low sea levels in the Quaternary, the formation of the massive sand dune islands of southern Queensland has occurred. Active or mobile sand blows as seen on Fraser Island will continue to expand under climate change if storm and wind conditions intensify.[12]

In a natural state, these dunes form resilient buffers to storm wave and surge erosion except in those cases where sand supplies are limited and the dunes are receding. In such cases, breaches of the barrier and overwash may lead to new entrances to lagoons, drastically changing tidal and salinity conditions in places such as the Gippsland Lakes. Where foredune ridges of the dunes have been built upon in Region 3, waves erode these sand buffers and attack built structures.

How beaches and foredunes will behave under rising sea levels along this coast is unclear in the short-term, given the resilience of the high foredunes, available nearshore sand supplies that can be moved onshore during calm weather conditions and the impact of beach rotation on sand build up to help dampen the erosive effects of storms.[13] There are problems in applying the simplified Bruun Rule to this coast, given the complex interrelations of sea level with wave conditions and sediment supply and the role of topographies.[14] There is evidence that a rise of up to 20 centimetres over the past 100 years or so has seen no significant shift in shoreline position on certain beaches in Region 3. A key question is when stable or accreting beaches are likely to switch to eroding beaches as a result of sea-level rise and more extreme storm events.

Low-lying lands around the shores of estuaries are under threat from rising high tide levels. There is some evidence already for land migration of mangroves at the expense of saltmarshes squeezed between higher land or built structures and the invading mangroves. The behaviour of intermittently closed lagoon entrances under climate change will probably differ from that of open estuaries and depend on local circumstances. In some estuaries the seaward bar could become permanent, in others the lake levels may fall more often due to higher levels of evaporation relative to freshwater inflow, and in some areas there will be more saline intrusions.[15]

Region 4 continues north from Fraser Island to Torres Strait. Many of the estuarine changes that may occur in other regions will take place here, depending on the interaction of catchment and tidal hydrodynamic and sediment supply factors. There are also concerns over the stability of sand islands and coral cays, where higher tides may already be a factor in eroding shorelines and inundating island depressions.

Of great concern is the ability of the Great Barrier Reef to keep up with sea-level rise and remain a major buffer to oceanic wave conditions. If any part or the entire reef suffers from bleaching or acidification to the extent that corals either become more easily destroyed by storms or grow less quickly, then mainland and island shores will be subjected to higher energy wave conditions. Generally, beaches along these shores are more sediment deficient than those farther south and may therefore recede at higher rates under the influence of locally generated winds and irregular tropical cyclones.

Conditions for landward migration of mangroves should persist in estuaries and along protected shores unless deltaic accretion can keep up with the rate of sea-level rise. Saline intrusion during dry season periods under higher sea levels in deltas such as the Burdekin is also likely, impacting on ecosystems and groundwaters.

As in northern Australia, there is a need to consider the geomorphic impacts of more intense ‘super’ cyclones operating on higher sea levels. Such events on a sea level rising 50 centimetres or higher will locally form new deposits, or cheniers, over mud flats many kilometres inland.

Photo credit: Alistair Hobday

4.3 Ecosystem vulnerability to climate change

All coastal ecosystems will be affected in some way by climate change. It is difficult to predict which types of ecosystems on what parts of the coastline may be affected the most. However, prominent among the ecosystems which will be affected are those nearshore environments that face inundation from sea-level rise and shoreline erosion, leading to loss of habitat. This includes beaches, mangroves, saltmarshes and seagrasses. For the more offshore coastal habitats, such as coral reefs, sea surface temperature is considered to have the most important potential impact.

This section reviews the projected climate change impacts on six specific Australian coastal ecosystems: coral reefs, macroalgae, mangroves, saltmarsh, seagrasses, and beaches. These ecosystems do not function as independent habitats. There is considerable interdependency among them, and impacts on one can have major consequential impacts on others.

4.3.1 Corals

Description and distribution

Much of Australia’s northern shores is lined by extensive coral reef ecosystems, which include the Great Barrier Reef on the east coast and Ningaloo Reef on the west coast (Figure 4.5). The highest diversity of reef-building corals in Australian waters is found on the Great Barrier Reef.

Australian coral reefs are an extension of the Indo-Pacific Coral Triangle (Figure 4.6), which contains 76 per cent of all known reef-building coral species and 37 per cent of known coral reef fish.[16] Many coral reefs within the Coral Triangle are highly threatened: about 40 per cent of coral reefs in south-east Asia have been lost over the past 40 years.[17] In contrast, Australian coral reefs are the focus of progressive management, so their importance globally is increasing as reefs elsewhere are becoming degraded. They may become an important refuge for coral and fish species if reefs further north are lost.

Australian coral reefs provide critical habitat for a diversity of fauna and flora that includes more than 400 species of corals, 4,000 species of molluscs and 1,500 species of fish.[18] The rich ecosystems of coral reefs depend on myriad interactions and functional groups to provide an inherent resilience to the effects of disturbance events.

Coral reefs provide resources and habitat for commercially important fish and crustacean species. They also play a critical role in coastal protection, moderating the impacts of waves on Australia’s coasts. Coral reefs are critical to Australia’s economic wellbeing: they are the basis for Australia’s tourist industry, generating an estimated $6.1 billion in revenue from tourism each year.[19]

Decline in water quality and overfishing are thought to be the primary near-term threats to Australian coral reefs, but now the reefs face growing risks from climate change.

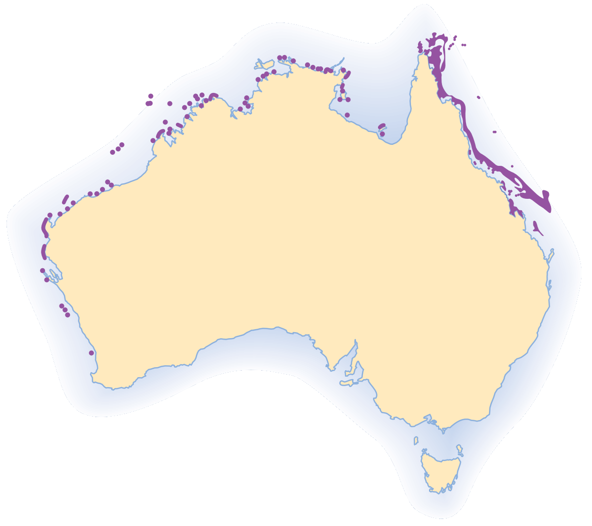

Figure 4.5 Distribution map of tropical coral reefs in Australia.
Source: Short and Woodroffe 2009[26]

Habitat sensitivity to climate change

Many components of Australia's coral reef ecosystems are sensitive to environmental change.[20] The occurrence of mass coral bleaching events over the past couple of decades are early signs of the severe ecological consequences for coral reefs of ocean warming. Bleaching occurs when the symbiosis between corals and the unicellular algae (zooxanthellae) that live within the coral tissues disintegrates, and is known to be triggered by exposure to water temperatures 1–2°C above average maximum Summer temperatures for 4–6 weeks. Bleached corals can recover their symbiotic algae populations if warming is short-lived, but if warm conditions persist they can die.

Sensitivity to bleaching varies among different coral types, so bleaching events can result in a shift in coral community composition.[21] If conditions are favourable, damaged reefs can recover in a decade or two. However, if affected reefs are exposed to chronic stresses (such as elevated nutrients, sediments or contaminants), or if stressful temperatures recur, recovery can be protracted or even prevented. In severe cases, reefs can shift from coral dominated to macroalgal dominated.

By the middle of this century, projected increases in water temperatures may result in thresholds for mass coral bleaching being exceeded annually in Australian waters.[22] A succession of coral bleaching events will severely compromise the ability of reefs to recover[23], with major implications for coral reef biodiversity, reef productivity and socioeconomic values.[24]

Corals' sensitivity to bleaching may be exacerbated by factors such as poor water quality due to increasing input of pollutants and fertilisers from land runoff, while fishing on coral reefs may reduce the ability of reefs to recover from bleaching events.[27] Alteration of other environmental variables, such as increasing storm intensities, and alteration of water salinity and water movement will also influence coral reef sensitivity to bleaching.

There is growing evidence that increased ocean acidification can reduce coral calcification rates and result in net dissolution of calcifying communities.[28] Cores from massive *Porites* corals on the Great Barrier Reef show a decline in coral calcification and growth of around 13 per cent since 1990, suggesting that warming temperatures and declining aragonite saturation levels are already affecting Australian corals.[29] The declines in aragonite (calcium carbonate) saturation state of sea water expected by 2100 may severely compromise the growth of coral and affect reef accretion.[30] Further evidence suggests that ocean acidification can exacerbate coral bleaching, increasing coral sensitivity to a warming climate.[31]

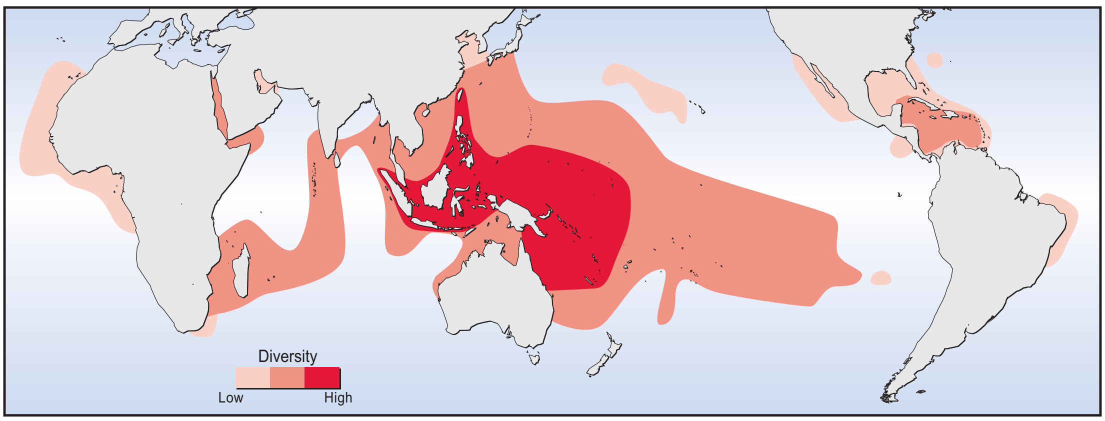

Figure 4.6 Global distribution of coral biodiversity (low, medium and high), illustrating the high-biodiversity Indo-Pacific region.
Source: UNEP – WCMC 2002[25]

Corals live in warm, well-lit water, so a rise in sea level at any specific location will increase the depths at which corals are found, unless coral reef growth and accretion keep pace with sea-level rise. Sea level has risen by an average of 1.7 millimetres per year over the 20th century, and that rate appears to have accelerated recently to about 3 millimetres per year.[32] The rise is slow compared to the rates of coral growth (20 centimetres per year[33]) and hence is not a major challenge to healthy coral populations. However, the projected increasing rates of sea-level rise, coupled with the slower growth and accretion rates due to warming temperatures and ocean acidification, may compromise the ability of coral reefs to keep pace with future sea-level rise.

Reefs will change rather than disappear entirely – some species are already showing far greater tolerance of climate change and coral bleaching than others. However, the recent Outlook Report for the Great Barrier Reef concluded that if atmospheric concentration of carbon dioxide continues to increase to 500ppm, hard corals will become functionally extinct and coral reefs would be eroding rapidly.

4.3.2 Macroalgae

Description and distribution

Macrolagae (commonly known as 'seaweeds') occur in waters all around Australia, from species growing on coral reefs to the giant kelp forests in southern waters. There may be 3,000–7,000 species in Australian waters, many of which are undescribed.

The brown algae (commonly called 'kelps') are among the most widely recognised macroalgae. Kelp species make up a small proportion of Australian marine macroalgae, but they are the dominant foundation organisms in their habitats and are thought of as bioindicators of the integrity of temperate reef ecosystems.[34] Macroalgal species are distributed wherever persistent hard substrate receives enough light. One species, *Macrocystis pyrifera*, can form large floating canopies up to 30 metres above the sea floor in the form of 'kelp forests'.[35] This habitat architecture is inhabited by diverse assemblages of animals and smaller seaweeds, and the primary production of kelp is also utilised by a broad community of organisms.[36]

Photo credit: ©CSIRO

Photo credit: Alistair Hobday

The distributions of some kelp species are limited to Tasmania or other particular areas, such as south-east or south-west Australia. For example, *Macrocystis* kelp forests are found predominantly in south-east Australia, were waters are cool and relatively nutrient-rich.[37] Overall, the highest diversity is found in southern regions. Some species are recognised as vulnerable or endangered, and thus may already be at different risk from climate change.

Distributions of kelp species in Australia and elsewhere are shaped by temperature, nutrients, turbidity, light penetration, wave action and sand scour, and the relative prevalence of herbivores and their predators.[38] Large declines of giant kelp and other macroalgae have been attributed to rising sea temperature[39], but deforestation, agriculture, urban development and other land-use changes might have changed sedimentation and runoff characteristics, reducing the quality of kelp habitat in some settings. For example, in South Australia there is concern about historical and continuing loss of canopy-forming algae. There is evidence of wholesale loss of canopy-forming algae (up to 70 per cent) on parts of the Adelaide metropolitan coast since major urbanisation.[40]

Giant kelp canopy losses have probably been greater than 50 per cent in Tasmanian waters over the past 50 years, which has been largely attributed to warming waters associated with climate change.[41] Again other factors, such as changes in coastal runoff, sedimentation[42] and invasive herbivores and algae, may have contributed to that decline. Recent invasions of the sea urchin *Centrostephanus rodgersii* in Tasmanian kelp forests have caused extensive deforestations[43], and some of this opened space is now occupied by an invasive Japanese kelp *(Undaria pinnatifida)*.[44] These southward range

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Figure 4.7 Distribution of rocky reefs in Australia.
Note: This is the required habitat for macroalgae, but does not equate exactly to macroalgal distribution.
Source: Short and Woodroffe 2009[45]

expansions might well have been initiated by the strengthening of the East Australian Current[46], and this might represent a quasi-permanent and fundamental shift in these Tasmanian kelp forests, with more changes to come.

Habitat sensitivity to climate change

Understanding of the sensitivity and vulnerability of most macroalgal species to climate impacts is still developing. Macroalgal species and habitats are sensitive to a variety of physical factors, including thermal regime, light availability (water clarity), wave action, shore topography and, in the case of intertidal species, desiccation. The exposure to a number of these variables will change in future, and different species will show varying sensitivity to future changes. Exposure to climate variables such as storm energy will vary with depth and latitudinal locations and will depend on the occurrence of suitable (usually hard) substrata on which macroalgae

Box 4.3 Macroalgal ecosystems: Important for fisheries production

Climate-related ocean warming along the east coast of Tasmania has been linked to the southward movement of an invasive sea urchin from New South Wales to Tasmanian waters.[47] The urchin *(Centrostephanus rodgersii)* is a voracious kelp grazer and in regions where the urchin is common kelp forests are removed, resulting in so-called 'urchin barrens'. The biodiversity in urchin barrens is much less than in kelp forests.[48]

Important fishery species, such as abalone, are also negatively affected by the urchin and have lower abundance in urchin barrens.[49] While the abundance of the urchin is expected to increase with climate change, and potentially affect the distribution of kelp forests and fishery species, one adaptation possibility is to protect or translocate large lobsters, which are suspected to be effective predators on urchins. Without some adaptation, this important coastal habitat is likely to be less common in future.

Photo credits: Alistair Hobday

can grow. The habitat range in which a species occurs will influence sensitivity to climate change. For example, a species which only occurs in shallow zones is likely to be more sensitive to external stressors than a species which occurs at greater depths.[50]

Macroalgal species vary in their thermal tolerances. For example, species that currently exist within only one temperature band may struggle to adapt to warming temperatures, while species that currently exist over a broad range of thermal regions are expected to have wider thermal tolerances and are more likely to withstand warmer temperatures.[51] Macroalgal species that are widely distributed may have characteristics that make them less sensitive to external stressors than species with restricted distributions.[52] Additionally, wide distributions may also indicate high connectivity via ocean currents.[53] It is assumed that species with narrow latitudinal ranges are more specialised and may therefore be less resilient to environmental change than species with wide geographic ranges.

Macroalgae communities tend to occur in several recognisable functional types dominated by particular growth forms such as filamentous (i.e. growing as long thin threads that may intertwine to form a dense mat), foliose (i.e. growing in thin sheet like forms resembling leaves), and canopy forming (i.e. growing from the seabed to form canopies). These different community types may have differing responses to climate change, with differential susceptibility to a range of factors. Canopy forming species such as kelps which form large 'stands' (e.g. *Ecklonia* species) may be more vulnerable to a range of factors such as wave impacts, high temperatures and low nutrients than turf forming and foliose species.[54] They are also vulnerable to overgrazing by invasive species.[55] The physical size of a macroalgae species can reflect the ability of the species to dominate coverage in a community of species, thereby gaining greater access to light for photosynthesis. Should such species be adversely affected there may be large and lasting effects on the composition of algal communities. Filamentous turf forming algal communities have become dominant in chronically disturbed areas near urban centres.[56]

Photo credit: © CSIRO

Overall, the sensitivity of macroalgal habitats to climate change is likely to be significant and related to existing stressors in the same region, such as coastal pollution. Under conditions expected in this century, global warming is likely to affect the southern macroalgal species most dramatically. The composition of the algal habitats will be modified, and species richness will change.

4.3.3 Mangroves

Description and distribution

Mangrove communities are diverse assemblages of trees and shrubs that are found fringing much of the tropical and subtropical coastline of Australia in wave-sheltered areas. The most extensive communities are found in the tropics (Figure 4.8). They occupy around 1 million hectares of the sheltered intertidal areas of estuaries, bays and islands.[57] The mangrove flora of Australia is one of the most diverse globally. Over half of the world's mangrove plant species are found in Australia with the northern regions of Australia harbouring the most diverse communities.

Mangroves act as an important buffer between land and sea, filtering terrestrial discharge, decreasing the sediment loading of coastal waters and maintaining the integrity of coastlines.[58] Mangroves are highly productive systems, performing a valuable role in nutrient and carbon cycling. Mangroves act as a nursery and breeding habitat for marine species such as fish, crabs and prawns, including many commercially valuable species.[59] They also support populations of a variety of terrestrial species, such as bird species.

Mangroves have demonstrated adaptability and resilience. They can be quite aggressive colonisers, and research suggests that they may have even increased coverage in parts of the Sydney coastal

Figure 4.8 Distribution of mangroves in Australia.
Source: Short and Woodroffe 2009[60]

basin in recent years.[61] However, they remain under threat from coastal development, river catchment modification and pollution. Over a third of the world's mangrove forests have been lost over the past 50 years, primarily through coastal development and clearing for aquaculture and agriculture.[62] The rate of loss in Australia is low compared to that in many other countries, but mangrove habitat is being cleared in Australia for land development. Mangroves in Australia are also threatened by changes in land use and catchment modification which may alter hydrodynamic regimes.

Habitat sensitivity to climate change

The major climate change threats to mangroves are considered to be rising sea level and alteration of rainfall patterns, especially a reduction in rainfall in conjunction with increasing temperatures. Mangroves grow in calm intertidal areas on shorelines with a low profile, so a small rise in sea level may inundate large areas of mangroves.[63] For example, inundation mapping suggests that around 100 square kilometres of wetlands (mainly mangroves) may be lost from Kakadu World Heritage Area by 2100 (Figure 4.9).

However, the response of mangroves to sea-level rise and inundation is a complex story and will depend on coastal dynamics. If the rate of vertical sediment

Photo credit: © CSIRO

accumulation (or accretion) by mangrove communities exceeds sea-level rise, then mangrove areas might not alter or might even increase. Conversely if sea-level rise is greater mangroves may retreat landwards.[64] Field studies in a mangrove swamp in Cairns found that 80 per cent of suspended sediment brought in from coastal waters at spring flood tide was trapped in the mangroves, resulting in a rise of the substrate of 1 millimetre per year.[65] Presumably, this mangrove swamp can keep pace with sea-level rise of the same rate or less.

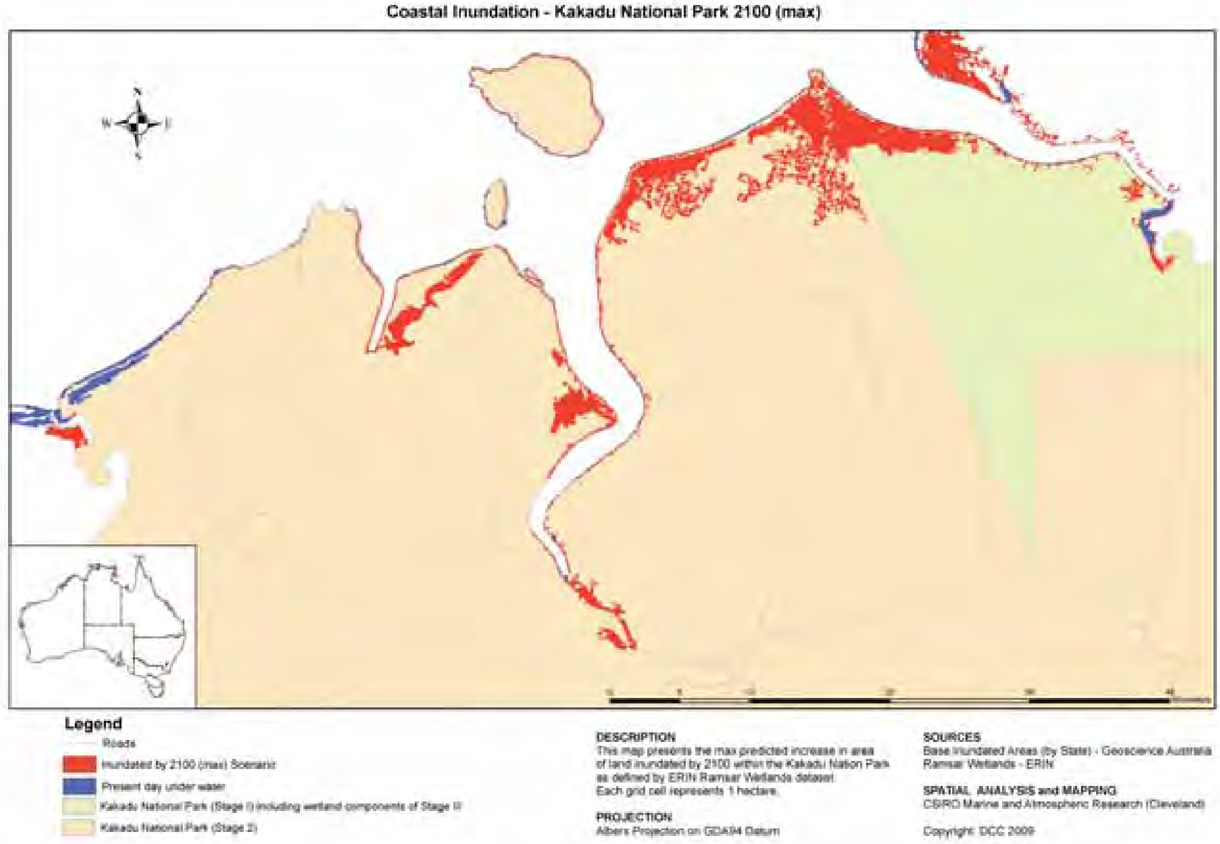

Figure 4.9 Inundation in the Kakadu World Heritage Area.
Blue: regions currently subjected to inundation. Red: additional area subject to inundation by 2100.

Research also shows that rising sea levels in northern Australia in the geological past might be linked to extensive mangrove development, as mangroves colonise the intricate networks of marine bays and estuaries formed on the drowning coastline.[66] Large areas of northern Australia and eastern Australia were covered with extensive mangroves during the mid-Holocene period.[67] The red mangroves (Rhizophoraceae) had greater dominance during past periods of sea-level rise, suggesting that they may increase in dominance in the future at the expense of other species.[68]

By contrast, in areas where suspended sediment load in coastal waters is low, mangroves might not be able to track rising sea levels.[69] Mangroves growing in such areas, such as on carbonate settings or low islands (for example, many of the Great Barrier Reef islands), may be vulnerable to sea-level rise over the next century.[70]

However, the availability of suspended sediments is not a sufficient indicator by itself to determine the vulnerability of mangroves to sea-level rise.[71] Other factors controlling the elevation of mangrove sediment surfaces include sediment type and water storage, below-ground root growth and decomposition rates, and the degree of compaction pressures on the sediments. There may also be situations in which mangroves can keep up with rising sea levels by converting additional organic matter into sediment base.

The hydrology of mangroves is complex; tidal inundation, rainfall, groundwater seepage and evaporation all influence soil salinity and have a profound effect on mangrove growth. Rainfall influences the composition and productivity of mangroves, as well as the sedimentation levels of estuaries.[72] Large reductions in annual rainfall, as expected in south-west Australia and to a lesser degree on the east coast can result in changes in growth form, shifts in mangrove community composition, or large-scale mortalities. Decreases in rainfall will reduce the volume of input to groundwater and increase surface water salinity, thus reducing mangrove productivity through saline stress and increasing mangrove vulnerability to sea-level rise.[73]

Coastal development and lands adapted for human use (for example, walls around farm lands) may hinder the landward migration of mangroves and result in areal loss due to coastal squeeze. To prevent loss of these important habitats, it is necessary to manage coastlines to allow the natural evolution of mangroves (that is, to reduce the threat of coastal squeeze and to reduce or eliminate other stressors). Such planning would enable coastal managers to minimise both coastal disruption and losses of these valued ecosystems.

4.3.4 Saltmarshes

Description and distribution

Coastal saltmarsh ecosystems are fragile areas of saltwater wetland habitat occupied by communities of salt-tolerant vegetation, usually reduced in stature (<0.5 metres tall) and adapted to harsh growing conditions, such as high salinity, full light exposure and moisture extremes. They occur worldwide on lowenergy coasts, usually in the shelter of estuaries and open lagoons, between the highest astronomical tide and mean high water neap tide.[74] The formation of these ecosystems requires a gentle gradient between land and sea in areas where waves do not scour away plant growth.

Saltmarshes provide extensive ecosystem services, including biofiltration, gas regulation, carbon and nutrient retention, physical protection of coastlines during storms, and habitat for fauna, algae and microbial communities, many of which are unique. A recent study found that high intertidal saltmarsh habitat had a greater abundance of fish than adjacent mangroves. Material is transferred between saltmarshes, mangroves and even coral reefs by mobile fauna through their life processes, such as grazing, predation and excretion.[75]

Saltmarsh communities are distributed all around the Australian coastline, particularly on the north and east coasts (Figure 4.10). They often occupy a position landward of mangroves and grade into terrestrial vegetation on the landward side. Tidal regimes generally control the distribution of saltmarsh: lower areas within a marsh are often subject to daily inundation by saline waters at high tides, while some upper marsh communities will only be reached by the highest tides.[76]

This progression of different zones of inundation, salinity and drainage has led to distinct changes in vegetation across saltmarsh communities. A typical community comprises samphires (succulent maritime shrubs and annuals), marine grasses (couch) and mixed herbs, reed swamps (salt rush) and *Casuarina* species, in a progression from the sea to the land.[77]

Photo credit: Periplus/Wikimedia Commons

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Figure 4.10 Distribution of saltmarshes in Australia.
Source: Short and Woodroffe[78]

Habitat sensitivity to climate change

Many changes in climate variables will influence the physiology, ecology and resilience of saltmarshes. These include increases in atmospheric CO_2 concentrations, warming of air and sea temperatures, rising sea level, increasing tidal amplitudes, potential colonisation by mangrove propagules carried on flooding tides, changes in ocean circulation, rainfall patterns, and frequency and intensity of storms. Reduced rainfall can also lead to salinisation and mangrove invasion of saltmarsh and freshwater wetlands.

However, the dominant impact of climate change is likely to be sea-level rise. This is because saltmarshes are trapped by a coastal squeeze (between impacts of urban development on the land side and impacts of climate change and its effects on mangroves on the sea side). Responses to past climate change have shown that as sea-levels rise and mangroves migrate inland, saltmarsh would naturally migrate further inland too. However, reductions in the area of saltmarsh are likely to occur if accretion cannot keep pace with rising sea level. This is most likely in areas of low tidal range, where rainfall is reduced, and where sediment inputs are not sufficient to contribute to the maintenance of surface elevation. Unfortunately, human modification of the coastal zone by building structures such as roads and sea walls prevents landward migration of saltmarshes as sea-levels rise, severely limiting the flexibility of saltmarsh responses.

Other human activities have decreased the resilience of saltmarshes to cope with climate change. Humans have cleared and modified saltmarshes for human use, disrupted connectivity, increased nutrient inputs, and altered sediment dynamics. To conserve the saltmarshes and the ecosystem services they provide, Australia will need to manage the coastal zone in a way that enhances its resilience to climate change. A concern with significant loss of saltmarsh habitat is that it could liberate the huge pool of carbon stored in wetland sediments to coastal waters or the atmosphere. Loss of diversity of flora and fauna is also likely with reductions in saltmarsh area and encroachment of mangroves into freshwater marshes. Sediment trapping, carbon sequestration and nutrient cycling will be reduced by declines in wetland cover, resulting in higher turbidity and higher nutrient loading in nearshore waters. Carbon and nutrient subsidies to nearshore waters would also be reduced, resulting in reductions in the productivity of nearshore food webs.

Box 4.4 Saltmarsh ecosystems: Importance for Australian birds

Saltmarshes are important foraging habitats for a range of migratory and local birds, including orange-bellied parrots, wading birds and birds of prey.

From late March onwards, orange-bellied parrots leave Tasmania and begin arriving on the mainland. The main concentrations of the small populations occur in two saltmarsh areas in Port Phillip Bay and along the beaches of south-east South Australia. They feed on saltmarsh plants, particularly glasswort species *(Sclerostegia arbuscuia* and *Halosarcia halocnemoides)*. It is estimated that there are fewer than 500 orange-bellied parrots left; loss of the winter saltmarsh habitat is likely to lead to extinction of the species.

The eastern curlew *(Numenius madagascariensis)* is the largest wader in the world and migrates between the Northern and Southern Hemisphere summers. It spends September–March feeding in Australia and the remainder of the year migrating to and from breeding areas in northern mainland Asia. The estimated population of eastern curlews is 28,000 in Australia. The distribution of most of the eastern curlew population in Australia during the non-breeding season is in areas with extensive tidal mudflats and saltmarshes, mainly around the south-eastern, eastern and northern parts of Australia, including Tasmania.[79]

Photo credit: © Dave Watts/AUSCAPE

The saltmarsh species potentially most affected by warming temperatures are those that are found only in the cool temperate zone. They include *Centella cordifolia* (Apiaceae), *Sarcocornia blackiana* (Chenopodiaceae), *Baumea arthrophylla* (Cyperaceae) and *Gahnia trifida* (Cyperaceae).

Targeted management responses are needed to preserve saltmarshes.[80] This includes the creation of buffers around saltmarshes to increase their resilience, and making available land to accommodate landward migration of saltmarsh.

4.3.5 Seagrasses

Description and distribution

Seagrasses are marine flowering plants that can form vast meadows in shallow coastal waters all around the Australian coastline (Figure 4.11). Seagrasses usually grow completely submerged and pollinate via water movement. Seagrasses have a typical plant structure, with leaves, roots and underground stems called rhizomes that can represent a considerable portion of the plant biomass. They reproduce by flowering and fruiting but can also spread through branching and growth of rhizomes. Seagrasses occur over a depth range from the intertidal to 30 metres or more in very clear water, but the mean depth of occurrence for most species is in the top few metres.

Australia has the world's highest diversity of seagrasses and most extensive seagrass beds. Of the 60-plus species found globally, over half occur in Australian waters.[81] Seagrass beds play a vital role in nutrient and carbon cycling and act as a buffer between the land and the sea. They also baffle water flow, trap sediments and filter coastal waters. Seagrass beds form important habitat for many species of fish and crustaceans, including exploited species, so declines in seagrass cover are often detrimental to local economies.[83] Studies in New South Wales suggest that 70 per cent of fish caught commercially and recreationally are associated with seagrasses or mangroves at some stage of their life cycles.[84] Seagrasses also support internationally important populations of endangered species, such as fish, green turtles and dugongs.[85]

Figure 4.11 Distribution of seagrasses in Australia.
Source: Short and Woodroffe[82]

Temperature and water clarity are the major factors controlling the biogeographic distribution of seagrasses in Australian waters. Large-scale declines of seagrass beds, both in Australia and globally, have been attributed to a loss of water quality from increased land use and coastal development.[86] Australia has lost extensive areas of seagrass habitat in the past 50 years, particularly in southern regions.[87] For example, coastal development and declining water quality have contributed to a loss of 50 per cent of seagrass bed area in Cockburn Sound, Western Australia.[88]

At present, the greatest threat to seagrass beds is from non-climate anthropogenic pressures, which, coupled with the extra stressors of a rapidly changing climate, threaten their persistence and resilience.[89]

Habitat sensitivity to climate change

Seagrass beds are under threat from both anthropogenic and natural causes. Natural events, such as coastal erosion, abnormally high temperatures, cyclones, storms and heavy and prolonged rain (resulting, for example, in large-scale plumes of turbid water discharging from rivers) can all damage or destroy seagrass beds. Recovery of seagrass communities from disturbance may take many years, depending on the severity and extent of impact. Seagrasses are likely to be vulnerable to climate change, particularly warming temperatures and altered rainfall, wave and storm regimes. Those factors may negate potential increases in productivity due to increased CO_2 levels.

Temperature is a major factor controlling the biogeographic distributions of seagrasses in Australian waters.[90] As climate warms, tropical species are expected to extend their ranges southwards and, depending on resource availability and dispersal abilities, temperate species will retreat. The result will be shifts in community composition as a consequence of variability in the rates of species responses. The potential to shift ranges southwards is limited by the southern coast of Australia. Coupled with high human populations living along the coast in temperate Australia, particularly in the south-east, and the fact that the greatest warming of Australian waters is predicted off south-east Australia, this suggests that some cold-temperate seagrass beds may be highly vulnerable to warming temperatures.

Seasonal or rapid increases or drops in temperature can also trigger flowering in seagrass species, and warming temperatures may disrupt these seasonal triggers. For example, regular flowering

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of the seagrass *Posidonia australis* occurs between April and June in south-western Australia, probably induced by a seasonal decline in water temperature.[91] However, annual flowering of *P. australis* is rare further north in Shark Bay and in the warmer waters of central New South Wales, where the threshold decline in water temperature to trigger flowering may occur less frequently.[92] As warming increases, episodes of *P. australis* flowering may become even rarer in the northern meadows, thus increasing their vulnerability to catastrophic disturbances; the deposition of seed banks after flowering is an important process to aid recovery.

Wind stress will determine the wave exposure at coastal sites, which controls attributes of seagrass beds and community composition. Increased wave exposure and increased local current speed will enhance mechanical disturbance, which may damage seagrass and resuspend sediments, making it difficult for seedlings to establish or persist.[93] It has been found that the percentage of area covered by seagrass plants declines with increasing wave exposure and/or current speed.[94]

As seagrasses tend to be carbon limited, an increase in atmospheric CO_2 will lead to a higher proportion of dissolved CO_2 in ocean waters, favouring seagrass productivity. However, the projected alterations in temperature, ultraviolet irradiance and storm regimes may act to negate the benefits of increased CO_2.

4.3.6 Beaches

Description and distribution

Around 49 per cent of the Australian mainland coastline is composed of sandy beaches (comprising 10,865 beach systems).[95] Most of the Australian population lives close to the coastline, and 'beach culture' forms an integral part of the Australian identity. It is difficult to imagine a marine habitat that is more important to Australian society for recreational and aesthetic activities. More people use sandy beaches than any other type of coastal habitat, so beaches underpin the economy in many coastal regions.[96]

The intrinsic ecological values and functions of beaches are often perceived as secondary to their economic value but are probably even more valuable. Beaches, together with their offshore sandbanks and coastal dunes, provide extensive buffering of natural coastal habitats and coastal developments through disturbance regulation, erosion control and storm protection.[97]

A typical beach also provides habitat for several hundred species of invertebrates,[98] many of them buried in the sand. Crabs, insects and shorebirds feed on these invertebrate beach dwellers. The surf zone of beaches is an important feeding ground for many juvenile fishes.[99] Beaches also provide unique

Box 4.5 Seagrass: Importance for dugong feeding

Dugongs *(Dugong dugon)* are herbivorous marine mammals which forage almost exclusively on seagrasses in tropical waters. They are highly threatened in much of their range, and a large proportion of the global dugong stock is believed to be in Moreton Bay, Queensland, and Shark Bay, Western Australia. Their dependence on seagrass means that they are associated with coastal habitats that bring them into contact with human activities. Current dugong numbers are well below historical levels, but good management of seagrass meadows will probably allow populations to increase.

Cyclones and storms can have long-lasting impacts on dugong populations. For example, 1,200 square kilometres of seagrass beds were destroyed in Hervey Bay in 1992 following two cyclones and a major flood event. A record number of strandings of dead dugongs, apparently due to starvation, were recorded some months later in adjacent coastal areas. Large numbers of surviving dugongs abandoned the area.

Dugong distribution is limited by cold temperatures, so climate change may enable dugongs to move further south. Dugongs have recently been sighted as far south as Sydney. A southwards expansion of seagrass beds may enable dugongs to become permanent residents further south of current ranges. However, the potential area for seagrass beds in New South Wales is less than in Queensland.[100]

Photo credit: Alistair Hobday

Photo credit: Karen Willshaw/Oceanwideimages.com

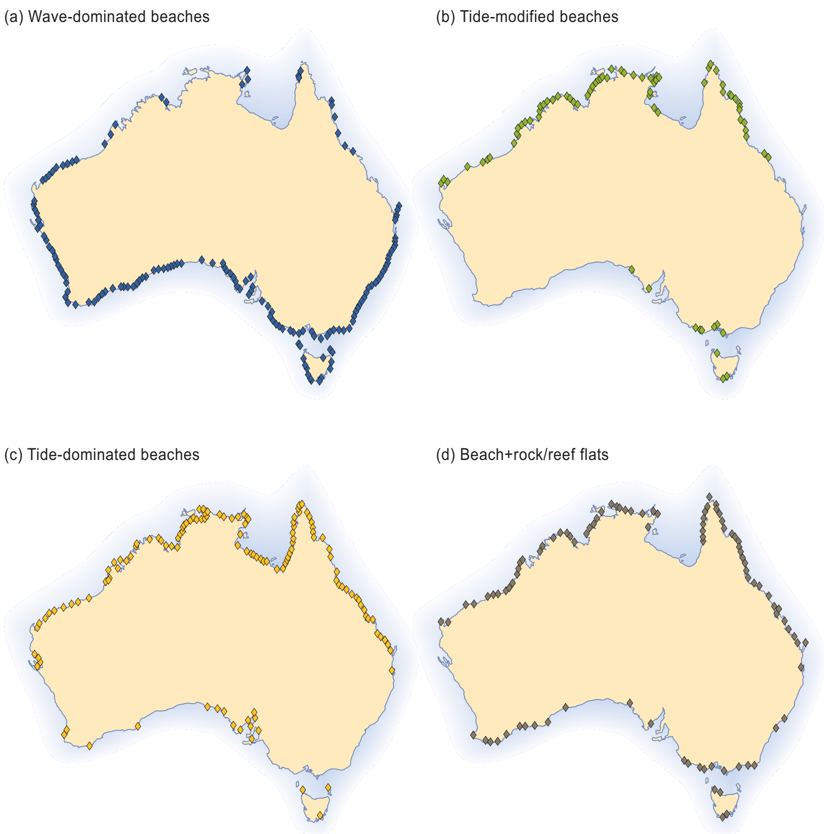

Figure 4.12 Distribution of the four major Australian beach types.
Source: Short and Woodroffe 2009; and OzCoasts[101]

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Box 4.6 Beaches: Important habitat for turtle nesting

Six of the seven species of marine turtles can be found nesting on sandy beaches around tropical and subtropical Australia, including the endemic flatback turtle Natator depressus. Females come ashore during the breeding season and lay their eggs in nests dug in the sand above the high water line. Young turtles hatch 45–70 days later and make their way to the sea.

Rising sea levels, increases in wave heights, coastal erosion and increased cyclone intensities may all increase the risk of tidal inundation of nests at higher beach levels and result in significant nest and egg loss. Sandy beaches are dynamic systems, undergoing continual processes of erosion and accretion as sea levels and ocean climate alter. As long as beaches can evolve naturally, there should be a continuum of nesting beaches for marine turtles on regional scales. However, beaches that are trapped in a coastal squeeze between human developments and climate change will be least resilient, especially considering the current recession of most sandy beaches globally.

