

Queensland Coastal Processes and Climate Change

Minister's foreword



Queensland's extensive and unique coast is one of our icons. We have the longest coastline on Australia's eastern seaboard and 85 per cent of Queenslanders live near the coast. It is an essential element of our state and our lifestyle. Therefore, it is vital that we understand its natural processes, such as wind, waves and tides, and how climate change may impact them.

Coastal communities are already familiar with the risks of living on the coast, which include cyclones, erosion, and storm surges. Although we already experience these coastal events, they are expected to increase in frequency and intensity as a result of global warming.

Queensland Coastal Processes and Climate Change, the first of its kind in Queensland, discusses how these natural processes have shaped the coast and how climate change will affect them.

It divides the coast into five regions and outlines the vulnerability of each to climate change impacts. With the onset of climate change, the differences between coastal regions will become more apparent and our more vulnerable regions will pose greater management challenges.

The document shows that a projected sea level rise of 0.8 metres by 2100 will increase coastal erosion and inundation, causing damage to the environment, property and infrastructure.

The Queensland Government, through the Department of Environment and Resource Management, is committed to providing planners, policy and decision makers with the latest climate science to support their decision making.

Improving community understanding of the risks and impacts of climate change to Queensland's coast was identified as a key priority in the Queensland Government's climate change strategy *ClimateQ: toward a greener Queensland* and as an initiative in the *ClimateSmart Adaptation Plan 2007–2012*.

Additionally, the Government has placed a greater emphasis on the impacts of climate change with the new *Queensland Coastal Plan* including provisions for climate change in planning decisions. We have also invested \$8 million in the Improved Coastal Mapping Project to develop better mapping for the entire Queensland coast.

Combined with the new *Queensland Coastal Plan*, the Improved Coastal Mapping Project and the regional climate change projections, the release of this document provides an additional resource to help protect and manage Queensland's coastlines.

The Honourable Kate Jones MP

Minister for Environment and Resource Management

Contents

Minister's foreword.....	i
Executive summary.....	1
Chapter 1: Coastal processes.....	4
Key messages	4
The Queensland coast.....	4
Coastal processes.....	5
Waves.....	5
Tides.....	7
Coastal influences.....	7
Tropical cyclones	7
East Coast Lows	8
Coastal dynamics.....	10
Short-term erosion	10
Long-term erosion	11
Coastal accretion	11
Management options	12
Prevention	12
Sand nourishment	12
Sea walls, groynes and artificial reefs.....	13
Chapter 2: Climate change impacts.....	14
Key messages	14
Queensland's vulnerable coast	14
Sea level rise.....	15
Global sea level rise.....	15
Local variations in sea level rise.....	16
Tropical cyclones and storms	17
Storm tides and high sea level events	17
Coastal erosion	18
Ecological impacts	19
Beaches.....	20
Mangroves	20
Saltmarshes.....	20
Coral reefs.....	20
Seagrass.....	20
Chapter 3: Regional Vulnerability.....	21
Key messages	21
Regional Variability	22
Gulf of Carpentaria	23
Torres Strait	26
Northern Queensland Coast	28
Central Queensland Coast.....	31
Southern Queensland Coast.....	32
Chapter 4: Coastal planning and adaptation	35
Key messages	35
Coastal planning	35
Queensland coastal legislation	37
Climate change adaptation	38

Chapter 5: Research.....	40
Key messages	40
National overview	40
Queensland initiatives	42
Future challenges.....	43
Glossary	44
References	47

List of figures

Figure 1: Features of waves and the factors affecting their size	6
Figure 2: The components acting together to produce a storm tide—highest astronomical tide (HAT), mean water level (MWL), Australian Height Datum (AHD), still water level (SWL)....	9
Figure 3: Beach erosion/accretion cycle showing no permanent sand loss or coastline retreat.....	11
Figure 4: Long-term beach recession showing profile displaced landward due to permanent sand loss.....	11
Figure 5: A summary of the globally averaged sea level rise projections for 1990–2100.....	15
Figure 6: Sea level variations over the last 140 000 years.....	16
Figure 7: Sea level rise from 1993–2008 in the Australian region expressed as millimetres per year. The changes in coastal sea level data (measured from tide gauges) over the same period are shown by the coloured circles (data from the National Tidal Centre). This indicates the variations in the rate of sea level rise around Australia since 1993	16
Figure 8: The multiplying effect of sea level rise on high sea level events in Australia.....	18
Figure 9: Application of the Bruun Rule showing erosion of the upper beach and offshore deposition under sea level rise (SLR).	19
Figure 10: ‘Coastal squeeze’ under sea level rise due to the impact of coastal development. As sea level rises, the area available for the saltmarshes and mangroves to migrate landward reduces due to coastal development close to the coast.....	20
Figure 11: The varying influence of tides, wave, cyclones and East Coast Lows along the Queensland coast	22
Figure 12: Gulf of Carpentaria: this tide-dominated coast frequently experiences tropical cyclones.....	23
Figure 13: Typical geomorphology and sediment type of the Gulf of Carpentaria coast	24
Figure 14: Torres Strait: this mixed wave and tide-dominated coast rarely experiences tropical cyclones	26
Figure 15: Northern Queensland coast: this tide-dominated coast frequently experiences tropical cyclones	28
Figure 16: Tide-modified beach shown at low tide with the steep narrow beach face and a 100-metre wide, low-tide terrace cut by one small rip	29
Figure 17: Storm surge recorded at DERM storm tide gauges.....	30
Figure 18: Central Queensland coast: tide-dominated and frequently experiences tropical cyclones	31
Figure 19: Tide-dominated beach showing the narrow beach and wide, flat, essentially featureless intertidal sand flats with mangroves (HT: high tide; LT: low tide).....	31
Figure 20: Southern Queensland coast: this wave-dominated coast experiences East Coast Lows as well as cyclones	32
Figure 21: Wave-dominated beach showing the offshore bar and trough, with rip feeder currents converging to flow seaward as a rip current (arrows).....	32
Figure 22: Adaptation options for coastal building.....	36

List of tables

Table 1: Estimated costs and benefits of residential adaptation in southern Queensland in 2030 (Source: CopyrightCommonwealth of Australia reproduced with permission ³).	38
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Executive summary

Queensland's coasts are known for their significant economic, recreational, residential, aesthetic, cultural and ecological values. However, being natural systems they are affected by environmental and anthropogenic forces. Variations in these forces can alter coastal features such as coastal landforms, the width of beaches or position of the coastline.

An understanding of coastal processes and the impact of these influences is essential for all Queenslanders living on the coast or concerned about its future. Without this understanding it is difficult to put the projected impacts of climate change—rising sea levels, increased risk of storm surge and inundation, and increased rates of coastal erosion—into perspective.

Living on the coast comes with the risk of coastal hazards. There have been 207 major events resulting in coastal erosion and flooding, property damage and loss of life from storms and tropical cyclones along the east coast since 1858. The highest storm surge of 14 metres occurred during Tropical Cyclone (TC) Mahina in 1899 at Bathurst Bay, Cape York killing over 400 sailors and pearl divers.

Queensland's coast can be divided into five coastal regions each with different characteristics and vulnerability to coastal hazards. With the onset of climate change, these differences will become more apparent, and the more vulnerable areas will pose greater management challenges.

Queensland Coastal Processes and Climate Change describes these five coastal regions, the physical processes (waves, tides, tropical cyclones and East Coast Lows) that shape our coast and the impacts that can be expected as a result of climate change.

The document outlines the advantages and disadvantages of a range of management options and some of the Queensland Government initiatives that support better planning for the impacts of climate change. The new *Queensland Coastal Plan* includes a new State Planning Policy and Coastal

Hazards Guideline and incorporates a sea level rise factor of 0.8 metres and a 10 per cent increase in maximum cyclone intensity associated with climate change over a 100 year planning period.

The new *Queensland Coastal Plan* (including coastal hazard maps to be used for planning purposes), the Improved Coastal Mapping Project which will deliver accurate and up-to-date interactive mapping identifying vulnerable areas of the Queensland coast and provide a visualisation of the impacts of climate change and regionally focused climate change projections, are essential resources for the protection and management of Queensland's coast and its communities. By providing the latest and best information on climate change and the state's dynamic coastal region, the Queensland Government is helping Queenslanders to understand, plan for and adapt to the projected impacts of climate change.

This publication is intended as a resource for decision makers and the general public in trying to understand the form and function of Queensland's coast and its vulnerability to a changing climate. It does not discuss the complex dynamics of estuaries, inlets and coastal wetlands or the impacts of climate change on these systems. Neither does it address the ecological values of Queensland's coast nor the potential impacts of climate change on them in any detail. It is also not a risk assessment, although the vulnerabilities of each coastal area are highlighted.

The key messages of chapters 1–5 from *Queensland Coastal Processes and Climate Change* follow.

Coastal processes

- Coastal processes are complex and it is important that the community is adequately informed.
- To understand the potential impacts of climate change on the coast requires a good understanding of natural coastal processes.

- Waves, tides and weather systems interact to produce a wide range of impacts on the diverse coastal environments of Queensland. These impacts require different management techniques.
- The sandy beaches that dominate the Queensland coast are dynamic with the position of the coastline fluctuating naturally as conditions alter.
- Management plans are being continually improved to recognise and respond to the dynamic nature of the coast and the impacts of climate change.

Climate change impacts

- Climate change is expected to lead to:
 - ▶ a sea level rise of 0.26–0.79 metres by 2100
 - ▶ a 20 per cent increase in rainfall associated with tropical cyclones (within 100 kilometres of the eye)
 - ▶ changes in the regional and local frequency of tropical cyclones. However, it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged
 - ▶ increases in both the mean and maximum wind speed of tropical cyclones in some locations.
- Impacts of climate change on the Queensland coast include:
 - ▶ increased frequency of extreme sea level events
 - ▶ increased coastal erosion
 - ▶ increased risk of damage to property and infrastructure from inundation and erosion.
- Sea level does not rise uniformly and varies regionally.
- Inundation and erosion from sea level rise is likely to adversely affect coastal ecosystems through habitat loss in near-shore and intertidal environments such as beaches, mangroves, saltmarshes and seagrass beds.

Regional vulnerability

- Variations in factors such as wave energy/direction, tidal ranges, influence of cyclones and storms, the proximity of reefs and headlands, anthropogenic activities and geological processes have created five coastal regions in Queensland.
- Each of these five coastal regions experience different levels of exposure to coastal hazards, such as erosion and inundation, and therefore require different management responses.
- Identifying sections of the Queensland coast which are more vulnerable to climate change impacts such as sea level rise, erosion and inundation is necessary for effective coastal planning management and community resilience.
- The extensive low-lying areas of the Gulf of Carpentaria are vulnerable to the increased frequency of extreme sea level events and storm tide inundation.
- The low-lying Torres Strait islands are extremely vulnerable to increased frequency of extreme sea level events and loss of land through permanent inundation from rising sea level.
- The Northern Queensland coast is characterised by low wave energy and coarser sandy beaches and can be severely eroded during tropical cyclones. The low coastal landforms (e.g. dunes) are very vulnerable to storm tide inundation.
- The Central Queensland coast has classic tide-dominated coasts with wide gently sloping intertidal flats that are prone to storm tide inundation.
- The Southern Queensland coast is characterised by long stretches of fine sandy beaches with high dune systems and high-energy wave conditions. Increased coastal erosion poses significant threats to this highly developed coast.

Coastal planning and adaptation

- Climate change impacts, including rising sea levels, increased risk of storm tide inundation and coastal flooding, and increased coastal erosion are likely to affect property and infrastructure along Queensland's highly developed and populated coast.
- Most of Queensland's major settlements are located on the coast, exposing them to increased climate change risks.
- Extreme coastal inundation and erosion events could become more frequent, resulting in high clean-up and asset maintenance costs.
- Avoiding and reducing future risk is the most cost-effective adaptation response to climate change.
- The Queensland Government is committed to preparing Queensland's coastal communities and infrastructure for the impacts of climate change. The new *Queensland Coastal Plan* includes specific provisions about sea level rise to ensure that coastal protection and future development decisions are based on contemporary climate change science.

Research

- It is imperative to establish a sound scientific basis to effectively respond to climate change in Queensland coastal communities.
- Incorporating climate change into decision making for coastal management will take significant resources and time. However, given the Intergovernmental Panel on Climate Change sea level rise estimate of up to 0.79 metres by 2100, there is sufficient time to undertake the necessary planning and implementation.
- The sea level rise figure used in the new *Queensland Coastal Plan* will continue to be reviewed and improved with the latest climate change information.
- The Improved Coastal Mapping Project will help identify vulnerable areas of the Queensland coast and visualise the impacts of climate change including sea level rise, storm tide inundation and coastal erosion.



1. Coastal processes

Understanding the dynamic nature of the coast and how it is shaped by processes such as winds, waves and tides provides an appreciation of how changes to these processes associated with climate change impact the coast.

This chapter provides an understanding of the form and function of Queensland's coastal zone and the influences which shape it. It also explains how variations in these influences can alter the coast in ways that affect its vulnerability to coastal hazards in a changing climate such as higher sea levels and an increasing number of intense cyclones.

Key messages

- Coastal processes are complex and it is important that the community is adequately informed.
- To understand the potential impacts of climate change on the coast requires a good understanding of natural coastal processes.
- Waves, tides and weather systems interact to produce a wide range of impacts on the diverse coastal environments of Queensland. These impacts require different types of management techniques.
- The sandy beaches that dominate the Queensland coast are dynamic with the position of the coastline fluctuating naturally as conditions alter.
- Management plans are being continually improved to recognise and respond to the dynamic nature of the coast and the impacts of climate change.

The Queensland coast

The coast is where the ocean meets the land. Queensland's mainland coastline is over 9500 kilometres long and extends from west of Karumba on the Gulf of Carpentaria to the Queensland–New South Wales border at Coolangatta.

Queensland coasts are diverse, comprising a mix of sandy beaches, rocky headlands, low-lying mud and sand islands, coral atolls and rocky islands. The interaction of coastal processes with the various landforms creates a very complex and dynamic natural system.

The most characteristic of these landforms are the gently sloping, sandy beaches which make up 66 per cent of the Queensland coastline¹. The sandy areas are often backed by beach-ridge plains (a broad sequence of beach ridges)¹ and usually bordered seaward by rocky headlands or tidal inlets, or fringed by coral reefs. Culturally and economically, these sandy beaches are the most valued feature of the coastal zone, but they are also the most dynamic.

Queensland is internationally renowned for these sandy beaches. In 2006, the gross tourism value of the Gold Coast beaches was estimated at between \$106 million and \$319 million². Queenslanders also enjoy living close to the ocean—85 per cent of the state's population (3.8 million people) live within 50 kilometres of the coast⁴.

This coastal population is growing. In 2009, the Gold Coast, Moreton Bay and the Sunshine Coast experienced the largest population increases (after Brisbane) in Queensland⁴. Coastal areas further north, most notably Cairns, Townsville and the Fraser Coast (Hervey Bay), have also recorded large population increases⁴.

Although a coastal lifestyle may seem idyllic, this complex and dynamic environment poses risks to coastal communities from hazards including storm tide inundation, coastal erosion, cyclones and sea level rise inundation.

Despite these hazards, many people think of beaches as constant, stable features. As far back as the 1960s and 1970s, when the Gold Coast experienced record erosion events, coastal residents were not fully aware of the potential risks to roads and houses. A survey of the Gold Coast community asked respondents about their experiences during the 1972 and 1974 storm events

which caused severe erosion and damage to homes and infrastructure⁵. The survey is the only of its kind and was conducted in the mid-1990s.