A warming climate is likely to have significant impacts on marine turtles. Adult females can overheat while on land for nesting and the successful development of embryos occurs within a defined thermal range.[102] Similarly, the sex of turtle hatchlings is determined by nest temperature (more females are produced at warmer temperatures). Even small changes in temperature can result in large changes in the sex ratio of hatchlings. This suggests that warming of a couple of degrees Celsius, well within the warming expected over the coming century, could potentially result in some Australian beaches becoming 100 per cent female producing. In the worst case scenario, some tropical populations will decline and eventually become locally extinct. While further research is needed, it seems clear that a warming climate will affect turtle populations through changes in the sex ratios of hatchlings.

Marine turtles are long-lived and might not reach sexual maturity for many decades. A loss of nesting beaches and/or changes in sex ratios of hatchlings will have long-term impacts on the persistence of marine turtle populations. Protection of nesting beaches will be an management strategy to increase the capacity of marine turtle populations to adapt to climate change.

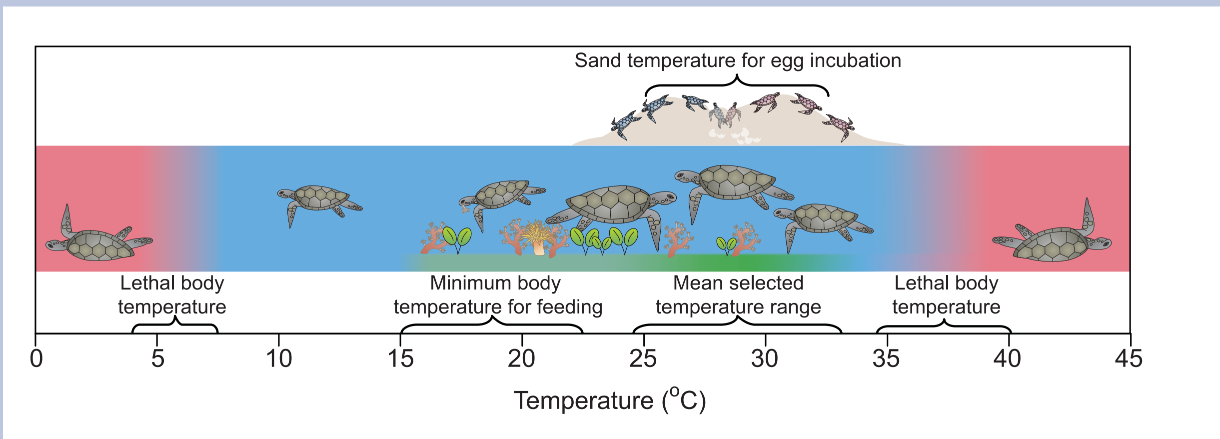

Figure 4.13 Operating temperatures for marine turtles. (Minimum body temperature for feeding – except for leatherback turtles). Source: GBRMPA 2007[103]

Photo credits: © Commonwealth of Australia (GBRMPA) ecological services, such as the filtration of large volumes of seawater, and the removal and recycling of nutrients, pollution and detritus from the system.[104] Endangered species such as sea turtles, fur seals and seabirds find critical habitats for breeding on Australian beaches.

Short identified 15 types of beaches around Australia: six wave-dominated types, three tide-modified types, four tide-dominated types, and two types in which rock flats or fringing coral reefs dominate the intertidal to subtidal zone.[105] Wave-dominated beaches prevail around the southern half of the continent, while tide-modified and tide-dominated types are more prevalent across the northern half (Figure 4.12). Beaches fronted by rock flats occur right round the coast, whereas those fronted by fringing coral reefs are restricted to the tropical northern half. Each beach type also differs with regard to a number of parameters, including breaking wave height, mean sediment grain size, and relative tidal range.

Increasing human populations in coastal areas are placing enormous stress on beaches globally and in Australia.[106] Beaches are trapped by a coastal squeeze between urban development on the land side and the impacts of climate change on the sea side. Unconstrained beaches can change shape and extent naturally in response to storms and variations in waves and currents.

With an increase in sea level and an increase in storm intensity, beaches are likely to erode and migrate inland. However, human modification of the coastal zone severely limits the flexibility of beach responses to climate change.[107] For many Australians, climate impacts on the nation's beaches will be experienced first hand through loss of property or access for recreation. Because natural shoreline retreat is today constrained along most developed coastlines by human infrastructure, it is likely that there will be future compression and loss of sandy beaches.[108] In recent years, coastal properties and infrastructure in south-east Queensland and northern New South Wales have been increasingly threatened by severe storms and the ensuing loss of beach width and habitat. Management actions such as beach nourishment, using sand sources from different habitats (lagoon entrance, off shore) will temporarily modify habitat conditions.

Habitat sensitivity to climate change

Beaches are the home to hundreds of species.[109] The largest and most mobile species spend only part of their time on beaches, either nesting or feeding there (for example, fish, seabirds, turtles). Resident species tend to be small, and subsurface. Beach communities are characterised by species adapted to a highly dynamic environment; these include microbes, primary-producing microscopic algae and invertebrates (mostly nematodes, crustaceans, polychaetes and molluscs). Total abundance (and productivity) of these organisms decreases with increasing size, while biomass follows the opposite trend.[110] Most is known about the macrofauna (organisms retained on a 1 millimetre mesh), whereas little is known about the meiofauna and microbes which are important in carbon cyclying. The remaining discussion therefore focuses on macrofauna.

In general, the species richness and abundance of beach communities are driven by a combination of physical processes that are best summarised by latitude, tidal range, sand-grain size and beach-face slope.[111] In this context, climate warming is likely to operate at the community level by decreasing the effective latitude, thereby increasing macrofaunal species richness, but decreasing total abundance.[112] In terms of community composition, warming would most severely affect those species living close to their upper thermal limit and especially those unable to acclimatise or adapt. Although Brown and McLachlan[113] expected temperature effects on beaches to be subtle, species lacking dispersive larval stages (for example, some crustaceans) could be at particular risk of extinction. Moreover, even dominant filter feeders such as bivalves (molluscs) on beaches can be highly sensitive to temperature change, which in some cases can result in mass mortalities, with dramatic consequences for community structure.[114]

If increased storminess contributes to the suspension of fine sediments and their offshore transport, the increase in mean grain size on beaches will result in declining abundance and species richness. This effect has been demonstrated on small scales, where coarse tailings from mining operations cause localised declines in community abundance.[115]

Declining ocean pH is likely to affect both the physical and the biological components of beaches, the latter because many sediments have high (often biogenic) carbonate fractions, and the former because many beach species have calcified exoskeletons (outer shells). However, due to a complete absence of studies, the magnitude of these effects remains unknown.

Finally, sea-level rise driven by climate change will affect beach communities through habitat loss and fragmentation, but this will be restricted largely to areas suffering from coastal squeeze. As sea-level rises, supralittoral habitats (ie habitats above the high tide mark) will be lost first,[116] eliminating fauna of greatest conservation concern, including turtles and birds.[117] Where habitats are lost, the unique fauna of the beach will be replaced by those of sea walls and surf zones, with concomitant changes in biodiversity and ecosystem functioning. Where large sections of beach are lost (for example, to protection of coastal strip development), it is possible that the source-sink dynamics between fine-grained, gently sloping beaches and coarse-sand, and steep beaches might be disrupted.[118] This would lead to further reductions in biodiversity on steep, coarse-sand beaches.

Many impacts considered here are based on expert judgement because of the lack of directed studies, but understanding of the consequences of interactions among climate-driven impacts is even more difficult. For example, increased storminess might result in greater nearshore mass of dislodged seaweed (or 'wrack'). Where wrack washes ashore, it provides food and microhabitats for supralittoral life forms, including insects and small cructacea called talitrid amphipods.[119] Yet the effects of warming, which might increase rates of wrack decomposition, could counteract these beneficial effects by reducing oxygen availability in the underlying sand.[120] Climate change could also result in the disruption of feeding and migration activities of beach clams through an increase in mobile wrack in the surf.[121] It is likely that the balance of these interactions will ultimately determine the consequences of climate change for beach communities, but understanding at this level remains elusive.

4.4 Conclusion

Climate change will drive changes to both landforms and habitat conditions in a range of coastal environments. Within each of the four broad coastal regions identified in this report, there is the potential for enhanced shoreline erosion, beach loss, saline inundation of wetlands, and modification of tidal systems for land-based areas. Oceanic, shallow seas and embayments are also likely to be affected by higher sea temperatures, acidification, and changing storm patterns.

Many environments are influenced by the impacts of non-climate forces such as urban development and nutrient supplies from agricultural lands. All these factors will interact in complex and to some extent unpredictable ways, requiring careful monitoring and adaptive management strategies to help minimize adverse impacts.

Coastal ecosystems likely to be most at risk from climate change include estuaries and associated wetlands, coral reefs, constrained tidal flat communities and beaches where there is a lack of sediment replenishment.

5

CHAPTER

CLIMATE CHANGE RISKS TO SETTLEMENTS AND INDUSTRY

Photo credit: Port of Melbourne Corporation

KEY FINDINGS

- Australia's residential population is exposed to the increasing hazards of climate change in the coastal zone:
  - Of the 711,000 existing residential buildings close to the water, between 157,000–247,600 properties are identified as potentially exposed to inundation with a sea-level rise scenario of 1.1 metres.
  - Nearly 39,000 buildings are located within 110 metres of 'soft' shorelines and at risk from accelerated erosion due to sea-level rise and changing climate conditions.
- The current value of existing residential buildings at risk from inundation ranges from $41 billion to $63 billion (2008 replacement value).
- The analysis for Victoria, Tasmania and New South Wales identifies inundation from an extreme event (1-in-100 year return period), which is consistent with the risk management concept in current planning guidelines. Where modelled storm tide for a 1-in-100 year event was not available, inundation from a modelled high tide event was assessed (Queensland, Western Australia, South Australia and Northern Territory).
- There are many facilities supporting the delivery of community services in close proximity to the coastline. They include 258 police, fire and ambulance stations, 5 power stations/sub stations, 75 hospitals and health services, 41 landfill sites, 3 water treatment plants, and 11 emergency services facilities which are located within 200m of the shoreline.
- The delivery of essential services such as electricity generation and wastewater management will increasingly be impacted by inundation, erosion, the effects of sea water intrusion into coastal freshwater systems and drainage systems, and increased corrosion.
- There are significant vulnerable communities in the coastal zone including Indigenous communities. The remoteness, and in many cases low elevation, of several island communities will also place them at risk.
- Coastal industries will also face increasing challenges with climate change, particularly the tourism industry, and will need to plan to manage projected risk.

5.1 Risks to built environment assets – a national overview

With most cities and much of Australia's industry in the coastal zone, a concentration of infrastructure in the region has emerged which over time has been exposed to natural hazards that have caused damage to property and infrastructure and loss of life.

Much of this infrastructure has been constructed without regard to climate change. Chapter 2 describes how climate change will bring higher sea levels, more intense extreme events and is likely to lead to a switching point beyond which stable coasts become eroding coasts. Such changes could impact heavily on parts of the built environment and could lead to disruption of supply of services and other social and economic impacts.

The risk to the built environment from climate change is clearly not just a function of the climate hazard. Risks also arise from the extent to which a society can anticipate and prepare for an impact, how the society and its assets respond to the impact itself, and the capacity for recovery after a discrete impact. For the built environment these aspects of risk relate to how well our planning systems constrain development in high-risk areas; the requirement of all construction to accord with design, engineering, construction and maintenance codes and standards; and the effectiveness of approaches to prepare for and recover after natural disasters.

This first pass assessment focuses particularly on risks to residential buildings from inundation and erosion. The method used is simple and is described in Chapter 3. The quantitative analysis identifies buildings likely to be impacted by either inundation or erosion from climate change; their capacity to withstand or recover from that impact is not assessed.

Managing risk from extreme events is not a new concept in planning guidelines; generally an extreme event has been defined as the risk from a 1-in-100 year event. Current planning guidelines require proposed developments located in coastal areas to manage risks from these events through siting and design features. In the analysis undertaken for this assessment inundation risk from an extreme event (a 1-in-100 year event) was assessed where modelled storm tide data for the whole state coastline was available (Victoria, New South Wales and Tasmania). For the other states where storm tide values have not been modelled, inundation risk was analysed for a sea-level rise of 1.1 metres with an allowance included for a modelled high tide event (as opposed to the 1-in-100 year event). This means for Queensland, Northern Territory, Western Australia and South Australia the risk from inundation modelled in this assessment is not the risk from a 1-in-100 year event. Future modelling for these states using 1-in-100 year storm tide data would be expected to increase the total number of residential buildings at risk.

While the first pass assessment does not spatially consider the risks from climate change to other types of infrastructure or to the provision of services, a qualitative summary of the implications of climate change for transport and essential services in the coastal zone is at section 5.2. Further information on coastal communities vulnerable to climate change is at section 5.3 and risks to coastal industry are described in section 5.4.

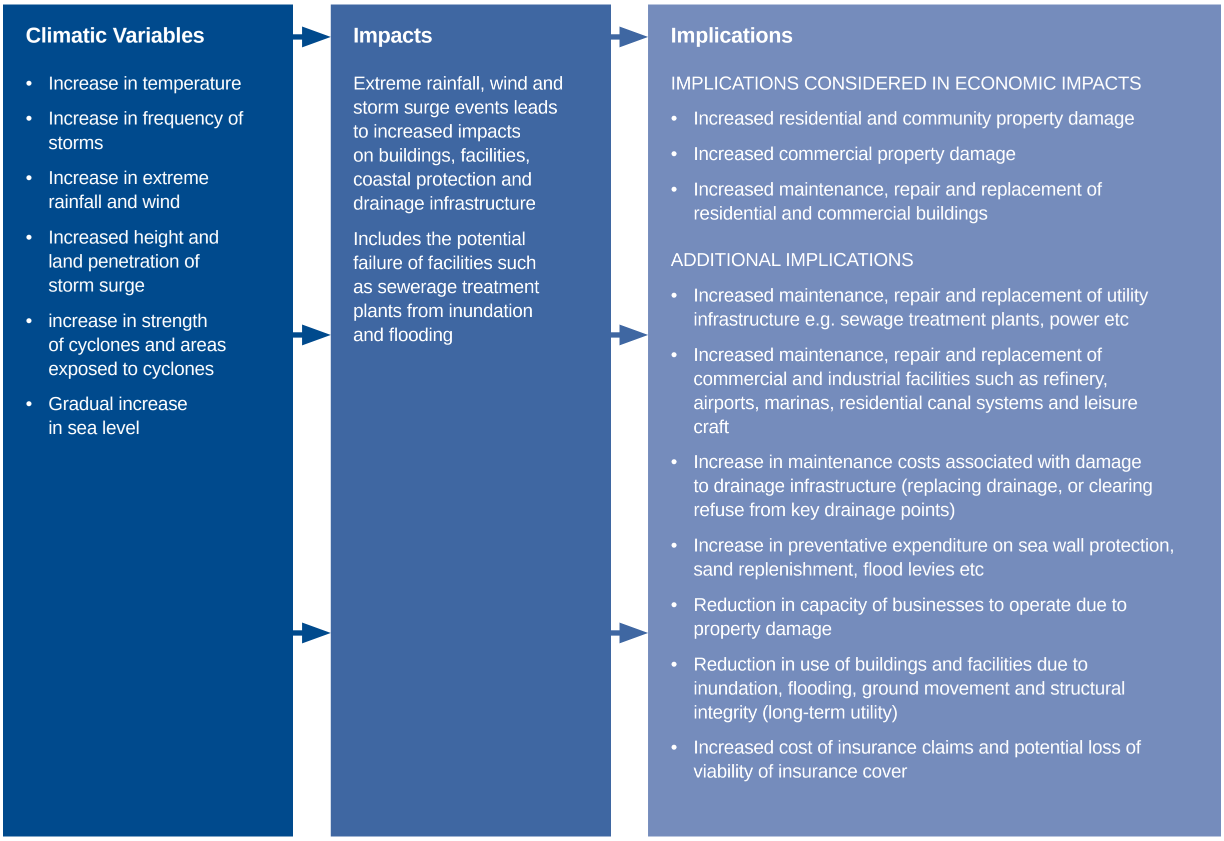

Figure 5.1 Impact storyline for buildings in coastal settlements commissioned by the Garnaut Climate Change Review. Note: The impact of cyclones on buildings has not been factored into the impacts of this study as it is being considered under a separate assessment of the Garnaut Climate Change Reivew. Source: Maunsell 2008[1]

5.1.1 Impacts of climate change on buildings in coastal settlements

As noted by the Parliamentary Committee Report *Managing our coastal zone in a changing climate: the time to act is now* of October 2009, there are 711,000 addresses sited within 3 kilometres and under 6 metres elevation of Australia's coast. Much of Australia's stock of commercial buildings, industrial facilities, airports, ports, hospitals, schools, and other economic and social infrastructure are also in close proximity to the coast.

The Garnaut Climate Change Review commissioned analysis of the impacts of climate change on coastal buildings using a number of scenarios. Figure 5.1 outlines the range of impacts and their implications identified in that analysis[2], many of which relate to property damage and increased costs of maintenance and repair in response to that damage. For most scenarios analysed, the magnitude of the impacts reached moderate to high levels in the period 2031–2070, and five of the seven scenarios predicted up to high or extreme impacts to coastal settlements by the end of this century.

Damage costs from extreme climate events in the coastal zone are already high. The total estimated cost of major floods, tropical cyclones and severe storms between 1967 and 1999 was $28.6 billion. This represented over 75 per cent of the total cost of natural disasters in Australia during that period.[3] As outlined in Chapter 2 climate change will increase the overall magnitude of such extreme weather events and in some cases will increase their frequency.

Cyclones are a regular feature across northern Australia and occasionally they have tracked further south. Cyclones that make landfall near coastal communities can be devastating. In March 2006 *Cyclone Larry* made landfall near Innisfail in north Queensland, with wind gusts of up to 240 km/hr. There was significant damage to coastal townships, infrastructure and crops, and flooding of coastal rivers.[5] The cost of insured losses alone was estimated at $540 million, with total damage costs estimated at more than $1 billion.[6] Modelling by Risk Frontiers[7] suggests that if the cyclone had directly impacted Cairns the insurance losses could have been in the order of $1.5–$4 billion, and up to $8 billion for a category 5 cyclone. Much of the damage (60–80 per cent) from the cyclone was to residential infrastructure built before the mid 1980's, after which time building standards in North Queensland were enhanced (Figure 5.2).[8]

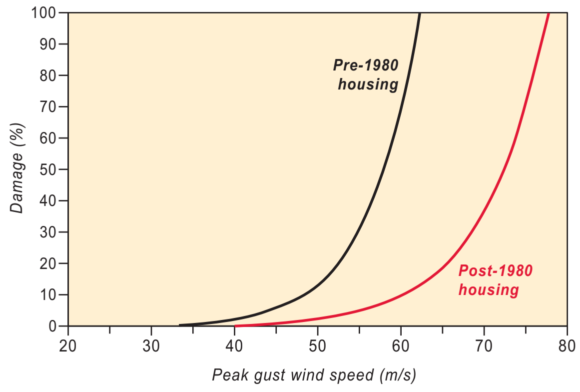

Figure 5.2 Impact of building code improvement on housing damage from wind gust. Source: Stewart and Li 2009[4]

Coastal areas generally are subject to greater impacts from extreme wind events than inland areas and climate change could increase the intensity of wind gusts. This could lead to a significant increase in damage to buildings as illustrated in Figure 5.3 where a 25 per cent increase in wind gust speed generates a 650 per cent increase in building damage. A preliminary study of the risk to buildings in Australia from extreme wind gust speeds found that building Standard specifications may not be adequate for Brisbane, Sydney and Perth when the combined hazard of cyclonic and non-cyclonic winds is considered.[9]

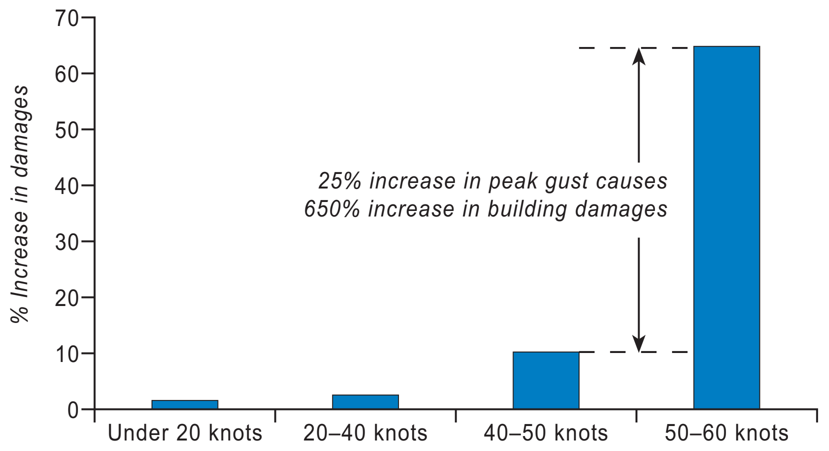

Figure 5.3 Increase in building damage as a result of increased wind gust speed. Source: Insurance Australia Group 2003[10]

Photo credit: Newspix/Angelo Soulas

Bulk carrier Pasha Bulka aground stranded off Nobbys Beach in Newcastle, 9 June 2007.

Australia's southern coastal areas are also vulnerable to the effects of extreme weather with severe storms that sweep south along both west and east coasts. East coast low systems dominate the east coast and across southern Australia, the passage of intense low pressure systems can also result in severe wave and wind damage. Between 1967 and 1999 the estimated cost of severe storms in Australia was over $9 billion, in large part due to the increasing coastal population density.[11]

The risks to natural and built assets associated with these events can be heightened when they occur in clusters and affect low-lying areas such as deltaic plains, estuaries and coastal lakes. These areas can be affected simultaneously by river floods and wave-driven storm surges. They are also particularly susceptible to erosion under high energy conditions causing dramatic shifts in shoreline position.

Box 5.1 Development in the Mandurah region, Western Australia

Mandurah has been one of the fastest growing areas in Australia over recent decades. Between 1986 and 2006, the built up area of Mandurah and the surrounding region, shown in Figure 5.4, increased by over 80 per cent and the population tripled. While the majority of development during that period was above 3m elevation, there was a more than 40 per cent increase in development in low-lying areas (below 3m), representing a quarter (23km^2) of the built up area in 2006.

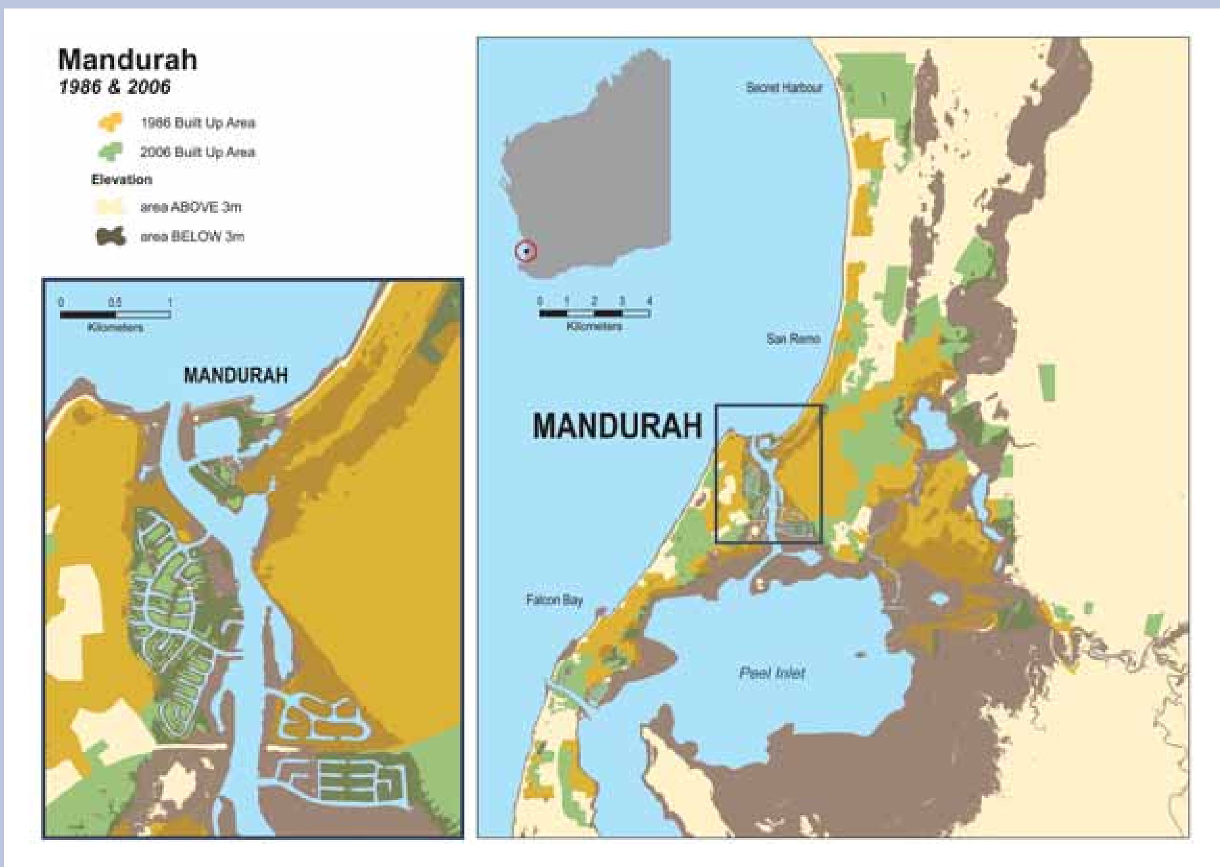

Figure 5.4 Mandurah development at 1986 and 2006 with elevation shown below and above 3 metres.
Source: Geoscience Australia 2009


Photo credit: Gosford City Council

Results of coastal erosion in Wamberal 1978.

This combination or cluster of extreme storms is usually associated with La Nina conditions. Clustering may occur over a period of one to four years as was the case from 1974 to 1978. The storms of 1974 generated widespread erosion along the entire eastern seaboard. The lack of beach recovery in the next few years allowed for further house destruction in a storm in 1978.

The risk of damage to settlements from a climate event and climate change is also due to the number of buildings exposed to that event. Over the past few decades there has been rapid growth in many Australian coastal settlements including the emergence of the Gold Coast and other new coastal cities and towns.[12] Box 5.1 below shows the extent of recent development in Mandurah, Western Australia. In this area there has been substantial development since 1986 in low-lying areas. As described in Chapter 1 the sea change phenomenon is expected to continue into the future, and as a result coastal risk is likely to continue to increase.

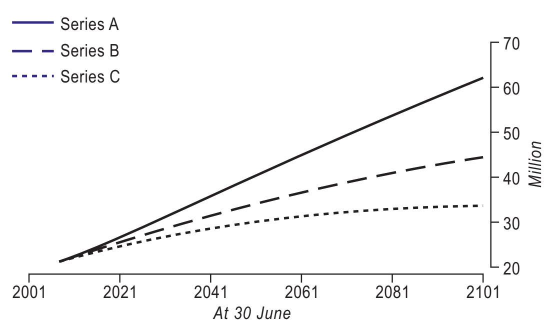

Figure 5.5 Population growth projections for Australia 2008–2101. Series B largely reflects current trends in fertility, life expectancy at birth, net overseas migration and net interstate migration, while Series A and Series C are based on high and low assumptions for each of these variables respectively.
Source: ABS 2008[13]

Australia's population, which was estimated at 21 million in mid-2007, is projected to increase significantly. The Australian Bureau of Statistics has forecast an increase to between 30.9 and 42.5 million people by 2056, and to between 33.7 and 62.2 million people by 2101 (see Figure 5.5).[14] These projections are based on the growth and change in population based on current fertility, mortality, internal migration and overseas migration, with an extrapolated 'high' and 'low' scenario. The combination of global climate change and global population pressures may lead to successive Australian governments accepting more overseas migration. Recently, a new Intergenerational Report being prepared by the Australian Government has projected that Australia's population will grow by 65 per cent to reach over 35 million people in 2049.[15] Based on current trends much of this growth would be accommodated in coastal settlements and cities.

5.1.2 National estimate of residential buildings at risk

As noted above, it has been estimated that approximately 711,000 addresses are located within 3 kilometres of the shore and in areas below 6 metres, with more than 60 per cent of those addresses located in Queensland and New South Wales.[16] This analysis also found that the majority of those addresses are adjacent to sea-connected coastal waters, alongside lakes or lagoons, river banks and estuaries, rather than directly facing the open ocean.

The inundation analysis for this report has refined the above estimate, and has identified between 157,000 and 247,600 existing residential buildings at risk of inundation with a sea-level rise of 1.1 metres. New South Wales has the greatest exposure (between 40,800–62,400 residential buildings at risk) followed by Queensland (35,900–56,900), Victoria (27,600–44,600), South Australia (25,200–43,000), Western Australia (18,700–28,900), Tasmania (8,700–11,600) and the Northern Territory (up to 180) (Figure 5.6). Storm tide estimates (for a 1-in-100 year event) were included in the analysis for New South Wales, Victoria and Tasmania only. For other states only modelled high water level was included in the analysis, so actual exposure to extreme events would be expected to be higher.

The current replacement value of existing residential buildings at risk from inundation ranges from $41 billion to $63 billion. The replacement value data and the number of buildings at risk are drawn from the National Exposure Information System database.

Estimates of residential buildings at risk of inundation are based on current assets only. Given projections that Australia's population could double by 2100 (Figure 5.5), significantly increased exposure of coastal assets would occur in the future in the absence of adaptation measures.

Soft shorelines prone to instability were also identified, based on shoreline characteristics in the National Coastal Geomorphology Mapping (Chapter 3). Nationally, nearly 39,000 residential buildings are located within 110 metres of potentially erodible shorelines, with nearly 40 per cent of those buildings located in Queensland (see Figure 5.7). It should be noted that there was no consideration of existing protective structures in this assessment.

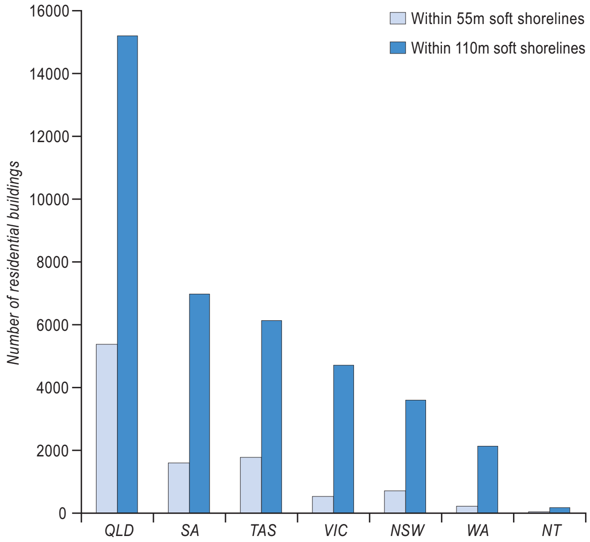

Figure 5.7 Number of residential buildings located within 55 and 110 metres of 'soft' coastlines.[17]

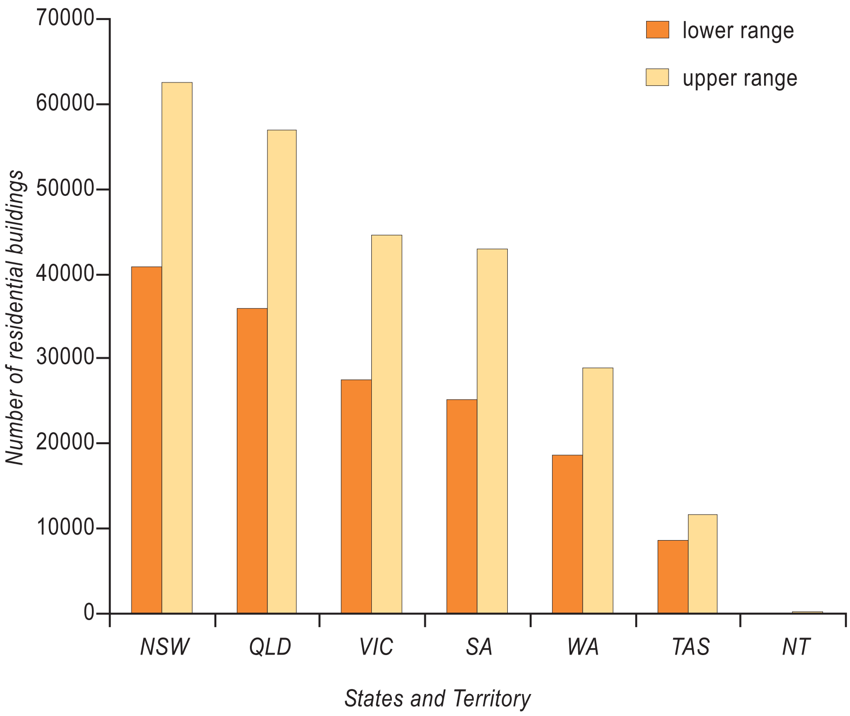

Figure 5.6 Estimated number of existing residential buildings at risk of inundation from a sea-level rise of 1.1 metres (including 1-in-100 storm tide for New South Wales, Victoria and Tasmania, and high tide event for other states and the Northern Territory).

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5.1.3 New South Wales

Key findings

- Between 40,800 and 62,400 residential buildings in New South Wales may be at risk of inundation from a sea-level rise of 1.1 metres and storm tide associated with a 1-in-100 year storm.
- The current replacement value of the residential buildings at risk is between $12.4 billion and $18.7 billion.
- Local government areas (LGA) of Lake Macquarie, Wyong, Gosford, Wollongong, Shoalhaven and Rockdale represent over 50 per cent of the residential buildings at risk in New South Wales.
- New South Wales has fewer residential buildings located within 110 metres of 'soft' erodible shorelines than many other states. There are approximately 3,600 residential buildings located within 110 metres and 700 buildings within 55 metres of 'soft' coast.

The population context

New South Wales is home to almost one third of Australia's population with nearly seven million residents.[18] Over 60 per cent of the population (4.4 million) lives in Sydney[19], Australia's most populated city. The coast is also home to a large share of the population, with about 20 per cent (1.38 million people) living in coastal local government areas beyond the Sydney region. All of the coastal LGAs have continued to increase in population over recent years, with a third experiencing growth rates higher than the state average in 2007–08.[20] The LGA of Tweed on the New South Wales-Queensland border experienced both the highest rate of growth and the largest population increase of the coastal LGAs in the year to June 2008. Wollongong, Lake Macquarie and Newcastle also experienced large population increases, while high growth rates were recorded in Port Macquarie-Hastings, Coffs Harbour, Shellharbour, Byron and Ballina.[21]

Photo credit: A.D. Short

Lake Conjola.

Photo credit: A.D. Short

The nature of the coast

About a third of the state's open coast comprises hard rock coast, most of which is robust sloping rocky shores, although cliffs are present in the Sydney region and near Jervis Bay. These cliffs are subject to occasional rock falls onto their adjoining rock platforms or waters below the cliff face.[22]

Sandy coasts comprise nearly half (45 per cent) of the open coast, and the majority of these are backed by soft sediment plains which imply a potential for coastal recession and sustained frontal dune erosion with sea-level rise. Shallow flood-tidal deltas at the mouths of the numerous estuary mouths and the entrances of intermittently closed and open coastal lakes and lagoons are highly sensitive to changing wave and tidal conditions.

Muddy and soft-rock shores are only a minor feature of the state's open coast, however these types are likely to be major shoreline types within the estuaries and tidal lagoons of the coast.[23]

Existing risk

East coast lows generate severe beach and fore dune erosion, storm surges across flood-tide deltas into estuaries, as well as severe wind damage along the coast. In northern New South Wales, tropical cyclones have similar impacts. Flooding of low-lying agricultural lands and towns also occurs with these events.

The flooding event of 2007 in the Newcastle area highlights the economic and social impacts from riverine flooding, coincident with a major coastal storm (Box 5.2). In the Newcastle LGA, some 5,000 cars were written off and 10,000 properties inundated.[24] Fortunately the peak rainfall event in Newcastle in 2007 coincided with low tidal (neap) conditions[25] so there was not also the flooding impact associated with a storm surge. The same event, one week either side, would have resulted in far worse flooding throughout the low-lying suburbs around the harbour.

New South Wales is already known to have localised areas of erosion, such as in Byron Bay (Belongil Beach).

5

Box 5.2 Newcastle flood planning

Newcastle experienced severe flooding in 2007 when heavy rainfall caused flash flooding over vast areas of the city. Flood depths reached 1.8 metres affecting about 10,000–15,000 properties with more than 1,000 inundated above floor level. Grounding of the MV Pasha Bulker on Nobby's Beach also occurred due to this intense storm.

Newcastle City Council's research modelling and floodplain planning undertaken over a number of years was confirmed by this storm event. Some areas where flooding had not been experienced in living memory, but where computer modelling before the 2007 event predicted potential flood risks, were unfortunately profoundly affected by the 2007 flash flooding. The same modelling also predicts flash flooding could be significantly more severe than that experienced in 2007.

As well as documenting the long history of flooding in the Newcastle LGA, the models predict severe potential risk from flash flooding, riverine flooding and flooding from ocean inundation. The small and steep catchments around Newcastle mean that rainfall is channelled very quickly onto the floodplain with very little warning. Add this to a legacy of development on the floodplains, means the flood exposure of properties within the Newcastle area is high, with estimates of about 22,000 properties (or 1 in 3 lots) potentially affected by all types of flooding – including ocean flooding.

Sea level flooding is considered more manageable than flash flooding. It is estimated some 3,000 properties could be at risk of flooding from a moderate storm surge event on top of a sea-level rise of 0.9 metres. A worst case scenario from sea flooding could affect more than 4,500 properties (Figure 5.8). Risk to life is more manageable for sea level flooding, since it appears that there would be sufficient warning to evacuate people to high ground. Options being considered to manage sea level flooding include voluntary purchase and relocating properties, while recognising there may be significant inherent barriers to implementation such as community acceptance and unfavourable cost-benefit outcomes.

Concept planning for all forms of flooding has indicated that city-wide, the economic cost of retreating from high risk to life and very frequent inundation exposure could be about $2 billion. A concept flood planning approach for all the types of flooding has been developed which accepts some risks, and promotes shelter in place for flash flooding where feasible. This approach is estimated to cost about $200 million, and is being developed by Council into a city-wide Floodplain Risk Management Plan by 2011. More information can be found on Council's web site (www.newcastle.nsw.gov.au)

Source: BMT WBM 2009[26]

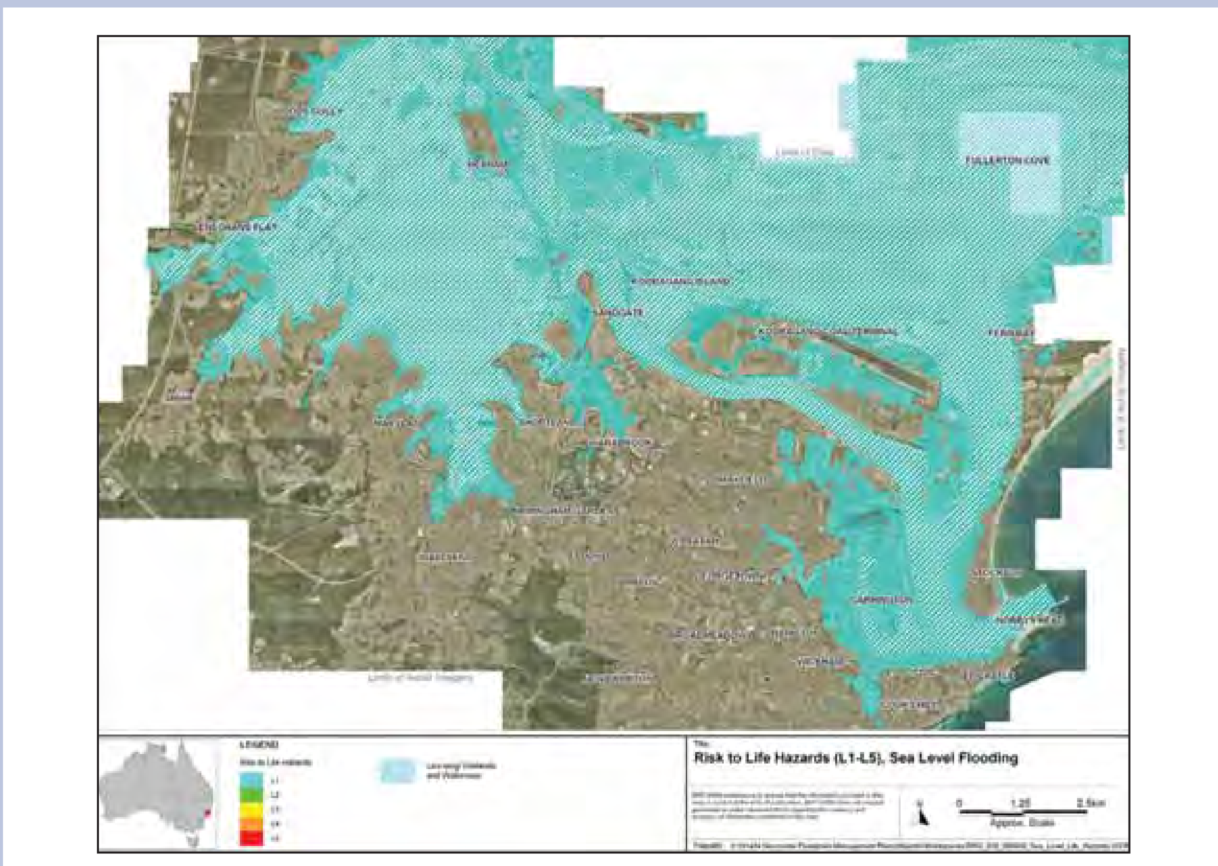


Figure 5.8 Extent of inundation from probable maximum sea flooding. Source: BMT WBM 2009.

During the 1974 storms (estimated as a 1-in-200 year event), extensive erosion occurred along the coastline. The Manly pier inside Sydney Harbour was destroyed and there was loss and damage to coastal property.[27] At Collaroy Beach in Sydney's northern suburbs, inappropriate coastal development over the last 100 years along the narrow beach has resulted in an ongoing history of erosion and property damage. Many affected properties in the area are now fronted by sea walls with the council also buying back at-risk properties.[28]

With an increasing frequency of high sea level events expected over the coming decades, the impact at localised 'hot spots' may increase in frequency and it is likely that new 'hot spot' areas will emerge over time. During 2009, Old Bar, near Taree has experienced erosion of beach front properties leading to appeals for government assistance.

Climate change risk to settlements

Inundation analysis suggests that between 40,800 and 62,400 residential buildings in New South Wales may be at risk of inundation from a sea-level rise of 1.1 metres and storm tide associated with a 1-in-100 year storm. The current replacement value of the residential buildings at risk is between $12.4 billion and $18.7 billion.

Based on this analysis, New South Wales has the highest number of residential buildings at risk of inundation around the Australian coastline. However, it should be noted that storm tide was only incorporated into the analysis for New South Wales (excluding wave setup), Victoria and Tasmania.

Photo credit: Newspix/David Clark

Severe beach erosion along Belongil Beach at Byron Bay, May 2009, where many metres of sand were washed away.

Photo credit: Newspix/Craig Greenhill

Collaroy Beach.

Methodology – key points and caveats

- Inundation analysis is based on 1.1 metres of sea-level rise using medium resolution elevation data.
- A *storm tide allowance* (1-in-100 year event) based on CSIRO modelling is included in the analysis for Tasmania, Victoria and New South Wales, although storm tide values for New South Wales are likely to be underestimates as they do not include a wave setup component.
- For the other states where the CSIRO modelling was not available (Queensland, Western Australia, Northern Territory, and South Australia) an allowance for *modelled high water level* (e.g. high tide) was included in the analysis.
- The analysis does not take account of existing coastal protection, such as seawalls, or riverine flooding associated with intense rainfall events.
- The inundation analysis is of existing residential buildings only (sourced from NEXIS database).
- More detailed analysis may change the relative order of local government areas and the magnitude and timing of projected impacts.
- Refer to Chapter 3 for further details.

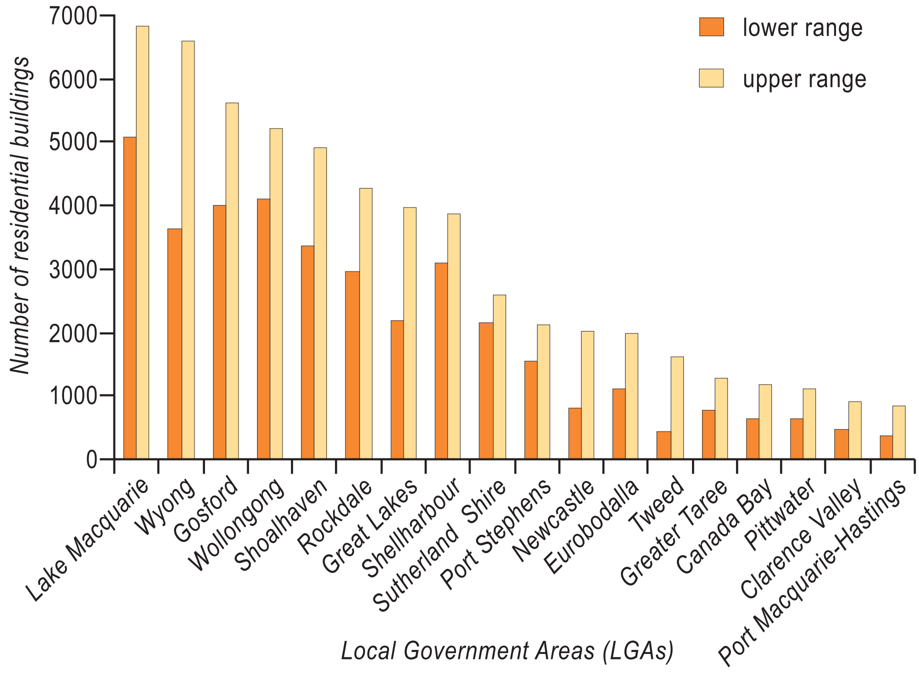


Figure 5.9 Estimated number of existing residential buildings in New South Wales at risk of inundation from a sea-level rise of 1.1 metres and a 1-in-100 year storm tide.

Local government areas that have the greatest level of risk are Lake Macquarie, Wyong, Gosford, Wollongong, Shoalhaven and Rockdale, which collectively represent over 50 per cent of residential buildings at risk in New South Wales (upper range; Figure 5.9). Inundation footprints of some regions are shown in Figures 5.10–5.12.

Between 5,100 and 6,800 buildings in the LGA of Lake Macquarie may be affected by sea-level rise and storm tide inundation by 2100, with the upper range representing around 10 per cent of the current residential building stock. This number is comparable to the results of topographical mapping of coastal and estuarine regions by the New South Wales Department of Planning[29], which found some 6,500 addresses on the Lake Macquarie waterway foreshore below 2.5 metres AHD and at risk of inundation by 2100 from the combination of sea-level rise and flood (Box 5.3).

Lake Macquarie, together with Wyong and Newcastle, was also included in an assessment in 2009 of the implications of sea-level rise and flood events for the Hunter and Central Coast region of New South Wales.[30] This study identified areas of residential, commercial and industrial assets in the Hunter and Central Coast region as at risk to sea-level rise by 2030 and 2070. The study also highlighted a threshold risk; sea-level rise combined with a storm event could potentially result in a total breach of certain sand dune areas by 2070, causing significantly higher damage to ecosystems and infrastructure (see Box 5.4).

The inundation analysis (Figure 5.9) also indicates that the LGAs of Great Lakes, Rockdale (bordering Botany Bay) and Shellharbour have a high proportion of existing residences at risk within their boundaries, with a substantial 18–20 per cent of existing buildings potentially affected by 2100 (upper range estimate).

The vulnerability of Rockdale to sea-level rise and other climate change factors was highlighted in a recent study by the Sydney Coastal Councils Group. This study *Systems approach to regional climate change strategies in metropolises* focused on the capacity of the 15 councils to adapt to climate change (see Box 5.5). The study identified spatially areas within the LGA boundaries that were vulnerable to climate change risks, including from sea-level rise and storm surge events. The Rockdale LGA, situated on the edge of Botany Bay, features as particularly vulnerable to the future impacts of sea-level rise. Sydney airport, which is located within the Botany Bay local government area, has an increased risk of inundation with climate change (see Box 5.14).

Figure 5.10 Images of Port Stephens in 2009 and with simulated inundation from a sea-level rise of 1.1 metres and a 1-in-100 year storm tide using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD

Figure 5.11 Images of Narrabeen/Collaroy (Pittwater LGA) in 2009 and with simulated inundation from a sea-level rise of 1.1 metres and a 1-in-100 year storm tide using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD

Figure 5.12 Images of Tweed Heads in 2009 and with simulated inundation from a sea-level rise of 1.1 metres and a 1-in-100 year storm tide using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD

Erosion due to higher sea levels is also a key risk for coastal areas. In New South Wales there are approximately 3,600 residential buildings located within 110 metres of 'soft' erodible shorelines, of which approximately 700 are located within 55 metres of 'soft' coast. Of the coastal LGAs, Sutherland and Port Stephens have the highest number, with approximately 650 residential buildings within 110 metres of 'soft' shorelines in both local government areas, and about 170 and 220 within 55 metres, respectively (Figure 5.13). Similarly, Shoalhaven (~380), Eurobodalla (~300), Rockdale (~280) and Byron (~160) have a relatively high number of residential buildings within 110 metres of 'soft' coast, with Eurobodalla also having almost 70 buildings within 55 metres. In the absence of coastal protection measures or other adaptation strategies, these buildings are likely to be at risk of increased erosion with sea-level rise and storm surge due to their location and the nature of the shoreline.

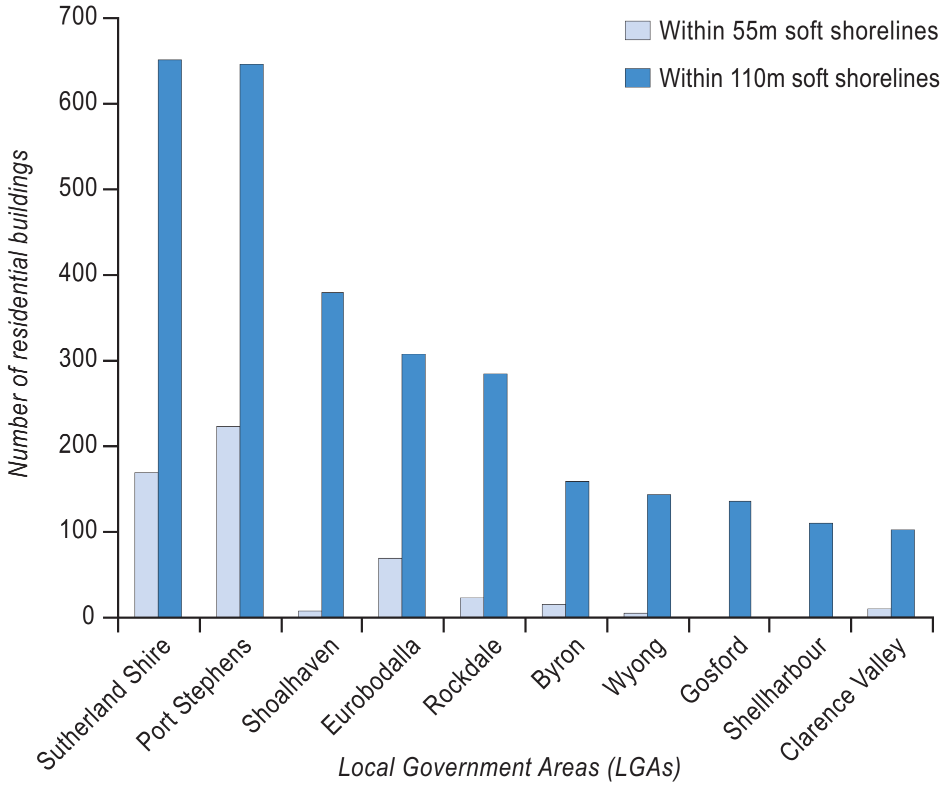


Figure 5.13 Number of residential buildings located within 55 metres and 110 metres of 'soft' shorelines in New South Wales.

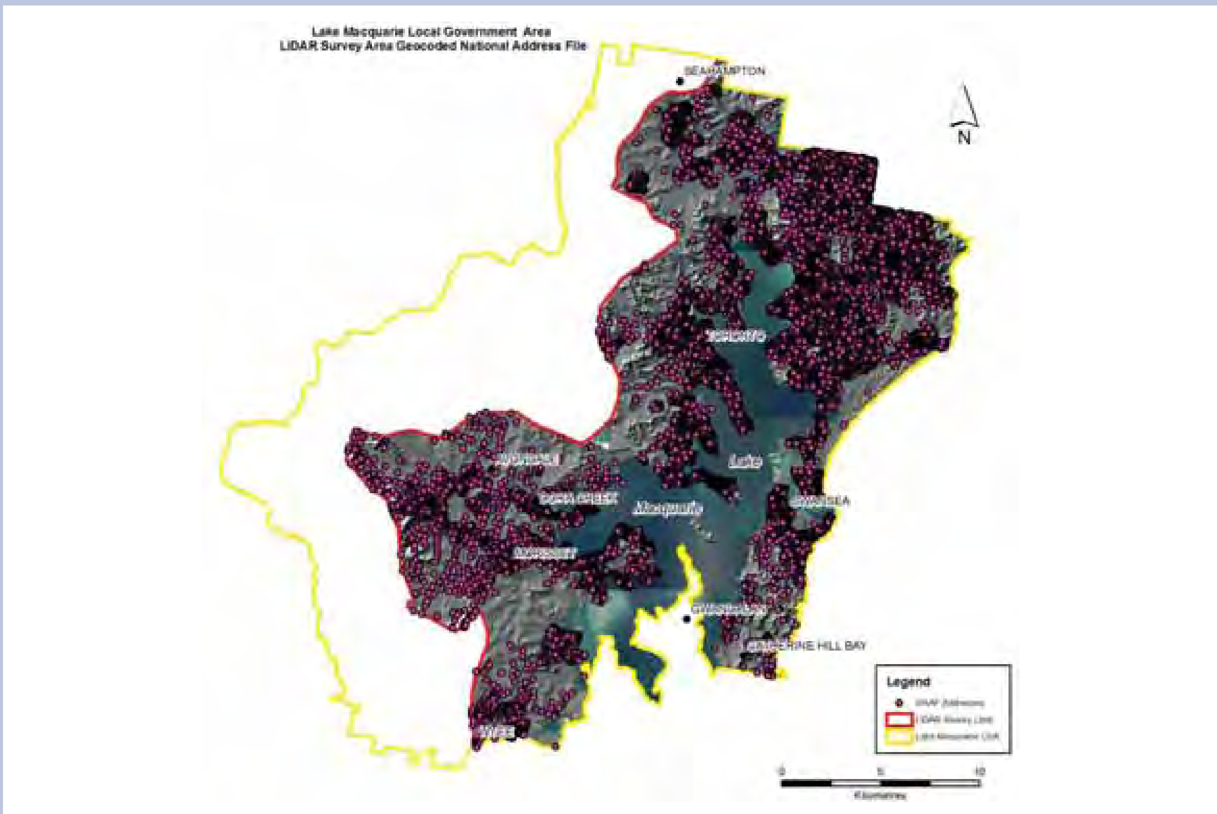
Box 5.3 Lake Macquarie – an example of sea-level rise and adaptation planning

Lake Macquarie City Council used the results of the New South Wales Department of Planning LiDAR (Light Detection and Ranging) survey of the Hunter and Central Coast region[31] to support a proactive adaptation approach to planning for sea-level rise for the City.

The LiDAR data provided highly accurate (±15 centimetres vertical accuracy) topographical mapping for coastal and estuarine areas between zero and 10 metres AHD. By overlaying topographical data with other spatial data, it was possible to make a first pass estimate of the potential impact of sea-level rise on built and natural assets. For example, it indicated that more than 6,500 addresses on the Lake Macquarie waterway foreshore were below 2.5 metres AHD (Figure 5.14), the approximate height of a 1-in-100 year flood event combined with sea-level rise by 2100. Similar overlays for infrastructure (roads and railways) and ecosystem types (including wetlands) indicated the need to plan for anticipated sea-level rise.

Council's approach to climate change has involved adopting a sea-level rise planning level of 0.91 metres by 2100, which is consistent with the figure of 0.90 metres contained in the draft state government Sea-Level Rise Policy (April 2009).

Council has adopted the 0.91 metres figure to develop decision and support tools for planning and development assessments in the City, ensuring a progressive adaptation to sea-level rise. Planning and development decisions made now will still be ‘in effect’ in 50 to 100 years, which places a duty of care on Council to plan for the future, based on the best available information. The proposed rate for sea-level rise allows Councillors, Council staff, and the community to develop policies, carry out more detailed studies, and make planning and development decisions that are suitable for the predicted change in conditions.



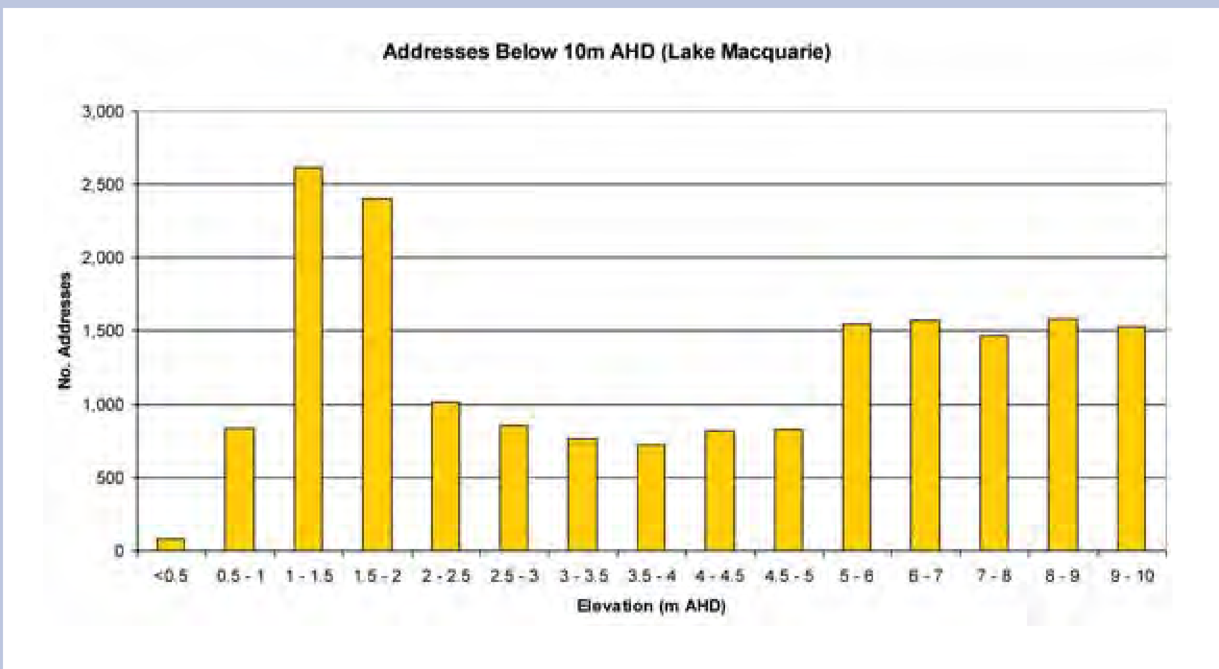


Figure 5.14 Distribution of addresses in LiDAR survey area of Lake Macquarie City LGA (above), and the number of addresses by elevation below 10m AHD for the mapped area. Source: NSW Department of Planning 2008[32]

Box 5.4 Hunter and Central Coasts – coastal vulnerability assessment

An assessment of the implications of sea-level rise and 17 flood events on human settlements, infrastructure and land use planning, as well as for estuaries, their foreshores and ecosystems, was undertaken in mid-2009 for the Hunter and Central Coast region.

Photo credit: Photolibrary

Aerial view of Newcastle.

The study examined climate projections for the years 2030 and 2070 (assuming a sea-level rise of 14.6 centimetres by 2030 and 47.1 centimetres by 2070) and analysed ecological, economic and social vulnerability. Each of the three areas of vulnerability were then mapped onto a spatial layer to allow an analysis of potential synergistic or cumulative effects for particular locations and regions.

Considerable areas of future human built environments (residential, commercial and industrial) were identified as potentially at risk of exposure to sea-level rise and increased storm rain intensity and flooding. If town planning were to continue on a business as usual basis, vulnerability would rise as follows:

Local Government Area (LGA)	2030 area vulnerable to sea-level rise and flood extremes	2070 area vulnerable to sea-level rise and flood extremes
Newcastle	4969 ha or 50% of the built area	5456 ha or 49% of the built area
Lake Macquarie	2022 ha or 11% " "	2491 ha or 11% " "
Wyong	3399 ha or 22% " "	5029 ha or 24% " "

The compounding effects of intensity of rainfall, storm events and flooding accompanying sea-level rise are likely to be responsible for most of the damage to the urban built environment, rather than sea-level rise acting alone. Gradual sea-level rise would permit adaptive responses by managers, allow the property market to price in risk and minimise the threat of serious damage. This conclusion does not hold if sea-level rise is abrupt.

Ecological communities including mangroves, coastal heaths, coastal banksia, scribbly gum and paperbark forests were also identified as vulnerable to sea-level rise combined with extreme storm events.

The coastline along the Hunter and Central Coast region is also characterised by significant stretches of sandy beaches that are exposed to wind and waves. The study noted that several coastal beach dune areas are susceptible to beach recession by 2070; with beaches such as Stockton Beach, Belmont Beach, Caves Beach, Catherine Hill Bay, Budgewoi Peninsula Beach, The Entrance, North Beach and Shelley Beach all noted as vulnerable. Additionally, a threshold risk of sea-level rise combined with a storm event potentially causing a total breach of a dune area was noted, which could cause significantly higher damage to ecosystems and infrastructure.

Major social vulnerabilities identified included nursing homes especially at Sandgate, a hospital at Morriset, relocatable home parks at Swansea, Chain Valley Bay and Bonnells Bay, housing commission neighbourhoods, new suburbs in Maryland and Woongarrah, the residential area of north Toukley and retirement villages at Canton Beach, Bonnells Bay, Wyee Point and Belmont.

Adaptive planning can reduce future settlement vulnerability. Most Councils have implemented some predictive and precautionary revisions to planning schemes and processes. Well structured adaptive planning was shown to reduce the potential for future damage to urban areas by as much as 46 per cent.

Source: Brunckhorst et al. 2009[33]

5

Box 5.5 Sydney Coastal Councils Group

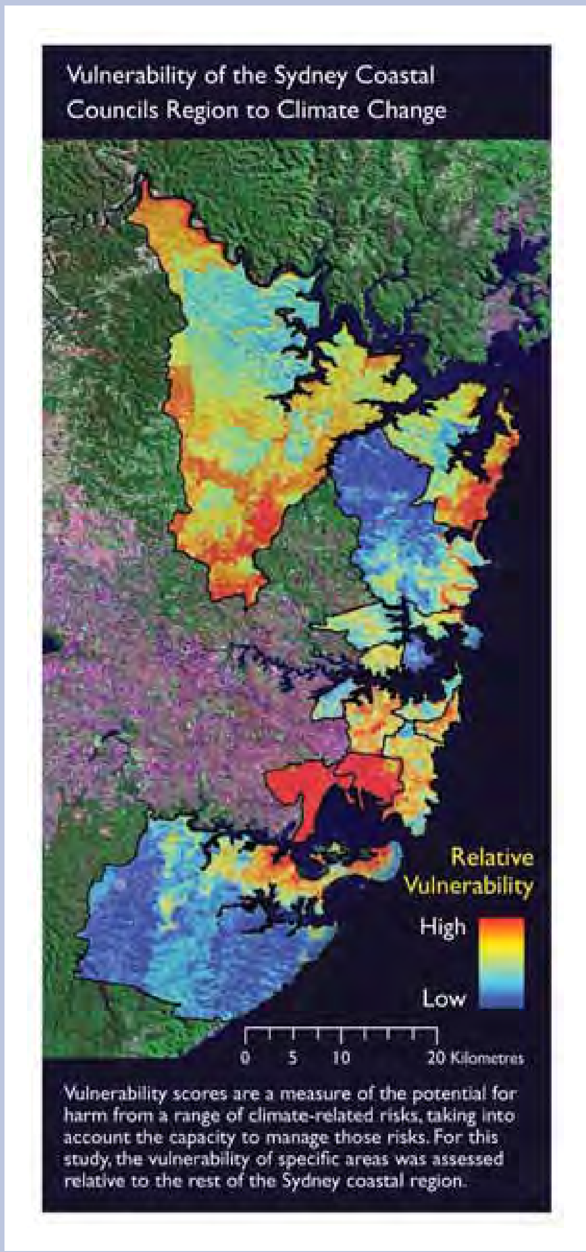
The *Systems approach to regional climate change adaptation strategies in metropolises* project focussed on the capacity of 15 Sydney coastal councils to adapt to climate change. Stage 1 of the project involved the assessment and mapping of climate change vulnerability throughout the region. The assessment was based on potential climate impacts including:

- sea-level rise and coastal hazards
- extreme rainfall and urban stormwater management
- extreme heat and human health effects
- bushfire
- natural ecosystems and assets.

These were assessed against three main groups of exposure, sensitivity and adaptive capacity indicators. The study found that overall the inner city councils of Botany Bay, Leichhardt, North Sydney, Randwick, Rockdale and Sydney, had the highest levels of climate change vulnerability. Sea-level rise was a key driver of risk for the Botany Bay, Leichhardt, Manly, Rockdale and Sydney councils, all of which were considerably more vulnerable than the average.

The vulnerability for each local government was spatially variable because of different levels of climate exposure, higher sensitivity to damage and/or a limited capacity to adapt with almost every Council having at least one impact area to which it had a high degree of vulnerability. Interestingly the study found that demographics, socio-economic conditions and response capabilities are often equally, if not more, important than biophysical hazards, in determining the level of vulnerability to climate change and the potential for harm.

The study identified that the most common barriers to managing climate change included differing levels of community social capital; perceptions of risk and knowledge; the need for infrastructure risk appraisal; planning and development; and existing decision-making processes.



This project was recently awarded the 2009 Eureka Award for 'Innovative solutions to climate change'.

Further information on the project is available at www.sydneycoastalcouncils.com.au

Source: Preston et al. 2008[34]

5.1.4 Queensland

Key findings

- Between 35,900 and 56,900 residential buildings in Queensland may be at risk of inundation from a sea-level rise of 1.1 metres.
- Based on this analysis, Queensland has the second highest number of residential buildings at risk in Australia. However, inundation analysis for Queensland does not include storm tide associated with a 1-in-100 year storm, which would increase the area of exposure.
- The current replacement value of the residential buildings at risk is between $10.5 billion and $16 billion.
- Local government areas (LGA) of Moreton Bay, Mackay, the Gold Coast, Fraser Coast, Bundaberg and the Sunshine Coast have the highest level of risk, collectively representing almost 85 per cent of residential buildings at risk of inundation.
- There are approximately 15,200 residential buildings located within 110 metres of 'soft', erodible shorelines, of which approximately 5,400 are located within 55 metres of 'soft' coast.

The population context

In the five years to June 2008, Queensland experienced the highest population growth (total increase in population and rate of increase) compared to any other state or territory in Australia.[35] During this period, the state's population increased by almost 485,000 people. This was largely attributed to growth in south-east Queensland, which represented 69 per cent of the state's population increase.[36] A longer-term demographic trend over the last 4–5 decades has led to new towns and cities being established in the region along the coast, most notably the Gold Coast and Sunshine Coast.[37]

With the exception of capital cities, coastal areas have shown the greatest population growth in Australia over recent years.[38] In the year to June 2008, the Gold Coast, Moreton Bay and the Sunshine Coast experienced the largest population increases (after Brisbane) in Queensland. Of the coastal LGAs beyond the south-east region, Cairns had the highest rate of population growth and the largest increase in population. Townsville and the Fraser Coast (including Hervey Bay) also recorded large population increases.[39]

The IPCC AR4 has noted that population growth and associated coastal development, particularly in south-east Queensland and Cairns, will exacerbate risks from climate change.[40]

The nature of the coast

Queensland generally has a very high proportion of open sandy coasts (73 per cent), and in particular sandy coasts backed by soft sediment plains (45 per cent), of which some proportion may include a muddy component. These shores are potentially at risk of significant recession with sea-level rise, and give Queensland coasts a high vulnerability to this type of shoreline instability, especially around shores of large coastal bays (e.g. Moreton, Hervey).[41]

Rocky shores are generally a minor component of Queensland coasts compared to other states, although significant rocky coasts that are resilient to erosion are found in areas such as the Whitsunday Islands and Hinchinbrook Island.

Coral coasts (including fringing coral reefs) are a significant feature of the Queensland coast, but have not been considered here because the Great Barrier Reef was not included in the initial National Coastal Geomorphology Mapping. However, shoreline erosion of islands (sand cays) in the Great Barrier Reef region is highly likely under sea-level rise.[42]

Photo credit: William Prince Collection and DEWHA

Erosion along the Gold Coast in 1967.

Photo credit: © Commonwealth of Australia (GBRMPA)

Heron Island.

Photo credit: Peter Otto, Bureau of Meteorology

Damage to houses in Innisfail, Queensland caused by Tropical Cyclone Larry.

Existing risk

Coastal areas in Queensland are already exposed to natural hazards; while tropical cyclones are the main coastal hazard for low-lying lands along the Queensland coast, the occasional occurrence of east coast lows off the southeast section of the state during winter months can also have devastating impacts, as in 1967. Major cyclone, flood and storm events between 1967 and 1999 (approximately 70 events in total) cost Queensland almost $8 billion (1998 dollar estimates).[43] In 2006, damage costs from Cyclone Larry were estimated at more than $1 billion.[44] The Brisbane floods of 1974, the cluster of cyclones and east coast low storm events in 1967 that led to massive erosion along Gold Coast beaches, and Cyclone Larry are some of the most well known extreme climate events in Queensland's recent history.

An average of 1.2 cyclones per year occur within 500 kilometres of Brisbane.[45] A risk assessment of south-east Queensland[46] identified over 9,500 properties at risk of over-floor inundation from a 1 per cent annual exceedance probability (AEP) (1-in-100 year) storm tide event associated with a cyclone. The estimated number of developed properties at risk from inundation from a more severe 0.1 per cent AEP (1-in-1000 year) storm tide event was close to 30,000, including 39 public safety facilities and 77 water, power and other critical facilities.[47]

Regions further north are also at risk from cyclones. For instance, 19 tropical cyclones occurred within 75 kilometres of Mackay between 1862 and 2000, with 13 people drowned by a storm tide in 1918.[48] A risk assessment of Mackay identified that a 1 per cent AEP storm tide associated with a tropical cyclone could affect almost 2,200 buildings with above floor inundation.[49] A more serious 0.2 per cent AEP (1-in-500 year event) storm tide event, equivalent to the 1918 event, could impact over 4,000 buildings with above floor inundation, including residential, commercial and industrial buildings, and flood over 160 kilometres of roads.[50]

The town of Cairns is also considered vulnerable to the impacts of cyclones (Box 5.6), with some critical infrastructure in low-lying areas including the airport, already vulnerable to the highest tides.[51] King tides regularly threaten homes along the Arlington Esplanade in Clifton Beach, with residents having to sand bag their properties to prevent inundation in some cases.[52]

Climate change risk to settlements

Inundation analysis suggests that between 35,900 and 56,900 residential buildings in Queensland may be at risk of inundation from a sea-level rise of 1.1 metre. The current replacement value of the residential buildings at risk is between $10.5 billion and $16 billion.

Based on this analysis, Queensland has the second highest number of residential buildings at risk in Australia. If storm tides were included in the inundation analysis for Queensland it is likely that a higher number of properties would have been identified as at risk.

Local government areas that have the greatest level of risk are Moreton Bay, Mackay, the Gold Coast, Fraser Coast, Bundaberg and the Sunshine Coast, which collectively represent almost 85 per cent of residential buildings at risk of inundation in Queensland from a sea-level rise of 1.1 metres (upper range; Figure 5.15). The coastal LGAs of south-east Queensland are all represented within the top ten LGAs at risk. Inundation footprints of some regions are shown in Figures 5.16 and 5.17.

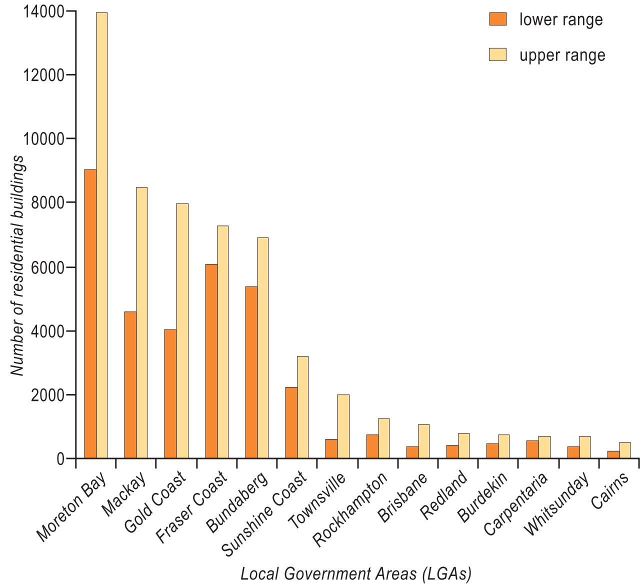


Figure 5.15 Estimated number of existing residential buildings in Queensland at risk of inundation from a sea-level rise of 1.1 metres.

Figure 5.16 Images of the Gold Coast in 2009 and with simulated inundation from a sea-level rise of 1.1 metres using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD

Figure 5.17 Images of Bundaberg in 2009 and with simulated inundation from a sea-level rise of 1.1 metres using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD

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Methodology – key points and caveats

- Inundation analysis is based on 1.1 metres of sea-level rise using medium resolution elevation data.
- A *storm tide allowance* (1-in-100 year event) based on CSIRO modelling is included in the analysis for Tasmania, Victoria and New South Wales, although storm tide values for New South Wales are likely to be underestimates as they do not include a wave setup component.
- For the other states where the CSIRO modelling was not available (Queensland, Western Australia, Northern Territory, and South Australia) an allowance for *modelled high water level* (e.g. high tide) was included in the analysis.
- The analysis does not take account of existing coastal protection, such as seawalls, or riverine flooding associated with intense rainfall events.
- The inundation analysis is of existing residential buildings only (sourced from NEXIS database).
- More detailed analysis may change the relative order of local government areas and the magnitude and timing of projected impacts.
- Refer to Chapter 3 for further details.

Between 9,100 and 14,000 buildings in the LGA of Moreton Bay may be affected by inundation from sea-level rise by 2100, with the upper estimate representing almost 11 per cent of the current residential building stock. A significant proportion of the existing building stock in the Mackay (20 per cent), Fraser Coast (17 per cent) and Bundaberg LGAs (16 per cent) may also be at risk.

CSIRO[53] has recently estimated that approximately 10 per cent of the population and 2.9 per cent of residential buildings in south-east Queensland may be currently at risk from inundation associated with a 'current climate' 1-in-100 year storm surge event. Under climate change, this could increase to 14 per cent of the south-east Queensland population and 5.2 per cent of residential buildings by 2030, without factoring in population growth. The estimated cost of structure and content damage from such an event could increase from $1.2 billion in 2009 to over $2.2 billion in 2030.[54] Additional costs associated with household cleaning and interim accommodation could increase from an estimated $270 million in 2009 to approximately $470 million by 2030.

CSIRO[55] also estimated that over 70 per cent of commercial buildings in south-east Queensland are currently located within 5 kilometres of the shoreline. Approximately 3 per cent are currently at risk from inundation associated with a 'current climate' 1-in-100 year storm surge event and this could almost double to 5.7 per cent by 2030.

Erosion due to higher sea levels is also a key risk for coastal areas. In Queensland there are approximately 15,200 residential buildings located within 110 metres of 'soft', erodible shorelines, of which approximately 5,400 are located within 55 metres of 'soft' coast. Of the coastal LGAs, the Gold Coast has the highest number, with approximately 2,300 and 4,750 residential buildings within 55 metres and 110 metres, respectively, of 'soft' shorelines (Figure 5.18).

Photo credit: Bruce Miller

Similarly, Moreton Bay and the Sunshine Coast have approximately 2,250 and 1,850 residential buildings, respectively, within 110 metres of 'soft' coast, of which approximately 800 and 430 are within 55 metres of 'soft' shorelines, respectively. In the absence of coastal protection measures or other adaptation strategies, these buildings may be at risk of increased erosion with sea-level rise and storm surge due to their location and the nature of the shoreline.

Population growth in coastal areas may also increase the number of people and infrastructure exposed to climate change risks. The inundation analysis undertaken for this report is on the basis of current building stock and does not take account of future population growth. However Queensland, and in particular the south-east region, has experienced significant population growth over recent decades that is expected to continue in at least the near future. For instance, the *South East Queensland Regional Plan 2009–2031* estimates that 754,000 extra residential homes will be needed between 2006 and 2031 to provide for the growing population.[56] Figure 5.19 highlights that the Gold Coast, Moreton Bay and the Sunshine Coast will continue to be key growth areas in Queensland.

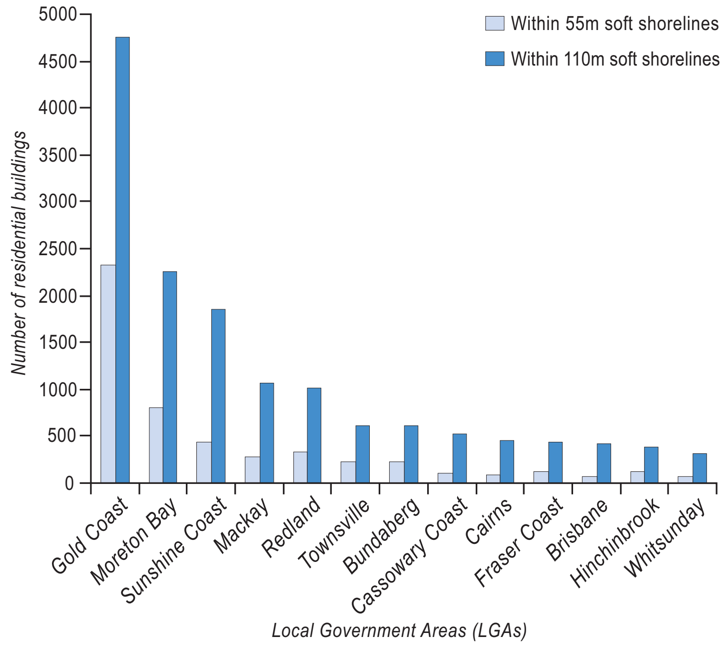

Figure 5.18 Number of residential buildings located within 55 metres and 110 metres of 'soft' shorelines in Queensland.