It found that:

- every decade there is a turnover of 70 per cent of the beachfront population
- over 90 per cent of beachfront residents interviewed during a period of calm weather believed that they would not be affected by erosion
- respondents perceive significant storms that cause severe erosion to be very rare events (they actually have about a 1 in 6 year return period)
- many respondents did not accept that 30 to 40 metres of beach recession could occur due to natural erosion
- property owners believe that a hard surface or structure, for example a sea wall, is the best protection against coastal erosion
- respondents perceive that a 1 in 100 year event will not occur for 100 years. This figure is, however, a probability stating that there is a 1 per cent (or 1 in 100) chance of the event occurring in any given year
- pressure from the media and community to build sea walls after storm events suggests that coastal processes and the dynamic nature of Queensland's coast continue to be poorly understood.

The Queensland coast is constantly changing due to both naturally occurring processes (e.g. variations in sediment supply, sea level, weather patterns) and, more recently, man-made changes to the coasts (e.g. sea walls, groynes and channel dredging). Natural processes, such as coastal erosion, become 'problems' when

they threaten property and infrastructure. As coastal processes are often not well understood, the 'solutions' may create even more problems. Careful, considered management is needed to accommodate the needs of the community and maintain the natural environment.

The geomorphology of the coast (the way it looks and how it functions), its vulnerability to certain hazards and their relative impacts at a given location, are the product of a complex interplay of physical factors. Sediment inputs, the exposure to waves, the tidal range and climatic forces (prevailing winds and cyclones) vary along the length of the Queensland coast¹.

Coastal processes

Coastal processes are the marine, physical, meteorological and biological activities that interact with the geology and sediments to produce a particular coastal system environment¹. The variability and interaction of waves and tides along the Queensland coast results in different coastal environments.

Waves

Ocean waves originate as distortions of the water surface produced by local winds blowing over the sea⁶ (hence the term 'wind waves'). The size of a wave is determined by the:

- length of fetch (distance of open water over which the wind has blown)
- wind duration (the period of time the wind has blown over a given area) and direction
- wind speed (energy)
- depth of water.



The Queensland coast has a high residential value (Source: DERM).

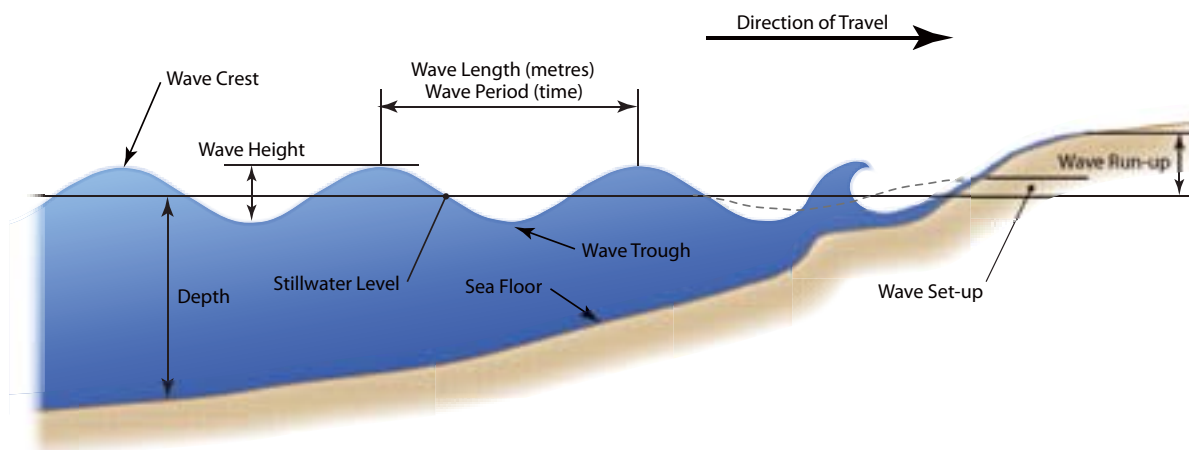


Figure 1: Features of waves and the factors affecting their size (Source: DERM)

The greater each of these factors, the larger the wave produced. The length of fetch and wind duration probably have the most influence on wave size. The presence of islands or reefs can reduce fetch length. The longer the wind blows over the water, the larger and more high energy waves it generates. Waves are described by their height, length, period and direction from which they travel.

Wave height is the distance between wave trough and wave crest. Wave length is the distance between the crests of the wave. Wave period is the time it takes for consecutive wave crests to pass a stationary point.

As waves break on a beach, they raise the mean water level above the still water level of the sea, this is called a wave set-up (Figure 1). Wave run-up is the vertical distance above mean water level reached by the uprush of water from waves across a beach or up a structure (Figure 1). Wave run-up is a function of the beach steepness, wave height and wave period.

All waves start as wind waves; however, as they travel from their origin they transform into lower, longer, faster and more regular 'swell' waves which can travel hundreds of kilometres¹. Most of the Queensland coast receives low, short, wind waves, with swell waves only reaching the coast south of Fraser Island. Waves on the Queensland coast can originate from cyclones in tropical Queensland, East Coast Lows (intense low-pressure systems) in Southern Queensland, south-east trade winds on the east coast, north-west winds in the Gulf of Carpentaria and from local sea breezes¹. The influence of these sources varies seasonally and regionally.

In Southern Queensland, swell waves can travel unimpeded towards the coastline and usually dominate wind waves. Waves usually approach the coastline from the south-east due to the influence of predominantly south-east winds blowing over long fetches in the Tasman Sea.

In Central and Northern Queensland, the Great Barrier Reef (GBR) prevents the majority of swell waves from reaching the coastline. Waves here are predominantly wind waves trapped within the narrow fetch and shallow waters between the coastline and the GBR. Shallow water depths in the GBR lagoon and the Gulf of Carpentaria (both averaging less than 100 metres) limit the size of waves. Swell waves do occasionally pass through gaps in the GBR.

Overall, this means that the Gulf of Carpentaria and areas of the coasts protected by the GBR experience waves lower in height, shorter in period and more irregular than those along the Southern Queensland coast.

Wave energy and direction influences sediment transport. The larger, more powerful swell waves can transport large volumes of sand along the coast. For example, the Gold Coast in Southern Queensland has transport rates of 400 000–500 000 cubic metres per year, whereas the Northern and Central Queensland coasts generally transport significantly less (40 000–50 000 cubic metres)¹.

Tides

A tide is the periodic rise and fall of marine waters (oceans, seas and bays) caused by the gravitational forces between the Earth, moon and sun. The heights of the tides vary during the month and throughout the year due to changes in these forces.

Higher tides called spring tides, occur every 14 days during the new moon and full moon (when the gravitational forces of sun and moon are in line). Smaller tides, called neap tides, occur during the rest of the month during the moon's first and last quarters. The two spring tides that are the highest for the year—one during summer and one during winter—are called king tides.

Most of Queensland experiences semi-diurnal tides, that is, two high and two low tides each day, with the tide turning approximately every 6 hours.

Queensland's tidal range (the vertical distance between the level of water at high tide and low tide) varies and can be described as:

- **micro-tidal**—tidal range less than 2 metres (characteristic of open ocean coasts in Southern Queensland)
- **meso-tidal**—tidal range between 2–4 metres (characteristic of Northern Queensland)
- **macro-tidal**—tidal range over 4 metres (characteristic of the Central coast. A maximum spring tidal range of 8 metres occurs in Broad Sound, north of Gladstone).

Coastal influences

Queensland coastal processes are influenced by prevailing winds and extreme events such as tropical cyclones and East Coast Lows. The south-east trade winds associated with high-pressure systems are the dominant force generating most of the waves on the Queensland coast. However, low-pressure systems (in the form of tropical cyclones and East Coast Lows) also directly impact the Queensland coast. The frequency of these storm systems can occur in cycles influenced by climatic factors such as the El Niño Southern Oscillation (ENSO) and the Inter-decadal Pacific Oscillation (IPO), also known as the Pacific Decadal Oscillation^{7,8,9}.

'Cool' periods of the IPO correspond to periods of Southern Queensland's most severe storms. Examples of this are the very intense storms from 1967–1974, erosion events on the Gold Coast in January 2009 and catastrophic flooding across most of Queensland during December 2010–January 2011. However, the 'warm' periods of the IPO from 1977–2008 produced relatively calm weather conditions along the Southern Queensland coast⁸.

Tropical cyclones

Tropical cyclones are intense low-pressure systems with winds of at least 63 kilometres per hour moving in a clockwise direction (in the southern hemisphere) around a small calm 'eye'¹⁰. Tropical cyclones have a major impact on most of the Queensland coast, particularly in the north where they gain energy from high sea-surface temperatures. Cyclones rarely form south of 25°S in Queensland because Southern Queensland has cooler sea-surface temperatures. Cyclones that do affect Southern Queensland have travelled from the north and are likely to be of reduced intensity.

Tropical cyclones typically occur between November and April. An average of 4.7 tropical cyclones per year affect the Queensland Tropical Cyclone Warning Centre area of responsibility which extends from the Torres Strait to northern New South Wales¹¹. Only some of these make landfall and cause property damage, flooding and inundation in coastal communities.

Three components of a tropical cyclone combine to create the total cyclone hazard—strong winds, intense rainfall and ocean effects (including extreme waves and storm surge). Extreme waves generated by strong winds can cause several metres of severe coastal erosion. The combined action of severe winds and tropical cyclones on the ocean causes a local rise in sea level called a storm surge^{12,13}. When the storm surge combines with the normal astronomical tide and wave set-up, the resultant storm tide can cause damaging flooding in coastal areas.



The Dunk Island Resort pool before and after TC Yasi, North Queensland (Source: Courier Mail).



Erosion along the Gold Coast from 1966–7 East Coast Lows and TC Dinah (Source: DERM).

There have been 207 major events (including coastal erosion and flooding, property damage and loss of life) from tropical cyclones along the east coast since 1858¹¹. The highest storm surge of 14 metres occurred during Tropical Cyclone (TC) Mahina in 1899 at Bathurst Bay, Cape York killing over 400 sailors and pearl divers. More recently in February 2011, TC Yasi crossed the Queensland coast near Mission Beach, south of Innisfail. It was the largest and most intense cyclone since 1918 and produced the third largest storm surge on record—5.33 metres at Cardwell.

East Coast Lows

East Coast Lows are intense low-pressure systems which often develop during the winter months along the east coast of Australia. They are difficult to predict and can cause severe coastal erosion along the Southern Queensland and New South Wales coasts¹. East Coast Lows often occur in clusters, creating long periods of strong winds which generate high-energy waves that can lead to severe coastal erosion and flooding. In 1966–67, a series of East Coast Lows and TC Dinah caused severe erosion along Gold Coast beaches threatening coastal properties.

Storm surges and storm tides

Storm surge is a local rise in sea level caused by the combined action of severe winds and low-pressure systems (East Coast Lows and tropical cyclones) on the ocean^{12,13}. When storm surge is combined with normal astronomical tide and wave set-up, it creates a storm tide. The height of the storm tide (or storm tide level) increases as these factors combine to raise the water level above normal levels and push the water up against the coast. When a storm tide level is higher than the Highest Astronomical Tide (HAT), it is likely to cause inundation and flooding in coastal areas.

The storm tide level must be accurately predicted to determine the likely extent of inundation from a storm¹². The destructive capacity of a storm tide depends on the height of the tide at the time that the cyclone crosses the coast. The higher the tide, the more likely it is that destructive flooding and erosion will take place.

The inundation produced by a storm tide is exacerbated by wave overtopping and localised intense rainfall and can lead to coincident flooding if combined with the effects of riverine (freshwater) flooding.

Figure 2 illustrates how the different components combine to produce a storm tide. One of these components, storm surge, is caused by the interaction of the extreme wind-driven currents and the coastline, which raises coastal water levels above the predicted tide, producing the still water level (SWL). Extreme wind-generated ocean waves and combinations of swell and local wind waves are also driven towards the coast above the SWL. This causes large volumes of water to be pushed against the coast. As the waves break on the coast, some of their energy is transferred to vertical wave set-up, yielding a slightly higher mean water level (MWL). In addition, waves running up the sloping beach (wave run-up) combined with the elevated SWL, allows them to reach the foredunes with enough height and energy to cause considerable erosion and contribute to the coastal flooding.

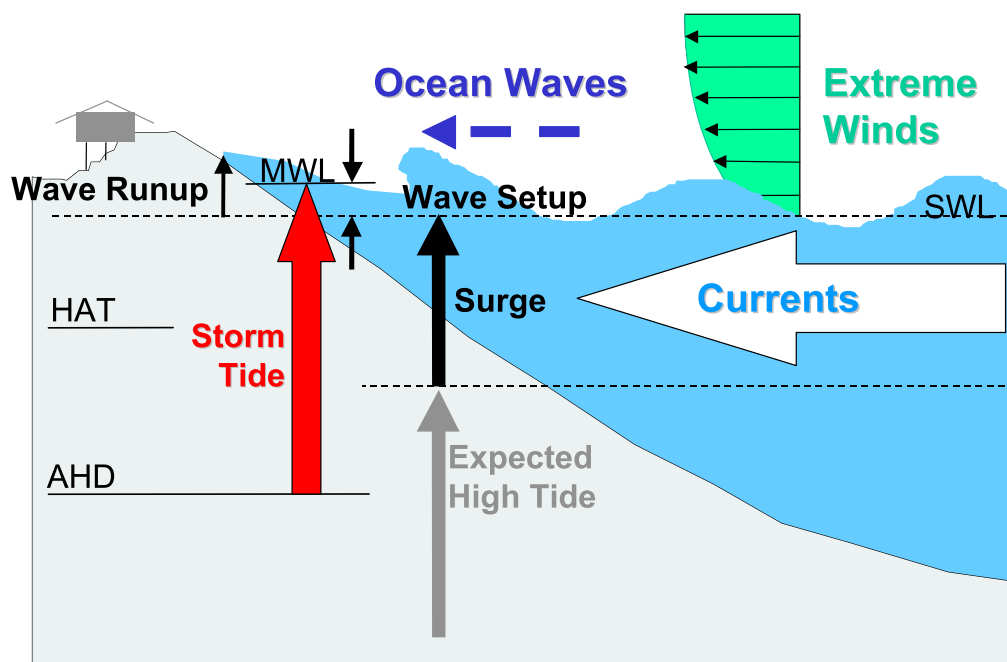


Figure 2: The components acting together to produce a storm tide—highest astronomical tide (HAT), mean water level (MWL), Australian Height Datum (AHD), still water level (SWL). (Source: Harper¹²).



The 5.33 metre storm surge during TC Yasi, 3 February 2011, damaged the Cardwell esplanade and deposited sand and debris well above normal levels (Source: Courier Mail).

Coastal dynamics

The interaction of coastal processes with coastal landforms creates a very dynamic system. Beaches are often thought of as the sandy part of the coast, but to a geomorphologist the ‘active beach system’ extends from the landward part of the dune system seaward beyond the intertidal zone.

Open sandy beaches make up about two thirds of Queensland’s coast, and almost half of these extend landward plains composed of soft sediment¹. This soft sandy coastline shifts landwards and seawards during natural phases of erosion (removal of sand) and accretion (build up of sand). Sand moving onshore or offshore can result in beach erosion, dune build-up or the formation of near-shore sand bars. These dynamic processes caused by waves, tides and winds occur over a range of time scales.