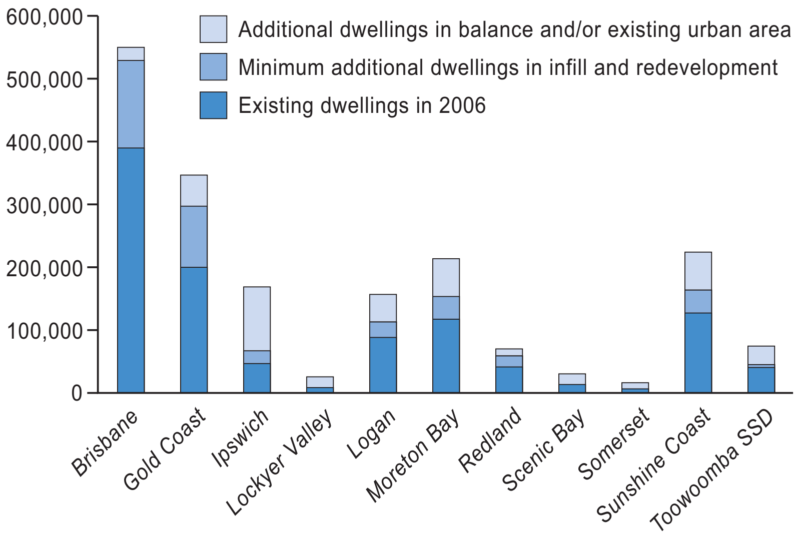

Figure 5.19 Distribution of dwellings by local government area in 2006 and to 2031. Source: Queensland Government 2009[57]

Box 5.6 Tropical cyclone and storm tide risk in Cairns

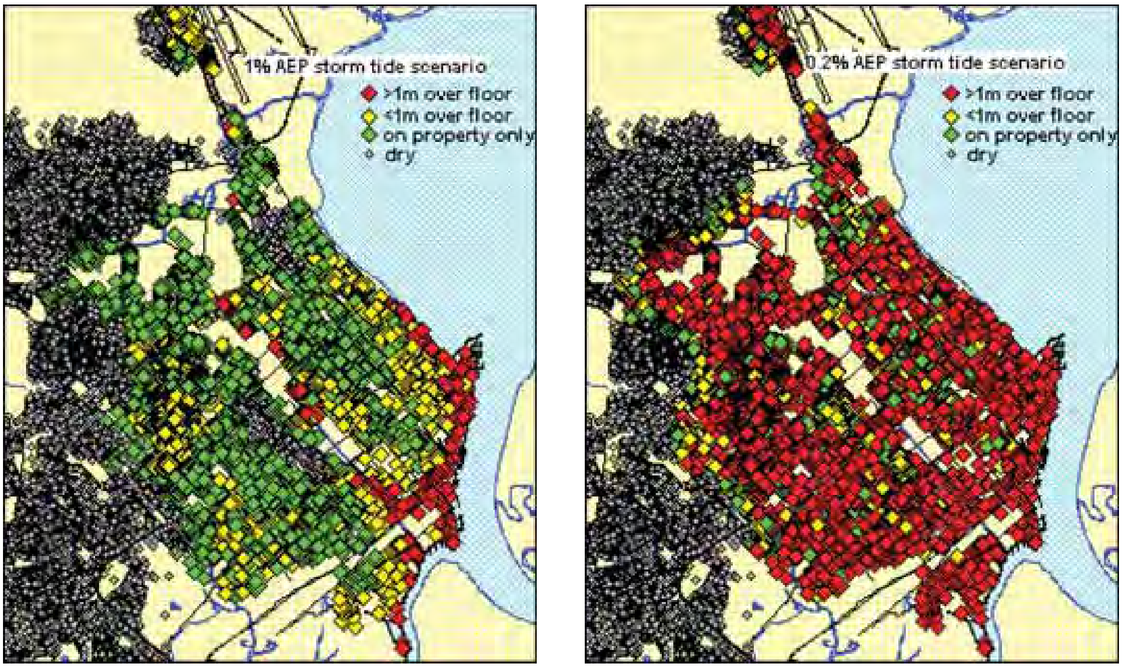

Figure 5.20 Modelled impact of a 1 per cent AEP (left) and 0.2 per cent AEP storm tide scenario (right).Source: Granger et al 1999.[58]

A large number of people, critical services, and commercial and tourist activities are located in low elevation areas of Cairns at risk of storm tides.[59]

A risk assessment[60] found that a 1 per cent AEP (1-in-100 year) storm tide event (2.15m above AHD plus wave set up, shallow water wind waves and breaking sea wave) associated with a cyclone could affect more than 2,500 buildings with above floor inundation (Figure 5.20) and flood up to 100 kilometres of roads with 0.5 metres or more of water. Under this scenario, over-floor inundation would also affect the Calvary Hospital, police headquarters, an ambulance station, Cairns City Council head office, and nineteen other critical facilities (based on 1999 locations).[61]

A more severe 0.2 per cent AEP (1-in-500 year) event with a storm tide of 3.39 metres above AHD (plus wave set up, shallow water wind waves and breaking sea wave) could affect over 8,800 buildings with above floor inundation (Figure 5.20). Over 90 per cent of the buildings in the city, Parramatta Park, Portsmith, Machans Beach, Manunda and Cairns North could be impacted. It is also likely that 35 critical facilities would be inundated with more than 1m of water (above floor level) and more than 15,000 people may need to be evacuated from inundated areas.[62]

A 0.1 per cent AEP (1-in-1,000 year) storm tide event associated with a high Category 3 or Category 4 cyclone could be devastating. It should also be noted that these estimates are from the impacts of storm tide alone, and do not account for the impacts of cyclonic winds and intense rainfall that would also be associated with a cyclone.

CSIRO has undertaken research into the impact of potential changes to tropical cyclones from climate change for the Cairns area.[63] The modelling of a 10 per cent increase in cyclone intensity indicated that the area inundated by a 1-in-100 year event could more than double under climate change (Figure 5.21).

Source: Granger et al. 1999[64]; McInnes et al. 2003[65]; Nicholls et al 2007[66]

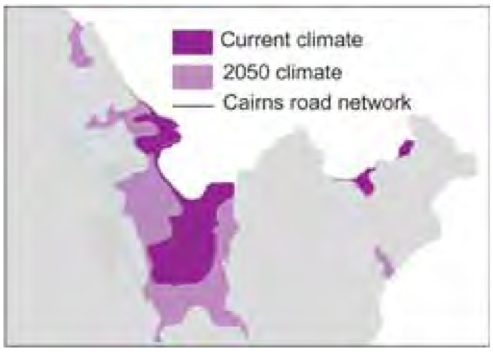

Figure 5.21 Storm surge extent from a 1-in-100 year storm under the current climate and 2050 climate. Source: Nicholls et al. 2007

5.1.5 Victoria

Key findings

- Between 27,600 and 44,600 residential buildings in Victoria may be at risk of inundation from a sea-level rise of 1.1 metres and storm tide associated with a 1-in-100 year storm.
- The current replacement value of the residential buildings at risk is between $6.5 billion and $10.3 billion.
- Local government areas (LGA) of Kingston, Hobsons Bay, Greater Geelong, Wellington and Port Phillip collectively represent close to 70 per cent of the residential buildings at risk in Victoria
- There are approximately 4,700 residential buildings located within 110 metres of 'soft' erodible shorelines.

The population context

Almost a quarter of Australia's population resides in Victoria.[67] A significant proportion live along the urban coast of metropolitan Melbourne (including the Mornington Peninsula) and Geelong, with increasing population growth in regional coastal communities, such as the Surf Coast LGA.

In 2007–08, the largest population growth and highest rate of increase in Victoria occurred in the outer suburban LGA of Wyndham (increase of 8,900 people), which is located on a coastal plain on the western side of Port Phillip Bay.[68] Wyndham has been identified as an urban growth corridor in *Melbourne 2030* [69], and will also be the location of *Wyndham Harbour*, a new $440 million waterfront development.[70]

In regional Victoria, the highest rate of growth is along the coast. In 2007–08, the Greater Geelong LGA had the largest population growth (increase of 3,000 people).[71] This continued the growth trend of the previous decade (1996–2006) during which the population increased by over 22,000 people.[72] The coastal LGAs of Surf Coast (3.6 per cent), Bass Coast (2.3 per cent) and Queenscliff (2.2 per cent) showed the fastest population growth in regional Victoria in 2007–08.[73]

The nature of the coast

About a quarter (24 per cent) of the Victorian open coast is hard rock shore, the majority of which is classified as cliffed, reflecting in part the exposure of the western Victoria coast to high wave energy. While a large proportion is classified as sandy coast, much

Photo credit: Victorian Government Department of Sustainability and Environment

Erosion along Ninety Mile Beach.

of this is also classified as rocky coast with at least 20 per cent of the coast being sandy beaches backed by bedrock. These may erode but will not exhibit significant shoreline recession except where the rock is a soft-rock type.[74]

Over 29 per cent of the Victorian open coast is sandy coast backed by soft sediment, with potential for significant shoreline retreat with sea-level rise. Ninety Mile Beach in East Gippsland is an example of this type of coast and was significantly eroded in 2007.

Cliffed soft-rock shores are also a notable feature of the Victorian open coast (6 per cent) compared to most other states; these include the well known soft limestone coasts near Port Campbell which are actively receding and can be expected to recede faster with sea-level rise.

Muddy shores (which include many muddy-sand tidal flats) figure significantly in Victoria (33 per cent), albeit these include shores in Corner inlet and Westernport Bay which arguably are not open coast shores but coastal re-entrants. Nevertheless these are shores with high potential for mobility with sea-level rise, including significant retreat. Subsidence may also add to this potential in the area around Corner Inlet.[75]

Photo credit: A.D. Short

Dutton Way in Portland.

Existing risk

Coastal areas in Victoria already have some risk of exposure to natural hazards without the compounding effects of climate change. For instance, Lakes Entrance in East Gippsland is a low-lying town vulnerable to inundation from flooding and storm surge (Box 5.7).

Coastal erosion can also be of concern for some beaches due to the dynamic nature of the coastline and the impacts of development. For instance, a 4.5 kilometre sea wall has been built along Dutton Way in Portland to halt coastal erosion that threatened a road. The erosion is thought to have been caused by a breakwater that was built in 1960.[76]

A number of beaches around Port Phillip Bay are also affected by erosion. A recent report[77] has prioritised 30 beaches for nourishment projects around the Bay to address coastal erosion. The top seven prioritised beaches include Altona, Elwood, Mt Martha North, Portarlington, North Aspendale, Half Moon Bay and Eastern Beach Geelong. Initial cost estimates for nourishment of these seven beaches alone is more than $6 million.[78]

Photo credit: Newspix/Andrew Batsch

Mt Martha Beach, Victoria.

Box 5.7 Gippsland Lakes and Lakes Entrance

One of the most vulnerable coastal areas in Australia is that of the Gippsland Lakes including Ninety Mile Beach and Corner Inlet. Many of the issues confronting this region are detailed in a report to the Gippsland Coastal Board.[79] A narrow and in part receding coastal barrier naturally blocks off low-lying islands and coastal flats bordering the lakes (Figure 5.22).

As was shown in 2007, the region is subject to a convergence of driving forces. Catchment riverine floods raise lake levels that have difficulty escaping to the sea through the 'trained' entrance at Lakes Entrance at times of high tide coupled with a storm surge accompanying high waves. Strong local winds act to raise water levels in the down-wind sections of the lakes enhancing the flooding effects.[80] The result is extensive inundation of low-lying townships, such as Lakes Entrance.

Historical records show that flood levels at Lakes Entrance have reached 1.8 metres AHD. Much of the terrain on which this township has developed is situated below this level[81], as shown by the visualisation of 1.8 metre AHD flooding in Figure 5.23. Added to the existing risk for the region are the compounding possibilities of continued land subsidence facilitating more barrier recession and inundation in the southern part of the region. A breach of the Ninety Mile Beach barrier, exposing the lakes to a new tidal inlet and salinisation, together with the impacts of rising sea levels (especially as the warm East Australian Current moves farther south) and enhanced effects of storm surges are likely to lead to collapse of existing lake ecosystems and changes to land use in east Gippsland.

Photo credit: Victorian Government Department of Sustainability and Environment

Figure 5.22 Eroding beach and dune at Ninety Mile Beach south of Seaspray in 2007 showing an exposure of exhumed tidal flat and backbarrier sediments as the sand barrier recedes landwards.

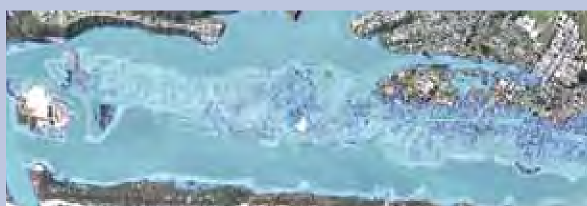

Figure 5.23 Simulated 1.8m AHD flooding in Lakes Entrance. Source: Wheeler et al. 2007[82]

Source: Gippsland Coastal Board 2008[83]; Wheeler et al. 2007[84]

Methodology – key points and caveats

- Inundation analysis is based on 1.1 metres of sea-level rise using medium resolution elevation data.
- A *storm tide allowance* (1-in-100 year event) based on CSIRO modelling is included in the analysis for Tasmania, Victoria and New South Wales, although storm tide values for New South Wales are likely to be underestimates as they do not include a wave setup component.
- For the other states where the CSIRO modelling was not available (Queensland, Western Australia, Northern Territory, and South Australia) an allowance for *modelled high water level* (e.g. high tide) was included in the analysis.
- The analysis does not take account of existing coastal protection, such as seawalls, or riverine flooding associated with intense rainfall events.
- The inundation analysis is of existing residential buildings only (sourced from NEXIS database).
- More detailed analysis may change the relative order of local government areas and the magnitude and timing of projected impacts.
- Refer to Chapter 3 for further details.

Climate change risk to settlements

Inundation analysis suggests that between 27,600 and 44,600 residential buildings in Victoria may be at risk of inundation from a sea-level rise of 1.1 metres and storm tide associated with a 1-in-100 year storm. Based on this analysis, Victoria has the third highest number of residential buildings at risk of inundation in Australia. The current replacement value of the residential buildings at risk is between $6.5 billion and $10.3 billion.

Local government areas that have the greatest level of risk are Kingston, Hobsons Bay, Greater Geelong, Wellington and Port Phillip, which represent close to 70 per cent of residential buildings at risk in Victoria (upper range; Figure 5.24). With the exception of Wellington, all four LGAs are located on Port Phillip Bay.

Inundation footprints of Altona in Hobsons Bay LGA and Geelong are shown in Figures 5.25 and 5.26.

Between 6,400 and 9,000 buildings in the LGA of Kingston may be affected by storm tide by 2100, with the upper range representing 30 per cent of the current residential building stock. While the LGA of Queenscliff has a relatively smaller number of buildings at risk in comparison to Kingston, a quarter of the existing residential building stock may be at risk of storm tide inundation by 2100. A significant proportion of residential buildings in Hobsons Bay, Wellington and Port Phillip may also be at risk, with the upper estimates representing between 17 per cent and 22 per cent of the current building stock.

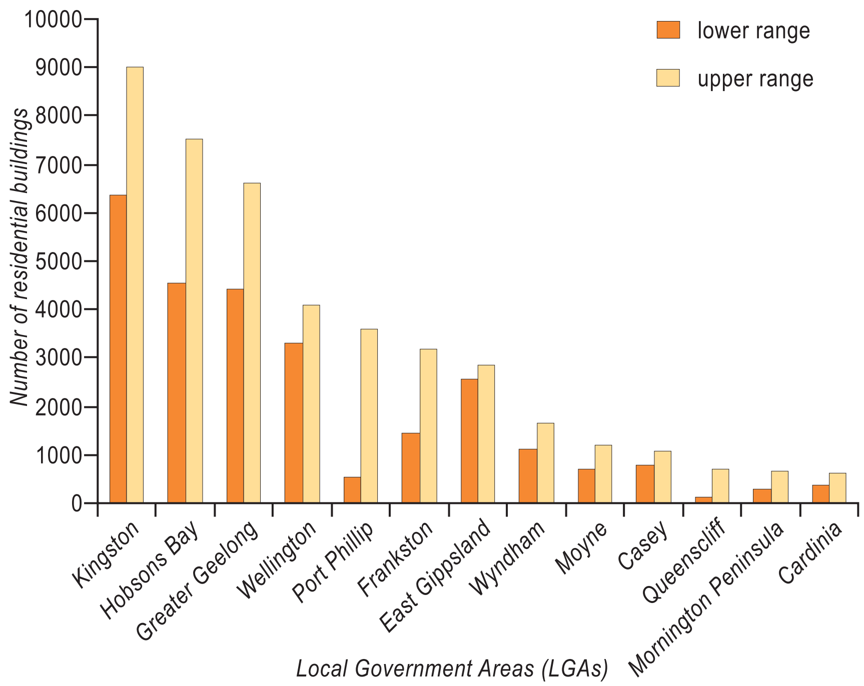

Figure 5.24 Estimated number of existing residential buildings in Victoria at risk of inundation from a sea-level rise of 1.1 metres and 1-in-100 year storm tide.

Figure 5.25 Images of Altona (Hobsons Bay LGA) in 2009 and with simulated inundation from a sea-level rise of 1.1 metres and a 1-in-100 year storm tide using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD

Figure 5.26 Images of Geelong (Greater Geelong LGA) in 2009 and with simulated inundation from a sea-level rise of 1.1 metres and a 1-in-100 year storm tide using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD

Approximately 15 per cent of the residential buildings in the LGA of Moyne in south west Victoria may also be at risk of inundation by storm tide. The small coastal town of Port Fairy accounts for some of this risk, with recent modelling of sea-level rise, storm tide and increased rainfall intensities highlighting the compounding effects of climate change impacts (Box 5.8).[85]

The Port Phillip LGA, which has the fifth highest level of risk in Figure 5.24, has been the focus of a recent study of the potential impacts of climate change (refer to Box 5.9). Mapping of storm surge and sea-level rise projections in the City of Port Phillip identified the St Kilda foreshore and the area immediately surrounding the Elwood Canal as being particularly vulnerable to inundation.[86] The study also noted the compounding effects of stormwater flooding during severe storms.

Four of the five local government areas that comprise the Western Port Region (Frankston, Casey, Mornington Peninsula, Cardinia and Bass Coast) are within the top LGAs shown in Figure 5.24. A recent study[87] of the impacts of climate change in the region found that the extent of inundation from a 1-in-100 year storm surge event could increase by up to 63 per cent by 2070, with implications for approximately 1,000 existing dwellings (Refer to Box 5.10).

Although the inundation analysis for this report has not included analysis of commercial buildings and transport infrastructure, these assets will also be at risk of inundation. The recent study of the Western Port Region[88] identified that the inundation exposure of roads is expected to increase by 73 per cent by 2070, with an additional 37 kilometres of roads potentially exposed to 1-in-100 year storm surge events. Sections of the Nepean Highway and other public infrastructure could also be exposed to 1-in-100 year storm surge events, as could the Blue Scope Steel industrial facility, some Esso/BHP Billiton facilities in Hastings, and the Harwood aerodrome in Casey.

The recent Port Phillip study (Box 5.9) also identified a number of commercial and tourist areas that may be affected by the combined effects of storm surge inundation and storm water flooding, including the commercial and tourist precinct of Acland Street, the Catani Gardens, St Kilda Sea Baths, The Esplanade and Beaconsfield Pde, and the St Kilda Marina.[89]

Erosion due to higher sea levels is also a key risk for coastal areas. There are approximately 4,700 residential buildings located within 110 metres of 'soft', erodible shorelines in Victoria, of which approximately 550 are located within 55 metres of 'soft' coasts. Of the coastal LGAs, the Mornington Peninsula has the highest number, with approximately 1,140 residential buildings within 110 metres, and 90 within 55 metres of 'soft' shorelines (Figure 5.27). Similarly, the Greater Geelong and Bayside LGAs have approximately 750 and 620 residential buildings, respectively, within 110 metres of 'soft' coast. There are also properties along the barrier dunes of Ninety Mile Beach in Gippsland that would be at risk; many more would be exposed around the lakes if the sand barrier was breached and a new inlet created. In the absence of coastal protection measures or other adaptation responses, these buildings may be at risk of increased erosion with sea-level rise and storm surge due to their location and the nature of the shoreline.

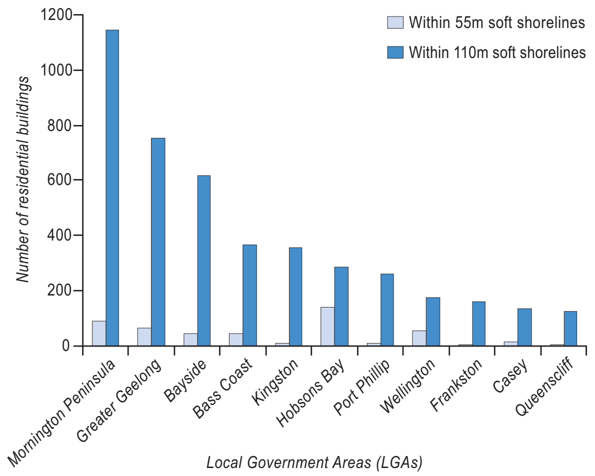

Figure 5.27 Number of residential buildings located within 55 metres and 110 metres of 'soft' shorelines in Victoria.

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Box 5.8 Port Fairy regional flood study

The coastal town of Port Fairy in the LGA of Moyne is vulnerable to climate change, particularly sea-level rise and higher rainfall intensity. Modelling of three scenarios of sea-level rise, storm surge and higher rainfall intensities highlight the potential for significant impacts by 2100 under future climate change. As shown in the below table, the number of properties at risk of inundation could increase significantly with climate change.

The study also highlighted the potential shift in the frequency of flood events as a result of climate change. For instance, a 1 per cent AEP (1-in-100 year) event under the current climate could have a shorter recurrence interval with climate change. This has implications for future planning, particularly as flood damage in Port Fairy increases considerably with storm events above the current 5 per cent AEP (1-in-20 year event).

Source: Bishop and Womersley 2009[90]

	Existing climate	Moderate impact scenario	Intermediate impact scenario	High impact scenario
Scenario	1% AEP (1-in-100 year event)	0.4m mean sea-level rise 0.03m storm surge 30% increase in rainfall intensity on 1% AEP	0.8m mean sea-level rise 0.07m storm surge 50% increase in rainfall intensity on 1% AEP	1.2m mean sea-level rise 0.1m storm surge Hydrograph based on estimated 1946 flood characteristics
Above floor flooding	50	114	143	211
Properties inundated	141	110	86	20
Additional dwellings at risk of inundation	-	50	74	286
Total properties subject to inundation	191	274	303	517

Box 5.9 City of Port Phillip – a case study

A recent study has identified that sea-level rise is expected to be the most significant climate change issue for the City of Port Phillip, due to the associated impacts of coastal erosion and storm surge.

A risk assessment of coastal erosion and storm surge highlighted four key risks, including:

- ‘Infrastructure instability’ due to the potential effects of erosion and storm surge on the base of buildings and infrastructure. Luna Park, the St Kilda Baths, the St Kilda Pier and Marina, and residential properties in the vicinity of the Elwood Canal were identified as being at risk.
- Loss of beaches due to coastal development preventing the landward movement of the shoreline. The Middle Park and St Kilda beaches are considered the most vulnerable.
- Impacts on planning zones, due to the increased exposure from climate change influencing local planning.
- Flooding of coastal properties due to reduced protection from eroded beaches, particularly during severe storms and storm surge events. Property values may be affected as a result.

It is anticipated that the two most significant risks from storm surge up to 2020 will be the impacts on beaches and local planning (in preparation for projected flooding and other impacts in the longer-term), with ‘infrastructure instability’ also a potential issue from coastal erosion in the short-term. By 2050, flooding of coastal properties is also expected to be a significant risk, with the risk increasing further by 2100.

Mapping of storm surge and sea-level rise projections (refer Figure 5.28) identified areas particularly vulnerable to inundation both now and under climate change. These include the St Kilda foreshore and the area immediately surrounding the Elwood Canal.

It is also important to note that there are an estimated 4,000 residential properties at risk of flooding from waterways and drains under a ‘current climate’ 1-in-100 year storm event. A 1-in-100 year storm under climate change would impact a larger area.

Figure 5.28 Projected storm surge inundation in the City of Port Phillip (including sea-level rise; based on 2007 data).

Source: City of Port Phillip 2007[91]

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Box 5.10 Impacts of climate change on settlements in the Western Port Region

The five local government areas of Bass Coast, Cardinia, Casey, Frankston and Mornington Peninsula form the Western Port region of Victoria. Climate change threats likely to impact the region include coastal inundation and erosion from sea-level rise and storm surge, extreme rainfall and inland flooding, and changes to fire weather conditions.

Simulations undertaken by CSIRO suggest that the extent of inundation from a 1-in-100 year storm surge event could increase by up to 63 per cent by 2070. Within the shorter term (2030), the land area at risk of inundation from storm surge is likely to increase by only 4-15 per cent. In addition, the frequency of such events could increase, with a storm surge associated with a 1-in-100 year storm today potentially becoming a 1-in-20 year to annual storm surge event by 2070.

By 2070, inundation from a 1-in-100 year storm could affect more than 1,000 existing dwellings and property to a value of approximately $780 million[92]. The Mornington Peninsula Shire appears to have the highest level of exposure, accounting for approximately 60 per cent of the exposed population and dwellings in 2070.

The study used sea-level rise scenarios of up to 0.17 metres for 2030 and up to 0.49 metres for 2070, which were combined with wind speed change scenarios to calculate 1-in-100 year storm surge height return levels.

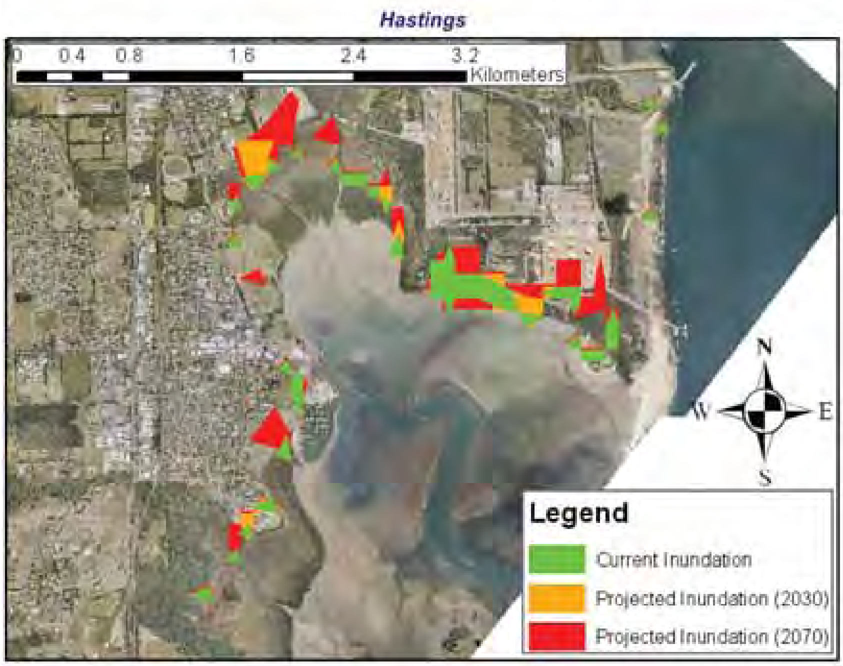

Figure 5.29 Current and projected area of inundation from 1-in-100 year storm surge events in Hastings (Mornington Peninsula Shire Council).

Source: Kinrade et al 2008[93]

5.1.6 Tasmania

Key findings

- Between 8,700 and 11,600 residential buildings in Tasmania may be at risk of inundation from a sea-level rise of 1.1 metres and storm tide from a 1-in-100 year storm event.
- The current replacement value of the residential buildings at risk is between $2.4 billion and $3.3 billion.
- Local government areas (LGA) of Clarence, Central Coast, Break O'Day and Waratah/ Wynyard LGAs collectively represent 50 per cent of residential buildings at risk in Tasmania (upper range estimate).
- Between 1,850 and 2,250 residential buildings in the LGA of Clarence may be affected by sea-level rise and storm tide inundation by 2100, equivalent to approximately 10 per cent of the existing residential stock within the LGA.
- There are approximately 6,100 residential buildings located within 110 metres of 'soft' erodible shorelines, of which approximately 1,800 are within 55 metres of soft coast.

The population context

Tasmania's population of almost 500,000 people is largely concentrated along the coast, with around 75 per cent of Tasmanians residing in coastal local government areas.[94] In the year to 2008, the coastal LGAs of Kingborough and Sorrell in south-east Tasmania recorded the largest population increase and highest growth rate, respectively, of all local government areas.[95] In addition to being home to most of the population, the coast is also where major industries are located, highlighting the social and economic significance of the coastal region.[96]

The nature of the coast

Compared to other states a very high proportion of Tasmania's open coast is hard rocky coast (about half), and much of this is cliffed. This reflects Tasmania's exposure to high wave energies and relatively limited sand supply to large sections of the coast, and means that large sections of coast are unlikely to recede significantly due to erosion related to sea-level rise within human lifetimes.[97]

Sandy coasts make up most of the other half of Tasmania's open coast, and these are dominated by sandy shores backed by soft sediments (which are potentially prone to significant recession with sea-level rise). At least 20 per cent of these are sandy shores backed by bedrock, which may erode with sea-level rise but are less at risk of significant shoreline recession.


Photo credit: A.D. Short

Cape Pillar.

Soft rock and muddy coasts are a very minor component of Tasmanian's open coast.[98]

Existing risk

Coastal areas in Tasmania already have some exposure to storm surge, erosion and other natural hazards without the compounding effects of climate change. For example, approximately 240 square kilometres of coastal area in Tasmania is currently vulnerable to storm surge flooding (average 2-year return period).[99]

As in many areas around Australia, residential development within 100 metres of the coast has continued over recent decades. Some of this development has been sited in areas prone to erosion.[100] For example, the house in the below photo is located on a coastal cliff that is prone to slumping, with this kind of event likely to be exacerbated by climate change. There are also some shacks located on freehold land (previously Crown Land) that are vulnerable to coastal erosion or slumping, such as in Boat Harbour and Anson's Bay.[101]

A recent study of coastal locations in Clarence in south-east Tasmania identified four areas in which there is existing risk of erosion, inundation and high water tables.[102] These include the areas of Lauderdale and Roches Beach, Cremorne, Bicheno Street in Clifton Beach and South Arm Neck (Box 5.11).


Photo credit: Chris Sharples

House sited on a coastal cliff that is prone to slumping.

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Methodology – key points and caveats

- Inundation analysis is based on 1.1 metres of sea-level rise using medium resolution elevation data.
- A *storm tide allowance* (1-in-100 year event) based on CSIRO modelling is included in the analysis for Tasmania, Victoria and New South Wales, although storm tide values for New South Wales are likely to be underestimates as they do not include a wave setup component.
- For the other states where the CSIRO modelling was not available (Queensland, Western Australia, Northern Territory, and South Australia) an allowance for *modelled high water level* (e.g. high tide) was included in the analysis.
- The analysis does not take account of existing coastal protection, such as seawalls, or riverine flooding associated with intense rainfall events.
- The inundation analysis is of existing residential buildings only (sourced from NEXIS database).
- More detailed analysis may change the relative order of local government areas and the magnitude and timing of projected impacts.
- Refer to Chapter 3 for further details.

Climate change risk to settlements

Inundation analysis suggests that between 8,700 and 11,600 residential buildings in Tasmania may be at risk of inundation from a sea-level rise of 1.1 metres and storm tide associated with a 1-in-100 year storm event. Based on this analysis, Tasmania has a relatively small number of residential buildings at risk in comparison to other states. The current replacement value of the residential buildings at risk is between $2.4 billion and $3.3 billion.

The local government areas that have the greatest level of risk are Clarence, Central Coast, Break O'Day and Waratah/Wynyard on the north and east coasts, which collectively represent 50 per cent of residential buildings at risk in Tasmania (upper range; Figure 5.30). Inundation footprints of the Central Coast LGA and Kingston in the LGA of Kingborough are shown in Figure 5.31 and 5.32.

Between 1,850 and 2,250 buildings in the LGA of Clarence may be affected by inundation associated with sea-level rise and storm tide inundation by 2100. This represents an exposure risk to approximately 10 per cent of the existing residential dwellings within the LGA (upper range). A recent study for the Clarence City Council[103] assessed the erosion and inundation risks to 18 coastal locations. The report identified those areas that are currently at risk and those that have medium and longer-term risks associated with climate change (Box 5.11).

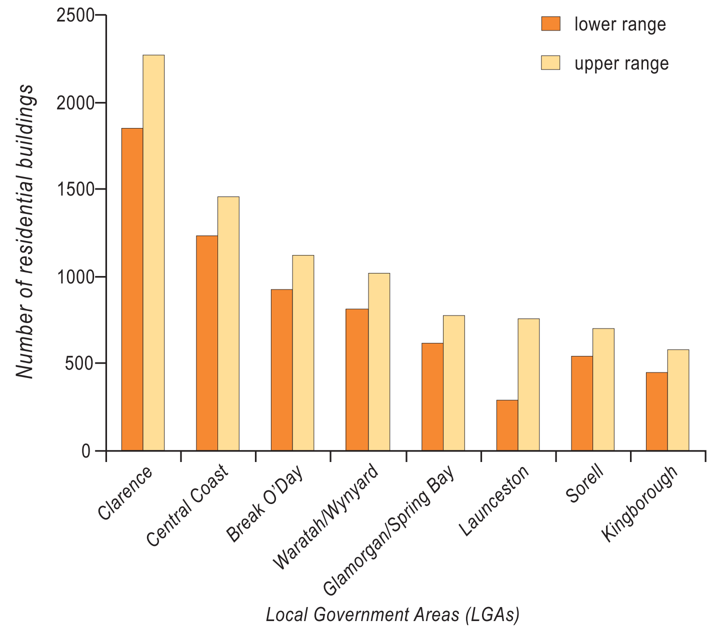

Figure 5.30 Estimated number of existing residential buildings in Tasmania at risk of inundation from a sea-level rise of 1.1 metres and a 1-in-100 storm tide.

Figure 5.31 Images of Kingston (Kingborough LGA) in 2009 and with simulated inundation from a sea-level rise of 1.1 metres and a 1-in-100 year storm tide using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD.

Figure 5.32 Images of Ulverstone in the Central Coast LGA in 2009 and with simulated inundation from a sea-level rise of 1.1 metres and a 1-in-100 year storm tide using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD.

A significant proportion of the existing building stock in the LGAs of Central Coast and Break O'Day may also be at risk of inundation, with upper estimates of 16 per cent and 23 per cent respectively. The local government area of Flinders has a relatively small number of buildings at risk (approximately 170) and is therefore not captured in Figure 5.30; however the number represents over 30 per cent of the existing residential stock in the LGA.

This inundation analysis has not included information on commercial buildings and transport infrastructure, although these assets will also be at risk of inundation. In 2008, the Tasmanian Government assessed assets at risk using a range of sea-level rise scenarios (Table 5.1)[104]. Assets identified at risk include critical infrastructure and services, such as emergency service facilities and sewerage and wastewater systems. Inundation or failure of these assets would significantly impact communities and coastal ecosystems.

Sea-level mark at Port Arthur

In 1841, a sea level mark of historical significance was made by Lempriere and Ross at Port Arthur. It is one of the earliest reference points in the world against which changes to sea level can be scientifically measured. Taking account of vertical movement of the land, the rate of sea-level rise is between 0.8mm/year and 1mm/year, with approximately 13 centimetres of sea level rise since 1841. This is consistent with rates of change recorded at Fort Denison in Sydney Harbour based on 82 years of data.[105]

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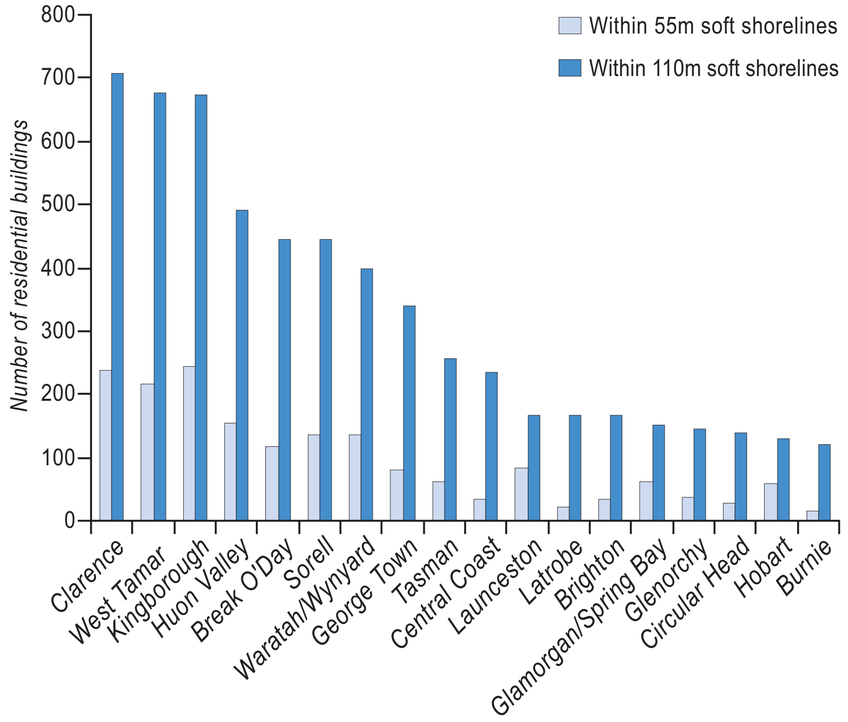

Figure 5.33 Number of residential buildings located within 55 metres and 110 metres of 'soft' shorelines in Tasmania.

Coastal erosion is also a key risk associated with climate change, particularly with an increasing frequency of high sea level events that will occur over the coming decades. Along Tasmania's coastline there are approximately 6,100 residential buildings located within 110 metres of 'soft', erodible shorelines, of which approximately 1,800 are located within 55 metres of 'soft' coast. Of the coastal LGAs, Clarence, West Tamar and Kingborough have the highest numbers, with between 670 and 700 residential buildings within 110 metres of 'soft' shorelines in each local government area, and over 200 within 55 metres of 'soft coast' in each LGA (Figure 5.33). Similarly, Huon Valley has close to 500, and Break O'Day and Sorell have around 450 residential buildings within 110 metres of 'soft' coast in each area. In the absence of coastal protection measures or other adaptation responses, these buildings may be at risk of increased erosion with sea-level rise and storm surge due to their location and the nature of the shoreline.

Photo credit: Chris Sharples

Eroding soft rock shore (clayey gravels) at Anson's Bay, north east Tasmania. The photo (2002) shows a poorly constructed 'coastal defence' that is collapsing because of undermining of the shore in front.

Box 5.11 Climate change impacts on Clarence coastal areas

The City of Clarence is located to the east of Hobart, Tasmania. Clarence City Council initiated a project in response to Council and community concerns about the potential impacts of a changing climate on coastal areas. The study provides an assessment of climate change risks to coastal areas for 2050 and 2100, based on a 'mid' and 'high' value of sea-level rise.

Sea level rise scenarios	2050	2100
Mid Scenario	0.2m	0.5m
High Scenario	0.3m	0.9m

The study examined 18 locations within Clarence City, identifying those that have existing and longer-term risks, as well as the potential impacts of more frequent and extreme storm surges, coastal erosion, rising ground water and increased flooding in coastal areas. For example, Roches Beach on Frederick Henry Bay has a history of erosion that is expected to accelerate with climate change in the absence of coastal protection measures. Modelling suggests that a 1-in-100 year storm under the 'current climate' could lead to erosion of 25 metres inland and place 19 houses at risk. With climate change, the extent of erosion could increase to about 95 metres inland by 2100 (high scenario) and place 195 houses at risk (125 under the 2100 mid scenario) (Figure 5.34).

The study also considered a range of possible adaptation responses for different climate change scenarios, including potential costs. For example, possible responses to storm surge and erosion at Roches Beach could include beach replenishment, dune protection and hardening, and progressive retreat, among others.

Figure 5.34 Erosion and recession hazard lines along the central section of Roches Beach. Source: Water Research Laboratory, UNSW

The cost of sand nourishment at Roches Beach was estimated at $2.6 million for the present day scenario and up to $23.2 million for the 2100 high scenario. Groynes could also be used to retain sand at an estimated cost of $3.5 million for the main Roches beach.

The use of sea walls along Roches Beach was also considered as a response and deemed not to be cost effective in the short-term. The total estimated cost of sea wall construction ranged from $18.5 million (today) to $34 million (2100 high scenario). The report also noted that the cost of sea walls will increase significantly with sea-level rise due to the costs increasing with the 'square of the height'. For example, doubling the height of a sea wall would quadruple the cost.

A community survey of the range of possible adaptation responses identified retreat as the least acceptable climate change response. Respondents to surveys generally accepted limiting development in higher risk areas, while fewer supported the removal of existing housing.

The report proposes a range of strategies covering the immediate to longer-term. Immediate options entail changes to planning and development controls to address future risks from erosion and inundation for proposed development, and short term works where risks are evident from current hazards. In the medium term, further studies were identified to (1) define hazards and risks to better understand the cost benefits for priority areas; (2) understand engineering design requirements and; (3) implement cost effective, well designed engineering measures. Over the longer-term (up to 25 years) the report noted the need for ongoing studies of actual change and understanding the effectiveness of initial responses and works, in addition to planning for long-term responses to changing (and ongoing) risks.

Source: SGS Economics & Planning 2007[106], SGS Economics & Planning and UNSW Water Research Laboratory 2008[107]

Table 5.1 Vulnerable assets in Tasmania for a 2100 maximum sea-level rise (2004 level +84 centimetres) inclusive of an additional 50m indicative buffer inland of the high sea-level rise scenario.
Source: Department of Primary Industries and Water 2008[108]

Asset	Risk	Area (ha) or number at risk
Reserves (for natural purposes), including land reserved under the *National Parks* and *Reserve Management Act 2002, Crown Lands Act 1976 and Forestry Act 1920,* 'natural parks' and 'park/reserves' with less formal status.	Large area susceptible, with most of areas containing high natural values (e.g. high conservation value vegetation types and geomorphic features, and threatened species). They are often also highly valued social assets.	Reserves – 37,941 ha State Forests – 427 ha Private reserves – 997 ha Other Public land – 8373 ha
Large Community & Public Buildings Community Care facilities, Hall/Community Centres, Sports Building and Sports Clubs.	Significant community buildings, often items or equipment of significant value that may not be easily removed. Some may be able to withstand periodic flooding, and disruption to services may not be critical, some structural damage is likely and clean up costs may stretch tight budgets. Facilities are generally strong focal points for local communities, resulting in high social impacts and some may also serve as focal points during emergencies, so their placement in a hazard zone may need consideration.	Boating, Surf clubs – 53 Sports clubs – 63 Sports buildings – 48 Churches – 22 Community care – 25 Halls – 28 Libraries – 13 Scouts – 17 Seniors – 4
Picnic areas & facilities both inside the Parks and Wildlife Service managed reserve system and outside, which are usually managed at the local level.	While these areas tend to have low levels of development and disruption from flooding is not usually critical, many are considered valuable community assets with high social value. Many in the formal reserve system are also in areas with high natural values.	Parks – 92 Camping – 37 Picnic – 122
School sites listed in the Tasmanian Street Atlas as a school, including primary, secondary (high) or college/matriculation, most of which are public.	Schools are very high value assets, focal points for the community, and sometimes have a role in emergency situations. Due to land zoning and infrastructure costs, moving schools will not be an option in the short or medium term. However, with such high consequence of impact, high sea-level rise scenarios will require eventual relocation.	12
Service Station sites listed in the Tasmanian Street Atlas as Service Stations, and likely to require an 'environmental permit'.	Flooding would probably cause significant structural damage, and is very likely to cause significant contamination/pollution of the general area.	38
Emergency Services Buildings facilities listed in the Tasmanian Street Atlas as State Police/Emergency Management Services. It does not necessarily include designated emergency service centres such as coordination, evacuation or recovery centres.	Flooding would probably cause some structural damage and to equipment. However, the greatest risks come from the presence of a focus for emergency coordination itself existing in a hazard area.	32
Sewage and Wastewater Treatment Plants Sites described as 'sewage' or 'wastewater', and including lagoons, plants and works. Does not include the sewage pipes and pumping stations.	These are critical community infrastructure, expensive to repair and/or re-locate and the capacity of the managing authority (usually Local Government) to undertake significant redevelopment is often limited, as it is often not just the site itself, but all infrastructure leading to and servicing that site as well.	22

Table 5.1 continued

Asset	Risk	Area (ha) or number at risk
Major Roads Primarily State Government managed roads, including National/State Highway, and major Arterial roads, but may also include some Local Government managed roads.	While road foundation integrity may not be a major issue due to the generally higher standard of construction, disruption to key transportation routes from flooding is likely to be very high. Bridge construction may need review for water flow, clearance levels and foundation/buttress integrity standards.	Highway – 140 km Arterial – 111 km
Local Roads including smaller Arterial, Feeder, and Access roads – Local Government primarily responsible	Social and economic value of roads significant to local communities, as well as often key emergency routes. Foundation integrity potentially subject to damage from flooding, in addition to disruption to accessibility. The primary manager of these assets, Local Government, is likely to require assistance due to their smaller resource base, especially given the potential magnitude of the issue.	Access – 706 km Feeder – 91 km Track – 437 km
Parks and Wildlife Service infrastructure Primarily built infrastructure such as major buildings and toilets	These high value assets are likely to be severely damaged by even minor flooding events, and are often more difficult to repair given their usual remoteness. Given high sea-level scenarios considerably increase the number of assets potentially impacted, there are significant risks to this category.	Buildings – 76 Track, toilets, picnic areas etc – 752
Waste Disposal Sites used for the disposal of waste, not including waste transfer stations, Includes open and closed sites.	Potential contamination and pollution arising from flooding events makes this a high risk category.	6
Storage Tanks and facilities storing materials such as explosives, gas and chemicals, either above or below ground.	These facilities may suffer structural damage from flooding, and there is a high chance of pollution or contamination.	67

5.1.7 South Australia

Key findings

- Between 25,200 and 43,000 residential buildings in South Australia may be at risk of inundation from a sea-level rise of 1.1 metres.
- The current replacement value of the residential buildings at risk is between $4.4 billion and $7.4 billion.
- Based on this analysis, South Australia has the fourth highest number of residential buildings at risk in Australia.
- In this assessment, the neighbouring local government areas (LGA) of Charles Sturt and Port Adelaide-Enfield collectively represent around 55 per cent of residential buildings at risk in South Australia (upper range estimate).
- There are approximately 7,000 residential buildings within 110 metres of 'soft' erodible shorelines of which approximately 1,600 are within 55 metres of 'soft' coast.

The population context

The majority of South Australia's population (over 90 per cent) live near the coast[109] and almost three quarters live in Adelaide.[110] The largest population increase in 2007–08 occurred in the Adelaide LGA's of Salisbury, Playford, Onkaparinga and Port Adelaide-Enfield adjacent to the Gulf St Vincent.[111] However, the fastest growing area was Victor Harbor (3.5 per cent) on the Fleurieu Peninsula. The Copper Coast recorded 2.7 per cent growth, and the coastal LGAs of Alexandrina (2.6 per cent) and Yankalilla (1.8 per cent) on the Fleurieu Peninsula also showed relatively high rates of population growth, continuing a trend of recent years.[112]

The coast has been subject to increasing levels of development over recent decades, as shown in Figure 5.35 of Victor Harbor. Between 1996 and 2000, the number of new residential dwellings constructed within 500 metres of the shoreline in South Australia increased from roughly 500 to 855 per year. The number was still almost 700 per year in 2006.[113] Population growth, 'sea change' retirees and increasing investment in holiday homes is expected to continue to drive coastal development into the future.[114]

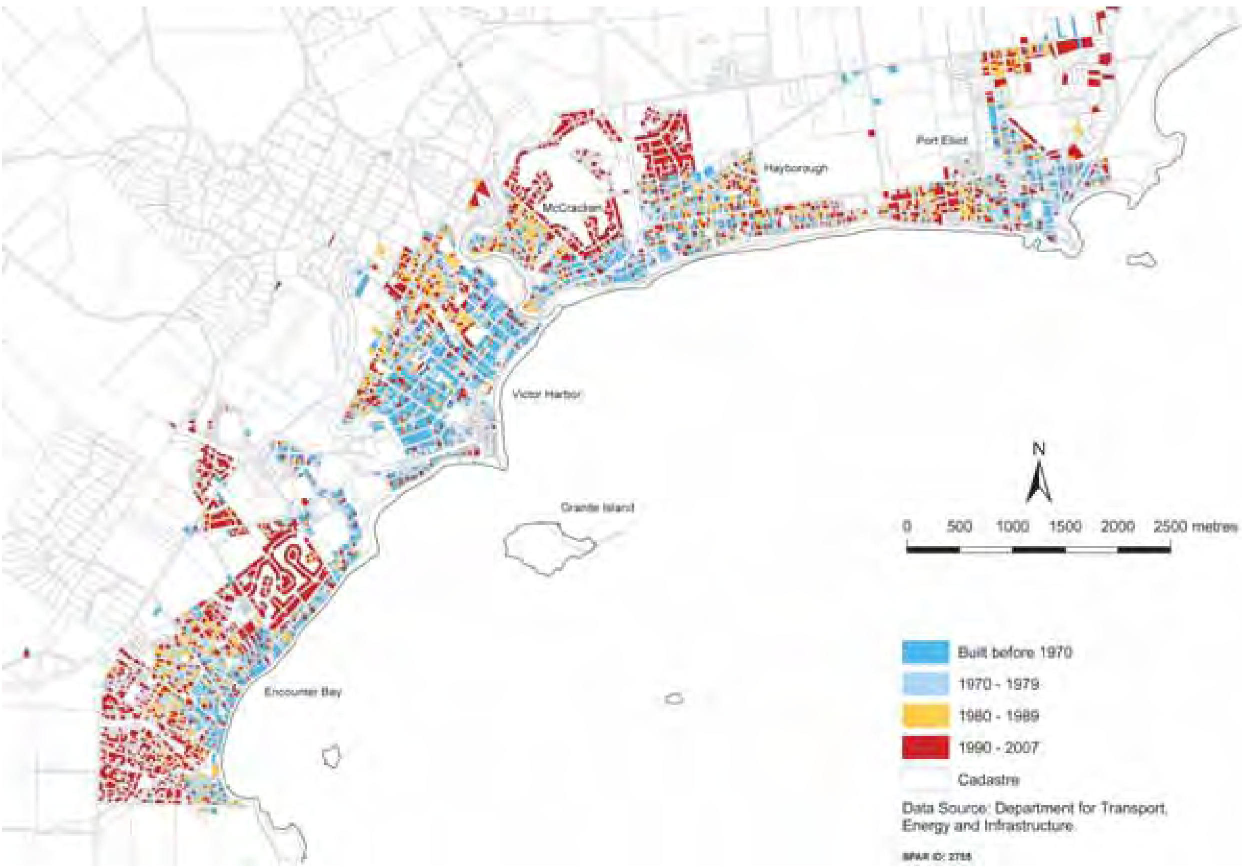

Figure 5.35 Coastal development in Victor Harbor and surrounding areas.
Source: SA EPA 2008[115]

The nature of the coast

Nearly half of the South Australian coast is sandy beaches (47 per cent). Over half of these sandy coasts are backed by soft sediment plains rather than bedrock, and hence have significant potential for shoreline recession and foredune destabilisation with sea-level rise.[116]

A moderate proportion of open coast shores are classified as muddy shores, including those at the head of the Spencer Gulf and Gulf St. Vincent.

Hard rock shores form a considerable proportion (34 per cent) of the South Australian coast. This reflects much of South Australia's exposure to high wave energies. Only a small portion of this (4 per cent) is robust gently-to-moderately sloping rocky coast, with the majority (30 per cent) being steep cliffs such as those of the Nullarbor coast, Eyre Peninsula and Kangaroo Island.[117]

Existing risk

Some coastal areas in South Australia are already exposed to natural and human forces without the compounding effects of climate change. Coastal erosion has been an issue for some years, particularly along Adelaide's metropolitan beaches. This is thought to be due to a combination of factors, including the natural movement of sand from south to north.[118] Other contributing factors include coastal development on foredunes and the substantial loss of seagrass meadows.[119] The construction of seawalls and beach replenishment since the 1970s has been used to protect coastal development and amenity.[120] The cost of beach management, including sand replenishment and sea-wall maintenance and upgrading, was around $1.7 million per year in 2005, with additional costs of approximately $1.9 million per annum for sand bypassing at Glenelg and West Beach Harbours.[121]

Photo credit: Photolibrary

Murray River and the Coorong.

Box 5.12 Port Adelaide seawater stormwater flooding study

The Port Adelaide flooding study assessed risks from seawater and stormwater flooding, with consideration of land subsidence and sea-level rise over the next century.

The Port Adelaide-Enfield peninsular is located between the Gulf St Vincent and the Port River near Adelaide. The study area covers approximately 10,000 hectares, and predominantly lies below the highest astronomical tide level. Sea walls and other flood mitigation measures protect the banks of the Port River.

Various studies have found that the Port Adelaide area has a history of land subsidence, which is believed to be largely the result of wetland reclamation and groundwater extraction from the aquifer. The combined impacts of local land subsidence and contemporary sea-level rise have led to net land subsidence of around 2.1mm/yr within the study area.

The study involved analysis of the 100 year storm tide level and simulation of inundation from three future scenarios of sea-level rise and land subsidence (Table 5.2). Upper and lower estimates were modelled for each scenario with the difference being the extent of water storage capacity in the non-tidal areas. For instance, if a non-tidal area has been exposed to rainfall before the storm tide event, there is a reduced capacity to store incoming inundation waters and so could lead to greater inundation (upper case).

Table 5.2 Future scenarios of sea-level rise and land subsidence.

Scenario	Sea-Level Rise (m)	Period of land subsidence (years)	Description
S0	–	–	Existing case – no sea-level rise or subsidence
S1	0.30	50	Complies with current requirements for infill development
S3	0.50	100	Based on IPCC projections for sea-level rise using medium values in the IPCC range +subsidence
S4	0.88	100	Based on IPCC projections for sea-level rise using high end values in the IPCC range +subsidence

Figure 5.36 indicates the extent of flooding for a current 1-in-100 year storm tide event (Scenario S0; blue shades), as well as the predicted extent of inundation for each of the upper case scenarios (S1–S4). The area of inundation increases to affect larger areas of residential and commercial buildings and roads.

5

Box 5.12 continued...

The estimated damage costs rise significantly with each scenario. The study suggests that damage costs from a 1-in-100 year storm tide could increase from an estimated $8–28 million for a current day event to $180–310 million with future scenarios of sea-level rise and land subsidence.

The study explored a range of abatement options, particularly sea defence measures. For example, a concept design involving the construction of a system of sea walls to protect against inundation would cost an estimated $24–31 million.

Source: Tonkin WBM 2005.[122]

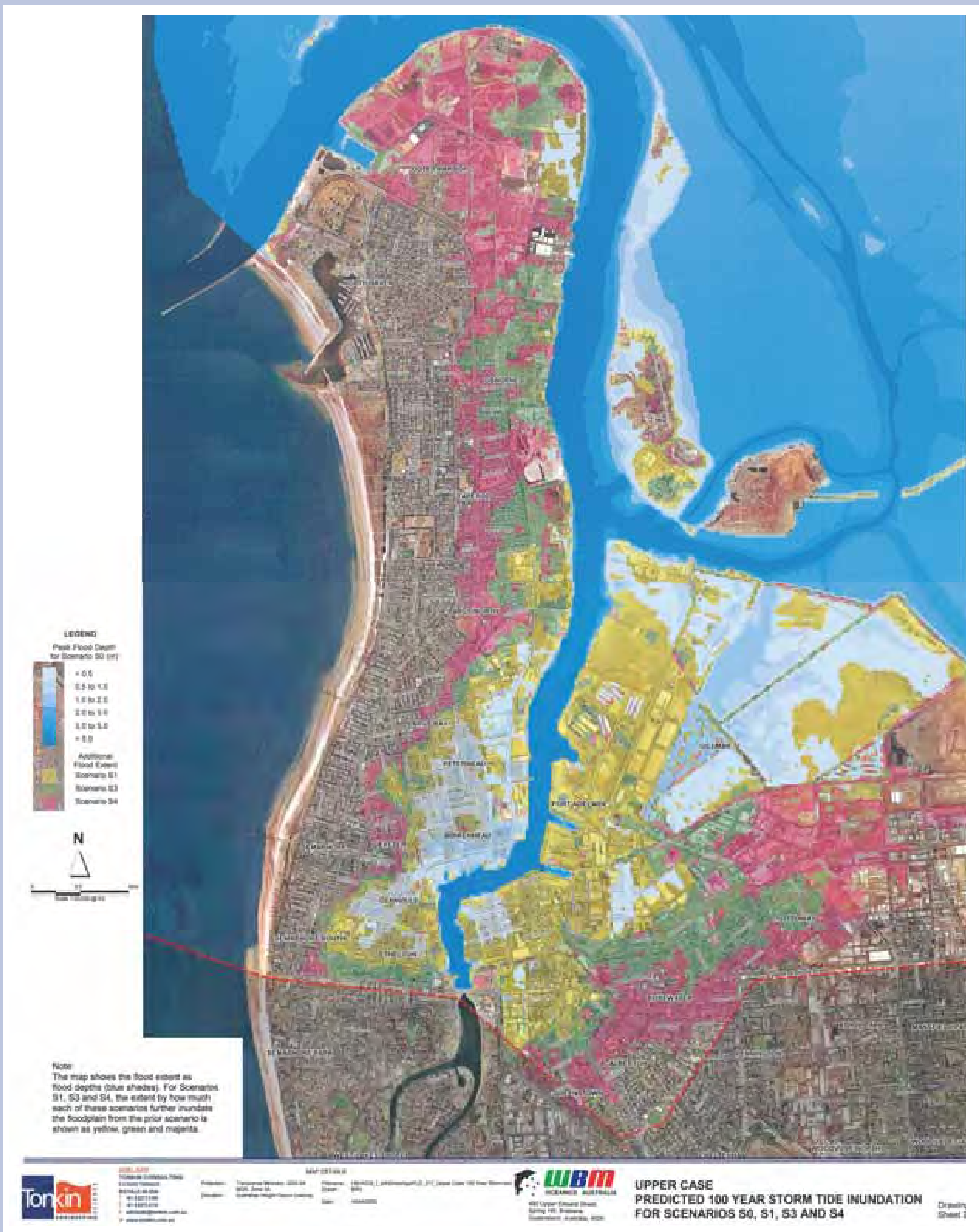

Figure 5.36 Extent of flooding in the City of Port Adelaide Enfield study area for a current 1-in-100 year storm tide event (Scenario S0; blue shades) and for each of the upper case scenarios (S1–S4).
Source: Tonkin WBM 2005.[123]

Photo credit: Department for Environment and Heritage SA

Rogues Point, Yorke Peninsula.

Substantial risks from sea and stormwater flooding also exist in the Port Adelaide-Enfield local government area, where significant redevelopment is underway. A recent flood risk management study[124] estimated that inundation from a 1-in-100 year storm could result in flood damage costs in the order of $8 million to $28 million under the present climate.This is expected to increase under climate change (Box 5.12).

Beyond the metropolitan area, there are also concerns with development strips along the regional coast. In particular, some shacks located on freehold land (previously Crown Land) are vulnerable to coastal erosion due to their close proximity to the shore.[125] These are expected to become increasingly exposed with climate change.

Climate change risk to settlements

Inundation analysis suggests that between 25,200 and 43,000 residential buildings in South Australia may be at risk of inundation from a sea-level rise of 1.1 metres. The current replacement value of the residential buildings at risk is between $4.4 billion and $7.4 billion.

Based on this analysis, South Australia has the fourth highest number of residential buildings at risk of inundation in Australia. If the inundation analysis included storm tides for South Australia it is likely that a higher number of properties would have been identified as at-risk.

The neighbouring local government areas of Charles Sturt and Port Adelaide-Enfield have the highest exposure to a sea-level rise of 1.1 metres, collectively representing around 55 per cent of the residential buildings at risk in South Australia (upper range; Figure 5.37). It is important to note that the coast of metropolitan Adelaide is currently protected by a system of sea walls and dunes, with the sea walls designed for a life of 50–100 years, in line with the South Australian sea-level rise policy.[126]

Methodology – key points and caveats

- Inundation analysis is based on 1.1 metres of sea-level rise using medium resolution elevation data.
- A *storm tide allowance* (1-in-100 year event) based on CSIRO modelling is included in the analysis for Tasmania, Victoria and New South Wales, although storm tide values for New South Wales are likely to be underestimates as they do not include a wave setup component.
- For the other states where the CSIRO modelling was not available (Queensland, Western Australia, Northern Territory, and South Australia) an allowance for *modelled high water level* (e.g. high tide) was included in the analysis.
- The analysis does not take account of existing coastal protection, such as seawalls, or riverine flooding associated with intense rainfall events.
- The inundation analysis is of existing residential buildings only (sourced from NEXIS database).
- More detailed analysis may change the relative order of local government areas and the magnitude and timing of projected impacts.
- Refer to Chapter 3 for further details.

An inundation footprint of sections of the Port Adelaide-Enfield and Charles Sturt LGAs is shown in Figure 5.38.

Between 8,850 and 14,100 residential buildings in the Charles Sturt LGA may be affected by sea-level rise by 2100, with the upper range representing over 30 per cent of all current residential buildings within the LGA. Over 24 per cent (higher estimate) of the existing residential building stock in the LGA of Port Pirie may also be at risk of inundation from sea-level rise by 2100. However, the small LGAs of Kingston, Grant and Robe on the south-east coast of South Australia have the highest proportion of at-risk dwellings. While the total number of buildings at risk may be relatively small, between 40–70 per cent of residential buildings in Kingston, around 35 per cent in Grant, and between 40–50 per cent of residential buildings in Robe may be affected by sea-level rise by 2100.

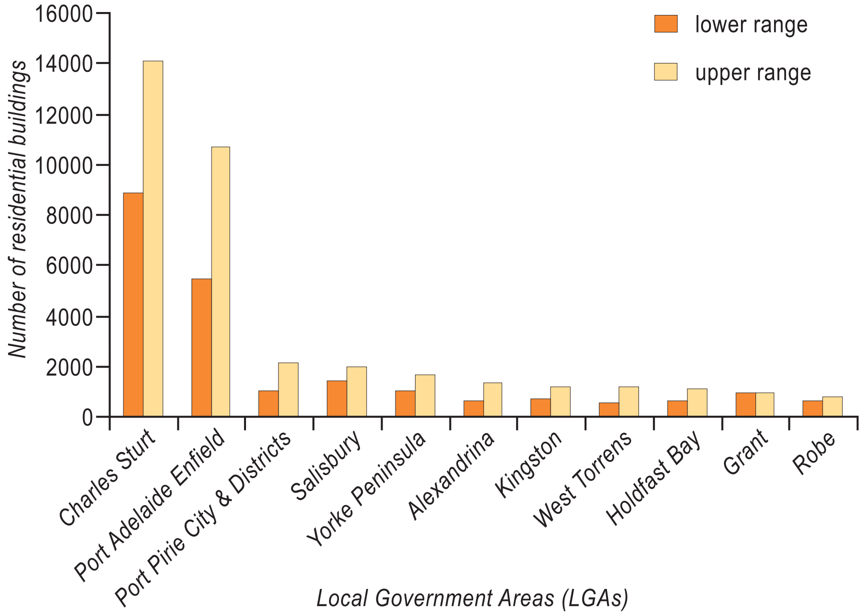

Figure 5.37 Estimated number of existing residential buildings in South Australia at risk of inundation from a sea-level rise of 1.1 metres.

Figure 5.38 Images of sections of the Port Adelaide-Enfield and Charles Sturt LGAs in 2009 and with simulated inundation from a sea-level rise of 1.1 metres using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD.

The analysis also suggests that 23 per cent of residential buildings in the City of Port Adelaide-Enfield could be affected by sea-level rise by 2100. A recent study[127] of seawater flooding risk to Port Adelaide identified that the estimated costs from flooding damage from the combined effects of sea-level rise (50–88 centimetres) and local land subsidence during a 1-in-100 year storm tide event could increase from $8–28 million for a current day event to $180–310 million under future scenarios (Box 5.12).

The Yorke Peninsula also has a significant number of residential buildings that may be vulnerable to climate change, with almost 20 per cent of the current residential stock at risk of inundation from sea-level rise by 2100 (Figure 5.37). A recent study[128] of four small coastal towns on the Yorke Peninsula suggests that without adaptation, annual average damage costs could reach around $1 million for Moonta Bay and Marion Bay and around $4 million for Port Broughton and Fisherman Bay by 2070 (based on a more conservative sea-level rise scenario of 0.47 metres). The study also noted that approximately 80 per cent of the built environment in Fisherman's Bay may be at high risk, largely due to inundation and wave action during storm surge events.

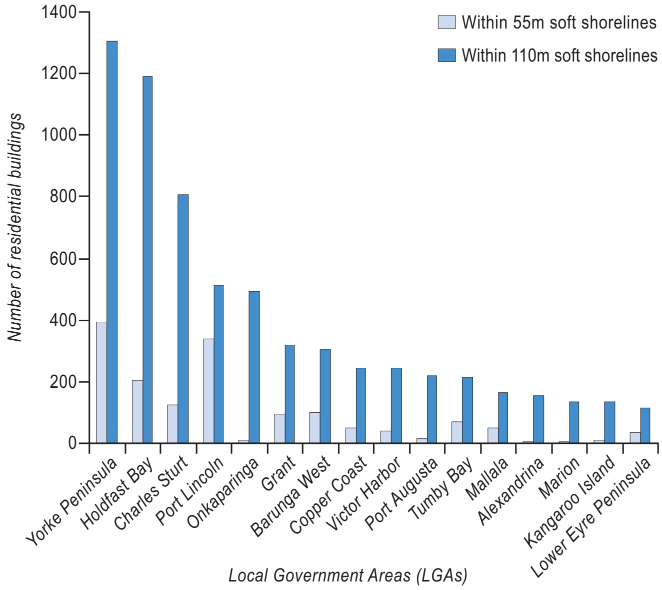

Figure 5.39 Number of residential buildings located within 55 metres and 110 metres of 'soft' shorelines in South Australia.

Management of the Murray mouth, the Coorong and Lower Murray lakes under climate change is complicated by the existence of barrages and controls over water flows in the Murray–Darling Basin. Adaptation responses will need to be informed by further studies to define future impacts associated with rising sea levels, reduced freshwater inputs and various hydrological changes in this estuarine – lagoonal region.

Erosion due to higher sea levels is also a key risk for coastal areas. In South Australia there are approximately 7,000 residential buildings located within 110 metres of 'soft' coast, of which approximately 1,600 are located within 55 metres of the shoreline. Of the coastal LGAs, the Yorke Peninsula and Holdfast Bay have the highest number, with approximately 1,300 and 1,200 residential buildings within 110 metres, of which approximately 400 and 200 buildings, respectively, are within 55 metres of 'soft' shorelines. The LGA of Charles Sturt also has 800 residential buildings within 110 metres of the 'soft' coast (Figure 5.39).

The LGAs of Port Lincoln, Onkaparinga, Grant, Barunga West, Copper Coast and Victor Harbor also have a significant number of buildings located within 110 metres of 'soft' coast. Port Lincoln and Onkaparinga both have approximately 500 buildings, and Barunga West, Grant, Copper Coast and Victor Harbor have between 240 and 320 residential buildings within 110 metres of 'soft' shoreline. In the absence of coastal protection measures or other adaptation responses, these buildings may be at risk of increased erosion with sea-level rise and storm surge due to their location and the nature of the shoreline.

5.1.8 Northern Territory

Key findings

- Up to 180 residential buildings in the Northern Territory may be at risk of inundation from a sea-level rise of 1.1 metres.
- The current replacement value of the residential buildings at risk is between $23.5 million and $57.7 million.
- Up to 190 residential buildings in the Northern Territory are located within 110 metres of 'soft' erodible shorelines.

The population context

The Northern Territory represents just over 1 per cent of Australia's population.[129] The territory experienced the third highest rate of growth of all states and territories in the five years to 2008 (9.9 per cent or 1.9 per cent per year), with Darwin the fastest growing of all capital cities over the same period (12.3 per cent) and home to over half of the territory population.[130]

The Northern Territory has a large percentage of lands under Indigenous management, around 48 million hectares or 36 per cent of the Northern Territory. Communities in these areas are small and dispersed.[131]

The nature of the coast

The open coast exhibits a very high proportion of muddy shores, mainly muddy tidal flats with mangroves (31 per cent), which are a characteristic of northern Australian tide-dominated coasts. These will be very mobile shores in response to climate change and sea-level rise; although many will recede and be over-washed during cyclone events, accretion is likely on some of these coasts (due to increased rainfall supplying increasing amounts of river sediment to the coast).[132]

Compared to the rest of Australia, the open coast has a high proportion of low-profile soft rock coasts (15 per cent). These are actively receding and will continue to progressively recede with sea-level rise. In contrast, hard rock (robust) shores are a comparatively minor component of this coast.

Photo credit: A.D. Short

Hut Point.

Sandy shores are also moderately common in the Northern Territory, although in contrast to other states a higher proportion is bedrock backed (18 per cent) and thus less prone to recession with sea-level rise.[133]

Existing risk

Coastal areas in the Northern Territory are already exposed to natural hazards without the compounding effects of climate change. This includes tropical cyclones and associated storm surge, flooding and coastal erosion among other natural hazards.

The most significant cyclone event in Australia's history was Tropical Cyclone Tracy, which devastated Darwin in 1974. Seventy-one lives were lost, thousands of homes destroyed and over 70 per cent of the population evacuated.[134] Direct and indirect costs of Cyclone Tracy have been estimated at between $1.9 billion and $4.2 billion (1998/1999 dollars), and cyclones have accounted for over 90 per cent of costs from natural disasters in the Northern Territory since 1967.[135] While measures such as improved building standards have been implemented since Cyclone Tracy, the risk from the 2–3 cyclones that occur on average in the region each year[136] cannot be completely mitigated.

Coastal erosion has also become a concern for some cliffs at East Point and Nightcliff in Darwin. A recent study[137] for the Darwin City Council has identified that sections of the coast have been eroding at an average rate of 0.2–0.4 metres per year over the last few decades and some areas of erosion are now close to roads and residential buildings. The study[138] also identified that a more rapid erosion rate of 5 to 10 metres over a matter of weeks could occasionally affect parts of the coast.

The erosion is a natural occurrence caused by wave action and other factors, and compounded in some sections by groundwater flows and stormwater and surface runoff. Some areas may be vulnerable under climate change, with the erosion likely to be exacerbated by sea-level rise.[139]

Photo credit: National Archives of Australia

Darwin in the aftermath of Cyclone Tracy, 1974.

Photo credit: Shelley Franklyn

Cliff erosion in Nightcliff, NT.

Climate change risk to settlements

Inundation analysis suggests that up to 180 residential buildings in the Northern Territory may be at risk of inundation from a sea-level rise of 1.1 metres. The current replacement value of the residential buildings at risk is between $23.5 million and $57.7 million. If the inundation analysis included storm tides for the Northern Territory it is likely that a higher number of properties would have been identified as at-risk.

Local government areas (LGA) that have the greatest level of risk are Litchfield, the 'Unincorporated' area and Darwin, which represent over 85 per cent of residential buildings at risk of inundation in the Northern Territory from sea-level rise by 2100 (upper end; Figure 5.40). An inundation footprint of the Darwin LGA is shown in Figure 5.41.

Around 75 buildings in the LGA of Litchfield may be affected by inundation from sea-level rise by 2100, with the upper estimate representing about 1 per cent of the current residential building stock. The other local government areas have comparably small percentages of current residential stock at risk of inundation, with Wagait the highest at less than 3.5 per cent.

Erosion due to higher sea levels is also a key risk for coastal areas, as highlighted by the current erosion concerns in East Point and Nightcliff in Darwin. Along the Northern Territory coast nearly 190 buildings are located within 110 metres of 'soft', erodible coasts. The majority of these buildings are in Darwin, with between 60 and 170 residential buildings located within 55 metres and 110 metres, respectively, of 'soft' shorelines. In the absence of coastal protection measures or other adaptation responses, these buildings may be at risk of increased erosion from sea-level rise and storm surge.

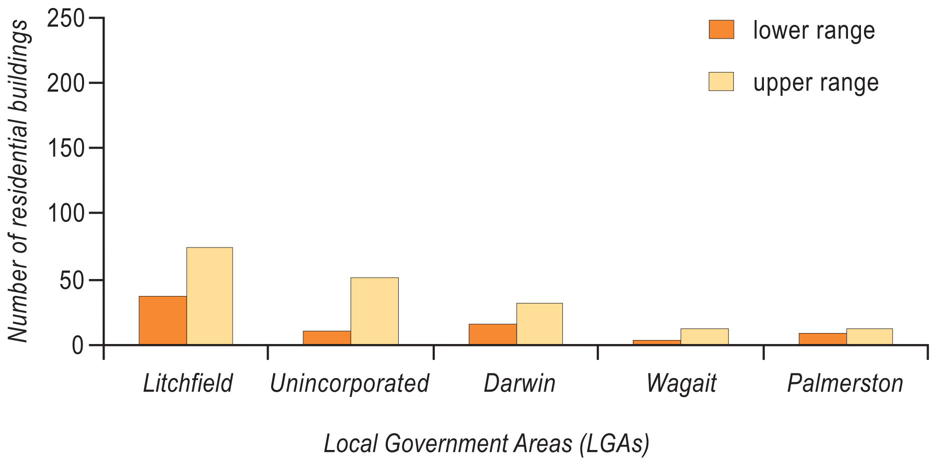

Figure 5.40 Estimated number of existing residential buildings in the Northern Territory at risk of inundation from a sea-level rise of 1.1 metres (the 'Unincorporated' area surrounds the LGAs of Darwin, Litchfield and Palmerston).

Figure 5.41 Image of Darwin in 2009 and with simulated inundation from a sea-level rise of 1.1 metres using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD.

Methodology – key points and caveats

- Inundation analysis is based on 1.1 metres of sea-level rise using medium resolution elevation data.
- A *storm tide allowance* (1-in-100 year event) based on CSIRO modelling is included in the analysis for Tasmania, Victoria and New South Wales, although storm tide values for New South Wales are likely to be underestimates as they do not include a wave setup component.
- For the other states where the CSIRO modelling was not available (Queensland, Western Australia, Northern Territory, and South Australia) an allowance for *modelled high water level* (e.g. high tide) was included in the analysis.
- The analysis does not take account of existing coastal protection, such as seawalls, or riverine flooding associated with intense rainfall events.
- The inundation analysis is of existing residential buildings only (sourced from NEXIS database).
- More detailed analysis may change the relative order of local government areas and the magnitude and timing of projected impacts.
- Refer to Chapter 3 for further details.
- The Tiwi Islands and East Arnhem LGA were not captured in the analysis.

Another important issue for the Northern Territory is the impact of cyclones and associated storm surge, with some studies suggesting the intensity of cyclones may increase with climate change. A recent vulnerability assessment[140] of climate change impacts on Darwin identified that cyclone and storm shelters can accommodate only a small proportion of the existing population of Darwin, although plans for further shelter provision will address this to some extent. Most shelters are built to withstand a Category 4 storm, however these may need to be reassessed with future climate change. While crucial infrastructure such as power stations, water treatment plants, sewage treatment plants and hospitals are required to be designed to survive a 1-in-2,000 year event, only a small percentage of Darwin's total buildings are guaranteed to conform to post-2001 strengthened building code requirements.[141] There is also concern that some residents are not fully aware of the capacity of their homes to withstand cyclone damage and as such may be unable to make informed decisions about protecting or evacuating.

The Darwin vulnerability assessment also identified that there is significant variation in population exposure to storm surge with quite small changes in the size of the storm surge zone.[142] For an increase in the storm surge zone of 400 metres inland, an additional 9,000 people could be affected by storm surge.[143] Some lengths of railway and a large number of minor roads could also be impassable due to storm surge from major events.

5.1.9 Western Australia

Key findings

- Between 18,700 and 28,900 residential buildings in Western Australia may be at risk of inundation from a sea-level rise of 1.1 metres.
- The current replacement value of the residential buildings at risk is between $4.9 billion and $7.7 billion.
- Local government areas (LGA) of Busselton, Mandurah, Rockingham and Bunbury have the highest level of risk, collectively representing over 60 per cent of residential buildings at risk in Western Australia.
- There are approximately 2,100 residential buildings located within 110 metres of 'soft' erodible shorelines, of which approximately 200 are within 55 metres of soft coasts.

The population context

Western Australia has the longest coastline of any Australian state or territory. It has been the fastest growing state for the past two years (2006–2008) and now represents over 10 per cent of Australia's population.[144] It is home to more than 2 million people that are largely concentrated in the south-west, with the Perth region accounting for 75 per cent of growth in 2007–2008.[145]

Two particular coastal growth hotspots in Western Australia are Mandurah and Busselton. Between 2003 and 2008, Mandurah's annual average growth rate was the second highest of all Australian major population areas.[146] More than 50 per cent of new residents to Mandurah in 2006 moved from Perth and over a quarter were 60 years of age or older, reflecting the 'sea change' phenomenon.[147]

Photo credit: ©iStock.com/Tobias Lauchenauer

Mandurah canal estate.

Photo credit: Ian Eliot

The nature of the coast

Western Australia has a very long open coast (20,513 kilometres[148]), however nearly half of this (9,748 kilometres) is found in the intensely convoluted Kimberley coast (including islands) between Derby and Bonaparte Gulf, much of which is hard rock coast including cliffs.[149]

About a quarter (26.5 per cent) of the coast comprises sandy shores, of which probably somewhat over half of these are backed by soft sediment (and therefore with potential for significant recession), while a slightly smaller proportion is bedrock-backed and thus has less potential for recession with sea-level rise. Sandy shores comprise roughly half of the Western Australia coast south of the Kimberley.[150]

Muddy shores (commonly broad tidal flats) are another significant element of the Western Australian open coast (26 per cent), and are associated with extensive tidal flats in the region between Exmouth and Derby, and to a lesser extent in the Kimberley.[151]

The coastal length statistics indicate that a significant proportion of the Western Australian coast is hard (or undifferentiated hardness) rocky coast (28 per cent), however note that this is probably an under-estimate since a high proportion (27 per cent or 5,616 kilometres[152]) of Western Australian shores are not classified into any coastal landform stability class, owing to gaps in the source data. These gaps are most extensive in the northern half of Western Australia. Moreover, the data at the state scale do not differentiate areas of calcarenite rocky coast subject to existing erosion and which may experience accelerated local erosion as sea level and wave climate changes.[153]

Photo credit: Dave Tanner/The West Australian

Erosion along Perth beach near Floreat Surf Club, 1978.

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Photo credit: NearMap Pty Ltd

Aerial images showing erosion of North Beach in Perth after a winter storm.

Photo credit: Don Ward/Bureau of Meteorology

Flooding of Riverside Drive from storm surge.

Existing risk

There has been no experience of devastating natural events during Perth's short history. Over the past century no widespread natural disaster has killed more than five people or resulted in insurance losses worth over $100 million.[154] However, there are still significant risks associated with wind, storm surge, and erosion from wave action, along the vast coastline.

Tropical cyclones pose a significant risk in the northwest of Western Australia with the Broome–Exmouth region the most cyclone-prone of Australia's coastline.[155] The 'cyclone region' is generally considered to be the area north of Geraldton, however cyclones have been known to penetrate southwards.

Tropical Cyclone Alby passed near Perth in 1978 causing approximately $39 million (2003 dollars) in damage and the loss of five lives.[156] Storm surge associated with the cyclone led to significant coastal erosion and inundation, including the flooding of low elevation areas of Busselton and Bunbury. The tide reached 1 metre above the highest astronomical tide in Busselton due to a significant storm surge of 1.3 metres.[157]

However, the more common hazards in the south-west of the state are 'cool season' storms. Over the past four decades, the greatest insurance losses from natural hazards in the south-west region have been due to severe storm events.[158] In May 2003, a storm tide half a metre above highest astronomical tide (recorded at Fremantle) caused substantial coastal erosion and flooding of low-lying areas that affected roads around the Swan River.[159] The building foundations of a Mandurah home in a canal estate were also impacted.

Methodology – key points and caveats

- Inundation analysis is based on 1.1 metres of sea-level rise using medium resolution elevation data.
- A *storm tide allowance* (1-in-100 year event) based on CSIRO modelling is included in the analysis for Tasmania, Victoria and New South Wales, although storm tide values for New South Wales are likely to be underestimates as they do not include a wave setup component.
- For the other states where the CSIRO modelling was not available (Queensland, Western Australia, Northern Territory, and South Australia) an allowance for *modelled high water level* (e.g. high tide) was included in the analysis.
- The analysis does not take account of existing coastal protection, such as seawalls, or riverine flooding associated with intense rainfall events.
- The inundation analysis is of existing residential buildings only (sourced from NEXIS database).
- More detailed analysis may change the relative order of local government areas and the magnitude and timing of projected impacts.
- Refer to Chapter 3 for further details.