Rocky coasts such as headlands and the Whitsunday Islands which are more resilient to erosion are generally a minor component of Queensland coasts compared with the rest of Australia.

Short-term erosion

Short-term erosion is the product of natural beach fluctuations. It occurs over a period of days as a result of extreme weather events such as a severe storm or cyclone activity.

Figure 3a shows a cross-section (‘profile’) of a beach in its normal (‘equilibrium’) state before a storm. It has a well developed, vegetated dune system with a foredune behind the smaller incipient dune.

During a storm, strong wave action erodes sand from the beach, creating an erosion escarpment, destroying the incipient dune and moving the sand seawards (Figure 3b). After the storm passes, normal wave processes transport the sand back onshore, restoring the incipient dune and the equilibrium state of the beach (Figure 3c). By having a well-developed, vegetated dune system, the beach in this example has sufficient sand to restore the beach to its original state after a storm. This highlights the importance of maintaining coastal dunes.

Compared with erosion; however, beach accretion is generally a much slower process. For example, it may take several years for a beach to return to its pre-storm condition after one major storm or several smaller storms in quick succession.

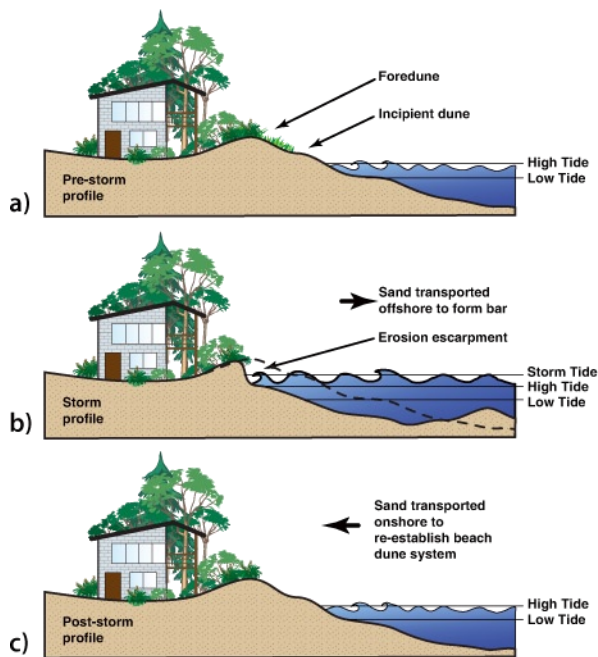


Figure 3: Beach erosion/accretion cycle showing no permanent sand loss or coastline retreat (Source: DERM).

Long-term erosion

Long-term erosion is continuous and often caused by a reduction in the amount of sand being transported on the beach. This is illustrated in Figure 4, which begins with the same scene as Figure 3 showing a cross-section of a typical beach in an equilibrium state (Figure 4a).

During a severe erosion event, the frontal and incipient dunes are removed leaving a large erosion escarpment as sand is transported seaward to form an offshore (storm) bar (Figure 4b). If too much of that sand is lost seaward and there is not enough new sand coming into the system, the beach will not be restored to its original state and the coastline will retreat landward and eventually coastal property may be threatened (Figure 4c).

Long-term changes in coastal morphology are also related to geological processes such as uplift or the reduction in land levels which can change sea levels and alter sediment transport patterns.

Many of Queensland's coastal landforms are broad, relatively young coastal plains backed by much older dunes dating back to the Pleistocene period (12 thousand to 2 million years ago). An exception is the Sunshine Coast which is experiencing long-term erosion¹⁴. In many locations along the

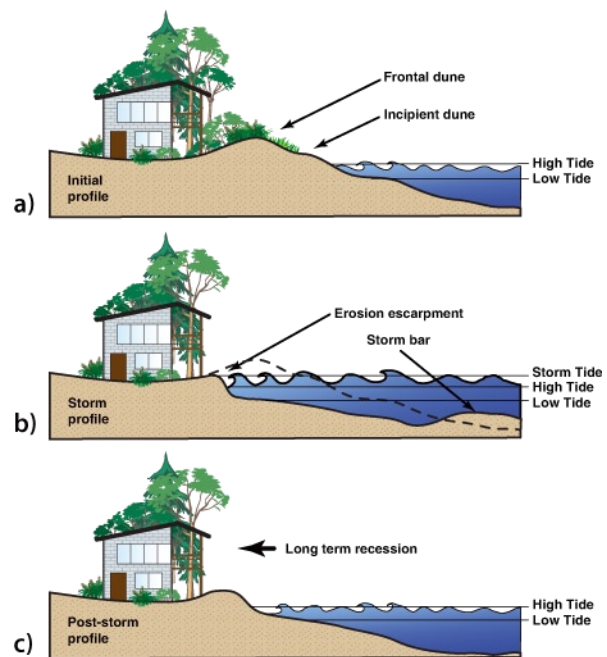


Figure 4: Long-term beach recession showing profile displaced landward due to permanent sand loss (Source: DERM).

Sunshine Coast, the coastline is eroding into the Pleistocene dunes, exposing extensive areas of dark cemented sand. This is commonly seen after severe storms where the thin veneer of Holocene sand (deposited 10–12 thousand years ago) is removed by erosion.

Where there are insufficient quantities of modern-day sand from rivers or offshore, longshore transport processes can remove more sand from the coast than is supplied. This type of erosion 'problem' is not easily solved as there is an ongoing sand deficit and recurring erosion problems. Maintaining a retreating coastline requires constant sand nourishment from other sources to retain the beach, or the construction of sea walls to protect developments.

Coastal accretion

In some locations the coast is naturally accreting. If there is more sediment coming into the system than going out, the excess sediment accumulates and the coastline can advance seawards ('prograde').

Occurrences of prolonged accretion are rare along the Queensland coast; however, cyclic patterns of accretion have been observed. For example, the increase in south-easterly and easterly winds during 1980–84 correlated with an 80 metre advance ('progradation') of the coastline

immediately adjacent to the mouth of the Black River, north of Townsville. However, an increase in the frequency of north-easterly winds after 1985 correlated with the retreat of the coastline landwards by 80 metres, indicating a cyclic pattern of accretion and erosion¹⁵.



Rainbow Beach, south of Fraser Island is an example of a retreating beach showing the yellow Holocene sand capping the white Pleistocene sands (Source: DERM).

Management options

Coastal erosion becomes a problem when it threatens property and infrastructure. The complexity of coastal systems means that it is often difficult to determine the cause of long-term erosion as the natural pattern may be disrupted by natural processes such as climatic or geophysical changes or by human activities such as the construction of hard coastal protection structures or dredging.

Prevention

Preventing development in areas prone to coastal erosion is the best way to avoid problems from coastal erosion. Queensland coastal planning legislation generally requires that land development be set back outside the area prone to coastal erosion (erosion-prone areas). This allows for the natural fluctuations of the coastline, protects development from the potential impacts of coastal erosion and significantly reduces or eliminates the need for future coastal protection works.

Since 1984, erosion-prone area maps for the Queensland coast and tidal waters have been available from the Queensland Department of Environment and Resource Management (DERM)

indicating areas potentially vulnerable to coastal erosion. Updated coastal hazard maps are now available on the DERM website indicating areas prone to erosion and storm tide inundation with a sea level rise of 0.8 metres.

The appropriate width of an erosion-prone area must accommodate both short and long-term erosion over the planning period, generally 50–100 years. Determining the width of the erosion-prone area involves estimating long-term erosion rates, the extent of short-term erosion corresponding to a ‘design’ storm event (cyclone or East Coast Low) and choosing a specific ‘planning period’.

Where the width of the buffer zone has not been sufficient and coastal erosion becomes a problem, common management techniques include:

- sand nourishment
- hard protection works such as sea walls
- groynes
- artificial reefs.

Sand nourishment

The nourishment of beaches with imported sand allows the width of beach lost by erosion to be restored and natural beach processes to be maintained. Sand may be trucked in, dredged or require the establishment of permanent sand pumping systems such as the Tweed River Entrance Sand Bypass at the southern Gold Coast.

The Queensland Government prefers coastal protection works that involve sand nourishment techniques over erosion control structures wherever feasible as they maintain natural coastal processes and retain the amenity of the beach. However, finding ongoing sources of sand can be difficult and regular nourishment can become expensive.



Palm Beach sand nourishment 1996 (Source DERM)

Sea walls, groynes and artificial reefs

When eroding coastlines threaten property or infrastructure, the last defence is the construction of sea walls. Sea walls protect property and infrastructure but can reduce beach amenity. They also have secondary impacts, as these hard structures interfere with natural beach processes and often result in reduced sand deposition and deterioration of the original beach. Sea walls should therefore only be used as a last resort and in conjunction with soft management approaches such as sand nourishment.

In response to severe erosion in the 1960s, a boulder sea wall was constructed along Surfers Paradise on the Gold Coast. During the generally calmer conditions over the subsequent 30 years sand buried the wall. The Gold Coast City Council's ongoing program of sand nourishment has maintained the beach amenity, as well as protected property and infrastructure.



The newly constructed seawall along Surfers Paradise in 1974, before it was buried with sand (Source: DERM).

Groynes trap sand on the up-drift side, resulting in beach accretion. Although this might solve the local erosion problem, it also stops the supply of sand on the down-drift side. This serves only to transfer the erosion to another area, where it may or may not create a new problem.



Groyne on Bramston Beach, North Queensland (Source: DERM).

Artificial reefs are not commonly used for coastal protection as they are very expensive, but may offer multiple benefits such as providing marine habitat and favourable surfing conditions. In 1999, the Gold Coast City Council installed an artificial reef at Narrowneck Beach. It was an expensive structure made of geotextile bags filled with sand. The reef successfully provided coastal protection and marine habitat, but it has been less effective at creating good surfing conditions¹⁶.



Artificial reef at Narrowneck, Gold Coast (Source: Gold Coast City Council).

Queenslands coasts are dynamic environments and iconic beaches are naturally susceptible to the varying wind patterns, waves and tides resulting in coastal erosion or less commonly accretion. Good management practices achieve a balance between the protection of coastal property and retaining the natural coastal processes. Climate change is likely to increase the frequency and magnitude of the hazards already experienced by coastal communities and is discussed in Chapter 2.

2. Climate change impacts

The previous chapter provided an overview of the physical processes that interact to influence the form and function of the Queensland coast. An understanding of these processes is critical to appreciating that this complex and dynamic system is likely to be significantly impacted by the projected changes associated with climate change, such as sea level rise and more frequent intense cyclones.

Over the millennia, the coastline has changed many times in response to variations in environmental conditions. However, the Queensland coast is now highly developed and accommodates most of Queensland's population. This makes the response of the coast to climate change a highly significant issue for coastal communities and is the focus of Chapter 2.



Aftermath of storm tide on the Hull Heads Community, south of Mission Beach after TC Yasi (Source: Courier Mail)

Key messages

- Climate change is expected to lead to:
 - ▶ a sea level rise of 0.26–0.79 metres by 2100
 - ▶ a 20 per cent increase in rainfall associated with tropical cyclones (within 100 kilometres of the eye).
 - ▶ changes in the regional and local frequency of tropical cyclones. However, it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged.
 - ▶ increases in both the mean and maximum wind speed of tropical cyclones in some locations.
- Impacts of climate change on the Queensland coast include:
 - ▶ increased frequency of extreme sea level events
 - ▶ increased coastal erosion
 - ▶ increased risk of damage to property and infrastructure from inundation and erosion.
- Sea level does not rise uniformly and varies regionally.
- Inundation and erosion from sea level rise is likely to adversely affect coastal ecosystems through habitat loss in near-shore and intertidal environments such as beaches, mangroves, saltmarshes and seagrass beds.

Queensland's vulnerable coast

Queensland's climate is changing. Recent reports, the Queensland Government's *Climate Change in Queensland: What the Science is Telling Us 2010*⁹ and CSIRO and the Bureau of Meteorology's *State of the Climate*¹⁷ tell the same story—Queensland is getting warmer. The average temperature in Queensland has risen by almost 0.9 °C since 1950 and the last decade was the hottest on record.

This warming trend is expected to continue. Over the next 40 years, Queensland can expect an increase in temperature of between 1.0 °C and 2.2 °C, as well as reduced rainfall across Queensland, except Cape York. Queensland's coast may also be subjected to higher sea levels and increased numbers of severe tropical cyclones.

Climate change projections suggest a sea level rise of 0.26–0.79 metres by 2100¹⁸ and increased intensity of extreme weather events. Climate change poses considerable risks to the Queensland coast, likely impacts include:

- sea level rise inundation—permanent inundation of land due to a rise in sea level and temporary (semi-diurnal) inundation from a shift in the extent of tidal inundation
- increased threat from storm tides that cause inundation and flooding
- increased coastal erosion
- risks to the coastal environment and its ecosystems.

The sandy beaches that dominate the Queensland coast are fragile coastal systems¹⁹ likely to experience significant erosion from cyclones, storm events and sea level rise. 85 per cent of Queenslanders live within 50 kilometres of the coast⁴ and population growth and associated development pressure in coastal areas is increasing.

Coasts are naturally dynamic and through natural processes of erosion and accretion they adjust to changing environmental conditions. However, human modification of the coast severely limits its capacity to respond to climate change. The protection of infrastructure will often come at the expense of the sandy beach.

Some of the most severe risks to coastal communities will come from coincident events—the combination of coastal (ocean water) flooding from storm tide with rainfall-induced riverine (freshwater) flooding.

Sea level rise

Global sea level rise

The *Intergovernmental Panel on Climate Change Fourth Assessment Report (AR4)*¹⁸ projects a range between 0.26–0.59 metres of sea level rise for the 21st century mainly based on thermal expansion and glacier melting (Figure 5 magenta bar). In the AR4 projections, what could not be modelled was not included.

However, the AR4 did indicate that a further 20 centimetres was possible (Figure 5 red bar) from the potential melting of ice-sheets (Greenland and Antarctic) raising the projection to 0.79 metres. The IPCC¹⁸ also emphasises that the contribution from changes in ice dynamics is highly uncertain and a larger rise cannot be excluded. For planning purposes the new *Queensland Coastal Plan* has adopted a figure of 0.8 metres by 2100, however this figure can be reviewed in the future.

The IPCC¹⁸ noted that thermal expansion of the ocean is the largest component of the projected sea level rise, contributing 70 to 75 per cent of the central estimate in the projections for all scenarios (Figure 5).

In its 2009 report *Climate Change Risks to Australia's Coast*, the Australian Government developed three scenarios for sea level rise by 2100: low (0.5 metres), medium (0.8 metres) and high (1.1 metres).

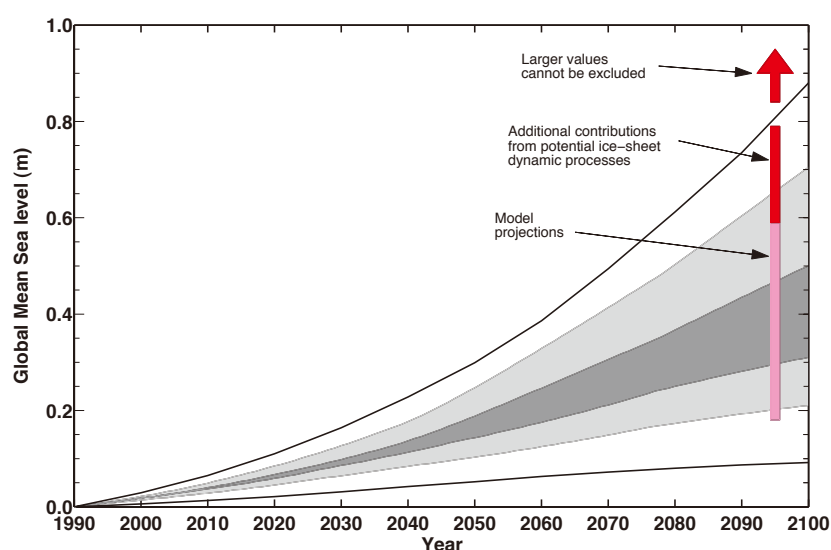


Figure 5: A summary of the globally averaged sea level rise projections for 1990–2100 (Source: Church et al.20).