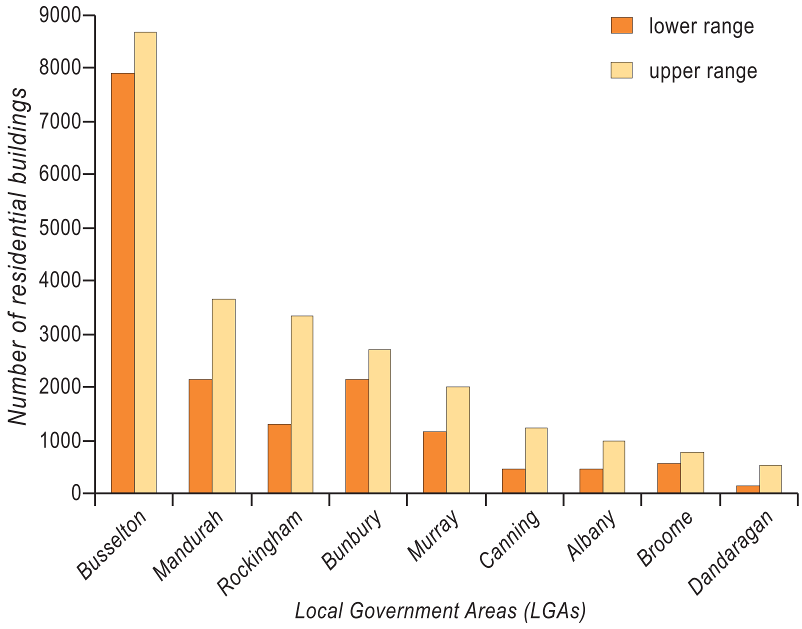


Figure 5.42 Estimated number of existing residential buildings in Western Australia at risk of inundation from a sea-level rise of 1.1 metres.

Climate change risk to settlements

Inundation analysis suggests that between 18,700 and 28,900 residential buildings in Western Australia may be at risk of inundation from a sea-level rise of 1.1 metres. The current replacement value of the residential buildings at risk is between $4.9 billion and $7.7 billion.

Based on this analysis, Western Australia has the fifth highest number of residential buildings at risk of inundation. If the inundation analysis included storm tides for Western Australia it is likely that a higher number of properties would have been identified as at-risk.

Local government areas that have the greatest level of inundation risk are Busselton, Mandurah, Rockingham and Bunbury, located in the south-west. These areas collectively represent over 60 per cent of residential buildings at risk in Western Australia (upper range; Figure 5.42). Inundation footprints for some regions are shown in Figures 5.43–5.45.

Between 7,900 and 8,700 residential buildings in the local government area of Busselton may be affected by sea-level rise by 2100, with the upper range estimates representing approximately 60 per cent of all current residential buildings within the LGA. The percentage of residential buildings at risk in both Bunbury and Murray is also relatively high, with upper range estimates of 24 per cent and 34 per cent of the existing housing stock, respectively. A significant proportion (around 21 per cent) of existing residential buildings may also be at risk in the smaller LGAs of Broome and Dandaragan.

Figure 5.43 Images of Mandurah in 2009 and with simulated inundation from a sea-level rise of 1.1 metres using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD.

Figure 5.44 Images of Bunbury in 2009 and with simulated inundation from a sea-level rise of 1.1 metres using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD.

Figure 5.45 Images of Broome in 2009 and with simulated inundation from a sea-level rise of 1.1 metres using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD.

The Canning LGA is located on the Canning River away from the immediate exposure of the coast. However, Figure 5.42 indicates that some residential buildings in the LGA have an exposure risk due to their low elevation. This reflects the tidal reach along the river and highlights that sea-level rise is not simply a coastal issue, with the Swan-Canning system potentially becoming more saline under climate change.[160]

Coastal erosion is also a key risk associated with climate change. A 2005 study of natural hazard risks in Perth[161] included an assessment of coastal areas that may be vulnerable to accelerated erosion due to sea-level rise, and noted a number of stretches of the coastline that warranted further investigation.

The study identified the stretch of coast between Bunbury and Mandurah as the most vulnerable to coastal erosion (Figure 5.46).[162] Sea-level rise may also cause erosion between Cape Naturaliste and Bunbury, particularly in the areas surrounding Bunbury and Busselton. While erosion is not a significant factor for most of the Perth coastline, three locations were identified as being susceptible to erosion. These areas in order of vulnerability are Port/South Beach, Swanbourne Beach and Pinaroo Point, with modelling indicating that 100–130 metres of Swanbourne Beach could be lost to erosion over the next century (based on sea-level rise scenario of 48 centimetres). The study indicated that the stretch of coast between Mandurah and Fremantle may not be vulnerable to erosion, although localised erosion is possible (Figure 5.46).[163] Refer also to Figure 4.4 for conceptual models of the different types of beach response in the Perth region to sea-level rise.

Along the Western Australian coast there are approximately 2,100 residential buildings located within 110 metres of ‘soft’, erodible shorelines, of which approximately 200 are located within 55 metres of ‘soft’ coasts. The coastal LGAs of Busselton and Mandurah have the highest number, with more than 350 residential buildings within 110 metres of ‘soft’ shorelines in each area (Figure 5.47). Similarly, Rockingham and Augusta-Margaret River LGAs both have approximately 250 residential buildings within 110 metres of ‘soft’ coast, of which almost 80 are within 55 metres of the shoreline in Augusta-Margaret River. In the absence of coastal protection measures or other adaptation responses, these buildings may be at risk of increased erosion with sea-level rise and storm surge due to their location and the nature of the shoreline.

Figure 5.46 Coastal erosion susceptibility in Perth. Source: Jones 2005[164]

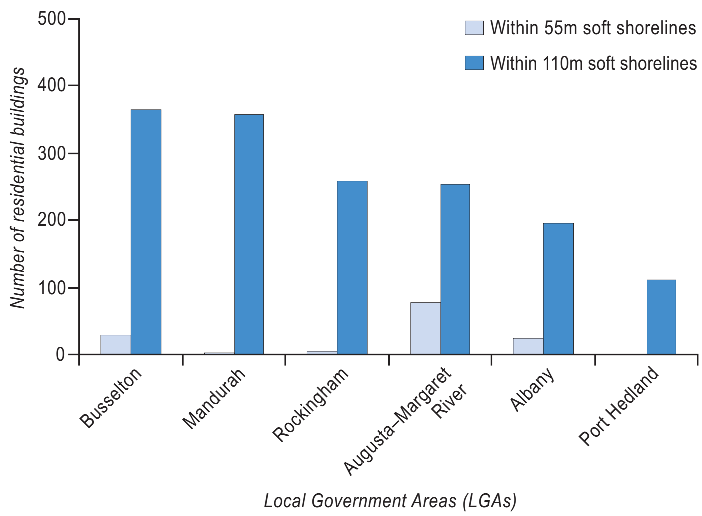


Figure 5.47 Number of residential buildings located within 55 metres and 110 metres of 'soft' shorelines in Western Australia.

5

5.2 Implications for infrastructure and services

Climate change impacts on infrastructure are expected to include accelerated degradation of materials and foundations of buildings and facilities, mainly due to rising sea levels, increased ground movement, changes in ground water affecting the chemical structure of foundations and fatigue of structures from extreme storm events.[165]

Increased temperature and solar radiation may also reduce the life of building and facility elements due to increased expansion and materials degradation of concrete joints, steel, asphalt, protective cladding, coatings, sealants, timber and masonry. Increased humidity in the coastal zone will also affect the rate of corrosion and material degradation. This has the potential to reduce the life expectancy of buildings, structures and facilities. Such degradation also increases the probability that extreme weather events will result in structural failure.[166]

Impacts on infrastructure in the coastal zone will have broader consequences for the community. A preliminary analysis of the location of infrastructure and community services reveals a large number of facilities within 200 metres and 500 metres of the coastline, and potentially at risk under a changing climate (Table 5.3).[167] Of concern is the number of hospitals, police, fire and ambulance stations very close to the coast. Compromising the functionality of these services during an extreme weather event can result in significantly greater impacts than might otherwise occur and could have life and death consequences.

This section summarises the likely implications of climate change for ports and airports in the coastal zone and the provision of essential services.

5.2.1 Transport infrastructure – ports and airports

Ports

Ports and shipping are crucial to Australia's international trade carrying 99 per cent of Australia's total merchandise trade and 75 per cent of its value.[168] Climate change will bring more intense storm events including chaotic, heavy precipitation, high wind velocity, increased wave action and higher storm surges.

These events will lead to a range of impacts including: increased runoff and siltation requiring increased dredging; disturbance and distribution of currently entrained heavy metals and other pollutants; increased high wind stoppages under Occupational Health and Safety requirements; delays to berthing and cargo handling; coastal flooding; and required engineering upgrades to wharfs, piers, gantries and other cargo handling equipment.

The extent to which a port is affected by climate change is dependent on whether the port is exposed or sheltered and its location. Generally container ports are located in sheltered harbours close to cities, whereas bulk ports are often in open-ocean locations, close to production sites or transport hubs.

Port operation, particularly in draught-restricted ports, is highly dependent on predictability of tide, wave and weather patterns. Changes to those patterns may affect the ability of harbour masters to manage ports safely and efficiently.[169] Sea-level rise may result in greater penetration of wave energy into harbours potentially causing increased coastal erosion, navigation difficulties and damage to port infrastructure.[170]

Table 5.3 Transport and services infrastructure and facilities within 200 m and 500m of the Australian coastline.

	within 200m of the coastline	within 500m of the coastline
Regional infrastructure	120 ports 5 power stations/substations 3 water treatment plants 170 unidentified industrial zones 1,800 bridges	120 ports 11 power stations/substations 3 water treatment plants 170 unidentified industrial zones 2,795 bridges
Community services and facilities	258 police, fire and ambulance stations 75 hospitals and health services 46 government administration facilities 360 universities, colleges and schools 102 retirement/nursing homes 11 emergency services facilities 41 waste disposal facilities	702 police, fire and ambulance stations 199 hospitals and health services 107 government administration facilities 992 universities, colleges and schools 296 retirement/nursing homes 35 emergency services facilities 92 waste disposal facilities

Source: Geoscience Australia 2009, NEXIS database


Photo credit: Gladstone Ports Corporation Limited

Port of Gladstone.

Of particular concern to port operation, climate change could increase the severity of cyclones in northern Australia, and possibly extend their southward tracks along the Queensland and Western Australian coasts. This will increase the number of port closures, possibly quite significantly by mid-century.[171] Some ports for example require closure whenever a cyclone moves within a 300 kilometre radius of the port. The migration of cyclone affected areas southward will bring a new and complex set of challenges to ports, such as Brisbane, not currently cyclone affected.

An increase in the number of very hot days can also lead to increased downtime in ports as Australian stevedores stop work at 38° Celsius. While the number of days exceeding this threshold is expected to increase only slowly for the next couple of decades, in northern Australia the number increases considerably in the latter half of this century.

There are a range of economic consequences of port closure or downtime, including costs associated with the backlog of ships waiting to enter or leave the port, costs associated with providing assistance to vessels caught up in a storm event and broader economic impacts on port reliant businesses, freight transport networks and consumers.

The infrastructure analysis commissioned by the Garnaut review identified climate change impacts on (i) port productivity as a result of increased downtime, on (ii) capital expenditure to allow for changes in design and protection in response to sea-level rise and cyclones, and on (iii) operational expenditure from additional maintenance and repair costs. The following table shows the percentage shocks for select states for the best estimate climate change scenario (Table 5.4). These shocks were utilised in economic modeling of the costs of climate change impacts.

Port infrastructure can also be degraded by corrosion arising from ocean acidification, in combination with increased temperatures and sea-level rise. The most corrosive environment is the aqueous, high oxygen area of the inter-tidal splash zone which can lead to aggressive and rapid corrosion. The result will be a loss in the strength of the concrete – as the silicate structure is destabilised, leaching of the calcium from the concrete occurs and voids form within the concrete structure.[173] Higher sea levels also expose more of the jetty or wharf structure to corrosion.


Photo credit: Arthur Mostead

Table 5.4 Economic cost increases from climate change impacts on ports.

State	Productivity		Capital expenditure		Operational expenditure	
	2031–2070	2071–2100	2031–2070	2071–2100	2031–2070	2071–2100
Vic	4 per cent	5 per cent	9 per cent	11 per cent	7 per cent	8 per cent
NSW	4 per cent	5 per cent	11 per cent	13 per cent	7 per cent	8 per cent
WA	7 per cent	10 per cent	11 per cent	15 per cent	8 per cent	10 per cent
NT	5 per cent	9 per cent	6 per cent	10 per cent	6 per cent	9 per cent
Qld	8 per cent	11 per cent	13 per cent	17 per cent	9 per cent	11 per cent

Source: Maunsell 2008[172]

Box 5.13 Concrete structures and the implications of climate change

Concrete is one of the most common construction materials. Increased atmospheric carbon dioxide concentrations, temperature (and humidity) increases, and sea water splash can all accelerate the degradation process of concrete.[174] This will require costly and disruptive repairs during the service life of many concrete structures. [175]

A study examined the stresses, corrosion and shear failure of a typical reinforced concrete bridge girder over a 100 year period and found that the probability of corrosion initiation is up to 720 per cent higher for the worst case scenario.[176] Probabilities of failure are also up to 18 per cent higher in the worst than the best mitigation scenario.[177]

Photo credit: Port of Melbourne Corporation

Figure 5.48 Images of Brisbane airport in 2009 and with simulated inundation from a sea-level rise of 1.1 metres using medium resolution elevation data (not suitable for decision-making). © CNES 2009 / imagery supplied courtesy of SPOT Imaging Services and Geospatial Intelligence PTY LTD

Airports

There are a number of airports in low-lying areas in the coastal zone and at risk of inundation in the coming century as a result of climate change. Significant disruption can be expected to regional economies if a major capital city airport closed even for a short period of time. While there has been no comprehensive assessment of climate change risks to Australian airports, in the medium term it is possible that consideration will need to be given to protective works for a number of key airports, particularly Sydney and Brisbane.

5.2.2 Essential services

Similarly there has been little analysis of the implications of climate change for the provision of essential services in the coastal zone. Table 5.3 indicates facilities that are underpinning delivery of services are in close proximity to the coast and could be at risk of inundation and erosion as a result of climate change. Clearly any impact on such facilities would have broader consequences across the community. Following is a summary of potential impacts of climate change for water and wastewater, waste management and energy supply in the coastal zone.

Water and wastewater

Securing a reliable water supply for Australia's coastal residents outside of the capital cities is not only crucial for the survival of those communities but is also important for the Australian economy and society.[178] With much of Australia's population living within the coastal zone, significant water and wastewater infrastructure has been built to accommodate coastal cities and communities, with some assets located in very close proximity to the coast (Table 5.3).

A survey of coastal councils in 2005 noted the ability to provide good quality water to the community as a significant concern.[179] For many coastal councils' the most pressing water supply issue was associated with population pressure, as coastal towns were not planned as high growth communities. Many coastal communities also rely on local freshwater aquifers for the town water supply as well as irrigation

Box 5.14 Sea-level rise a threat to Sydney Airport

Sydney Airport is the busiest airport in Australia, handling 31.9 million passengers and 290,346 aircraft movements in 2007.[180] Situated next to Botany Bay, the airport has three runways, known as the 'East-West', 'North-South' and 'Third' runways. The airport is managed by Sydney Airport Corporation Limited.

Sydney Airport is almost entirely surrounded by waterways, with Botany Bay to the south, Botany Wetlands (incorporating the Sydney Airport Wetlands) to the east, Alexandra Canal to the north and the Cooks River to the west. The airport's proximity to Botany Bay and tidal waterways makes it vulnerable to future sea-level rise and storm surge. A sea-level rise of 1.1 metres combined with a storm surge would inundate parts of the airport, interrupting operations and causing damage to infrastructure.

Vulnerable areas include sections of runways, taxiways and aprons, and the northern perimeter road. The lowest lying areas (and hence the most vulnerable) are in the north section of the airport. For example, an open drain flowing under Qantas Drive and into the Alexandra Canal has a pipe with an invert level (IL) at minus 1m Australian Height Datum (AHD), meaning it is already below Mean High Water Level and at risk from relatively small rises in sea level. The northern airside perimeter road, which is critical for aircraft servicing, re-fuelling aircraft and moving freight, also runs through this section of the airfield, and is at a level of 1.5m AHD.

The physical effects of inundation would compromise seawall stability, degrade drainage and pavements, and damage airfield lighting/electrical systems, navigation aids and Air Traffic Control facilities. Significant rises in inundation levels would also affect the surrounding arterial road network and other facilities.

The combined effects of sea-level rise, storm surge and tidal action resulting in significant inundation of the airfield movement area could effectively close the airport. Any significant disruption to air services would have a compounding effect on airline networks and would cause problems to both domestic and international traffic because of the reliance of airlines on maintaining their schedules. A lengthy disruption caused by inundation of the airfield would cause airline network problems around Australia and internationally with economic losses to the airport, airlines, business and the tourist industry.

As the probability of airport closure and expected costs increases, some adaptation options include raising seawalls around the airport or installing locks in the Cooks River. If these activities were insufficient to adapt to sea-level rise, it may become necessary to raise the airfield and associated facilities by up to one metre (not over the entire airfield but principally the northern airfield areas). This would involve raising seawalls, importing fill, reconstructing runways and taxiways, and relocating air navigation and air traffic control facilities. It is estimated the cost of this would exceed $1 billion.

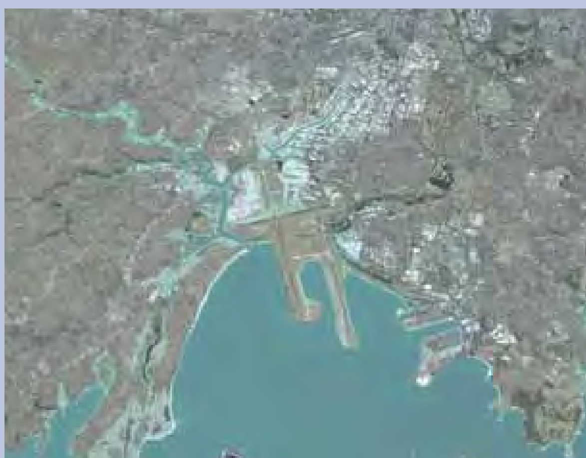
Consideration of possible sites for a second major airport for Sydney have taken place periodically over the past 60 years. However, community concerns, social, economic and environmental costs have so far proved a barrier to the construction of another site. The Australian Government and New South Wales Government have agreed to participate in a joint study to assess options, identify potential sites and evaluate investment strategies for delivering additional airport capacity for the Sydney region.

Note: heights above (or below) AHD are from Australian Mapping GIS and are accurate to the nearest 0.5m.

Source: AECOM 2009[181]

Photo credit: Photolibrary

Sydney airport.



Simulated inundation of Sydney airport for the first half of next century.

and industrial processes. A number of coastal freshwater aquifers will be increasingly exposed to saline groundwater intrusion with rising sea levels. Freshwater contaminated by seawater at the level of only 5 per cent renders it unsuitable for domestic water consumption and for some irrigation and industrial uses.[182] Rising sea levels can also raise coastal water tables, with these higher water tables potentially impacting infrastructure, including leakage to septic tanks, sewer systems, and basements and causing instability of swimming pools, tanks and some other subsurface structures.

Water and wastewater infrastructure can have an effective operational life of many decades. Stormwater pipes and drainage assets will also be exposed to the impacts of rising sea levels and may not be adequate to accommodate future changes in extreme rainfall and storm surge. Increasing maintenance and renewal costs of drainage assets and an increased risk of local flash flooding are likely to result. Saltwater may increasingly enter because of factors such as cracks in pipes caused by ageing or movement, and the presence of seawater reduces system capacity and increases operational costs.

Sydney Water undertook an initial assessment of the impacts of climate change on its water and wastewater operations. Six general areas of adaptation response were identified: *material selection*, researching new material resilient to climate change; *design standards* to cope with the change in extreme events; *maintenance regimes* to accommodate acceleration in the degradation of material and structures; *technologies* for alternative or new early warning and information systems; *planning* to meet changed physical conditions; as well as *cultural change* to raise organisational awareness.[183] Additionally the assessment identified stormwater assets at risk from sea-level rise and has an established work program to reduce the amount of saltwater entering the sewers that are laid below the high tide level.[184]

Waste – landfill

Waste management practices have evolved considerably in Australia since European settlement. Whereas waste was once burnt in open air dumps, now there is an emphasis on recycling with the disposal of residual waste in fully engineered landfills.

Box 5.15 Sydney Water – drainage assets and climate change

Sydney Water has implemented an inundation program to measure both flow and salt levels in sewers so that faults can be identified and fixed. Repairs reduce the energy and amount of chemicals used in the sewerage system. With sea-level rise, the frequency and extent of exposure to saltwater intrusion will rise, increasing costs.

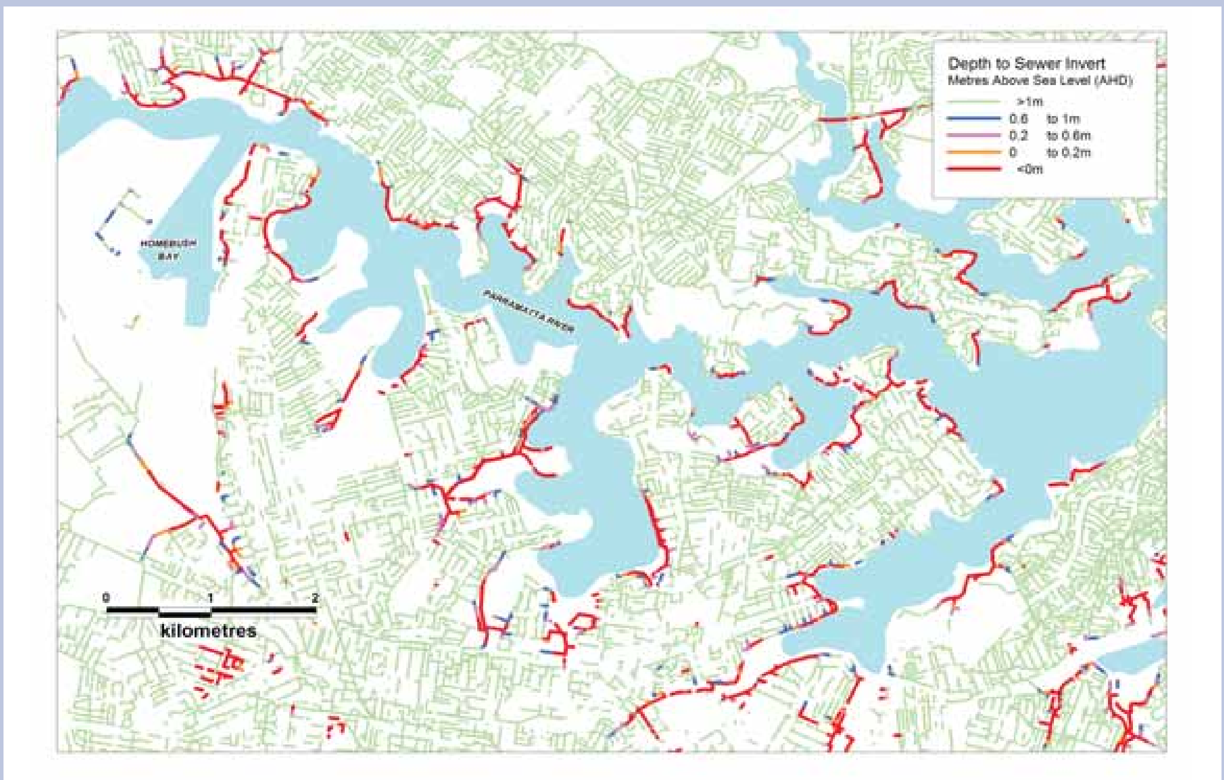


Figure 5.49 Sydney Water drainage assets at risk from sea-level rise.
Source: Sydney Water Corporation

Most state and local governments now prevent the construction of new landfills within 100 metres of a watercourse. However, there is a large legacy of many 'tips' and 'dumps' long closed, but located in areas vulnerable to the future impacts of climate change and sea-level rise. For example large, multi-million dollar landfills such as Cairns and Brisbane, are located in low-lying areas. At least 41 waste disposal facilities are located within 200 metres of the coastline (Table 5.2). Many town dumps were located in places that were undesirable or not suitable for community needs, were cheap to procure or required filling. As a result many old dumps are sited in or adjoining flood prone and low-lying lands. Areas abutting mangroves and salt marshes were, for decades, preferred places for the local tip.

There are approximately 600 medium to large operating landfills in Australia today and possibly several thousand small tips. These range from containing hundreds of tonnes of waste, up to engineered landfills holding tens of millions of tonnes of waste. Existing clay capping and vegetative cover is unlikely to be able to withstand the erosive power of waves acting directly on the fill batters of a landfill face, especially driven by the power of a tropical cyclone. Permanent inundation of the base of the landfill could also create significant leachate problems. The Cairns landfill for example is in the final stages of its life and is located adjoining low-lying mangroves. A significant rupture of the landfill cap or walls could see hundreds or thousands of tonnes of materials released back into the environment.

What is unclear is how many small dumps may exist, for which on site protection may not be cost effective, but may still cause pollution. The waste from these tips will need to be removed and relocated to inland landfills or recycled. The cost of relocation would range from thousands of dollars, to many millions depending upon the size of the landfill.

It is difficult to specify the types of materials disposed into landfills or the quantity that may be released back into the environment by progressive climate change related erosion. It is known however that most landfills contain quantities of oil, demolition waste, asbestos, pesticides, plastic and heavy metals fixed into the soil/waste matrix. If this were released back to the environment it would constitute a significant environmental hazard.

Energy supply

Many power plants are located in coastal areas for ease of access to sea water cooling, to obtain fuel supplies delivered by sea, and to be close to population centres. At least 11 power plants/substations are located within 500m of the coastline.

For power stations located very close to the coast storm surge and resultant flooding will obviously pose a great risk as will damage to powerlines from destructive winds. Generation facilities may cease operation in preparation for a flood and if infrastructure is flooded, delays in restarting generation will occur. If storm surge travels a long way inland, storm surge protection may be lacking for more inland substations and generators, as occurred for Hurricane Katrina which reached 24 kilometres inland and resulted in the replacement of over a million powerlines.[185]

Destructive winds can also increase salt aerosols deposits on electricity conductors, leading to flashovers and corrosion. Electrical components are particularly vulnerable to corrosion from saltwater, even with pressure cleaning immediately after a flood exposed equipment will have to be replaced sooner than would otherwise be the case.[186]

Any saline water intrusion in freshwater coastal aquifers or streams used as a supply for cooling water for a generator will also cause problems. Increases in cooling water temperature will also reduce the efficiency of the energy production cycle. Many power stations are subject to an upper temperature limit for discharged cooling water. On hot summer days the temperature of cooling water can be close to this specified limit and the power station will have to operate at a reduced load to accommodate water temperature requirements, and hot summer days are often times of peak energy demand.

5.3 Vulnerable communities

The analysis in section 5.1 highlights the risks to Australia's coastal communities from rising sea levels and other climate change impacts. Some coastal settlements will clearly be more vulnerable than others. Socio-economic characteristics will also influence the vulnerability of coastal settlements, however there has been very limited assessment of this to date.

The Sea Change phenomenon of the last few decades has brought with it a greater focus on community vulnerability. The Sea Change Taskforce, established to help coordination across local councils under pressure from rapid population growth, has funded a number of analyses about the social drivers and costs of the population shift. Generally coastal communities outside the capital cities have the highest proportion of low income households, the highest proportion of families receiving income support benefits, the highest median age and the highest 'elderly dependency'.[187] The sea change phenomenon impacts on many coastal communities within coastal towns. Much of the growth associated with sea changers are new jobs in occupations such as retail, restaurants, tourism and care giving sectors, with these jobs often being part-time or subject to seasonal fluctuations.[188]

5

Box 5.16 Climate change vulnerability in Torres Strait

The Torres Strait is a broad stretch of shallow water between the tip of Cape York and Papua New Guinea. The region includes over a 100 islands, coral reefs, sand banks and cays.

The region is home to 17 island communities with a total population of around 8,700 people. The inhabited islands vary significantly in their geography, from the low-lying mud islands of Boigu and Saibai close to Papua New Guinea coastline, to the western continental islands (which have similar geomorphology to the Australian mainland), the central coral cays of Poruma, Warraber, and Masig, and the eastern volcanic Islands of Mer, Erub and Ugar.

The communities which inhabit the region have strong cultural, economic, social and spiritual connections with their land and sea country which are governed by their distinct *Ailan Kastom* (Island custom).

Many communities are subject to significant coastal hazard issues with erosion and inundation directly threatening housing, infrastructure including roads, water supply systems, power stations, community facilities, cultural sites including cemeteries, traditional gardens and ecosystems. An anomalous high spring tide in January 2009 resulted in extensive flooding of island settlements (see photo).

Given the low-lying nature of several islands, and the extent of current inundation problems, vulnerability to sea-level rise is extremely high, particularly for Boigu and Saibai but also for the central coral cay islands, as well as several other communities located on low coastal flats.[189] Even small increases in sea level due to climate change are likely to have a major impact on these communities, with increasing frequency and extent of inundation, although for the coral cay islands there is some potential for moderation of this impact through onshore transport of reef sand and associated island growth. Large sea level increases could see several Torres Strait islands completely inundated, thus having enormous implications for the communities involved, their culture and identity, and may have implications for the security of Australia's northern border. As noted by Green[190] and Mulrennan[191]; under worst case sea-level rise scenarios it is likely that eventually relocation would be required from several communities involving considerable cost culturally, spiritually and economically.

Other potential impacts of climate change including changes to rainfall patterns, hotter weather and spread of diseases, as well as changes to ecosystems may also significantly impact Torres Strait Island communities, whose culture, subsistence and livelihoods involve traditional and commercial fishing, hunting and gardening and who are already vulnerable due to socio-economic factors and remoteness.

The extent of vulnerability of the region and its peoples to climate change together with the human rights implications are highlighted in the 2008 Native Title Report by the Aboriginal and Torres Strait Islander Social Justice Commissioner, which along with recent submissions[192] by the Torres Strait Regional Authority emphasise the need for immediate and comprehensive action to address the climate change concerns in the region.

Source: Dave Hanslow, Torres Strait Regional Authority

Photo credit: David Hanslow

King tide, Sabai January 2009.

The IPCC AR4 also notes that Indigenous communities in the tropical north, home to about 87,000 Indigenous people, are also considered to be very vulnerable to the impacts of climate change. Such communities often live in isolated areas that are poorly resourced, and tend to have greater health issues and lower incomes than other communities.[193]

A recent assessment of the implications of climate change for Indigenous communities noted a number of serious potential impacts, particularly around basic living conditions.[194] Current temperature and humidity in the tropical north can already be a challenging environment in which to live. Living conditions are likely to become more difficult with climate change expected to increase average temperatures by up to 3°C by 2070. Existing health issues may be exacerbated by climate change and new health risks are likely to emerge, including heat stress, respiratory illness and mosquito-borne diseases. Local energy provision and the maintenance of services, such as water, sewerage and transport, are also likely to require new critical investments, particularly in isolated indigenous communities.

Box 5.17 The vulnerability of the Australian Indian Ocean Territories

The Cocos Islands are a group of 27 low-lying coral atolls located in the Indian Ocean almost 3,000 kilometres north west of Perth. The economy of Cocos is basic and mainly driven by the public sector and Gross State Product is only $15 million.

Sea-level rise will be particularly challenging for the Cocos Islands since the island elevations range from only 1 to 4 metres above existing sea level. Any change in mean sea level combined with storm surge would have significant consequences for settlements and human activity, particularly for Home and West islands. About 80 per cent of the Cocos islands 600 inhabitants live on Home island and most of the houses are low set and exposed to inundation and flooding even during relatively low level events. Currently none of the buildings on Cocos islands are designed to cyclone rating standard. Transport infrastructure including two ports, roads, the airport, buildings and water resources are all at 'definite' risk of damage due to climate change (primarily sea-level rise and cyclone activity).

Christmas Island in contrast is the top of a sea mount rising 360 metres above sea level at its highest point and is located 360 kilometres south of Java. The Island has almost 1,500 residents and the major economic activity is phosphate mining which represents a third of Gross State Product (total Gross State Product $71 million). While the mining activities are not particularly exposed to climate change impacts, the port is. In addition to exports, almost all non-perishable goods to Christmas Island are delivered by sea. The main port at Flying Fish Cove already has restricted access due to ocean swells for much of the year and climate change is expected to exacerbate that constraint.

Photo dredit: iStockphoto.com/Alexander Hafemann

An island of the Cocos Keeling Island chain.

Source: Maunsell Australia 2009.[196]

While research identifying changes in tropical cyclone events is still preliminary, there is some indication that cyclone intensity may increase, which would require improved building standards. Climate change is also likely to cause disruption to the operation of transport and communications infrastructure, and the importance of airfields for emergency evacuation is likely to become even more critical if more frequent or intense storm activity is realised.

Torres Strait Island communities face particular challenges in living on small low-lying and exposed islands, several of which already suffer from inundation under king tides. Continuing inundation events for these islander communities will require the development of short-term coastal protection and may require long-term relocation plans for approximately 2000 Torres Strait islander peoples (Box 5.17).[195]

In total there are around 8,000 islands of Australia that are spread across the Pacific, Indian and Southern Oceans. The location and geomorphology of Australian islands will largely determine the extent in which they are impacted by climate change although in comparison to mainland Australia, settlements on islands are very isolated. Damage and destruction in such remote locations will be difficult and costly to recover from.

5.4 Risks to industry

As outlined in Chapter 1 much of Australia's industry occurs in or passes through the coastal zone. Climate change will increase a number of risks faced by industry, and bring new risks to some industries not previously exposed. This section provides a summary of existing knowledge on climate change risks to tourism, insurance, fishing, and oil and gas industries. Information in the section is illustrative; very few comprehensive assessments have been undertaken and publicly released that quantify the risks to coastal industries as a result of climate change.

5.4.1 Tourism

Tourism is one of Australia's major export earners and is a mainstay of many local regional communities. It is a key component of the economy of the Australian coastal zone.

Australia's tourism industry is particularly vulnerable to the effects of climate change and sea-level rise. Many of our tourism icons such as the Great Barrier Reef and coastal islands and beaches are in regions that are likely to be affected by storm surge, sea-level rise or increased cyclone intensity.


Photo Credit: Newspix/Kellie Block

Twin Falls, Kakadu National Park, Northern Territory.

A World Tourism Organisation report for the Second International Conference on Climate Change and Tourism in Davos, Switzerland in 2007 stated

> 'Climate, the natural environment and personal safety are three primary factors in destination choice, and global climate change is anticipated to have significant impacts on all three of these factors at the regional level. Tourists also have the greatest capacity to adapt to the impacts of climate change, with relative freedom to avoid destinations impacted by climate change… As such the response of tourists to the complexity of destination impacts will reshape demand patterns and play a pivotal role in the eventual impacts of climate change on the tourism industry.'[197]

A number of Australia's key tourism regions are at high risk to climate change impacts, notably the Great Barrier Reef and Ningaloo Reef, Kakadu and the Top End coastal wetlands. International tourists tend to seek out the most spectacular of Australia's tourist attractions. In fact 5.8 million visitor nights (35 per cent of total inbound tourism) are spent in tourism regions regarded as 'extremely vulnerable' to the effects of climate change.[198]

Due to the risk of increased cyclone intensity, increased sea surface temperatures leading to coral bleaching, and increased ocean acidification resulting in reduced coral formation, tropical north Queensland is probably the most threatened tourism region in Australia in terms of absolute numbers of holiday visitors exposed to the effects of climate change. It is also the region most researched and best understood.

North Queensland tourism's contribution to the national economy is estimated at greater than $2 billion per year.[199] Almost 10 million holiday visitor nights are spent in North Queensland and of these 50 per cent represent international tourists.


Photo Credit: ©Jean-Paul Ferrero/AUSCAPE

Bondi Beach, Sydney, New South Wales, Australia.

The proportion of visitors arriving for reef related tourism was 92 per cent for interstate tourists and 93 per cent for international tourists.[200]

Oxford Economics assessed the present value of the Great Barrier Reef to the Australian economy as 4.7 per cent of annual GDP. They valued the loss of the reef from coral bleaching as 3.5 per cent of annual GDP. Put another way they found the reef's Present Value to the Australian economy was $51 billion; the cost of coral bleaching would erode $38 billion of that value.[201] Kakadu in the Northern Territory is vulnerable to sea-level rise. Kakadu's unique freshwater wetlands are highly vulnerable to saltwater intrusion. A loss of wetlands, and the birds, reptiles and other animals it supports would result in a rapid decline in tourism numbers.[202] Increased temperatures will also reduce visitor comfort and increase the incidence of heat stress or heatstroke. Increased rainfall as a result of climate change will also extend periods of inaccessibility of park features, reduce visitor enjoyment and increase damage to tourism infrastructure.[203]

Highly developed areas such as the Gold Coast and Sunshine Coast also depend on tourism to support regional economies and are vulnerable to sea-level rise, erosion and storm surges. The low-lying nature of many of the tourism and housing developments, particularly canal estates and coastal housing, leave these areas vulnerable to storm inundation and beach erosion.

The tourism industry as a whole has shown itself to be highly adaptable and resilient to shocks. However, a large part of the industry consists of small operators who are more constrained in terms of mobility and flexibility to adapt to the impacts of climate change. They are therefore more vulnerable to significant economic losses.

The difficulties of adaptation faced by the tourism industry are clearly articulated by the Sustainable Tourism CRC

> 'Very few Small to Medium Enterprises (the vast bulk of the Australian tourism sector) are able to plan on time frames longer than a couple of years. As a result, making changes now (with associated costs) to address threats that may or may not eventuate in 10, 40 or 60 years time is not something that many of these smaller operators are willing (or able) to do.'
>
> 'If adaptation and mitigation strategies are to be implemented successfully, they need to be simple, cheap and effective with clear benefits.'

5.4.2 Insurance

The coastal zone is particularly vulnerable to sea-level rise and flooding, more damaging cyclones and catastrophic storms, and erosion as a result of climate change. The coastal zone also contains much of the infrastructure (homes, commercial and industrial buildings, ports and other physical assets) that is the client base of the insurance industry. Climate change will therefore significantly increase the exposure of residential and other buildings to potential loss and damage. But it will be the insurance industry which will be the first to bear the cost of any damages and losses resulting from any increase in extreme weather events.[204]

The specific costs to the insurance industry from climate change are difficult to predict with certainty. In some parts of Australia the insurance industry does not offer residential flood insurance. This is because until recently insurers have not been able to map, understand and price the risk of flooding in order to set a premium. The Australian insurance industry also does not generally cover the risks of storm surge, landslip and sea-level rise.[205] Risks from climate change will build on and compound these areas of existing risk and uncertainty.

Apart from increasing the difficulty in pricing risk, climate change affects the insurance industry's ability to pool risk. Already, 19 of the 20 largest property insurance losses in Australia have been weather related. Climate change exacerbates extreme weather events and reduces the ability to spread risk. As the Institute of Australian Actuaries noted in their submission to the Garnaut Review

> 'Independence of risk – the provision of insurance is premised on the 'rule of large numbers' such that risks are spread. The diversification of risk available from largely independent events allows insurers to operate with capital well below the total level of sum insurance coverage provided by the insurer. The greater the correlation of risks, the greater the requirement of insurers for access to capital and/or reinsurance, with a consequent increase in costs. Climate change, particularly if coupled with increased concentration of exposure in vulnerable locations, may exacerbate correlation of risks.'[206]

Notwithstanding these challenges, there is a broad move within the Australian insurance industry to understand and cope with the insurance impacts of extreme events. In particular, the insurance industry in Australia has already taken a proactive approach to improving understanding of flood hazard mapping and climate change risks.

Photo Credit: Gold Coast City Council Local Studies Library

Car bodies used to try and stop the progress of erosion on the Gold Coast, 1967.

Photo Credit: Gold Coast City Council Local Studies Library

Forty-four gallon drums filled with concrete to prevent further beach erosion on the Gold Coast, 1967.

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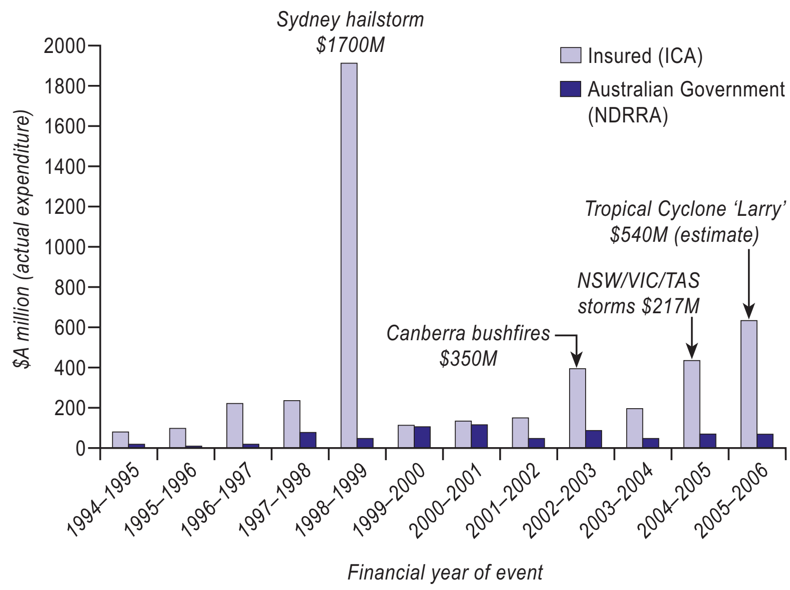

Figure 5.50 Cost of Australian Natural Disasters. Source: Middelmann 2007[207]

However, given the potential change in the structure and magnitude of the insurance industry's revenue base, costs from climate change may have implications for the industry's operation. It is important that the industry plan for these changes and their implications now.

The insurance industry has a key role to play in encouraging adaptation by policy holders through its capacity to provide financial and commercial incentives. Such initiatives could impact on the insurance industry's revenue base in the short term but can be expected to help to minimise costs to the insurance industry in the long term.

The global insurance company, Lloyds, calls for a 'new approach to underwriting'.[208] Historically the Australian insurance industry has operated with an underwriting loss, paying out more in claims than it takes in premiums. The profits derive from investments the insurers have made using a portfolio of premiums as capital. Greater claims might require a restructuring in how the industry underwrites.

Indeed, climate change may provide opportunities for the insurance industry to develop new and innovative products and services and even enhance premium income. For example, there may be important new market opportunities for insurance companies, given their expertise on risk, to provide climate risk management services. A recent report on the insurance industry states that

> 'As the world's largest industry, with unparalleled access to business and consumers, insurers have a matchless but largely untapped opportunity to provide critical risk management services to help society adapt to and mitigate climate change and, at the same time, climate-ready their industry'.[209]

The Insurance Council of Australia has recognised the imperative for the industry to adapt to a changing physical and business environment

> 'Continued development and adaptation of insurance products to suit the needs of the community is a critical issue that remains at the core of the competitive nature of the industry. As part of this development process it will be crucial to develop commercially viable products that not only serve consumers well, but maintain a sustainable industry capable of responding to extreme events.'[210]

Developing appropriate and effective adaptation responses will not be a simple task. It is likely that different adaptive strategies may be needed in different parts of the coast to take account of specific regional circumstances. It will be important that adaptation initiatives, including for example incentive schemes, are developed on a whole-of-sector basis and co-ordinated carefully with adaptation policies, initiatives and directions in other sectors. Maladaptation whereby policies, decisions, or initiatives result in increased vulnerability to climate change impacts needs to be avoided.

5.4.3 Fishing

As Chapter 1 outlines, the Australian fishing and aquaculture industries contribute around $2 billion to the Australian economy per year[211] and are an important part of the social fabric of many of our coastal towns and cities.

Climate change will, over coming decades, increasingly impact upon fisheries and aquaculture sectors. Expected changes to ocean temperature, currents, winds, nutrient supply, rainfall, ocean chemistry and extreme weather conditions will impact on these industries. However, climate change may present some new opportunities as well as challenges and threats for the sector. For example, there may be increased opportunities if tropical species move southward in response to a warming ocean.

According to the recently released report, *Implications of Climate Change for Australian Fisheries and Aquaculture – a preliminary assessment:*

> 'Australian fisheries and aquaculture management policies do not currently incorporate the effects of climate variability or climate change in setting harvest levels or developing future strategies.'[212]

The preliminary assessment finds that fisheries will be impacted differently according to the physical changes in the regional environment. South-east fisheries are most likely to be affected by changes in water temperature while northern Australian fisheries will be more affected by changes in precipitation. Western fisheries could be affected by changes in the Leeuwin Current.

The potential effects of climate change include:

- The South East demersal fishery includes a number of commercial species for which inshore estuarine habitats are important nursery areas. Climate change impacts on these habitats such as different precipitation patterns and sea-level rise could affect the dependent species. Species at the southern end of their range will be adversely affected by projected increasing ocean temperatures, with little room for further southward migration.[213]
- The recruitment of the Western Rock Lobster and other species has a strong link with the Leeuwin Current off the Western Australian coastline. Climate change could cause a systematic shift in the relationship between the Leeuwin current and larval settlement of the Western Rock Lobster.[214]
- Catches of prawns, barramundi and mud crabs in Northern Australia are related to summer rainfall. Changes in rainfall pattern and abundance will impact on these species. Extended periods of extreme temperatures in shallow estuarine waters may affect the distribution of prawn nursery habitat such as seagrasses.[215]

Photo credit: Bruce Miller

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Box 5.18 Tasmanian rock lobster industry: climate change issues

The Tasmanian rock lobster industry is the State's second most important wild harvest fishery with an estimated value of $72 million.

Climate related impacts have already been observed on the fishery and climate change in the future is expected to have further impacts and pose challenges for the industry.

Some of the climate change impacts expected are:

- Continued ocean warming may result in Tasmanian waters being unable to support rock lobster populations of an equivalent size as found today
- Declines in lobster biomass, initially in northern and north-eastern regions before eventually also potentially declining in the south. Significant declines may have implications for the industry
- Warming water temperatures are expected to spread the range of the sea urchin *Centrostephanus* which can significantly degrade marine ecosystems including lobster habitat.

However, a recent study has concluded that the Tasmanian rock lobster industry is reasonably well placed to adapt to and meet the challenges of the climate change impacts

- Although fisheries management policies do not currently explicitly consider climate change, fisheries management is beginning to actively integrate the longer term issues associated with climate change
- Current management of the stock suggests that the industry has the capacity to evolve and respond to longer-term trends

Adaptation options include taking account of climate change in managing lobster catch, establishing a long-term lobster monitoring program, controlling the population of sea urchins, and developing regional rather than statewide management tools for the Tasmanian rock lobster fishery.

Source: Pecl et al. 2009[216]

Photo credit: Bruce Miller

- Seasonal abundance of some pelagic species has been linked to the expansion and contraction of the East Australian Current. Climate change impacts on this interannual variation will likely affect the abundance of these species.[217]
- The Tasmanian Rock Lobster industry is likely to be affected as the biomass of lobsters in the northern and north eastern regions are reduced as a result of higher water temperatures. The Tasmanian rock lobster industry could be 'an early warning signal' for other Australian fisheries.[218]

Australia lacks baseline information on many fished stocks and this presents challenges for assessing the effects of climate change on fisheries and the communities they support. It is clear however that climate change will bring with it increased uncertainty for Australian fisheries.

Climate change impacts on existing fisheries will have consequences for coastal communities that are dependent on the fisheries. However, there are adaptation options available to the fishing industry to minimise any adverse impacts and to take advantage of future opportunities. Potential adaptation measures available to the aquaculture industry includes selective breeding, using alternative species, or moving production facilities to more suitable locations.

5.4.4 Oil and gas

The global demand for energy has driven rapid growth in Australia's petroleum production. Natural gas now provides around 23 per cent of all energy consumed in the world and demand is growing. Oil and natural gas make up 54 per cent of primary energy supply in Australia, coal being the other major contributor.

Australia's primary domestic sources of oil and gas are offshore, with the majority in Commonwealth waters adjacent to Western Australia. The total value of petroleum produced off the Pilbara coast in 2007–08 was $19.3 billion.[219]

The most significant impacts of climate change are any increase in the frequency and severity of cyclones and extreme storm events. Climate change will impact on different components and assets of the oil and gas industry, including fixed and floating offshore facilities, shipping, pipelines and on shore facilities. The impacts will likely be felt across the exploration, production and transport sectors of the industry. By 2030 an increased number of facilities off shore will likely face more extreme conditions more frequently, and this has the potential for incidents with more serious consequences (including damage to infrastructure, losses in production and injury to personnel or communities).

A recent study has found that climate change could reduce productivity in the Pilbara oil and gas sector by a percentage point and reduce the level of production by a further percentage point.[220] A fall in productivity will particularly affect profits earned by the companies, as well as royalties they pay. A fall in production will have flow-on effects to other business, contractors, communities and workers dependent on the oil and gas sector. It will also lead to a reduction in government tax revenues.Impacts on production will affect the national terms of trade.

Looking to the future, increasing frequency of high sea level events and potentially more intense cyclones can be expected to increase the risk of breakdowns and damage to the gas supply system including pipeline delivery infrastructure. The costs of power disruptions to Western Australia from impacts to infrastructure in the Pilbara are currently estimated as reducing Gross State Product by $69 million a day.

Exploration work is also disrupted by the passage of severe cyclones. Jack-up rigs conducting exploration drilling on the sea-bed are evacuated as a storm approaches. There are costs associated with closing down a rig and transporting the personnel to a safe location.

Photo Credit: ©Warren Faidley/AUSCAPE

Hurricane-damaged oil rig Thunder Horse, in the Gulf of Mexico 2005, a semi-submersible platform owned by BP, was found listing after the crew returned. The rig was evacuated for Hurricane Dennis.

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Box 5.19 The Pilbara oil and gas industry – climate change impacts and costs

The oil and gas industry in the Pilbara region is of national importance. It contributes substantially to national gross domestic product through the export and domestic supply to industry, of oil and gas, contributing to the economic and energy security of Western Australia and Australia. The known reserves and estimated resources off north-west Western Australia are globally significant with the Carnarvon Basin accounting for over 50 per cent of Australia's total known reserves. The recently approved Gorgon LNG project will surpass the NW Shelf as Australia's biggest ever resources development, while another globally significant development, the Wheatstone project, is planned to follow.

Potential climate changes that have implications for the Pilbara oil and gas sector include:

1. Increases in the intensity and frequency of extreme storm events, involving increases in wind speeds, wave heights and storm surges for the 1:100 year event

   These projected changes are likely to increase the annual average number of operational shut downs.

   The area of greatest risk for Pilbara oil and gas is the off shore areas, with some important secondary risk to infrastructure on shore. These areas are currently vulnerable to the threat of cyclones including cyclonic winds, waves, storm surges and flooding.

   Onshore settlements are also at risk with transport links such as pipelines to offshore infrastructure being exposed to the impacts of cyclones.

   It is likely that gas and oil tankers will experience increased disruption to their schedules. Severe storms will cause exploration rigs to cease operations, and production rigs to reduce output.

2. Increases in sea levels

   Sea level changes will increase rates of corrosion for jetties and wharfs due to the projected uplift action of waves on the under-side of jetties. Climate change will increase the need for maintenance on all berths. Extra costs of $8 million per annum have been estimated should companies tighten current five year maintenance cycles to four year cycles over the period to 2030.

3. Increase in average temperature and increase in number of days over 35 degrees C.

   Both increases in temperature and a potential increase in the number of hot days is likely to have an adverse impact on productivity, particularly for outdoor workers.

   Around twenty percent of annual production could be lost over a period of six months while critical infrastructure is repaired. The cost of lost production of LNG and natural gas could be as high as $600 million including a loss of $150 million in associated taxes and royalties.

   (These estimates are borne out by the Varanus Island gas accident which shut down production and cost $113 million in production losses. The total flow on costs to the WA economy has been estimated at up to $2 billion).

Source: SKM (in prep)[221],Coakes Consulting (in prep)[222]

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CHAPTER 6

COASTAL ADAPTATION – TOWARDS A NATIONAL AGENDA

Photo credit: © iStockphoto.com/Rainforest Agencies

KEY FINDINGS

- Climate change risks in the coastal zone are large, increasing and in some areas will be felt in the near-term. While these risks will unfold over time, there is a case to begin now with early national action to reduce current risks and avoid the building of new exposures.
- Avoidance of future risk is the most cost-effective adaptation response in most cases. Decisions on future development, particularly in areas highly exposed to the impacts of climate change, should not increase risk.
- There is a large legacy risk in the coastal zone from buildings and other infrastructure constructed in the past.
- Natural ecosystems provide valuable ecosystem services and can buffer many of the risks associated with a changing climate in the coastal zone. Planning is needed to maximise system resilience, allow for ecosystem movement and make explicit decisions about tradeoffs.
- Leadership by governments will be necessary if adaptation action in the coastal zone is to be effective. Government roles in planning and setting benchmarks will be central to risk management, and there is a high level of public good assets in the coastal region.
- Issues requiring further attention include developing standards and benchmarks, providing information, auditing infrastructure at risk, agreeing risk allocation frameworks, on-ground demonstrations of adaptation options, and local capacity building.
- States, territories, local government, industry and communities will have a primary role in on-ground coastal adaptation action. Where a national response is required, the Council of Australian Governments (COAG) can be an appropriate vehicle to progress reform.
- Major areas of science uncertainty need to be urgently addressed to inform adaptation and risk management in the coastal zone.
- This first pass assessment provides the basis for engagement on the importance of adaptation planning and the roles and responsibilities of governments, the private sector and the public in responding to the impacts of climate change in the coastal zone.

6.1 The case for national coastal adaptation action

Regardless of future reductions in greenhouse gas emissions, society will need to adapt to some level of changing climate and rising sea level. Although significant reductions in global emissions now may slow the rate and overall magnitude of sea-level rise during the mid to late century and beyond, sea-level rise for decades ahead is inevitable. Chapter 2 indicates that climate change will dramatically alter the shoreline around many parts of Australia and that a significant level of change is unavoidable. Chapters 4 and 5 describe risks to the natural environment, settlements and industry which will increase in coming decades. While adaptation policy is a very new field, early studies suggest that investment in adaptation is likely to be very cost-effective.

Projections of the absolute rate and magnitude of sea-level rise are still subject to uncertainty, but new research and information on climate projections have seen estimates generally revised upwards. Should there be substantial melting of the ice sheets sea-level rise of many metres could be triggered.

The magnitude of the coastal adaptation challenge nationally is large; Chapters 4 and 5 describe the

Photo credit: Newspix/Mark Cranitch

Lennox Head, New South Wales.

risks to communities, ecosystems and industry in the coastal zone. Across the six Australian states and the Northern Territory, residential properties alone, identified as exposed to risks from climate change impacts this century, are valued at between $41 and $63 billion. While those residential houses and supporting infrastructure were designed to withstand current climate, the location of many increasingly exposes them to damage from climate change.

While this assessment does not address the full range of risks to infrastructure or the national economy, it is clear even from the subset covered that a lack of effective adaptation to climate change impacts will have large implications for Australian society, national productivity and the long-term sustainability of the coastal zone.

Australians continue to flock to the coast. Rapid and ongoing population growth in coastal areas in the past few decades, which has led to the construction of more infrastructure and greater pressure on coastal ecosystems, has also increased the level of national risk to climate change impacts. Amenity migration is expected to continue for the next 15 years as baby boomers retire to coastal areas. To cater for this growth, developers increasingly purchase land in the coastal zone and seek rezoning for greenfield subdivisions. Some of this development is in low-lying land areas, and some development reflects the growing popularity of canal estate developments. Unless there are constraints on such land use decisions, made now and over the next few years, climate change impacts will exacerbate the risks property owners and governments face in the future. These and other decisions made in recent decades increase the vulnerability of the Australian community to the impacts of climate change.

Climate change risk is increasing at the same time that pressure on coastal development is increasing as a result of the need to meet rising demand for residential properties and associated coastal infrastructure. The rising value and number of coastal properties (as a result of this increasing supply) in turn exacerbates risk exposure from climate change impacts.

In Australia's coastal zone, therefore, existing risk areas are likely to intensify and perhaps expand over the short-term, with other at-risk areas emerging. In the medium-term it is possible that the Australian coast will start to experience more systematic impacts of rising sea levels and eroding shorelines, while over the longer term every coastal region will be impacted.

6.1.1 Need for early action on coastal adaptation

While many coastal communities are affected by current short-term weather events, such as high tides, sea-level rise is likely to have greater impacts on the outcomes of decisions with long-term consequences. Key questions for decision-making are under what circumstances do we need to anticipate adaptation to climate change, and when do we need to take adaptation action.

Consideration of climate change risks in the coastal zone suggests that starting to prepare now for adaptation to likely impacts is justified in a number of areas, particularly as sea-level rise is underway, and it will combine with storm surge and tides to generate more damaging events.

As described in Chapter 5, the near-term impacts of climate change, particularly sea-level rise, will increase for low-lying coastal communities already affected by king tides and current levels of storm surge. The recent and continuing rapid development of towns and cities in the coastal zone is a permanent change in land use that will increase national exposure to the risks of climate change. Similarly, the widespread trend towards constructing new buildings in tropical and subtropical coastal

Photo credit: ©iStockphoto.com/Patrick Oberem

Canal estate on the Gold Coast.

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Box 6.1 Economic and risk concepts for adaptation – a decision framework

Key economic principles and risk management approaches provide a useful framework for thinking about the implications of climate change for decision-making. A significant portion of climate change risk to coastal assets is in the future. In many cases, delaying on-ground action until some future point will be justified based on the assumption that investing to reduce coastal risk is worthwhile only if the immediate cost of the investment is less than the expected return from the investment over time.

The concepts of *uncertainty* and *discounting* are also relevant to decisions about whether adaptation action could be needed now. The level of uncertainty in climate change projections and in the timing of location-specific impacts can tend to justify deferring investment to minimise a risk of 'over-adaptation', particularly if it is assumed that knowledge will improve within a few years. Furthermore, a dollar today is usually preferred over a dollar in the future, and there is a reluctance to invest now to avoid a poorly quantified future cost.

Taking this into account, there are clearly circumstances in which preparing now for adaptation to climate change would deliver a positive net benefit and be justified, including:

- where preparing now costs little compared to the cost of likely future impacts and where other benefits could be expected from the investment
- where near-term impacts are certain and large (or the damage to be avoided is clearly unacceptable)
- where decisions are being made about assets with a long operational life, which can be expected to be around when there is high confidence that the climate will have changed
- where preparing now involves options that allocate (or clarify) risk.

The concept of *real options* can also assist in decisions where risk levels are unknown and not constant. 'Real options' seek to hedge against future risks, build on cost-benefit analysis and recognise that future streams of costs and revenues and the optimal timing for intervention cannot always be confidently predicted. Examples of real options in the coastal zone are leasing residential housing that is designed to be dismantled and relocated, constructing bridges in low-lying areas to withstand complete inundation, and purchasing land for future protection works where these meet a cost-benefit test.[1]

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regions on concrete slabs, rather than elevated on stilts, has increased the exposure of houses to damage from flooding in low-lying areas. In these instances, there is an immediate need to minimise practices that increase regional or national risk and which then transfers that risk to future property owners or governments.

Most of Australia's cities and industry are in the coastal zone, so the construction or refurbishment of long-lived infrastructure is highly concentrated in the region. Ensuring critical and regionally significant infrastructure is built or remodelled to withstand

Photo credit: Chris Sharples

Houses built on bedrock down to the high water mark at Opossum Bay beach at South Arm Tasmania.

future climate will be important. However, there is a considerable lead time for new building standards to be developed and then taken up across the total stock of infrastructure. Work commissioned by the Garnaut Climate Change Review estimated that, with an improved building code in place by 2015, around 20 per cent of buildings would be in compliance with that code by 2030. The proportion would increase to about half by 2070, by which time another amendment to the code, to reflect continuing climate change, would probably be required.[2]

Governments at all levels also need to be aware of the potential future costs of natural disasters, which currently cost around $1 billion per year on average.[3] Many extreme weather events occur in the coastal zone, and climate change will increase their frequency and severity, possibly exponentially (see Chapter 2). This could mean that the costs of natural disasters could double or more in the next few decades. Intervention to constrain increases in exposure to such hazards would be of economic and social benefit.

The combination of large and increasing risk from climate change in the coastal zone, the making of basically irreversible decisions on long-lived assets, and the lag effect in action to reduce risk indicate a need for early adaptation in many cases.

6.2 Barriers to adaptation

While adaptation policy is still a relatively new focus of climate change considerations, there is a growing awareness that aspects of our current approaches to coastal management might be a barrier to effective adaptation in the future. Some of these barriers relate to cultural, and others to institutional factors.

Chapter 1 highlights the relatively short period of European development of Australia's coastal areas during a time of relatively stable geomorphology. Despite a sea-level rise of 17 centimetres over the past century and a half, Australia's coastline has not yet suffered significant erosion in response, although (as noted in Chapter 2) a switch from stable to eroding coasts might not be too far into the future. Australian coastal structures, land use planning frameworks, ecosystem protection approaches and other institutional arrangements have been designed to align to this historical climate condition and a static sea level.

So far Australian coastal planners have not had to deal with the coastal dynamics experienced in other parts of the world, such as the mid-Atlantic coast of the United States, and the coasts of countries bordering the North Sea, such as the Netherlands. Australian experience with coastal hazards has tended to arise from short, sharp shocks, such as the 1974 storms that resulted in considerable damage to several communities along the New South Wales coast. This experience of relative coastal stability has perhaps contributed to why there is not an established coastal planning framework that uses a diverse array of mechanisms to deal with dynamic coastlines and increasing risk, from which adaptation planning could advance.

Photo credit: Newspix/News Ltd

Storm damage to Manly promenade, Sydney 1974.

The recent rapid growth in the coastal zone has given rise to a very large legacy risk and as a society, Australia will face challenges in deciding what to protect, redesign or relocate in the future. A barrier to this challenge is the prevalence of short-term strategies. The costs of planning for hazards like sea-level rise will be felt in part today, while the benefits might not accrue during the tenure of elected governments or project planners. Local officials tend to be responsive to community concerns, but most communities have a range of competing priorities and lack decision-making frameworks that value the avoidance of future risk. Recent social analysis and studies of cognitive dissonance also suggest that people tend to disregard new information on risk if it does not align with their current preferences.[4]

Another barrier arises from 'moral hazard'– the view that when problems arise the insurance industry or government will bail out or otherwise underwrite the costs of those who are imminently threatened or damaged by a natural event. That belief can discourage people and communities from preparing for long-term consequences. Society and governments have often tended to support those whose property has been threatened, rather than allowing them to face the consequences of the risk they assumed when they bought their property.

Diversity and a lack of clarity of roles and responsibilities can also be a barrier. The Australian Constitution sets out the responsibilities of the national government. Land-use planning and coastal management in general falls to the states, which set land-use planning frameworks and benchmarks. In all states, local governments are then responsible for day-to-day administration. One outcome of this has been a range of approaches among states, and that diversity is further magnified across local governments. Many national and state inquiries into coastal zone management have recognised inconsistent and uncoordinated approaches among state and local governments as a barrier to the integrated decision-making that is required.[5]

In recent decades, there has also been a noticeable reduction in the technical capacity of agencies involved in coastal management. This is a particular concern for local governments, which are at the forefront of climate change adaptation in local communities. While some local councils may be well equipped, it is increasingly apparent that many cannot bear the technical and financial burden of assessing the risk to their communities from climate change. Many also lack the resources to identify and implement cost-effective adaptation to reduce damage from inundation and more extreme events.[6]

Box 6.2 Summary of barriers to coastal adaptation

- Current planning and design specifications are based on historical climate and assume a static sea level.
- Short-term thinking often prevails – the future risks of climate change are generally beyond decision-making horizons.
- The expectation that the government or the insurance industry will support people whose property is threatened is a disincentive to prepare for future risk.
- Some parts of the current regulatory system encourage, or do not discourage, development in 'at-risk' areas, including existing use rights and the requirement in some areas to pay compensation for changes in land-use decisions.
- The complexity of institutional and inter-jurisdictional arrangements has hindered early consideration of risks from climate change, and the lack of a national mechanism for collaboration will inhibit adaptation if it is not addressed.
- Reduced technical capacity across local government, and some state based, agencies that are responsible for coastal management will impede the mainstreaming of cost-effective adaptation approaches.
- Local governments are at the forefront of local adaptation action, but in a number of areas they lack the capacity to assess and reduce climate risk.

Photo credit: John Baker and DEWHA

Revegetation of foredunes in the Corangamite region, Victoria.

In addition, some parts of the current regulatory framework act to inhibit adaptation to climate change. There is currently little mention of climate change in Australian legislation for local government. Where climate change is mentioned, it is generally as a matter that needs to be taken into account. While a lack of data, tools and capacity has left many local councils unsure about how to tackle climate change, the discretionary legislative framework has meant there is not a strong push for local governments, or indeed other tiers of governments, to fill this knowledge gap.[7] There are also a number of 'perverse' incentives that encourage land development in areas at-risk. Aspects of existing use rights are a barrier to the implementation of 'planned retreat' approaches in developed areas. Conversion of Crown land to freehold land in coastal hazard areas can increase existing use rights and complicate planning for risk management. Some planning principles, such as the legal concept of 'injurious affection', can also make it difficult for governments to constrain new development without being subject to compensation claims from affected landholders or developers.[8]

Finally, the lack of an effective mechanism for national coordination of adaptation in the coastal zone, if not remedied, will impede effective risk management. Climate change impacts in the coastal zone will have cross-cutting social, economic and environmental consequences, and narrow sectoral collaboration mechanisms or programs are not adequate. Clarity about the roles and responsibilities of each of the levels of government is needed as a first step in coordinating a national reform agenda. While all levels of government have a role, the Australian Government is not the default policy-maker. Indeed, the Australian Government's main program focus at present is the Community Coast Care Program managed by the Department of the Environment, Water, Heritage and the Arts. It focuses on protecting and rehabilitating coastal environments and critical aquatic habitats rather than the core drivers of increasing risk from climate change in the coastal zone.

Photo credit: John Baker and DEWHA

Revegetated dune area Mereweather Beach, Newcastle.

6.3 Towards a national coastal adaptation agenda

The economic and social value of beaches, infrastructure, industries and ecosystems in the coastal zone suggests that, while adapting to climate change could be costly in some areas, doing nothing is likely to be more expensive over the longer-term as substantial investments and assets are placed at risk.

Planned adaptation is part of a balanced and prudent response to climate change. Fundamentally, it is about proactively building our capacity to minimise, adjust to or take advantage of the consequences of that change. A number of common themes and characteristics lead to good adaptation in the coastal zone. These include the need to:

- develop a framework for understanding and managing risks, including understanding how climate change will affect current risk and the vulnerability of coastal assets, and any critical thresholds
- incorporate flexibility (that is, adaptive management) to deal with changing risks and uncertainties, and recognise the value of a phased approach (Figure 6.1)
- adopt a sequential and risk-based approach to factor climate change into new planning and investment decisions
- adopt the precautionary principle and avoid actions that will make it more difficult to cope with climate risks in the future
- make more conscious decisions about the extent to which risks are being transferred to future generations, and the basis on which tradeoffs between the built and natural environment are made
- maintain natural coastal defences and buffers as much as possible and encourage mechanisms for their enhancement
- realise the benefits from low-cost adaptation options that reduce future risk.

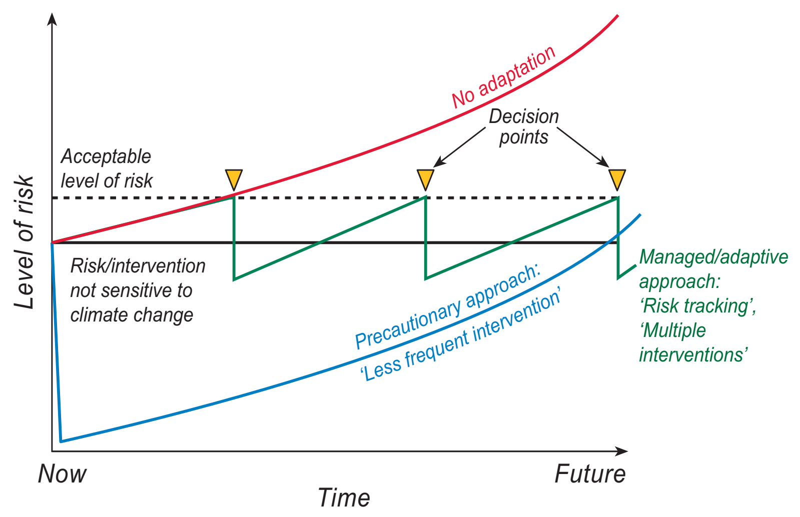

Figure 6.1 Different approaches to adaptation and their effects on the level of risk over time.
Source: New Zealand Ministry for the Environment[9]

Photo credit: Mackay Regional Council

The coastal buffer zone is visible in this aerial photo of Bucasia Beach, Mackay, Queensland.

6.3.1 Roles and responsibilities for coastal adaptation

Governments will have an important role in enabling coastal adaptation.[10] Land use planning frameworks and building codes will be fundamental in reducing future exposure and there are high levels of public interest and public good values in the coastal zone that will require some level of adaptation. Governments will also need to be involved in building adaptive capacity and setting the right conditions for efficient investment decisions to be made. This includes providing basic information and appropriate regulatory settings that promote efficient risk management. While not all adaptation action will require a national response, where a national response is required, the Council of Australian Government (COAG) can be an appropriate vehicle to progress reform.

The different levels of government are responsible for managing or regulating a large number of assets in the coastal zone. The Australian Government has a limited set of powers in coastal planning and management compared to the states. Each state government has, in turn, devolved some of its powers under legislation to local councils. States, territories, local government, industry and communities will have a primary role in on-ground coastal adaptation action.

The principle of subsidiarity has generally been applied, such that councils have power over matters at a local level, while strategic directions and plans are generally set at state level. In addition, some states retain coastal zone decision-making power over development that is designated to be of state significance. Various non-government sectors, such as water utilities, port authorities and insurers, all have roles that relate to the management of coastal areas and facilities. The critical question now is how the nation can best define those roles in a world of climate change within the constraints of current governance arrangements and still provide for effective adaptation.

The complex governance arrangements in the coastal zone can produce inertia (see Section 6.2), but leadership, clearer roles and responsibilities, and investment in critical national capability to enable government and corporate decision-makers to take an informed approach to managing climate change risks can overcome this.

The extent of the potential impacts will also require a role for individuals, business and the community in many adaptation responses. Policy approaches that clarify the limits of public sector capacity and/or willingness to protect coastal properties in areas of medium to high risk might also reinforce the private incentive to internalise coastal risks, which can reduce the expected value of damage over time.[11] Individuals will need to take responsibility for managing the risks to their property, including through insurance. It will be important to ensure that the actions of individuals do not lead to adverse implications for adjoining properties and the natural environment.

The insurance industry has a particular role in managing risk in the coastal zone. Higher insurance premiums and lack of access to insurance can send a powerful signal that provides a disincentive for investment in assets in high-risk areas and, where investment proceeds, can clarify the adaptation strategies that will be required. While insurance can be an efficient market-based economic tool to distribute and reflect actual risk for coastal properties, it is based on historical information and does not necessarily reflect long-term changes in risk. Its efficient application may also require detailed risk assessment relevant to the property level, much of which is currently not available. A key issue for governments is to ensure that there is no distortion to the market signal from insurance premiums.

6.3.2 Guidance for risk management

Adaptation planning should be developed on the basis of the best science and be updated periodically as new science becomes available. As outlined in Chapter 2, atmospheric and oceanic evidence for climate change is pointing more and more to what had previously been perceived as worse-case rates and extent of sea-level rise, ocean temperature warming, changes in rainfall and runoff patterns, and the intensity and distribution of extreme events. In the light of that evidence, it is appropriate to clarify national frameworks and standards to address risk from climate change impacts in the coastal zone.

There is clearly a relationship between the nature of a risk that confronts a particular place and the need for society to take steps to manage the risk. As the likelihood and consequence increase, the need for more restrictive provisions on land use will increase. The provisions may vary with regional and local circumstances, but a set of standards for land use planning and construction would be a key part of national capacity to manage the impact of extreme events and the long-term creep of rising sea levels. Without effective standards, in the decades ahead Australia will be continually confronted by the consequences of community conflict, environmental degradation, damage to property and infrastructure and loss of social amenity in coastal areas. Application of standards in land use planning and engineering to increase Australia's resilience to climate change risks will require a strong knowledge base on how risks will change in the future.

Risk based land use zoning

Risk based vulnerability zoning for land use planning is one approach the community may wish to consider as part of a broad risk management framework for the coastal zone (Table 6.1). The illustrative approach described in Table 6.1 is based on an assessment of best practice in Europe, New Zealand and the United States. Importantly, it recognises that risks and hazards can change over time, that risks will vary spatially, that the lifespan of assets in the coastal zone will vary in longevity and be of different value to society, and essentially that a one-size-fits-all approach will not work.

As well as spatial location, the different longevity, or asset life spans, and value of those assets requires consideration of a different but complementary tiered response in addressing rising sea levels. For example, long-lived and critical assets (such as hospitals, roads, port infrastructure and airports) require different standards from medium-lived assets (such as residential housing), while a reduced standard is appropriate for short-lived and lower value assets (such as recreational facilities).

Table 6.1 Potential approaches to land use zoning based on a hierarchy of risk standards.

Risk category	Application and planning response
Low risk areas	Defined by areas where there is little or no risk of erosion, flooding or long-term inundation at less than 1-in-1,000 year return periods under worse-case climate change scenarios to 2100. Planning response: no constraints on land use planning because of physical climate processes.
Medium risk areas	Defined as shorelines, tidal watercourses and low-lying lands subject to erosion, inundation and flooding at a 1-in-500 to 1-in-1,000 year return period. Planning response: no new construction of essential and critical infrastructure and public utilities unless designed to be capable of remaining operational during extreme climate events (suitable for most other development).
High risk areas	Defined as coastal areas likely to be affected by erosion, inundation and flooding at a return interval of between 1-in-500 and 1-in-100 years. Planning response: approval only for developments that can be relocated or designed to withstand the impacts of extreme events or flooding without causing adverse consequences for adjoining coastal areas.
Very high risk areas	Defined as coastal areas subject to erosion, inundation and flooding at a return interval of greater than 1-in-100 under worse-case climate change scenarios. Planning response: approval only for developments that are compatible with a high degree of land surface disturbance; existing high value assets in such areas should be the subject of restrictions on new development and on the management of potential adverse consequences on adjoining areas, in the light of the ability of the community to protect those assets and support their relocation over time.
Note: Current planning is generally based on assessing risks from a 1-in-100 year event. Events less frequent than this, e.g. a 1-in-1000 year event, are significantly larger in magnitude.	

Some states have started to incorporate a risk hierarchy in their planning guidelines. For example, Queensland's draft Coastal Plan 2009 describes a Development Assessment Code which links a range of guidelines for allowed development to coastal hazards under climate change conditions.[12]

Further, while planning for the potential impacts of sea-level rise out to 2100 and beyond may seem too long-sighted, a timescale of centuries is an appropriate benchmark for considering the footprint for major cities (Rome, Venice and London have existed for many hundreds of years and are now regarded as global cultural assets). Under a changing climate, with plausible sea-level rises of over 1 metre per century, this timescale has implications for the urban design and planning for most Australian capital cities. Additionally, land-use planning decisions may provide for the development of a house that has only a 50–60-year lifespan, but the zoning of that land has a far longer lifespan and signals the ability to build and rebuild indefinitely on the site into the future. Figure 6.2 illustrates an approach to considering timeframes for various decisions and developments.

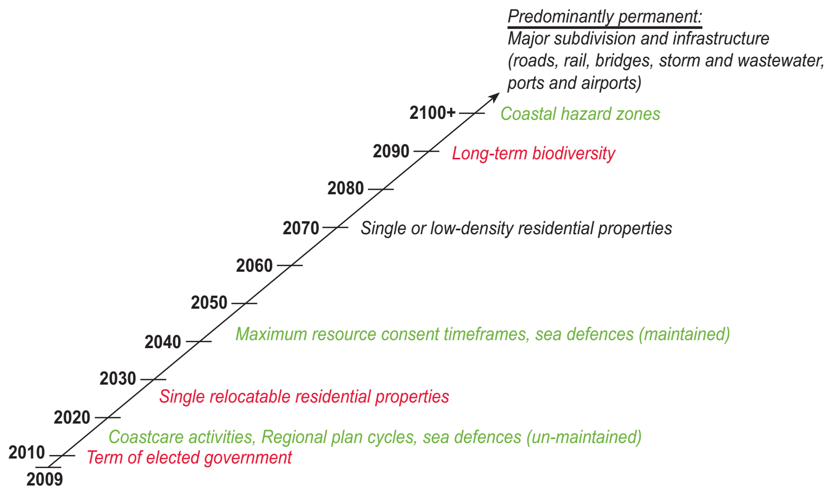

Figure 6.2 Timeframes for decisions and developments in the coastal zone.
Source: Adapted from New Zealand Ministry for the Environment[13]

Building and engineering codes and standards

The magnitude and geographic spread of climate change risks also suggest that we need to regularly review and update the regulatory framework for building, plumbing and construction, possibly every 15 years. The current building code is based on historical climate risk data, which over time could lead to an increasing risk of harm to building occupants. This is particularly important, given that projected changes in the frequency and intensity of extreme events are non-linear, and there is an increased risk of coincident climate events (see Chapter 2). Technical and engineering specifications, including specifications for the resilience and life of building materials, also need review and updating.

Early analysis is suggesting that the current building Standard for design under wind action (AS/NZS 1170.2:2002) may be inadequate under climate change conditions, particularly when considering the combined hazard of cyclonic and non-cyclonic winds for a number of densely populated regions including Brisbane, Sydney and Perth.[14]

The experience in the US in managing the impacts of Hurricane Katrina has led to reconsideration of engineering specifications for infrastructure. In particular risks to infrastructure emerged in places where they weren't expected, for example transverse stresses in bridges. Given the magnitude of legacy infrastructure in the coastal zone, there is a need for a national audit of critical infrastructure which may be subject to damage from climate change impacts.

Box 6.3 Houghton Highway Bridge Duplication Project

Hurricane Katrina in the United States provided many lessons that were taken into consideration during the design of the Houghton Highway Bridge duplication, between the Redcliffe Peninsula and Brisbane's northern suburb of Brighton in Moreton Bay. The Houghton duplication is one of the few bridges in Australia likely to be adversely affected by a storm tide, as it is at the southern edge of the tropical cyclone region and is also susceptible to east coast lows. The possible effects of high tides, storm surge, wave run up, and sea-level rise from global warming were included in the design considerations.

The bridge structure is designed to be above tide and wave height during a 1-in-2,000 year storm event. The bridge deck is 4 metres higher than the current Houghton Highway and it will be bolted down as an additional storm-immunity measure. The designers also considered the risks of wave loading, which led to the destruction of several bridges during Hurricane Katrina.

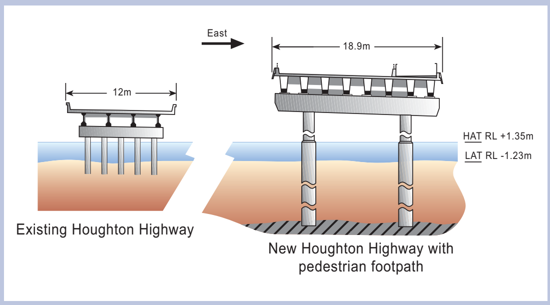

Figure 6.3 Existing (left) and duplicate (right) Houghton Highway Bridge.
Source: Cummings et al. 2008[15]

Approaches to cost-effective risk management

There are likely considerable benefits from the application of planning and building regulations to the future costs of managing climate change impacts. While there has been little research in this area, CSIRO have developed a preliminary estimate of the costs and benefits of the uptake of strengthened planning and building regulation on inundation of residential buildings for a 1-in-100 year storm surge event in south-east Queensland.[16] The analysis allows for population growth, and an increase in the height of storm tide due to sea-level rise and with that, the change in the return period for what was previously defined as the 'extreme event' but with the increase in sea levels would occur more frequently in the future. Table 6.2 shows the impacts of varying adaptation options in 2030 using today's dollars.

Taking a precautionary approach to planning new development, infrastructure and services to avoid coastal hazards over their lifetime is the most effective

Table 6.2 Estimated costs and benefits of residential adaptation in south-east Queensland for 2030.

Adaptation option	People affected 2030	Buildings affected 2030	Total cost 2030
Business as usual (same planning and building regulation as today)	616,000	124,800	$4 billion
Planning regulations tightened to allow no further risky development, building stock under same regulation	378,000	83,200	$2.6 billion
In addition to planning regulations tightened as above, retrofit/reclaim to maintain existing level of risk	270,000	47,900	$1.5 billion

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and sustainable long-term approach. For greenfield sites, appropriate regional planning can ensure that new development is outside defined hazard or risk zones. How to deal with existing development in identified at-risk areas is a more complex planning issue. In such cases, it will probably be impossible to avoid the risk and a mix of risk reduction and risk transfer approaches will be required. Figure 6.4 shows the relative contribution of risk management activities in adapting cost-effectively to coastal climate change risks.