While the low and medium figures were based on the IPCC projections, the 1.1 metre figure is based on post-IPCC research and includes estimates for ice-sheet contribution. This figure is consistent with that used in some other countries, however using the 1.1 metre figure instead of the 0.79 metres predicted by the IPCC¹⁸ has caused some debate in Australia.

Past sea level

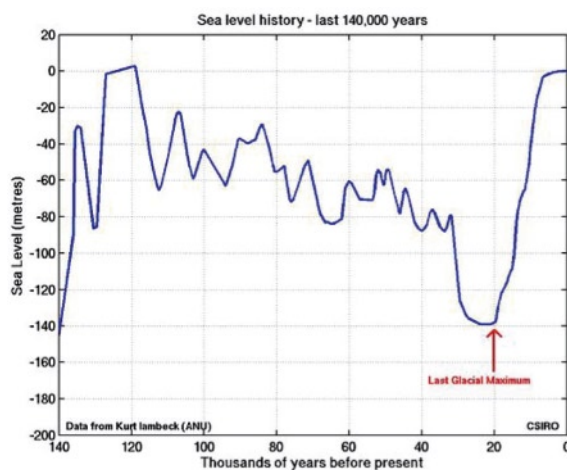


Figure 6: Sea level variations over the last 140 000 years (Source: CSIRO available at www.cmar.csiro.au/sealevel)

Sea level has varied significantly over geological time (Figure 6). During the last ice age ('glacial maximum'), sea level fell to more than 120 metres below its present level, as water was frozen and stored in ice sheets in North America, Greenland, northern Europe and Antarctica. As the ice started melting around 20 000 years ago, sea level rose rapidly at average rates of about 10–40 millimetres per year (1–4 metres per century), until sea level stabilised about 6000 years ago²⁶. Coral evidence from the Great Barrier Reef (GBR) suggests that local sea level was higher than present between 6000 and 2000 years ago²⁷.

Local variations in sea level rise

Although the IPCC AR4¹⁸ indicates a range in sea level rise of 0.26–0.79 metres, this is based on globally averaged increases whereas sea level rise varies regionally. While global sea level rise is a useful measure of the general direction of change,

there are substantial local and regional variations in the rates of sea level rise due to differences in topography, sediment type and coastal processes.

Data from tide gauges around the world shows that global sea level has risen by almost 0.2 metres since 1870²¹. Since 1993, sea level has been measured more accurately using satellite altimeters. Figure 7 shows the regional variations in the rate of sea level rise around Australia since 1993. The variations largely result from the movement of water within the oceans in response to wind patterns generated by climate phenomena such as the El Niño Southern Oscillation.

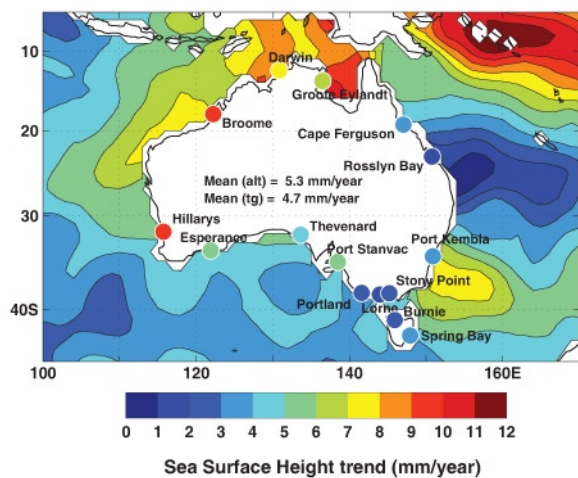


Figure 7: Sea level rise from 1993–2008 in the Australian region (measured from satellite altimeter data) expressed as millimetres per year. The changes in coastal sea level data (measured from tide gauges) over the same period are shown by the coloured circles (data from the National Tidal Centre). This indicates the variations in the rate of sea level rise around Australia since 1993. (Source: Church et al.²²).

Various sea level rise figures are being adopted for planning purposes by Australia's states and territories. These are based on the regional variations expected to occur as sea level rises²³.

Detailed modelling by CSIRO derived sea level rise projections for the east coast of Australia²³. Based on this modelling, the New South Wales Government adopted a sea level rise figure of 0.9 metres by 2100, which includes a regional variation of 14 centimetres. The modelling did not find the same regional variation for the Queensland and Victorian coasts²³. This in part explains why Victoria and Queensland have not included an allowance for regional variation and adopted the IPCC¹⁸ sea level rise figure of 0.8 metres by 2100^{24,25}.

It is clear from past evidence that most places do not experience the projected global rates of sea level change and that regional and local sea level are more important factors²⁸. Therefore, we can expect future sea level rise to vary from the global projections both regionally and locally.

Tropical cyclones and storms

Previous climate change projections for Queensland indicated an increased number of severe tropical cyclones and cyclones tracking further south³⁰. However, the validity of such projections continues to be debated within the scientific community. In 2006, the Tropical Meteorology Research Program expert panel released the *Statement of Tropical Cyclones and Climate Change*²⁹ which provided an overview of the discussions. More recently, in 2010, some of the expert panel have provided an update giving the level of confidence in the projections but maintaining the original 2006 projections for tropical cyclones.

It is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged under climate change, however, regional and local frequencies could still change substantially due to other meteorological influences such as ENSO³¹.

Some increases in both the mean maximum wind speed of tropical cyclones with warmer temperatures is likely in some locations, but not in all tropical regions³¹. Further studies are needed to increase confidence in projections that cyclone intensity will increase with climate change.

Rainfall rates are also likely to increase with warmer temperatures—projections suggest an increase of 20 per cent within 100 kilometres of the eye of the cyclone³¹.

Recent modelling projections do not show dramatic changes in tropical cyclone tracks, duration and areas of impact³¹ in contrast to previous projections which indicated that cyclones would move further south³⁰. However, the vulnerability of coastal regions to cyclones and associated storm tide inundation will still increase as development on the coast continues to grow. The vulnerability of highly developed parts of the coast, especially Southern Queensland will be at greater risk from coastal erosion and inundation.

Tropical Cyclone (TC) Larry caused record damage and economic losses in 2006. North Queensland has once again been impacted, this time by TC Yasi, the largest and most intense cyclone since 1918. The Category 5 system destroyed property and infrastructure. For example the combined impacts of storm tide and coastal erosion caused significant damage to the Bruce Highway at Cardwell. However the occurrence of two intense cyclones in recent years cannot be attributed to climate change. It is still unclear whether past changes in tropical cyclone activity (frequency, intensity and rainfall) can be attributed to natural variability or human-induced climate change^{31,32}.

Storm tides and high sea level events

Rising mean sea level will have dramatic consequences for many coastal communities in the future, caused in part by the increasing frequency of extreme sea level events such as storm tide.

Storm tides are produced by the combination of storm surge (a local rise in sea level caused by the combined action of severe winds and low-pressure systems such as East Coast Lows and tropical cyclones on the ocean) combined with normal astronomical tide variations and wave set-up.

The destructive capacity of a storm tide which is measured by the storm tide level depends on the height of the astronomical tide as the cyclone crosses the coast. The higher the astronomical tide, the greater likelihood of destructive flooding and erosion. The peak of the storm tide occurs as the cyclone or East Coast Low crosses the coast. If that coincides with a high tide, there is potential for very dangerous flooding of low-lying coastal land. The height of storm tides on the Queensland east coast is expected to increase with rising sea level and changes in tropical cyclone behaviour.

Changes in tropical cyclone behaviour are projected to cause an increase of over 0.1 metres in storm surge height over most of the Queensland coast³³. However, regional and local storm tide studies are needed to give a more accurate indication of the essential infrastructure and property at risk from inundation at specific locations.

So far, Queensland has escaped major damage from a storm tide. TC Yasi caused a peak storm surge of 5.33 metres at Cardwell on a falling tide. Had TC Yasi crossed the coast a few hours later at high tide, the damage would have been much worse.

Queensland coastal communities are extremely vulnerable to the risk of coincident flooding. As climate change leads to an increase in the magnitude of storm tides, their contribution to such coincident events poses a serious risk for coastal communities.

Relatively moderate levels of sea level rise are projected to cause large increases in the frequency of extreme sea level events. Based on the historical relationship between sea level rise and change in the average return interval of extreme sea level events, the research suggests that an extreme event that currently has 1 in 100 year chance of occurring, could increase its chance of occurring to more than once a year³⁴.

Figure 8 shows the effect of a 0.5 metre sea level rise on the frequency of high sea level events. The size of the circles shows the estimated multiplying factor for the increase in frequency of high sea level events. This multiplying effect between sea level rise and extreme events is likely to have the greatest effect on eastern Australia and major population centres³⁵.

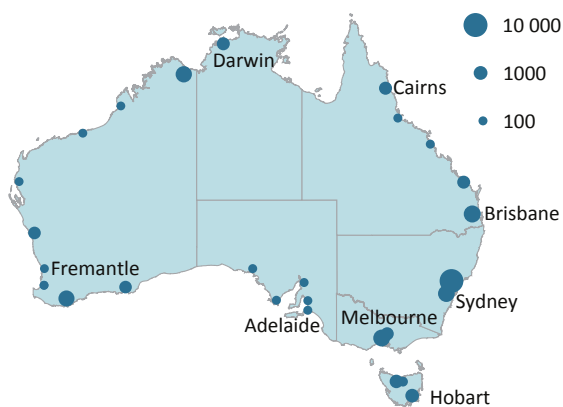


Figure 8: The multiplying effect of sea level rise on high sea level events in Australia (Source: Antarctic Climate & Ecosystems Cooperative Research Centre³⁵).

According to the Australian Government inundation assessment for Queensland, between 35 900 and 56 900 residential buildings in Queensland may be at risk of inundation under a projected

sea level rise of 1.1 metres by 2100³. The current replacement value of these at risk buildings is between \$10.5 billion and \$16 billion. Storm tides are not included in the assessment³, but it is likely that a higher number of properties would be identified as at risk if they were included. Mackay, Bundaberg, the Fraser, Sunshine and Gold coasts and Moreton Bay in Queensland, have the greatest risk of inundation from a projected sea level rise of 1.1 metres by 2100³. This accounts for almost 85 per cent of the residential buildings at risk in the state.



Damage caused during a high sea level event, Magnetic Island, North Queensland (Source: DERM).

Coastal erosion

Rates of coastal erosion along the Queensland coast are expected to increase as sea level rises. The Bruun Rule (Figure 9) estimates the extent of erosion in relation to sea level rise. However, it is still uncertain exactly how the coast will respond to the changing environmental conditions projected under climate change. In addition to rising sea levels, projected changes to atmospheric circulation systems may also cause changes to wave patterns. Changes in wave direction may alter the sediment budgets of coasts, causing increased erosion or realignment of the coast³⁶.

Increased numbers of severe tropical cyclones combined with stormier conditions during 'cool' phases of the IPO may also contribute to increased rates of erosion. If the severity or frequency of erosion events increases, there may be insufficient time between events for natural processes to replace eroded sediments. This results in a retreating coastline.

An increased rate of coastal erosion is a significant risk for coastal areas. In Queensland there are approximately 15 200 residential buildings located within 110 metres of 'soft', erodible coastlines, of which approximately 5400 are located within 55 metres³. The Gold Coast has the highest number, with approximately 2300 residential buildings within 55 metres, and 4750 within 110 metres of 'soft' coastlines³.

The fate of the Great Barrier Reef (GBR) under climate change is uncertain, but the GBR is currently an important factor influencing wave conditions along the Queensland coast. The GBR shelters the Northern and Central Queensland coasts and creates low-energy wave conditions. The GBR as we know it is only 6000 years old and during that time sea level has been relatively stable. If reef building fails to keep up with sea level rise or if large parts of the reef die, then these previously low-energy coasts may be subjected to high-energy swell waves²⁷. Such changes to the physical structure of the GBR would occur over long time frames, and may not necessarily result in increased coastal erosion. This is because swell waves, in addition to causing erosion, can also transport large quantities of sand onto the coast.



Coastal erosion impacting on structures at Tully Heads, North Queensland after TC Larry, 2006 (Source: DERM).

All coastal ecosystems will be affected in some way by climate change. Inundation and erosion are likely to lead to habitat loss in near-shore environments such as beaches, mangroves, saltmarshes and seagrass beds³. The following section briefly reviews a few of the many potential impacts of climate change on coastal ecosystems and ecology.

Estimating coastal erosion from sea level rise— The Bruun Rule

The most commonly used method for estimating the response of a shore to rising sea levels is known as the Bruun Rule. The Bruun Rule states that for every centimetre of sea level rise, the coast will erode 0.5 to 1.0 metres³⁷.

To maintain the same distance between the seafloor and mean sea level as sea level rises, sand must be eroded from the upper beach and deposited on the lower beach. In this way sand is not lost from the system and the beach maintains an equilibrium ('normal') profile as the coastline retreats.

The Bruun Rule does have its limits. It assumes steady wave conditions and does not account for longshore interactions. It is not strictly applicable on tide-dominated beaches, such as those common to Northern and Central Queensland coasts and the Gulf of Carpentaria.

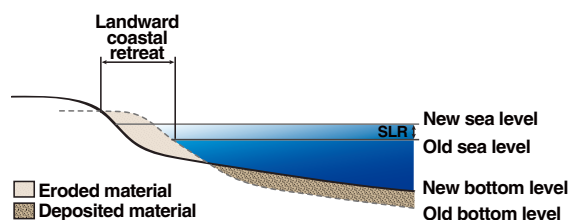


Figure 9: Application of the Bruun Rule showing erosion of the upper beach and offshore deposition under sea level rise (SLR) (Source: DERM adapted from ³⁷).

Ecological impacts

Climate change impacts, in particular sea level rise and more intense extreme weather events, are likely to significantly impact Queensland coastal ecosystems. However, prominent among the ecosystems which will be affected are those near-shore environments that face inundation from sea level rise and coastal erosion, leading to loss of habitat. This includes beaches, mangroves, saltmarshes, coral reefs and seagrasses.

Beaches

A typical beach provides habitat for several hundred species of invertebrates. Shorebirds feed on invertebrate beach dwellers (e.g. crabs, worms and insects), and the coastal zone is an important feeding ground for many juvenile fish. Many vertebrate animals, including endangered species of sea turtle and marine birds breed on Queensland beaches.

Beaches are likely to experience increased erosion and retreat landwards as sea levels rise and storms increase in intensity. Coastal protection structures, such as sea walls, may eventually lead to the loss of some beaches and their ecosystems³.

Mangroves

Mangroves maintain the integrity of coastlines and are highly productive systems, performing a valuable role in nutrient and carbon cycling and acting as a nursery and breeding habitat for marine fish, crabs and prawns, of which many are commercially valuable species. They also support diverse populations of terrestrial species, such as birds and insects.

The response of mangroves to sea level rise and inundation will depend on coastal dynamics. If the rate of vertical sediment accretion by mangrove communities exceeds sea level rise, then mangrove areas might not alter or they might even increase. By contrast, if sea level rise is too great, mangroves may retreat landwards or die out. Coastal development and lands adapted for human use may hinder the landward migration of mangroves and result in losses due to ‘coastal squeeze’³. Figure 10 shows the concept of coastal squeeze and changes to ecosystem extent due to sea level rise.

Saltmarshes

Saltmarshes are found on sheltered, low-wave energy coasts. They 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.

Saltmarshes are likely to migrate landwards in response to rising sea level. However, in developed areas, ‘coastal squeeze’ would prevent this. Significant loss of saltmarsh habitat could liberate the carbon stored in wetland sediments into coastal waters or the atmosphere. Loss of diversity of flora and fauna is also likely as saltmarsh areas are reduced and mangroves encroach into previously freshwater marshes³.

Coral reefs

Coral reefs protect the coast and provide critical habitat for immensely diverse fauna and flora. Coral reef ecosystems are very sensitive to environmental changes such as ocean warming and ocean acidification. For near-shore reefs coastal squeeze is likely to add to the existing pressures of declining water quality.

Seagrass

Seagrass beds provide the marine flowering plants that support internationally important populations of endangered species, particularly green turtles and dugongs. The large-scale decline of seagrass beds in Australia has been attributed to reduced water quality from increased land use and coastal development. Coupled with these anthropogenic pressures, a changing climate will further threaten the conservation of this important habitat.

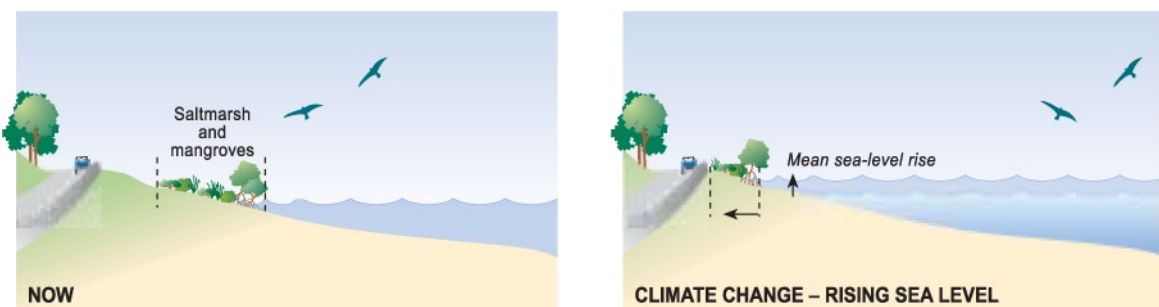


Figure 10: ‘Coastal squeeze’ under sea level rise due to the impact of coastal development. As sea level rises, the area available for the saltmarshes and mangroves to migrate landward reduces due to coastal development close to the coast. (Source: copyright Commonwealth of Australia reproduced with permission³).

3. Regional vulnerability

This chapter describes the five different coastal regions in Queensland created through different geographical settings and coastal processes and discusses how they will each be affected by climate change.



Hull Heads, south of Mission Beach after TC Yasi
(Source: Courier Mail)

Key messages

- Variations in factors such as wave energy, tidal ranges, influence of cyclones and storms, the proximity of reefs and headlands, anthropogenic activities and geological processes have created five coastal regions in Queensland.
- Each of these five coastal regions experience different levels of exposure to coastal hazards, such as erosion and inundation, and therefore requires different management responses.
- Identifying sections of the Queensland coast which are more vulnerable to climate change impacts such as sea level rise, erosion and inundation is necessary for effective coastal planning, management and community resilience.
- The extensive low-lying areas of the Gulf of Carpentaria are vulnerable to the increased frequency of extreme sea level events and storm tide inundation.
- The low-lying Torres Strait islands are extremely vulnerable to increased frequency of extreme sea level events and loss of land through permanent inundation from rising sea level.
- The Northern Queensland coast is characterised by low wave energy and coarser sandy beaches and can be severely eroded during tropical cyclones. The low coastal landforms (e.g. dunes) are very vulnerable to storm tide inundation.
- The Central Queensland coast has classic tide-dominated coasts with wide gently sloping intertidal flats that are prone to storm tide inundation.
- The Southern Queensland coast is characterised by long stretches of fine sandy beaches with high dune systems and high-energy wave conditions. Increased coastal erosion poses significant threats to this highly developed coast.

Regional variability

Variations in wave energy, tidal ranges, influence of cyclones/storms, the proximity of reefs and headlands, anthropogenic activities and geological processes along the Queensland coast have created five coastal regions:

1. Gulf of Carpentaria
2. Torres Strait
3. Northern Queensland
4. Central Queensland
5. Southern Queensland.

Each of these five regions has different characteristics, coastal management issues and vulnerability to climate change.

Figure 11 shows the varying influence of cyclones, waves, tides and East Coast Lows along the Queensland coast. For example, on the Southern Queensland coast, waves are the dominant process (shown by the large wave symbol) with tides having a lesser influence. It is therefore described as wave-dominated.

Further north, the Queensland coast is protected from large waves and is dominated by tidal processes, making it tide-dominated (indicated by the large tide symbol).

The size of the cyclone symbol reflects a strong influence in the Northern and Gulf coasts, and a lesser influence in the Torres Strait and Central coasts. East Coast Lows dominate the Southern Queensland coast.

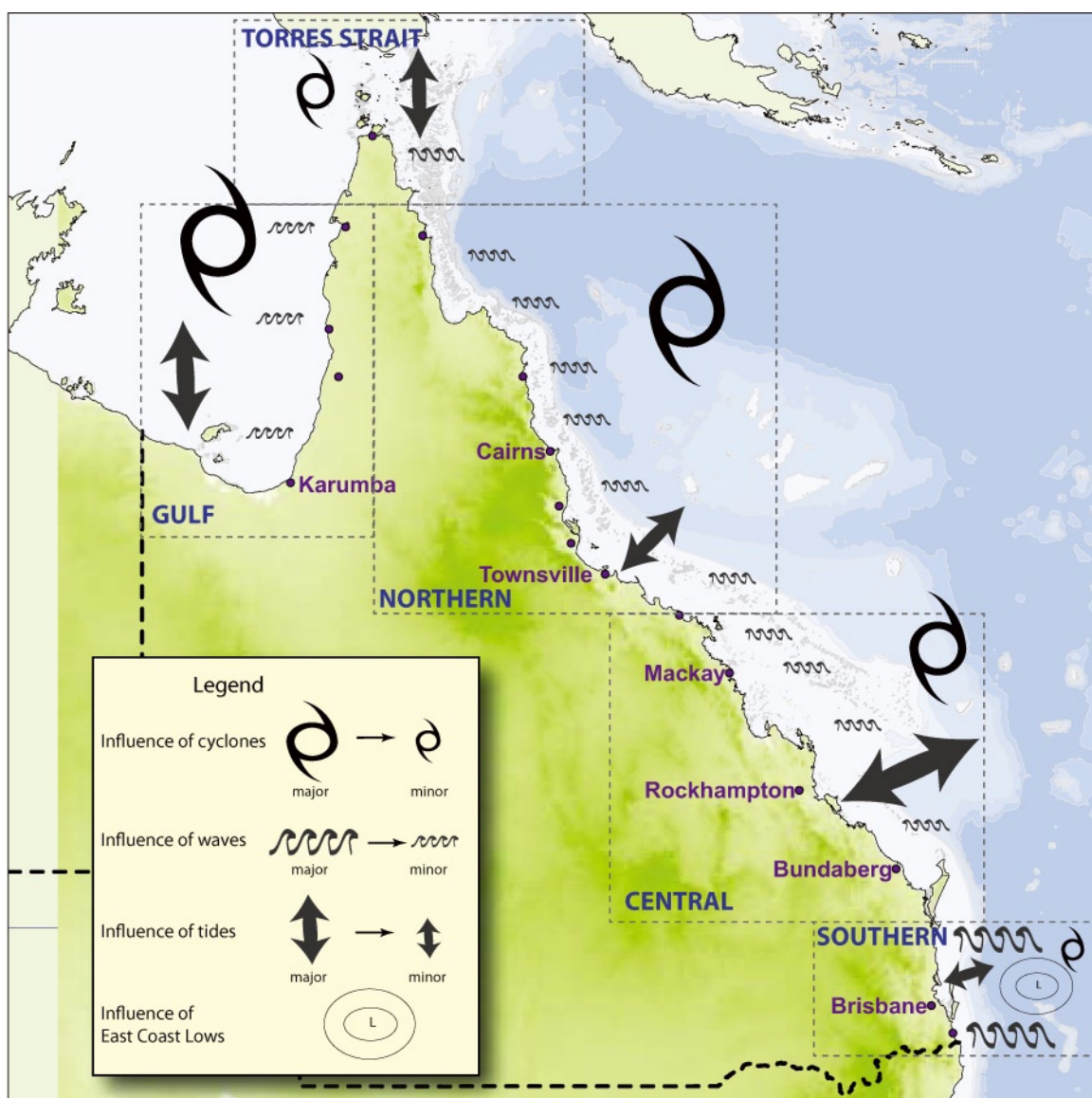


Figure 11: The varying influence of tides, wave, cyclones and East Coast Lows along the Queensland coast (Source: DERM).

All of Queensland is at risk from climate change; however, each coastal region has different risks depending on the dominant coastal processes and morphology.

The Southern Queensland coast is exposed to high-energy south-easterly swell waves and experiences a small tidal range. Research suggests that these micro-tidal coasts have a higher vulnerability to extreme high water events such as storm tides, compared to meso- or macro-tidal coasts³⁸. On a macro-tidal coast (with a five-metre tidal range), a storm generating a two-metre surge could occur without exceeding the elevation of the highest tide, however, on a micro-tidal coast (tidal range of less than two metres), a storm surge of two metres is always likely to exceed the highest level of the tide, creating a greater risk of inundation and damage from storms³⁸.

The highest sensitivity coasts are composed of Quaternary sands and occur along the open ocean sandy coasts, backed by low plains and dunes. Rocky coasts are considered low-sensitivity coasts.

Applying these findings to Queensland coastal regions suggests that while the rocky headlands will be resilient to climate change and sea level rise, most of Queensland's coast is highly sensitive, particularly the wave-exposed Southern Queensland coast. Also the impact of cyclone/storm-generated waves will potentially result in erosion and recession of the sandy coastlines while rocky headlands will remain stable on the Central and Northern Queensland coasts.

Gulf of Carpentaria

The Gulf of Carpentaria is a large shallow sea with a maximum depth of 60 metres, bordered by Cape York in Queensland to the east and Arnhem Land in the Northern Territory to the west (Figure 12). The climate is generally hot and humid with the dry months extending from May to October, and wetter months from November to April. During the wet season many of the low-lying areas of the Gulf are flooded.

Due to its remoteness and extreme climate, the region remains largely undeveloped and the integrity of its rivers, coastal swamps, saltpans and coastal zone remains largely intact¹. The land-locked nature of the Gulf of Carpentaria creates waves with a limited fetch and all coastal processes are related to the generally low wind waves. There are three sources of waves in the Gulf—the summer north-west monsoons, the dominant south-east trade winds and occasional tropical cyclones¹.

While north-west monsoons and cyclones usually only occur between November and April, the south-east trade winds dominate for most of the year. These winds generate short, low-to-moderate swell waves with an average wave height of 0.25 metres. Higher swell waves, 1–2 metres in height, occur along parts of the Gulf coast, north and south of Weipa, and impact on exposed beaches.

The tidal range is meso-tidal with a maximum spring tidal range of 2.6 metres in Karumba and 2.9 metres in Weipa. Tides in the Gulf of Carpentaria are irregular and unique. They vary from semi-diurnal (twice-a-day tides) in the north, to diurnal (once-a-day tide turning approximately every 12 hours) in the south.

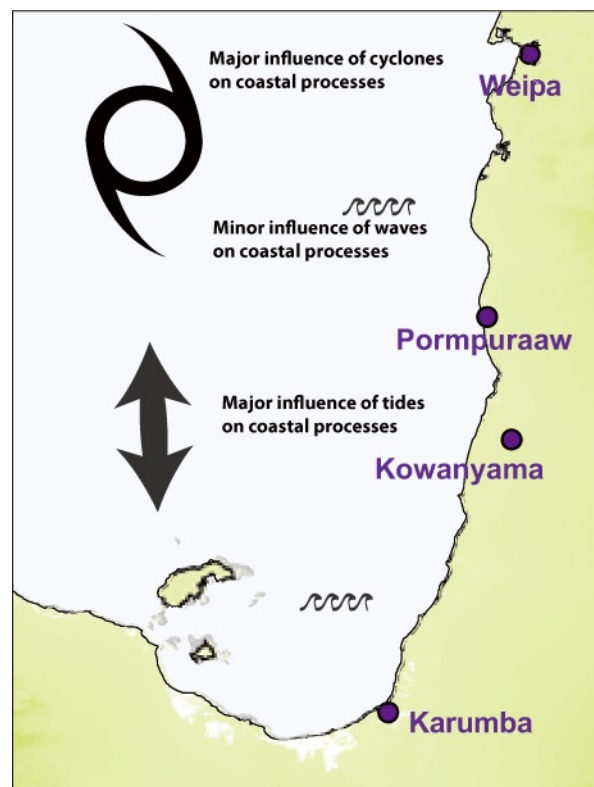


Figure 12: Gulf of Carpentaria: this tide-dominated coast frequently experiences tropical cyclones (Source: DERM).

The diurnal tide occurs because the Gulf of Carpentaria is a large, shallow, virtually closed body of water, and most of the tidal energy in the Gulf of Carpentaria takes 12 hours to travel north to south, over which time the tidal energy decays³⁹. This traps the semi-diurnal tide in the northern half of the Gulf resulting in diurnal tides at Karumba in the south.

Tides in the shallow waters of the Gulf are greatly influenced by local conditions such as barometric variation and wind stress. From December through to March, the prevailing monsoon north-west winds cause a rise of approximately one metre in the mean sea level on the south-eastern side of the Gulf.

The low wave energy, meso-tidal ranges and influence of cyclones in the Gulf create a distinctive coast. It comprises vast tidal flats with low-relief, cyclone-generated sand and shell ridges (cheniers) on muddy coastlines fringed by mangroves (Figure 13).

Tropical cyclones regularly impact the Gulf of Carpentaria in the summer months. Close to 100 cyclones have made landfall and affected the Gulf from 1885 to 2007¹¹. The Gulf is generally subject to low-energy ambient wave conditions; however, under tropical cyclone conditions, the available fetch can be quite large. A maximum wave height of 7.1 metres was recorded at Weipa in January 2008 during ex-tropical cyclone Helen⁴⁰. In 1923, the Douglas Mawson Cyclone caused large waves to hit Karumba and a storm surge inundated the coastal flats for many kilometres. At the same time Burketown reported a storm surge of 2.7 metres, and at Port McArthur it was between 2.4 and 5.5 metres¹¹.



Karumba Port, Karumba Gulf of Carpentaria (Source DERM).

Most of the coast in the Gulf is very low-lying and vulnerable to coastal flooding from the combination of storm tides associated with tropical cyclones, and freshwater flooding due to intense and prolonged cyclonic rainfall.