Risk transfer – insurance

Risk management through avoidance and reduction action will not completely remove coastal risks from climate change. There will remain some level of residual risk that will need to be addressed, often through risk transfer. The primary approaches to managing residual risk are insurance and risk acceptance, including coping with any associated consequences through emergency and disaster management.

Insurance is an important market mechanism which could support coastal adaptation. It can lessen the adverse impacts of climate change, particularly through extreme events, for businesses and households. If premiums reflect risks appropriately insurance can also provide incentives to take adaptation actions to reduce exposure to climate change impacts.

There are considerable gaps in insurance cover in the coastal zone as mentioned in Chapter 5. At present insurers generally have exclusions for ‘storm surge’, ‘action of the sea’, ‘high tide’, as well as for ‘erosion and subsidence’. A key reason for this is the lack of risk data on which to base premiums. Nearly a quarter of the population is also without building or contents insurance. Approaches to improve insurance cover of properties in the coastal zone need to be considered in developing a coastal adaptation response.

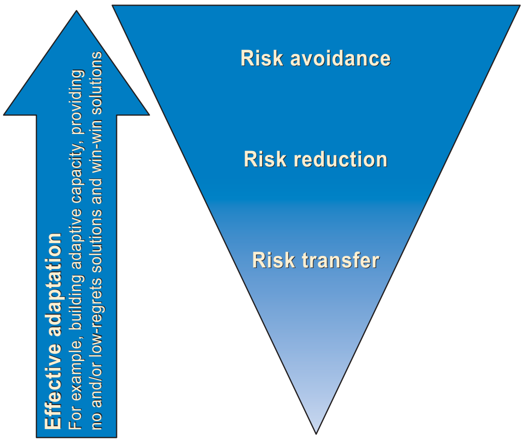

Figure 6.4 Contribution of risk management activities for effective adaptation to coastal climate change risks.
Source: New Zealand Ministry for the Environment[17]

The insurance industry is proposing a potential new measure for public consideration to help build community resilience to climate change impacts – coastal land value insurance.[18] Land value can represent the major component of a coastal property’s overall value, especially for vulnerable and expensive beach-front properties, yet land is not currently insured under home or contents building insurance policies. The industry suggests that an insurance fund could be established into which owners of low-lying coastal land would pay a regular levy so as to enable compensation when rising sea levels lead to their land becoming unusable.

Emergency management

Australia’s coastal settlements are exposed to a range of extreme weather events that draw heavily on Australia’s emergency response services. Over the last decade and despite the implementation of disaster reduction strategies, severe coastal storms, floods and cyclones have stressed the capacity of emergency services to respond quickly and cost the economy, communities and individuals many billions of dollars in lost lives, productivity, homes and infrastructure. In June 2007, severe flooding along New South Wales’ mid to north coast caused $1.35 billion in damage[19] and left many hundreds of people stranded.

The Ministerial Council for Police and Emergency Management (the Council) has recognised climate change as a very significant and strategic issue for emergency management[20] and is developing a national disaster resilience framework to foster more informed and safer communities. As part of its disaster reduction strategies, the Council has commissioned the Australian Emergency Management Committee to develop a climate change action plan. While still under development, the plan acknowledges that much of the work in preventing disasters lies in the planning and building regulation sectors of society and government.

Establishing links between land use planning, climate change and emergency management may help to introduce precautionary and consistent land use planning principles that reduce communities’ exposure to risks such as flood and bushfire. Improving the links between the development of building standards, climate change and emergency management, may increase the resilience of the built environment to extreme weather, such as storm and cyclone generated winds.

Knowledge to support risk management

The effective management of risk in the coastal zone by all spheres of government, industry and the community will require continued investigations of adaptation strategies and decision-support tools. In some areas scientific research will be vital in underpinning the development of these strategies and tools. Table 6.3 outlines key knowledge gaps and associated research tasks for risk management in the coastal zone.

Table 6.3 Knowledge Gaps and Related Research Needs for Australian Coastal Adaptation.

Knowledge Gap	Associated Research
Significant uncertainties regarding future rates of sea-level rise, particularly related to ice sheet processes. Wide range of current projection makes planning adaptation measures difficult.	Improved understanding of global averaged sea-level rise, including particularly ocean thermal expansion and the response of ice sheets to global warming. Improved understanding of the regional distribution of sea-level rise. Probabilities of plausible change.
Significant uncertainty of the amount and rate of coastal erosion that would occur with climate change including if and when a threshold change from accreting to receding beaches may occur around Australia's coastline.	Analysis of historical and geological coastal erosion. Improved quantitative models of beach erosion and linkage to improved estimates of global-averaged and regional sea-level rise. Improved knowledge of changes in ocean wave conditions and how they impact on coastal erosion. The relative contribution (in different regions) across the frequency spectrum from tidal periods and weather related events to decadal changes.
Significant uncertainties regarding the fate of El Nino Southern Oscillation dynamics under anthropogenic climate change.	Continued exploration of ENSO behaviour within coupled global climate models as well as improvement in ENSO forecasting and prediction systems. Implications for cyclones.
Potential implications of coincident events on coastal systems, such as combined effects of storm surge, wave action, extreme rainfall on coastal erosion and flooding.	Analysis of changes in the frequency of extreme events. Quantitative methods linking sea-level rise, storm surges, river floods, ocean waves and coastal erosion. Scenario analysis to identify where critical infrastructure is at risk of failure, during coincident, extreme events.
Access to high quality, high resolution topographic and bathymetric data for coastal modelling of biophysical and socio-economic impacts.	Increased acquisition, integration and dissemination of high resolution data sets to inform modelling and decision-makers of at-risk communities, particularly for settlements around estuaries and lakes. Vulnerability mapping.
Decision-support systems and tools to incorporate climate information into coastal management.	Analysis of urban design and planning frameworks to identify new approaches to adaptation for coastal settlements. Establishing criteria for new buildings and infrastructure to increase resilience to climate change across different regions. Design options for adapting existing buildings to climate change in different locations. Triggers for increased response to manage risk.
Little known about social vulnerability, cost-benefit of adaptation options and their social acceptability.	Development of social vulnerability criteria, and analysis of geographic spread of vulnerability and trends. Analysis of social diversity and resilience and effectiveness of incentives. Exploration of community attitudes to adaptation.

Source: Based on CSIRO submission to House of Reps Inquiry[21] and the draft National Adaptation Research Plan on Settlements and Infrastructure[22]

6.3.3 Scoping on-ground adaptation action

Every part of the Australian coast will be affected to some degree by the forces of climate change. While this national assessment of risk across Australia's coastal zone highlights some key areas of immediate risk, and areas where risks are likely to escalate into the future, there is also some risk in other areas. To ensure that we are well prepared and able to implement adaptation measures that protect public safety and valuable coastal assets, assessments across national, regional and local scales will be required. Ideally, those assessments will be 'nested' to some degree to improve information sharing and priority setting.

Regional assessments are likely to be the most cost effective approach to identify valuable assets that need to be protected or accommodated over time, including critical and regionally significant infrastructure. Regional assessments can also identify where socially vulnerable communities are, the limits to their adaptive capacity and areas of future risk where development should not occur. For areas that are already flood prone, an understanding of flooding

Photo credit: Newspix/David Clark

Sand pumping at Palm Beach, Queensland.

processes and the interaction with rising sea levels will be imperative. A key outcome of regional assessments will be information that supports the identification of adaptation options, and the triggers when an increased on-ground response is needed.

On the basis of known areas of existing and the projected extent of rise in sea level, it is evident a number of coastal regions will encounter increased risk faster than the average (for example from rapid population growth). Some of these areas suffer from relative socio-economic disadvantage or span

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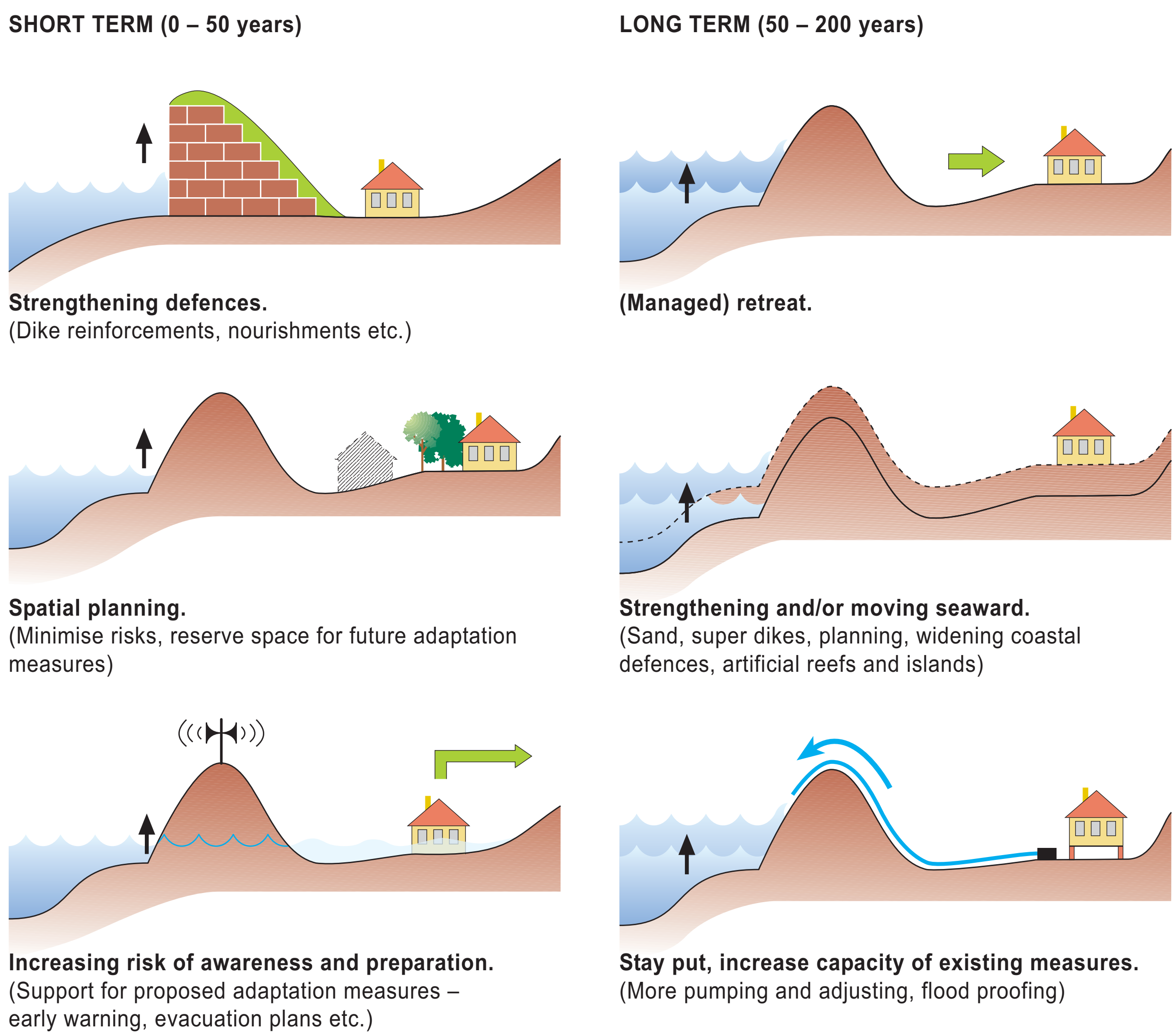

Figure 6.5 Adaptation options for coastal building.
Source: Adapted from Dutch Ministry of Transport[23]

Indigenous communities with strong cultural links to 'sea country'. The development of a targeted adaptation strategy is a high priority for these regions to identify and analyse the costs and benefits of adaptation options (such as accommodating climate change, retreating or abandoning), reduce barriers to adaptation, and drive partnerships to enable its implementation.

Countries that have had to develop adaptation strategies such as The Netherlands distinguish short or near-term adaptation options from the long-term (greater than 50 years). Figure 6.5 illustrates options for adapting a particular building, including how those options can change over time. They indicate ways in which the threats facing communities are generally addressed in low-lying regions of countries.

In Australia, it is important to examine the local and regional relevance of the three common approaches to managing the built environment in the coastal zone: protect, accommodate and retreat. For each approach the costs and benefits must be identified and evaluated (Appendix 1).

Protection involves construction of seawalls, dykes and other 'hard' engineering defences for the purpose of maintaining coastal assets in their current location. 'Soft' protective works such as nourishment of beaches are also included, but may necessitate repeated access to sand sources to maintain the beach extent.

Accommodation requires modification of existing structures such as building floor levels and various minor works including the installation of tidal flood gates on drains. It also involves provision of setbacks and buffers and preparation of emergency management plans all of which will allow continued or extended use of risk areas.

Planned or managed retreat as shown in Figure 6.5 provides for the relocation of built assets from a high risk to a lower risk site. Decisions about where to apply protection, retreat and accommodation measures will be difficult to make. In densely populated or highly capitalised areas, coastal protection is also likely to be preferred and, in some cases, will be cost effective even over the longer term. Particularly at risk are heavily capitalised shorelines, such as the Gold Coast where both hard and soft protection works are used. Seawalls are the most common form of shoreline protection in Australia – they have been constructed according to existing engineering standards or placed illegally to protect private housing. Larger engineering solutions may also be cost effective especially when the totality of private and public assets become threatened in major urban areas requiring dykes, barrages, pumps or some combination of works. The up and down-shore impacts of protective works can be considerable and need to be factored in any cost-benefit analysis.

Photo credit: A. D. Short

Rock seawall along Adelaide's West Beach.

Box 6.4 Barrages to protect major coastal cities – lessons from Europe

Various protection measures have been taken in other parts of the world to reduce the impacts of sea-level rise and storm surge. That experience can help us to identify preferred approaches to protection in Australia. Examples include the barriers and barrages described in the table below.
All these barriers close only when required and are left open at other times. This has the advantage of allowing ships to pass through and environmental flows to be released from rivers draining into the bays.

Name	Country or location	Completed	Structure	Cost (approximate)
Thames Barrier	London, United Kingdom	1982 after 30 years	Built across a 523 metre wide stretch of the Thames estuary, the retractable barrier divides the river into four 60-metre and two 3-metre navigable spans and four smaller non-navigable channels between nine concrete piers and two abutments.	A$956 million (£534 million)
Maeslantkering	Hoek van Holland / Maassluis, Netherlands	1997	Two retractable gates are housed in drydocks when not being used and automatically close when needed. The gates span a 360-metre gap.	A$746 million (€450 million)
MOSE Project	Venice, Italy	Expected 2012	MOSE consists of a system of retracting oscillating buoyancy flap gates able to isolate the Venetian Lagoon from the Adriatic Sea when the tide reaches above an established level.	A$7,080 million (€4,272 million)

Photo credit: Photolibrary

The retractable barrier on the Thames River, United Kingdom.

Photo credit: Rijkswaterstaat (part of the Dutch Ministry of Transport, Public Works & Water Management)

The Maeslant Storm Surge Barrier, The Netherlands.

This ensures that shipping and port activities continue as normal for most of the time and it maintains the ecological integrity of the bays. The barriers and barrages are usually raised or closed when storm surges or high tides reach a predetermined level.

Source: Advice from AECOM 2009[24]

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Building a protective structure of modest height is often quite affordable, but the cost of these structures rises significantly with the square of the height; a structure twice as high costs four times as much. Given sea levels are projected to rise for hundreds of years, protective structures may only play a role in protecting very high value assets and in transiting to a planned retreat phase for many locations around the coast that will be unable to sustain the ongoing and increasing expense of such structures. Already we can learn from Europe and Asia where major works have been undertaken to protect coastal assets.

Long lead times are required to plan, design, and gain the necessary approvals and to construct major infrastructure. For example, the design and implementation of the measures for the physical safeguarding of Venice commenced in 1982, but the MOSE project, which is subsequently being constructed to protect the city, is not expected to be completed until 2012. Given these constraints, planning and design considerations would need to be undertaken early to position Australian cities to respond effectively to future sea-level rise. This should include early identification of locations likely to require major works, in order that public and private sector urban and waterfront development proposals receive timely scrutiny during approvals processes.

The potential impacts of extreme sea-level rise on the infrastructure which underpins the functions of society can be extreme. Sewage treatment plants, airports, coastal roads and rail, buildings, ports, industrial facilities and cultural icons could be inundated either permanently or regularly, the latter through high tides and storm surges. Clearly, decisions have to be made to adapt infrastructure over time. This might include protecting low-lying assets with seawalls, dykes, storm surge barriers or tidal barriers or relocating to higher ground. Protecting low-lying assets will be costly. For example, providing dykes or sea wall protection around low-lying areas of Port Phillip Bay in Melbourne is estimated to cost up to $5 billion.[25] To prevent flooding along river catchments, flood/tide gates would be required on every river system feeding into the Bay, which would be likely to double the cost.

Box 6.5 Barrages or dykes for Sydney and Melbourne by 2100?

Many cities in Australia are built close to the sea and are therefore particularly vulnerable to rising sea level. The impacts on low-lying coastal cities could be very large. Residential, commercial and industrial zones of major cities could be inundated either permanently or regularly by high tides and storm surge exacerbated by climate change, disrupting services and damaging the local or even national economy. Choices clearly have to be made to adapt cities over time, by either protecting low-lying assets or moving them to higher ground.

As extreme storm surges on the Australian southeastern seaboard are in the order of 0.5 metres, storm surge barriers, such as those on the Thames or in Holland, would not be cost effective against a rise in sea level of several meters. Therefore, if it were necessary to protect cities such as Sydney or Melbourne, dykes would potentially need to be constructed around low-lying lands or across estuary entrances, as is done in the Netherlands.

A dyke across the entrance to Port Phillip Bay would be challenging to construct. 'The Rip' between the heads would require a dyke some 3 kilometres long and constructed in some 20 metre water depth. Despite this distance, 'The Rip' is relatively narrow compared with the circumference of the rest of the Bay, which is around 220 kilometres. The dyke would need to have locks to allow water and ships to pass. The locks would then be shut if a storm surge or high tide was forecast. However, because of the powerful currents and swells, constructing a dyke stretching across 'The Rip' would be a difficult engineering challenge and would be very expensive.

The Sydney metropolitan area comprises four major estuaries including Broken Bay, Sydney Harbour, Botany Bay and Port Hacking. Constructing dykes across these four estuary entrances would be a colossal undertaking. Thankfully, however, the foreshores, typically, are relatively steep and rocky, thereby having already some considerable allowance for future sea-level rise. Nevertheless, there are still low-lying foreshore areas that may need to be protected from inundation by dykes or seawalls, and major infrastructure, such as Sydney airport, which has runways extending well into Botany Bay, may need to be raised.

A project of comparable ambition and scale has been proposed for the Thames Estuary in England as rising sea levels there may cause the Thames Barrier to become inadequate by 2070. The proposed dyke would stretch up to 16 kilometres across the Thames estuary, making it one of the largest engineering projects Britain has undertaken. It would include locks to allow water to flow in and out of the Thames estuary according to the tides, but engineers would be able to shut the locks if a storm surge occurred. The dyke may also include a road and hydroelectric power station.

Source: Advice from AECOM 2009[26]

Photo credit: S. Daw

Glenelg, Adelaide.

However, even if the cost of protection was $10 billion for Melbourne alone, it would still be a lower cost alternative to losing low-lying infrastructure, building assets and the cost of disruption to the local economy and society.

In the long-term there will be a need to assess appropriate protective works for Sydney, Melbourne, Brisbane and other major urban centres. Bathymetry, land topography, tidal range, and expected storm surge elevation are factors to consider in any analysis of the costs and benefits of protecting urban assets. Dykes and pumps may be more cost effective than storm surge barriers or tidal barriers that could also provide an opportunity to harness tidal power. Although the financial and environmental costs of constructing major projective structures for our major cities would be high, the savings achieved by avoiding these cities becoming inundated could be large.

Climate change impacts on the Australian coast will require the implementation of many adaptation strategies. As many as 500 popular beaches may lose sand as sea level continues to rise. Communities will call for action to nourish depleted beach stocks. Already a program is in place in northern New South Wales and the southern Gold Coast to bypass the blocking Tweed River training walls and send up to 500,000 cubic metres of sand each year to the north. Adelaide's beaches have been replenished with sand since 1973 and the strategy for 2005–2025 involves continuing the existing program of beach nourishment and maintaining channels at Glenelg and West Beach harbours. The cost of implementing the strategy over the 20 years of its life was estimated to be about $70 million in today's dollars. This has since been reduced, possibly to around $56 million, by pumping sand onshore from near shore deposits.[27]

For many low-lying villages, towns and cities a progressive retrofit of public utilities will be required as sea level inundation impacts take greater effect. Roads, railways, electricity and sewerage networks are subject to increased frequency of tidal inundation. Invasion of more saline waters into these networks will also have effects. Adaptation planning to address these likely impacts must commence in the near future to maximise the capacity to align with planned maintenance and retrofit cycles.

Chapter 4 outlines the likely impacts of climate change on coastal ecosystems. Coastal policies need to maximise the resilience of coastal habitats, and regional plans should also allow for habitats to move in response to a changing climate and continue to provide ecosystem services and a buffer to likely impacts. Of particular importance are coastal habitats such as internationally recognised Ramsar sites (for example Kooragang Island in the Hunter River delta) located in highly developed areas are at risk and will require careful management to protect their values.

There has been very little analysis of costs and benefits of action to protect ecosystems from climate change impacts. One example is a study that evaluated the costs and benefits of options to prevent the intrusion of salt water into the Mary River wetlands in the Northern Territory. The wetlands have high biodiversity and are also highly productive, making a large contribution to the territory's barramundi and threadfin salmon yields and supporting cattle grazing in the dry season. The capital and maintenance costs of chokes and barriers were identified and compared with tangible and intangible ecosystem benefits. For each option assessed, the benefits of protecting ecosystem function significantly exceeded the costs of the barrier. The study concluded that salinity mitigation in the Mary River is economically sensible.[28]

6.3.4 Issues requiring further attention

The magnitude of risk from climate change in coming decades in the coastal zone highlights the imperative for a national debate on adaptation. As a society, Australia needs to discuss how high a risk is acceptable in coastal areas, and how the burdens of managing threatened coastal assets can be shared.

Coastal adaptation will be a long-term and changing agenda. The number of areas exposed to risks from current climate in the coastal zone, and the lead time for reducing risks to communities and infrastructure, indicate that we need to start preparing for climate change now.

Not all of the issues will require a national response and some will need to be pursued by individual states and territories and local government. Where a national response is required, COAG can be an appropriate vehicle to progress reform.

The following emerging issues are worth considering as part of any national coastal adaptation reform agenda. Progress in some of them is occurring in some states and territories including regional risk assessments. They are not in an order of priority and should not be considered a definitive list.

1. National standards and benchmarks for coastal development

Australia needs national standards and benchmarks to constrain future risk and address exposure of existing assets in the coastal zone. Clear planning rules and guidelines that define no-go zones for certain types of development must be shown in planning instruments and guidelines. Priorities include setbacks and sea-level benchmarks for different risk standards, and planning horizons that take into account the link between climate change and coastal geomorphology.

2. Regional risk assessments

Every part of the coast will be affected to some extent by climate change. Near-term and more distant climate change impacts on communities, industry, environments and infrastructure in all regions need to be better understood to manage future risk, particularly where current planning can assist in avoiding future development in high risk areas. Regional risk assessments also need to identify where there is a lack of adaptive capacity, and engage the community on future adaptation action plans, including protection of community values such as public access to the shoreline. Triggers need to be identified when increased on-ground response is needed to manage increasing risk. Importantly regional risk assessment and its incorporation in planning is not a one-off or short-term agenda, risks will continue to increase for decades or more.

There is benefit in regional risk assessments for adaptation linking to regional disaster risk reduction strategies. Regular reviews will be needed of emergency management approaches at regional scales to incorporate changing risks from climate change.

3. Demonstration strategies for areas exposed to high or extreme risk

For regions and communities with very high or extreme risks from climate change, there is a need to develop strategies that identify the on-ground action needed to manage those risks. Plans need to identify where climate change risks can be accommodated, where protection is required, how planned retreat could be undertaken, and the costs and benefits of early or delayed action. The offsite consequences and trade-offs of particular types of actions should be analysed. Importantly, trigger points relating to each key risk that would signal the need for a particular type of response need to be negotiated with communities. Significant community engagement in working through on-ground options will be essential.

4. Review and update Building Codes

Building codes and engineering specifications for infrastructure in high-risk areas in the coastal zone will need to be upgraded. The Building Code currently includes no provisions to minimise the risk of inundation from sea-level rise, and cyclones and wind speeds are also projected to change with climate change. Given that the climate will continue to change, ongoing review, for example every 15 years will be needed.

There is an opportunity to explore performance based responses in forward-looking standards that maintain acceptable levels of risk over the life of the structure.

Photo credit: A.D. Short

The surf club had to close and move when the seawall was built at Warilla.

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5. National audit of critical infrastructure in the coastal zone

Much of the infrastructure that underpins our society and economy is in the coastal zone, but little information is available about how climate change will affect its functioning and the services that it provides. An audit of critical national and regional infrastructure in the coastal zone is required.

6. Provision of information and tools essential for decision-making

Private and public decision-makers currently lack the information and tools, such as inundation modelling, needed to address climate change in many decisions. This assessment highlights the importance of having national science-based information, and reveals considerable gaps in readily accessible tools. Priorities include national scenarios on climate change targeted for the coastal zone and hazard mapping based on combined risks of erosion and inundation over time.

7. Research to reduce uncertainty about the magnitude of coastal risk from climate change

Research in key areas of science where uncertainty currently hinders effective risk management would be of net benefit. Hydrodynamic inundation modelling, informed by both climate science and geomorphology, is important in high-risk areas where significant assets could be threatened. Science to underpin integrated risk assessment is needed, including science that shows how the risks will change over time. There is also a need to better understand sea-level rise processes, with a particular focus on regional variation, ice sheet dynamic, trigger points for ice sheet melt and switching points to eroding rather than stable coastlines.

8. Risk allocation and insurance

Efficient decision-making will require clarity and communication about risk allocation and the degree of risk borne by asset owners. A risk allocation framework is needed to help governments, businesses and communities understand and manage the risks they face. The coastal zone is one of the key areas that would benefit from a national risk allocation framework. The insurance sector will be a key partner in these discussions.

9. Ecosystems review

Many ecosystems of national or global significance are in the coastal zone. While there is a widespread recognition that coral reefs are threatened by climate change, the risks to many other ecosystems are not well understood. There is a clear need to assess what is required to build the resilience of important ecosystems to climate change. This could involve identifying where horizontal or vertical movement might need to occur, ensuring that regional planning allows for such movement, and determining critical thresholds for sustainability or ecosystem service provision.

10. Community engagement

Much of the Australian population lives in the coastal zone. Adaptation strategies around the coast will require the engagement and support of the broader community. The success of that engagement is linked to broadscale information provision and risk education. Wide sharing of information on risks, risk allocation, adaptation options and responsibilities will facilitate informed engagement in the difficult decisions that some communities will need to make in the medium-term.

11. Build capability of local government

There is a need to build the capacity of those charged with management in the coastal zone to ensure that they have the knowledge, tools and skills to manage risk. Local government is responsible for key planning and land-use decisions that are critically affected by climate change risks and in many cases will not have the capacity in terms of resources and skills to do this effectively.

12. Inter-jurisdictional cooperation

The complexity of cross-cutting climate change risks in the coastal zone requires an effective inter-jurisdictional reform effort. The complex mix of roles and responsibilities in current governance system can be a source of confusion and inertia, creating potential barriers to efficient adaptation. A new national agenda will be needed to clarify roles and responsibilities and identify priority actions. This will require collaboration across jurisdictions on policy and technical matters, and will need to effectively engage local government.

Appendix 1: Adaptation options for buildings – protect, retreat, accommodate

Protection

Protection of the shoreline typically involves the construction of seawalls or other defences to maintain coastal assets in their current location. It includes the repeated nourishment of beaches with sand and engineering works, such as tide gates, to constrain flooding.

Many protection works will have a decadal life, as they will be constructed to a particular standard that will be exceeded over time with climate change. As indicated in Chapter 2, the effectiveness of beach nourishment will decrease over time as beaches switch from being stable to eroding.

Areas where ongoing coastal protection is a long-term option include highly developed urban areas with a long history of protection, and areas where there is a need to preserve irreplaceable cultural, Indigenous and heritage values.

The public will often call for protection when private property is threatened by coastal erosion. However, the use of protective structures can also lead to a false sense of security and encourage greater development in areas behind protective structures, than for similar locations that do not have protective barriers. Protection should only be considered as a long-term option as part of a wider management plan for the area.

Costs	Benefits
• Construction and ongoing maintenance costs could be high • Expectations that area will continue to be protected can limit the flexibility of retreat options in the future • Costs are likely to be much higher if structures fail, because their construction encourages development in protected areas compared with similar but unprotected areas • Impacts on areas upstream or downstream of protective works include loss of coastal and marine habitats	• Avoided damages or loss of land and structures • Continued public access to beaches and other recreational areas • Improved public safety

Accommodation

Accommodation includes a range of usually minor works to allow continued or extended use of at-risk areas. Measures include elevated floor requirements, increased setback requirements, and preparation of emergency evacuation plans.

Accommodation measures are often cost-effective in a transitional strategy. They are suitable for areas with modest to higher value assets where exposure to climate change risk is low to medium. An example is The Honeysuckles, Ninety Mile Beach, Victoria where new residents are required to provide a response plan to climate change, identifying how structures would deal with possible flooding and storms for the next 60 years, and a caveat is included on the property title to warn future owners of risk. While accommodation strategies may also generate a false sense of security, they do start to signal restricted access or development requirements and begin a difficult task of managing private ownership development expectations.

Costs	Benefits
• Marginal additional construction costs • Costs from loss or damage that may occur if measures not adequate • Possible reduction in investment values	• Continued use of land and infrastructure • Generally less impact on surrounding environment than protection measures • Generally cheaper than protective measures • Increased public safety • Promotes risk management

Planned retreat

Planned or managed retreat involves a decision to withdraw, relocate or abandon assets that are at high risk of being affected by climate change hazards in the coastal zone. In the longer term, planned retreat often provides the most cost-effective approach to managing risks to medium to high-value assets exposed to inundation or erosion risk.

Planned retreat, which can occur on a range of scales, can involve increased setback provisions, relocation of structures within properties, and rezoning of land (for example, to constrain ribbon development in high risk areas or to provide for horizontal migration of wetlands). It can include buyouts of properties.

At present there have been few experiences with planned retreat to deal with climate change, with the exception of Byron Bay. Lessons can also be learned from property relocations caused by the construction of new dams. In some areas, early community consultation suggests that there could be opposition to the early adoption of planned retreat. Options for implementing planned retreat would probably include a mix of regional planning, constraints on property title, financial instruments and insurance incentives.

Costs	Benefits
• Lost value of land, infrastructure, and social, economic and environmental values • Potential compensation costs for loss of land or infrastructure • Management costs associated with retreat plan (for example, removal of septic tanks as houses retreat)	• Increased public safety • Significantly lower ongoing maintenance costs than for protection measures • Reduced need for costly adaptation measures in future, should risks increase • Potentially allows for greater space for ecosystems to horizontally adapt

Glossary

Accretion	Growth of coastal shorelines by steady addition of sediments.
Adaptation	Adjustment in natural or human systems in response to climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.
Adaptive capacity	Ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.
Anthropogenic	Produced by human beings or resulting from human activities.
Average Recurrence Interval and Annual Exceedance Probability	The Average Recurrence Interval (ARI) and the Annual Exceedance Probability(AEP) are both a measure of the rarity of a rainfall event. ARI is defined as: *The average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration.* AEP is defined as: *The probability that a given rainfall total accumulated over a given duration will be exceeded in any one year.* How AEP relates to ARI with ARI expressed in years:

AEP	ARI
2%	50 year
1%	100 year
0.2%	500 year
0.1%	1000 year
0.01%	10000 year

Barrage	An artificial obstruction, such as a dam or irrigation channel, built in a watercourse to increase its depth or to divert its flow.
Bathymetry	Refer to the depth of the ocean. A bathymetric chart will show the depths of the sea floor.
Biodiversity	The numbers and relative abundances of different genes, species and ecosystems in a particular area.
Calcareous	A sediment, sedimentary rock, or soil type which is formed from, or contains a high proportion of, calcium carbonate in the form of calcite or aragonite.
Calcernite	A rock formed by the percolation of water through a mixture of calcareous shell fragments and sand causing the dissolved lime to cement the mass together. The calcarenite material is often a conglomerate varying from little shell material to nearly all fossil shells with little sand.
Carbon dioxide	A colourless, odourless gas that occurs naturally and is also emitted by fossil fuel combustion and land clearing. The atmospheric concentration of carbon dioxide has increased by about 31% since the Industrial Revolution. It is the main anthropogenic-influenced greenhouse gas affecting climate change.
Chenier	Beach ridge usually composed of sand or shells.
CO_2^e	Carbon dioxide equivalent concentration is used to compare the effect from various greenhouse gases.
Climate	Climate in a narrow sense is usually defined as the “average weather”. The classical period is of 30 years.
Climate model	A numerical representation (typically a set of equations programmed into a computer) of the climate system. The most complex and complete climate models are known as General Circulation Models.
Climate projection	A projection of future climate based upon simulations by climate models.
Climate scenario	A plausible and often simplified representation of the future climate, based on an internally consistent set of climatologically relationships.
Coastal geomorphology	The physical structures, processes and patterns associated with the coast, including landforms, soils, geology and the factors that influence them.
Coral bleaching	The paling of corals and other animals with zooxanthellae caused by the expelling of these symbiotic algae under stress. Bleaching occurs in response to physiological shock due primarily to periods of increased water temperature coincident with high levels of light. Bleaching can also be caused by changes in salinity or turbidity.
Demersal	Being or living on or near the bottom of the ocean.
East coast lows	Intense low-pressure systems which occur on average several times each year off the eastern coast of Australia.

Ecosystem services	Ecological processes or functions having monetary or non-monetary value to individual or society at large.
El Niño	See El Niño Southern Oscillation.
Endemic	Belonging or native to a particular geography, group, field, area, or environment.
El Niño Southern Oscillation	El Niño Southern Oscillation (ENSO) refers to widespread 2–7 year oscillations in atmospheric pressure, ocean temperatures and rainfall associated with El Niño (the warming of the oceans in the equatorial eastern and central Pacific) and its opposite, La Niña. Over much of Australia, La Niña brings above average rain, and El Niño brings drought. A common measure of ENSO is the Southern Oscillation Index (SOI) which is the normalised mean sea level pressure difference between Tahiti and Darwin. The SOI is positive during La Niña events and negative during El Niño events.
Exposure	Refers to the elements of risk which are subject to the impact of a hazard.
Geomorphology	The study of landforms, their origin, and evolution.
Glacier	A mass of land ice flowing downhill (by internal deformation and sliding at the base) and constrained by the surrounding topography (e.g. the sides of a valley or surrounding peaks). A glacier is maintained by accumulation of snow at high altitudes, balanced by melting at low altitudes or discharge into the sea.
Greenfield subdivisions	Subdivision on land that was previously rural land.
Greenhouse effect	An increase in the temperature of the earth's surface caused by the trapping of heat by greenhouse gases.
Greenhouse gases	Gases in the earth's atmosphere that absorb and re-emit infrared (heat) radiation.
Hazard	Is a source of potential harm or a situation with a potential to cause loss. It may also be referred to as a potential or existing condition that may cause harm to people or damage to property or the environment.
Holocene Period	The Holocene interglacial period is a geological epoch that began approximately 12–10,000 years ago and within which nearly all human civilisation developed.
Ice cap	A dome-shaped ice mass covering a highland area that is considerably smaller in extent than an ice sheet.
Ice sheet	A mass of land ice that is sufficiently deep to cover most of the underlying bedrock, so that its shape is mainly determined by the flow of the ice as it deforms internally and/or slides at its base.
Ice shelf	A floating ice sheet of considerable thickness attached to a coast (usually of great horizontal extent with a level or gently undulating surface); often a seaward extension of ice sheets. Nearly all ice shelves are in Antarctica.
Interglacial period	The warm periods between ice age glaciations. The "Last Interglacial" (before the current one), dated approximately 130,000 to 115,000 years ago.
Inundate	To cover with water.
La Niña	See El Niño Southern Oscillation.
Leachate	A product or solution often containing contaminants formed by leaching.
Littoral	In coastal environments the littoral zone extends from the high water mark, to areas permanently submerged.
Marine carbonates	Carbonates are rocks composed mainly of calcium carbonate $CaCO_3$, such as limestones and chalk. They may be formed by shells or skeletons of organisms.
Mitigation	Refers to those response strategies that reduce the sources of greenhouse gases or enhance their sinks.
Non-linearity	A process is called 'non-linear' when there is no simple proportional relation between cause and effect.
Palaeontology	The study of prehistoric life.
Pelagic	Relating to, or living in open oceans or seas rather than waters adjacent to land or inland waters.
Phenology	The study of the timing of recurring natural phenomena such as; leaves and flowers emerging, migratory birds appearing or eggs hatching.
Phytoplankton	Minute, usually single celled, free floating aquatic algae. Important source of organic material and energy in marine food webs.
Ramsar	The Convention on Wetlands, signed in Ramsar, Iran in 1971 is an international intergovernmental treaty dedicated to the conservation and "wise use" of wetlands.
Relative sea level	Sea level measured by tide gauge with respect to the land upon which it is situated.
Resilience	The ability of a social or ecological system to absorb disturbances while retaining the same basic infrastructure and ways of functioning, the capacity for self organisation and the capacity to adapt to stress and change.

Return period	A measure of risk used by engineers and insurers describing the average time between events of a given magnitude. For example, a one-in-100-year event has a 1% probability of occurring in any given year. See also Average Recurrence Interval and Annual Exceedance Probability.
Sea-level rise	An increase in the mean level of the ocean. Eustatic sea level rise is a change in global average sea level brought about by an increase in the volume of the world ocean. Relative sea level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land level subsidence. In areas subject to rapid land-level uplift, relative sea level can fall.
Slumping	When loosely consolidated materials or rock layers move a short distance down a slope.
Southern Oscillation Index	See El Niño Southern Oscillation.
Special Report on Emissions Scenarios	Scenarios described in the IPCC Special Report on Emissions Scenarios (SRES), published in 2000 and used as a basis for climate projections shown in the IPCC assessment reports. SRES scenarios are grouped into four families – A1, A2, B1 and B2, that explore alternative development pathways covering a range of demographic, economic and technological driving forces and resulting greenhouse gas emissions.
SRES A1FI	The most fossil fuel intensive scenario in the SRES, commonly viewed as one of the worst case scenarios.
Storm surge	Elevated sea level at the coast caused by the combined influence of low pressure and high winds associated with a severe storm such as a tropical cyclone. Includes wave run up and wave set up.
Storm tide	The total elevated sea height at the coast above a datum during a storm, combining storm surge and the predicted tide height.
Sustainability	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
Symbiosis	Interactions between different biological species. Symbiotic relationships may be mutuality, parasitic, or commensal.
Tectonics	Geological study of the earth's Lithosphere (crust and mantle). The Lithosphere consists of tectonic plates. There are currently eight major and many minor plates.
Thermal expansion	Refers to the increase in volume that results from warming water.
Threshold or tipping point	The point in a system at which sudden or rapid change occurs, which may be irreversible.
Uncertainty	An expression of the degree to which a value (e.g. the future state of the *climate system*) is unknown. Uncertainty can result from a lack of information or from disagreement about what is known or even knowable.
Vulnerability	Degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.
Wave run up	The ultimate height reached by waves (storm or tsunami) after running up the beach and coastal barrier.
Wave set up	The super-elevation in water level across the surf zone caused by energy expended by breaking waves.

Acronyms

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
AR4	IPCC Fourth Assessment report 2007
DEM	Digital Elevation Model
COAG	Council of Australian Governments
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GIS	Geographic Information Systems
IPCC	Intergovernmental Panel on Climate Change
LGA	Local Government Area
NEXIS	(Geoscience Australia's) National Exposure Information System
TAR	IPCC's Third Assessment Report 2001.

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'In many areas communities are going to be faced with some difficult tradeoffs. Climate change involves taking our heavily populated urban and peri-urban coastal society outside the established comfort zone of the recent past. A new national agenda must be prepared now to ready Australia for the hard decisions that will be required to reduce risk.'

Professor Bruce Thom, Member of the Wentworth Group of Concerned Scientists

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Human sign at St Kilda Beach, 17 May 2009, organised by Locals into Victoria's Environment.



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