Storm tide inundation can also cause saltwater intrusion into coastal wetlands. Extensive coastal wetland systems are at risk from salination if back dunes are breached and saltwater enters the freshwater drainage system between coastal dune woodlands. Cultural heritage values could be lost as a result of the destruction of resources, heritage sites and landscapes⁴¹.

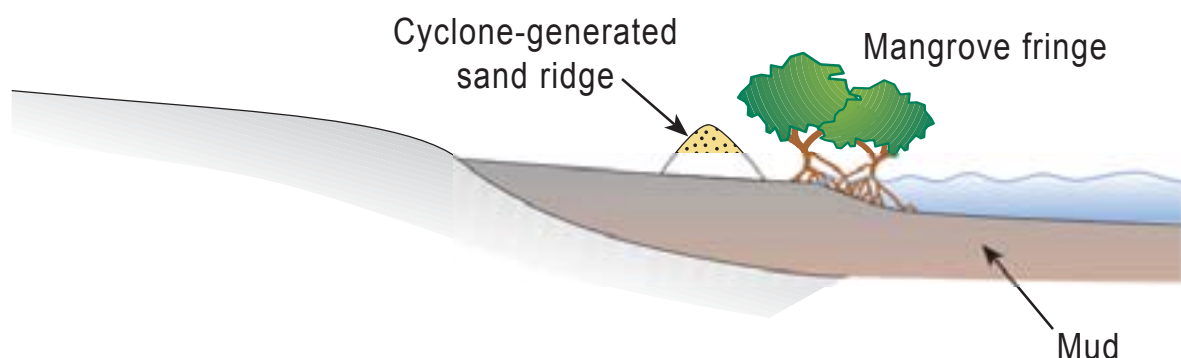


Figure 13: Typical geomorphology and sediment type of the Gulf of Carpentaria coast (Source: copyright Commonwealth of Australia reproduced with permission³).

Case study—Kowanyama

Kowanyama lies 20 kilometres inland of the Gulf of Carpentaria on the low-lying delta wetlands of the Mitchell River. Monsoonal rainfall often causes the area to flood during November through to April, and this is exacerbated by cyclones. The town has a population of 1200, and the airstrip, the highest point of the town at 9.6 metres above mean sea level, is the only link to Cairns when flooding cuts off the roads. This can last for up to four or five months during the wet season⁴¹.

Kowanyama and the neighbouring settlement of Pormpuraaw on the Edward River were destroyed by category 3 Tropical Cyclone Dora in January 1964 and had to be completely rebuilt. The towns have been spared such intense cyclones in recent times, but in January 2009, Category 1 TC Charlotte coincided with the highest astronomical tides and this resulted in large storm tides at Pormpuraaw. They overtopped back dunes and buried camp infrastructure under a metre of sand deposited by the water. If the highest astronomical tides and a cyclone of Dora's magnitude had coincided, the outcomes for Pormpuraaw and Kowanyama could have been much worse⁴¹.



The destruction from TC 'Dora' 1964
(Source: Kowanyama Aboriginal Land and Natural Resources Office, Cultural Heritage Archive).



Flooding of low-lying areas in Kowanyama during the wet season (Source: Kowanyama Aboriginal Land and Natural Resources Office, Cultural Heritage Archive).



Saibai Island, Torres Strait, the township is backed by low-lying mud flats (Source: DERM).

Torres Strait

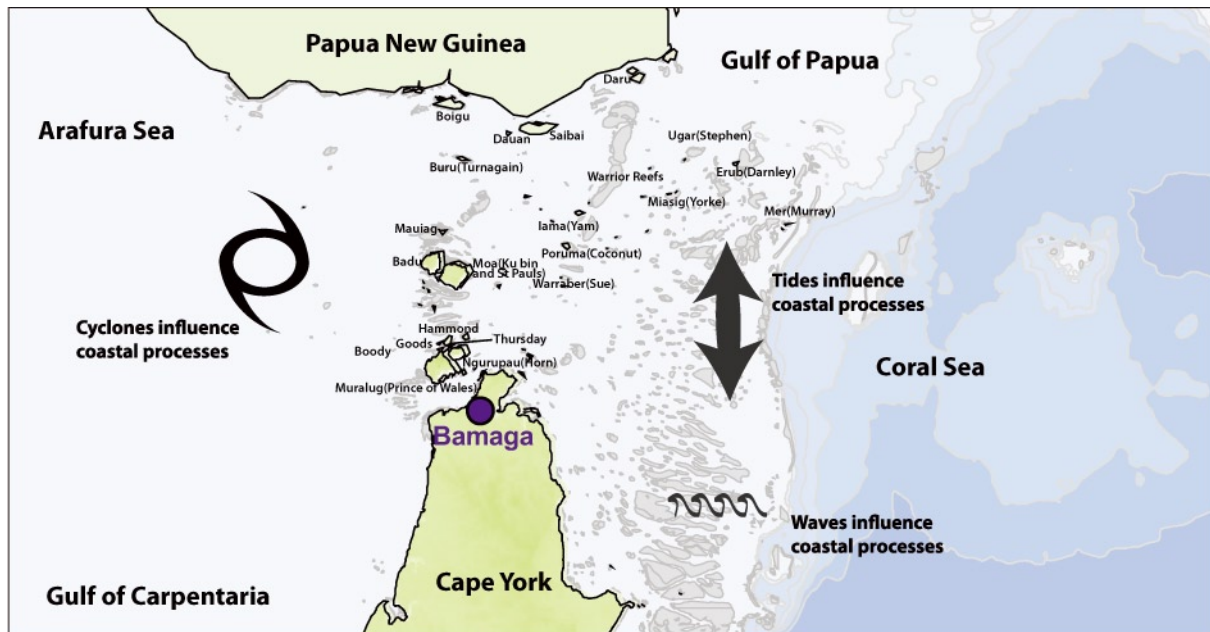


Figure 14: Torres Strait: this mixed wave and tide-dominated coast rarely experiences tropical cyclones (Source: DERM).

Torres Strait consists of a shallow (15–25 metres deep) shelf with 150 scattered islands, reefs and shoals, situated between north-eastern Australia and southern Papua New Guinea (Figure 14). The region is home to 17 island communities with a total population of around 8700⁴². The main population centres are on Thursday and Horn islands and most of the islands are uninhabited.

There are a variety of island types within the Torres Strait including granitic continental islands such as Waibene (Thursday) Island and Ngurupai (Horn) Island, volcanic islands such as Erub (Darnley) Island, sand islands such as Warraber (Sue) Island and mud islands such as Saibai and Boigu Islands.

To the north and closest to Papua New Guinea are the mud islands formed from sediment deposited by the Fly River. These extremely low-lying islands comprise layers of mud overlaying older coral reef and contain large areas of wetland, mangrove and brackish swamps.

Coral reefs grow throughout the Torres Strait, fringing high islands and forming large platforms and coral shoals.

Torres Strait is a mixed environment of waves and tidal currents. An important factor influencing the morpho-dynamics of the islands is the seasonally reversing wind regime. This is characterised by dominant south-easterly winds for the period from March to November and north-westerly winds over November to March⁴³. The islands are protected from high swells by the northern extent of the Great Barrier Reef. Small islands composed of sand and mud located in open ocean environments are extremely dynamic. Cycles of erosion and accretion related to changes in wind direction and strength occur in the Torres Strait over seasonal and decadal time frames⁴³.

Tides in the Torres Strait are complex and vary across the region due to complex bathymetry and the confluence of semi-diurnal tidal regimes in the Pacific/Coral Sea and diurnal regimes in the Indian Ocean. There is little accurate topographic (land height) and tide data for the region. Existing data is further complicated by seasonal changes in water level due to changes in wind patterns and atmospheric pressure, and to a lesser extent freshwater inflow and rain⁴³. The narrow, shallow passages through the Torres Strait Islands constrict tidal flows, increasing the strength of tidal currents up to four metres per second, with a meso-tidal range of approximately four metres.

The Torres Strait experiences fewer cyclones than other areas of Queensland, as most tropical cyclones track further south of the islands⁴⁴. However, they are still a significant hazard and major impacts include events in 1923, 1948 (which resulted in significant inundation at Saibai and Boigu), 1952, 1959, 1970 and 1972⁴⁵. Even low-intensity, relatively distant cyclones can cause problems for some of the islands when the storm surges they create occur in conjunction with king tides.

In addition to the effects of tropical cyclones, many of these low-lying communities are naturally subject to significant coastal hazards. Erosion and inundation directly threaten housing, infrastructure including roads, water supply systems, power stations, community facilities, cultural sites including cemeteries and traditional gardens and ecosystems. King tides in January 2009 and 2010 resulted in extensive flooding of island settlements.

Low-lying islands of Torres Strait are extremely vulnerable to sea level rise and are already experiencing inundation problems. This particularly applies to the mud islands of Boigu and Saibai, but also to the central coral cay islands and several low coastal flats on continental islands. Even small increases in sea level are likely to have a major impact on the islands and their communities.



Inundation of a jetty on Horn Island, Torres Strait during the January 2009 king tides (Source: Torres Strait Regional Authority).



Inundation on Thursday Island, Torres Strait during the January 2009 king tides.

A large rise in sea level could result in the permanent inundation of several Torres Strait islands with serious implications for these communities⁴⁶. In relation to the most obvious projected effects of climate change (sea level rise causing erosion and inundation), coastal protection works (hard structures) are frequently suggested. These are expensive and need to be evaluated on a case by case basis in terms of their benefits and unwanted consequences, against other soft options and other mechanisms such as relocation of infrastructure or retreat⁴³. Under the current rate of sea level rise; however, this threat and decisions on how to manage these communities are many decades away.



Overtopping of a seawall on Saibai Island, Torres Strait during the January 2009 king tides (Source: Torres Strait Regional Authority).

Northern Queensland Coast

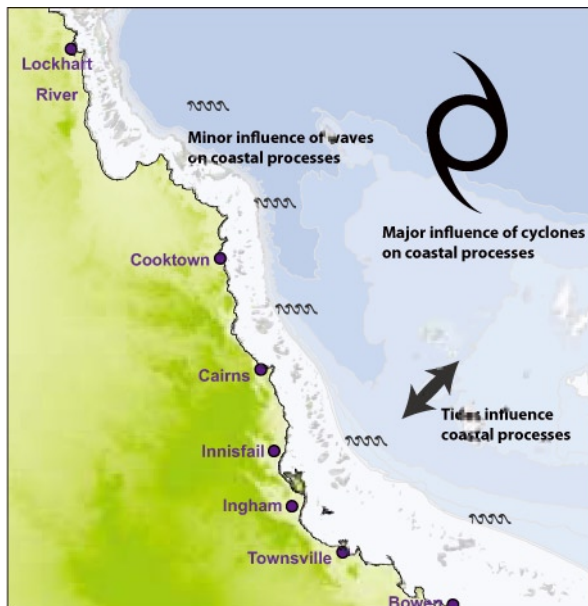


Figure 15: Northern Queensland coast: this tide-dominated coast frequently experiences tropical cyclones (Source: DERM).

The Northern Queensland region covers the area between Bowen in the south to Cape York in the north, and includes the coastal cities of Cairns and Townsville (Figure 15). The Northern Queensland coast consists of coarser sandy beaches with low dunes, fringed either by mangroves and near-shore reefs, or mangrove on muddy sediments in protected areas along the coast. The sheltering effect of the GBR creates low ambient wave conditions along the Northern Queensland coast with an average wave height range of 0.5–0.8 metres and short wave periods of 6 seconds.

Tides in Northern Queensland are classified as meso-tidal with a maximum spring tidal range of 2.2 metres in Cooktown to 2.9 metres in Townsville. Constricted tidal currents in the shallow tidal inlets average 1–2 metres per second.

The beaches in Northern Queensland are predominantly tide modified. Tides are the dominant process with the spring tide range is three to ten times greater than the wave height¹. However wave processes also influence the coast, distinguishing them from more sheltered tide-dominated coasts in Central Queensland.

The beach profile is characterised by a relatively steep, narrow beach, usually composed of medium-grain sand (Figure 16). At the low-tide mark it changes abruptly to a low gradient, finer sand, low-tide terrace, which can extend tens to hundreds of metres seaward. At high tide, waves pass unbroken over the terrace and only break on reaching the narrow beach. At low tide, the waves break on the outer edge producing a wide, shallow surf zone across the terrace. If rips are present, they will cut a channel across the terrace.

Tropical cyclones forming in the Coral Sea (or sometimes in the Gulf of Carpentaria) are a feature of this region and may severely impact the coast. Severe erosion from cyclones, in conjunction with anthropogenic activities has caused long-term erosion problems on many Northern Queensland beaches, threatening infrastructure and property.



The Strand after Cyclone Althea (Source: Unknown).



The Strand after the redevelopment, Townsville, North Queensland (Source: DERM).

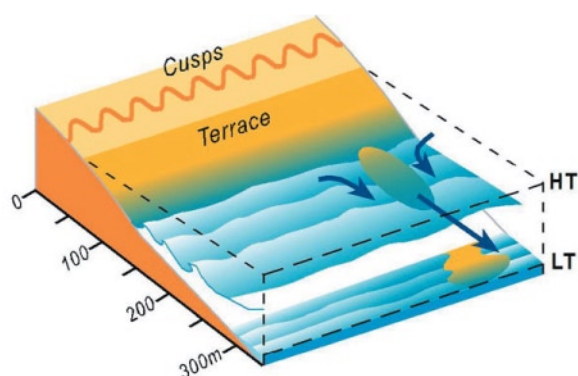


Figure 16: Tide-modified beach shown at low tide with the steep narrow beach face and a 100-metre wide, low-tide terrace cut by one small rip (Source: A.D. Short available at www.ozcoasts.org.au).



Example of a tide-modified beach, Bramston Beach, North Queensland (Source: A.D. Short).

In the 1940s, long-term erosion along the Townsville Strand led to armouring of the coast slope by concrete sea walls to control erosion. In 1972, following damage by TC Althea, a rock wall was constructed⁴⁸. Subsequent cyclones in 1997 and 1998 caused severe damage to the rock wall.

In 1999, the Townsville City Council redeveloped the Strand foreshore at a cost of \$30 million. The 2.5 kilometre foreshore was transformed from a single beach into several small beaches separated by headlands to prevent the loss of sand from the system. The sea wall was reconstructed and moved about 30 metres seawards, the headlands

and pathways were built from 390 000 tonnes of rock fill, and 400 000 tonnes of sand was sourced from the upper reaches of local rivers to renourish the beaches⁴⁸. The Strand beaches are designed to retain sand, but require renourishment after storm or cyclones. The work has been successful in protecting coastal infrastructure, while also enhancing the area's recreational values.

North Queensland's second largest city, Cairns, consists of low-lying areas bounded close to the coast by the mountains of the Atherton Tableland. These low-lying areas support a large population, critical services, and commercial and tourist activities and are particularly vulnerable to storm tide inundation and tropical cyclones. Climate change projections of more intense cyclones and sea level rise are expected to increase the risk to this coastal area.

A risk assessment found that a 1 in 100 year event with a storm tide of 2.15 metres above mean sea level (plus wave set-up and breaking waves) associated with a cyclone could inundate more than 2500 buildings and flood up to 100 kilometres of roads with 0.5 metres or more of water⁴⁹.

CSIRO modelling of a 10 per cent increase in cyclone intensity indicates that the area inundated by a 1 in 100 year event could more than double under the effects of climate change⁴⁹. Inundation would affect critical facilities including the Calvary Hospital, police headquarters, an ambulance station, and the Cairns City Council head office.

A more severe 1 in 500 year event with a storm tide of 3.39 metres above mean sea level (plus wave set-up, shallow water wind waves and breaking sea waves) could impact over 90 per cent of the buildings in the city, Parramatta Park, Portsmith, Machans Beach, Manunda and Cairns North and require the evacuation of more than 15 000 people from inundated areas⁴⁹.

These estimates are from the impacts of storm tide alone, and do not take into account the impacts of high winds and intense rainfall that would also be associated with a cyclone.

Case study— Tropical Cyclone Yasi

North Queensland recently experienced its largest and most intense cyclone since 1918. Category 5 Tropical Cyclone (TC) Yasi was 500 kilometres wide with an eye 30 kilometres across.

TC Yasi crossed the coast at approximately 00:30 AEST on 3 February 2011 near Mission Beach. Estimated wind gusts were up to 285 kilometres per hour; with maximum recorded winds up to 185 kilometres per hour. The coastal communities of Tully, Mission Beach, Cardwell and Dunk Island in the direct path of TC Yasi suffered extensive damage to property and infrastructure costing \$800 million.

Queensland Government storm tide gauges recorded a peak storm surge of 5.33 metres at Cardwell (Figure 17). Fortunately, the cyclone crossed the coast during a falling tide, averting more serious inundation. Had it made landfall just six hours later (at high tide) the water level would have been almost three metres higher.

Smaller storm surges were also recorded at Cairns (1.09 metres) and at Cape Ferguson, south of Townsville (2.01 metres). Historically the event ranks as the third-highest Queensland storm surge, behind Bathurst Bay, Cape York in 1899 (14 metres) and Burketown, Gulf of Carpentaria in 1887 (5.5 metres).

Strong winds associated with TC Yasi created high-energy wave conditions, causing erosion along the coast from Cairns to Townsville. The Queensland Government wave buoy located off the coast at Townsville recorded waves of up to 9.6 metres.



Port Hinchinbrook after Tropical Cyclone Yasi, February 2011 (Source: Courier Mail).

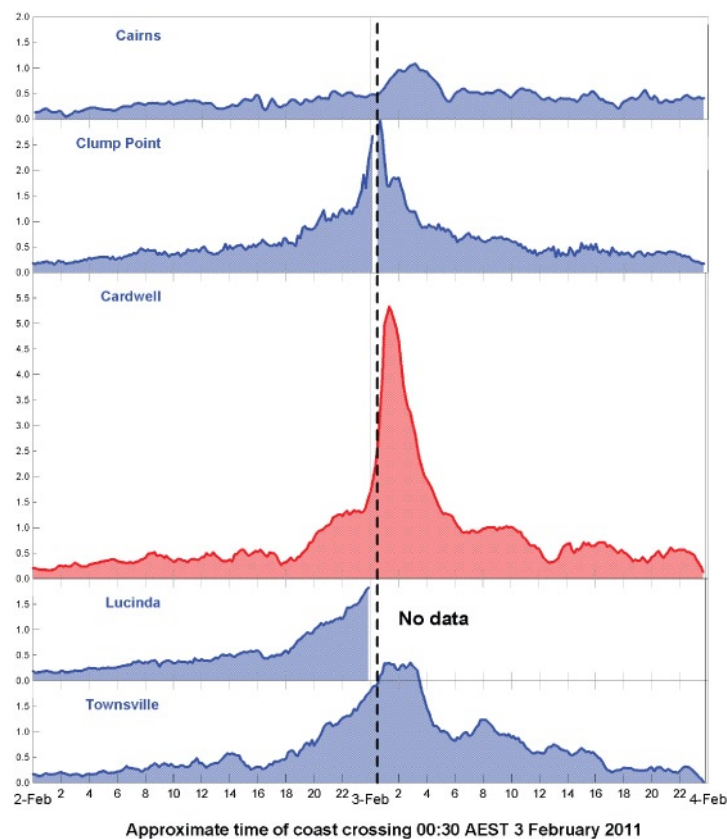


Figure 17: Storm surge recorded at DERM storm tide gauges (Source: DERM)

Central Queensland Coast

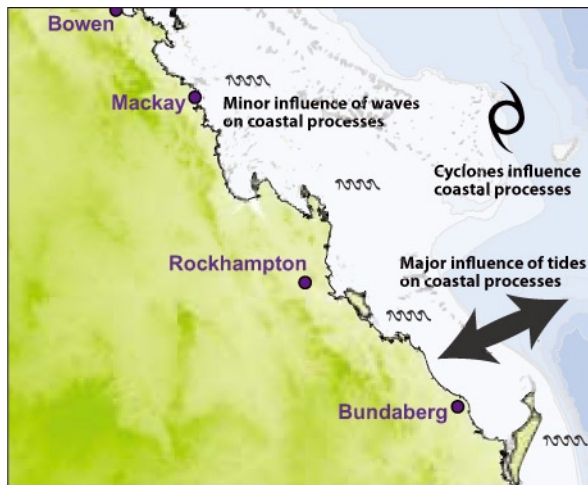


Figure 18: Central Queensland coast: tide-dominated and frequently experiences tropical cyclones (Source: DERM).

The Central Queensland coast extends from Mackay to the northern end of Fraser Island (Figure 18). The area is environmentally diverse with predominantly sandy beaches backed by broad, low beach-ridge plains. These are interspersed with extensive tidal mud flats in protected areas, wetlands and rocky headlands, islands and shoals. The GBR shelters the region from oceanic swell waves producing generally low wave energy conditions. This also promotes development of river deltas and the growth of extensive areas of mangroves on these coasts.

Wave heights range from 0.5 to 0.8 metres with short wave periods of six seconds. The Central Queensland coast experiences the highest tidal ranges in the state, with a maximum spring tidal range of 5.5 metres in Mackay, increasing to eight metres further south in Broad Sound.

Examples of tide-modified coasts can be found on the Central Queensland coast similar to those of North Queensland where wave energy is slightly higher. However, in areas sheltered from the waves, tidal processes are even more dominant. These tide-dominated beaches are characterised by narrow sandy beach fronted by very low gradient, flat, featureless intertidal mud flats, with mangroves often colonising the upper intertidal sand flats. The flats average 500 metres in width (Figure 19).

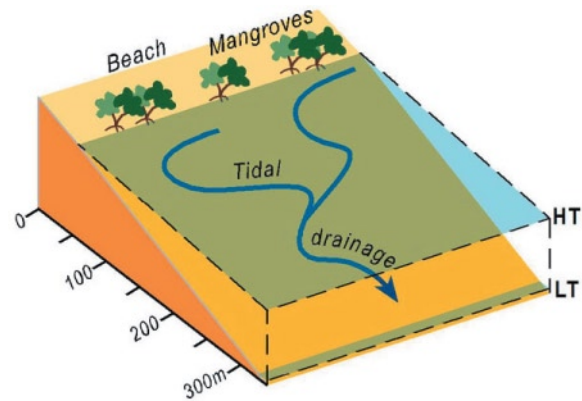


Figure 19: Tide-dominated beach showing the narrow beach and wide, flat, essentially featureless intertidal sand flats with mangroves (HT: high tide; LT: low tide) (Source A.D. Short available at www.ozcoasts.org.au).



Example of a tide-dominated coast with wide flat intertidal flats and mangroves—aerial view of the coast near Mackay, Central Queensland (Source: DERM).

The wide, flat coastal plain of Central Queensland makes it vulnerable to storm tide inundation^{12,13}. For example, a Category 4 cyclone hit Mackay in 1918 with the resultant storm tide approximately two metres above the Highest Astronomical Tide (HAT) or 5.47 metres above mean sea level. It caused extensive flooding and damage to infrastructure. The storm tide flooding and the following freshwater flood in the Pioneer River contributed to the loss of 31 lives¹³. Because many parts of the region are low-lying, a number of residential areas are prone to coastal flooding.

This vulnerability will likely be increased with more frequent high sea level events³⁵.

Mackay is low-lying, with an average elevation of less than 10 metres above the mean sea level. A risk assessment has been made of present-day Mackay using the same storm tide inundation level experienced in the 1918 cyclone. It indicated that over 5860 buildings and other structures would be inundated⁵⁰ with approximately 11 000 people, or 20 per cent of Mackay's population requiring evacuation.

Southern Queensland Coast

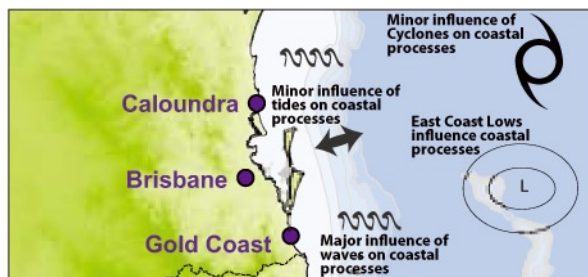


Figure 20: Southern Queensland coast: this wave-dominated coast experiences East Coast Lows as well as cyclones (Source: DERM).

The Southern Queensland coast extends from the northern end of Fraser Island to the New South Wales border at Coolangatta (Figure 20). It comprises long stretches of fine sandy beaches with high dune systems and is highly valued for recreation and tourism. Most of this area, particularly the Gold and Sunshine coasts, is highly developed with high-rise buildings and supporting infrastructure.

The exposed south coast is subject to high-energy wave conditions generated from east to southerly winds and producing high rates of longshore sand transport. On the Gold Coast, an average of 500 000 cubic metres of sand moves northwards every year.

The south coast experiences average wave heights of 1.0–1.5 metres and long wave periods of 9–10 seconds. Tidal ranges are the smallest in Queensland, with 2.1 metres at the Brisbane Bar, and 1.5 metres at Point Danger, Gold Coast.

The high-energy waves and low tidal range of this area identify it as wave dominated. The wave-dominated coasts of Queensland are generally long, exposed beaches composed of fine to medium sand. They lack delta landforms at river mouths due to the strong sediment transport processes.

Figure 21 shows a typical wave-dominated beach of the Sunshine and Gold coasts. It has offshore sand bars separated by deep rip channels and currents, and a wide surf zone.

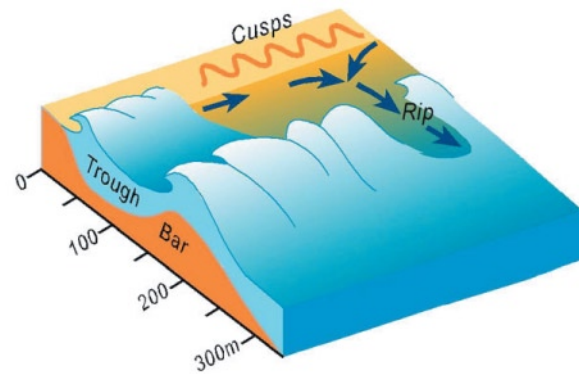


Figure 21: Wave-dominated beach showing the offshore bar and trough, with rip feeder currents converging to flow seaward as a rip current (arrows) (Source A.D. Short available at www.ozcoasts.org.au).



Example of a wave-dominated beach with shore parallel longshore bar separated by a wide deep longshore trough, North Stradbroke Island, Southern Queensland (Source: A.D. Short).

The extent and proximity of high-value property and infrastructure to the coast and the high tourism and recreation values of the beaches create complex management issues. The highest value area of this Southern Queensland coast is the Gold Coast, which was settled more than 100 years ago. Its biggest challenge is managing coastal erosion.

Changes in the position of the coastline through natural processes of erosion already threaten property and infrastructure and have the potential to adversely affect the tourism industry.

The majority of cyclones remain in the northern parts of Queensland, but occasionally they track southward bringing very high waves and wind conditions. Cyclones have generated waves up to 13 metres high off Gold Coast beaches. The Southern coast is also affected by East Coast Lows. They create stormy conditions and generate large swell waves (up to 17 metres off the Gold Coast) that can cause severe erosion.



Erosion at the Gold Coast, January 2009 (Source: DERM).

Storm events in conjunction with king tides in January 2009 caused widespread erosion along the Gold and Sunshine coasts. This was an unexpected event for Gold Coast residents, who often do not appreciate the dynamic nature of the coast⁵, especially given the calmer conditions that had generally prevailed from 1975–2005¹⁹. It is likely that many of the current residents were not there or do not recall either the severe erosion from the series of East Coast Lows that impacted the Southern Queensland coast in 1966–67, or the cyclones in 1967, 1972 and 1974.

These severe erosion events, estimated to have removed eight million cubic metres of sand¹⁹, resulted in the Queensland Government providing funding for the Gold Coast City Council to implement major works. This included the nourishment of beaches with millions of cubic metres of sand and the construction of boulder rock walls to protect coastal properties and infrastructure. This beach maintenance is ongoing. It requires continual sand nourishment with permanent sand-pumping infrastructure and improved dune management practices, including the removal of hard structures such as boardwalks.

While development close to the coast continues, local planning laws require developers excavating sand from building sites to add this back to the beach and dune system, and to construct sea walls for protection from extreme erosion events.



Erosion at Surfers Paradise due to a series of East Coast Lows and TC Dinah in 1966–7 (Source: DERM).

The Tweed River Entrance Sand Bypassing Project provides the best example of the extent to which coastal processes are managed on the Gold Coast. This is a joint initiative of the Queensland and New South Wales State governments. The bypass system began operating in May 2001 and delivers sand from the southern side of the Tweed River entrance to the southern Gold Coast beaches. The bypass was needed after the 1962 extension of the Tweed River training walls interrupted the natural supply of sand northwards and created erosion along Gold Coast beaches. The sand bypassing system has successfully restored the natural sand supply to the Gold Coast beaches.



Tweed River Entrance Sand Bypass, Gold Coast (Source: DERM).

Climate change poses significant risks to the highly developed Southern Queensland coast. In particular, the potential changes to wave direction³⁶ may have significant impacts on sand transport for this wave-dominated coast. High, wind-formed dunes common along the Southern Queensland coast, on Fraser Island for example, should continue to grow under climate change if storm and wind conditions intensify³ and will increase the resilience of the coast to erosion. However, where construction has taken place on dunes or sand supply is limited, the dunes' capacity to absorb the impacts of erosion is reduced. Gold Coast beaches are maintained through extensive armouring (i.e. the construction of sea walls) and ongoing sand nourishment.

Despite these efforts, successive high-energy wave events from the east could have destructive consequences for Gold Coast beaches¹⁹. Research indicates that coastal protection structures, such as the artificial reef at Narrowneck, do not enable the beach to absorb high wave events as well as the vegetated dunes at Broadbeach¹⁹. Projected increases in the severity of cyclones due to climate change may cause severe damage to Gold Coast beaches¹⁹.

Inundation is also a significant risk for this region. The CSIRO has assessed the likely impacts of coastal inundation in Southern Queensland under a range of sealevel rise projections—0.2 metres by 2030, and 0.5 metres by 2070⁵¹. CSIRO concluded that storm tides due to extreme weather events will be more intense and frequent and enhanced by sea level rise. For example the upper range of a current 1 in 100 year peak storm tide may reach 2.7 metres by 2030 and 3.0 metres by 2070. Whereas a current 1 in 500 year tide event may reach 3.4 metres in 2030, and 3.7 metres in 2070.

Higher and more frequent storm tides on the Southern Queensland coast puts about 227 000 people at risk of inundation from a 1 in 100 year storm tide⁵¹. If the population in Southern Queensland does not change, sea level rise could see this number increase to 245 100 people by 2030, and 273 000 people by 2070⁵¹. However, this figure is probably underestimated given that the Southern Queensland population is predicted to increase from the current 2.69 million to a projected 4.4 million by 2030.

Queensland's five coastal regions will each be affected differently by climate change impacts. For instance tide-dominated low-lying coasts in the north of the state are at risk from increased inundation whereas wave-dominated coasts in the south are under threat from increased erosion. Identifying sections of the Queensland coast which are more vulnerable to climate change impacts is necessary for effective coastal planning, management and community resilience.



King tides give an indication of the implications of higher sea levels (Source: DERM).



Coastal erosion of Palm Beach, Gold Coast 1960 (Source: DERM).



Houses threatened by erosion Palm Beach, Gold Coast 1960 (Source: DERM).

4. Coastal planning and adaptation

So far this publication has discussed how coastal processes shape the form and function of the coast. For example how variations in the relative influence of coastal processes, such as waves and tides, create different coastal regions in Queensland some of which are more vulnerable to coastal hazards, such as erosion and inundation, than others.

This chapter discusses coastal planning and management in Queensland including the new *Queensland Coastal Plan* which explores options to enable coastal communities to adapt to the expected impacts of climate change.

Projected higher sea levels and increased numbers of intense cyclones associated with climate change will increase the vulnerability of coasts to existing hazards. The extent of land affected by storm tide inundation, coastal erosion, permanent or temporary inundation as a result of sea level rise is likely to increase.

Most of Queensland's major settlements, ports and industries are located on the coast, exposing them to increased risks that have the potential to cause damage to property and infrastructure and loss of life. Therefore, planning for climate change and assisting coastal communities to adapt is critical.



Gold Coast nourishment 1995 (Source: DERM)

Key messages

- Climate change impacts including rising sea levels, increased risk of storm tide inundation and coastal flooding, and increased coastal erosion are likely to affect property and infrastructure along Queensland's highly developed and populated coast.
- Most of Queensland's major settlements are located on the coast, exposing them to increased climate change risks.
- Extreme coastal inundation and erosion events could become more frequent, resulting in high clean-up and asset maintenance costs.
- Avoiding and reducing future risk is the most cost-effective adaptation response to climate change.
- The Queensland Government is committed to preparing Queensland's coastal communities and infrastructure for the impacts of climate change. The new *Queensland Coastal Plan* includes specific provisions about sea level rise to ensure that coastal protection and future development decisions are based on contemporary climate change science.

Coastal planning

The vulnerability of the Queensland coast to natural hazards is expected to increase due to climate change. Coastal hazard impacts include damage by inundation, erosion or 'washing away' of facilities. Damage to infrastructure can include damage or disruption to power and communication services, sewerage, water supply and transportation links. Bridges and many major airports are vulnerable to sea level rise and storm surge. These hazards are expected to be exacerbated by the impacts of climate change.

The risk to the built environment from climate change is not just a function of the climate hazard, but also of the level of preparedness and response of the community and its recovery capacity.

Buildings and other infrastructure can have a life expectancy of 30–200 years; therefore, planning and construction decisions made now can have long-term consequences⁵².

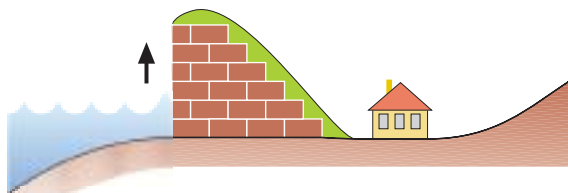
Sea level rise and storm surges associated with climate change could put existing Queensland buildings at risk which collectively have a replacement value of between \$10.5 billion and \$16 billion³. The damage bill from a projected 1-in-100 year storm surge in south-east Queensland in 2030 alone is estimated at \$2.2 billion³. Adaptation to climate change through the planning process and building standards is crucial to ensure that these effects are managed.

Without coastal protection measures or other adaptation strategies, buildings may be at risk of increased erosion from sea level rise and storm

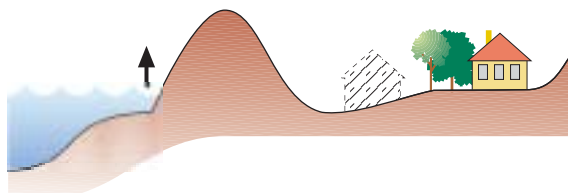
surge, due to their location and the nature of the coast. Defending coastal development against rising sea levels using sea walls or other structures carries economic, social and environmental costs. These include the loss of foreshore ecosystems and sandy beaches and their recreational, amenity and scenic values. The Queensland Government's preferred management option is sand nourishment. While it can be expensive it maintains the recreational amenity and scenic values of the coast. The projected impacts of climate change may require coastal communities to undertake significant adaptation actions.

Some of the large, expensive engineering options for adaptation that have been applied overseas such as dykes, barrages, pumps or some combination of works are illustrated in Figure 22.

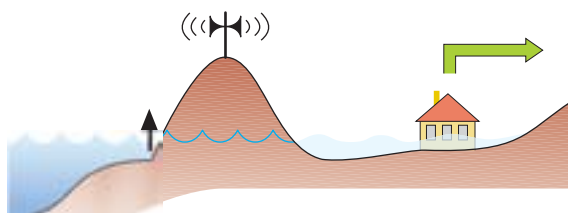
SHORT TERM (0 - 50 years)



Strengthening defences.
(Dike reinforcements, nourishments etc.)

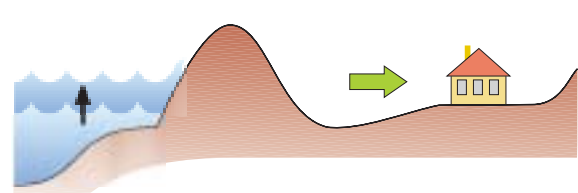


Spatial planning.
(Minimise risks, reserve space for future adaptation measures)

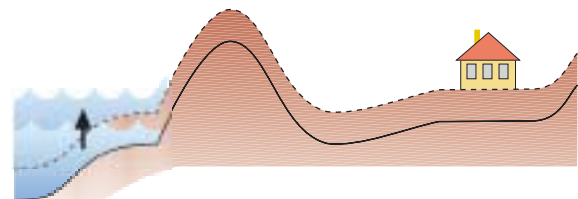


Increasing risk of awareness and preparation.
(Support for proposed adaptation measures - early warning, evacuation plans etc.)

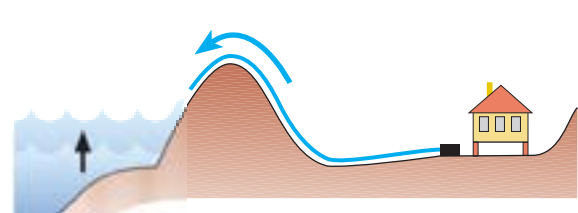
LONG TERM (50 - 200 years)



(Managed) retreat.



Strengthening and/or moving seaward.
(Sand, super dikes, planning, widening coastal defences, artificial reefs and islands)



Stay put, increase capacity of existing measures.
(More pumping and adjusting, flood proofing)

Figure 22: Adaptation options for coastal building (Source: Adapted from Dutch Ministry of Transport, copyright Commonwealth of Australia, reproduced with permission³).

However, as sea levels are projected to rise for hundreds of years⁵³, protective structures may only be applicable for very high-value assets. In the long term the community will have to adapt to higher sea levels.

Avoiding and reducing future risk is the most cost-effective adaptation response in many cases. Upgrading building and engineering codes and standards for construction and plumbing could ensure that future buildings and infrastructure are better adapted to climate change impacts. For example, elevating new residential buildings on stilts rather than constructing on-ground concrete slabs would decrease exposure to damage from flooding in low-lying areas.

Queensland coastal legislation

The Queensland Government has a range of legislation and policies relating to management of the coastal zone. However, the assessment of most coastal development applications has been devolved under legislation to local councils. In these cases, the local council acts as assessment manager and the Queensland Government acts as a concurrence agency providing advice on the applicability of Queensland coastal policies to the proposal.

If a coastal development application is likely to have a 'significant impact' on a matter of national environmental significance, it requires approval from the Australian Government under the *Environment Protection and Biodiversity Conservation Act 1999*.

The primary Queensland coastal legislation is the *Coastal Protection and Management Act 1995* (the Coastal Act). The Coastal Act establishes the framework for coastal management in Queensland through:

- protection, conservation, rehabilitation and management of the coast including its resources and biological diversity
- ecologically sustainable development of the coastal zone
- coordinated and integrated management and administration for developing the coastal zone
- a land surrender provision that applies to new subdivisions. The Queensland Government may require that the area of land in the erosion-prone area be surrendered for coastal management.

A review of the previous *State Coastal Management Plan*⁵⁴ recognised the need to increase its provision for climate change. The new *Queensland Coastal Plan*²⁴ includes an updated sea level rise figure and planning period of 0.8 metres by 2100, based on the upper limit of the most recent projections released by the Intergovernmental Panel on Climate Change in its Fourth Assessment Report¹⁸. This figure is used for determining coastal hazard areas which guide land-use planning and development decisions to reduce the risk to persons and property.

Under the new *Queensland Coastal Plan* coastal hazard risk assessments are to be based on:

- a planning period of 100 years for coastal development
- a sea level rise factor of 0.8 metres by 2100 due to climate change
- the 100 year average return interval for extreme storm event or water level
- a 10 per cent increase in cyclone intensity (relative to maximum potential intensity) due to climate change.

The new *Queensland Coastal Plan* also contains coastal hazard maps that show areas at risk from storm tide inundation. The default storm tide inundation area is based on a 0.8 metre sea level rise by 2100 due to climate change and represents an increase of 0.5 metres from the default level of 0.3 metres used in the *State Coastal Management Plan* (excluding areas with existing development commitments). The hazard maps also indicate erosion-prone areas based on this 0.8 metre figure. Large-scale regional maps, as well as property scale maps, are available for Coastal Plan Mapping, and Coastal Hazard Area Mapping on the DERM website.

The new *Queensland Coastal Plan* requires that development in areas vulnerable to storm tide inundation be located, designed and operated to mitigate against the potential impacts of a storm tide (e.g. by raising floor heights of habitable rooms). In future, land-use planning decisions will be required to consider the likely impacts of storm tide inundation and place new zones for urban purposes outside areas vulnerable to storm tide inundation.

Climate change adaptation

Climate change risks in the coastal zone are large, increasing and in some areas will be experienced in the near future. Early action will help reduce current risks and avoid the future impacts.

Avoidance of future risk is the most cost-effective adaptation response in most cases. Future development, particularly in areas highly exposed to the impacts of climate change, should be planned without increasing risk. There is a risk in the coastal zone from existing buildings and other infrastructure. Planning is needed to maximise system resilience and to allow for a coastal buffer and the shifting of ecosystems landward as sea level rises.

The new *Queensland Coastal Plan* uses risk-based vulnerability zoning for land-use planning by mapping areas at high risk from coastal hazards. It is expected that improved planning and building regulations will lower future costs of managing climate change impacts (Table 1).

CSIRO has made preliminary estimates 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 Southern Queensland³. The analysis allows for population growth and an increase in the height of the storm tide due to sea level rise. It therefore also factors in the change in the average return interval previously defined as the 'extreme event' that would be occurring more frequently with the higher sea levels. Table 1 shows the impacts of varying adaptation options in 2030 at current dollar value.

Adaptation to climate change on the coast is a complex social and economic challenge. Coastal climate change impacts are multi-causal and regionally variable, and effective approaches to coastal adaptation will have many interdependencies, involve behaviour change, and be socially complex. There is no single adaptation strategy that will work for the entire Queensland coast.

Regional assessments are useful for identifying socially vulnerable communities, 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 processes and the interaction with rising sea levels will be imperative.

A key outcome of regional assessments will be information that identifies adaptation options and the triggers which will determine when an increased on-ground response is required. For example, more information is needed to assist particularly vulnerable coastal areas such as the Torres Strait and Gulf of Carpentaria adapt to climate change.

Coasts with a higher capacity to cope with climate change, such as the Southern Queensland coast, will have increased risks as the expected increases in population are realised. Particularly at risk are heavily capitalised coastlines, such as the Gold Coast which has both hard and soft protection works.

Table 1: Estimated costs and benefits of residential adaptation in southern Queensland in 2030
(Source: Copyright Commonwealth of Australia reproduced with permission³).

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

A targeted adaptation strategy will help these areas identify and analyse the costs and benefits of adaptation options, reduce barriers to adaptation, and drive partnerships to support implementation. A common barrier to adaptation is that some local governments may lack the capacity to assess and reduce climate risk³.

The Queensland Government is supporting local governments through the release of the new *Queensland Coastal Plan* and Improved Coastal Mapping Project and investing in data collection and research into the impacts of climate change and sea level rise on the coast.

Local governments are also proactively addressing the challenges of climate change. For example, the Gold Coast City Council (GCCC) has recently released its *Climate Change Strategy*⁵⁵. The Gold Coast has high exposure to climate change, due in particular to its large coastal population and tourism-based economy. The GCCC aims to base decisions on local research and has partnered with local universities to undertake research. The GCCC is also investing in the identification and mapping of areas most at risk from the impacts of climate change including infrastructure and assets.

The Torres Strait Regional Authority has recently released a *Climate Change Strategy 2010–2013*⁴⁵. It recognises that the geomorphological, social, cultural and spiritual characteristics of the Torres Strait region make its communities among the most vulnerable in Australia. The strategy includes:

- monitoring sea level and surge through installation of a regional network of tide gauges supplemented with tide boards in individual communities
- refining island mean sea level datum and tidal predictions to attain more reliable data on tide levels and island heights
- high resolution digital mapping of islands and the Torres Strait to assist in modelling and mapping inundation
- detailed probabilistic inundation assessment and mapping, incorporating assessment of potential future greenhouse-enhanced conditions

- detailed assessment of vulnerable communities covering the adaptation options over various time horizons; options include sea walls, house-raising, levees, filling, relocation, social and cultural programs and emergency planning
- expanding coastal process/erosion research through a partnership with James Cook University⁴⁵.

Queensland's increasing population makes it vital that effective planning mechanisms are established to support adaptation to climate change. The new *Queensland Coastal Plan*, local government strategies, regional assessments and improved coastal mapping will help communities plan for and adapt to the likely impacts of climate change.



The highly developed Southern Queensland Coast (Source: DERM).

5. Research

The impacts of climate change and sea level rise in particular, are expected to increase erosion and inundation issues for Queensland coastal communities over the long term. The previous chapters have described the dynamic nature and variability of the Queensland coast. The coastal case studies demonstrate the particular vulnerabilities of the different areas to current hazards. Vulnerability of the coast is likely to increase under climate change. Many low-lying Queensland coastal communities regularly experience erosion and inundation that is likely to increase with rising sea levels and the more intense cyclones associated with climate change.

Adapting Queensland's coastal communities and infrastructure to the effects of climate change represents a significant challenge. The Queensland Government is committed to improving the ability of Queensland coastal communities to adapt to climate change through a range of initiatives including:

- *ClimateQ: toward a greener Queensland*
- the new *Queensland Coastal Plan* and new coastal hazard maps
- the Improved Coastal Mapping Project
- supporting the National Climate Change Adaptation Research Facility (NCCARF).

However, more information on the potential impacts of climate change on the Queensland coast is needed to provide a context for management decisions.

This chapter outlines some actions being taken by the Queensland Government in collaboration with local government, state and national agencies to assess the areas most at risk from impacts of climate change.

The Queensland Government is committed to climate research and is the only state with a dedicated centre for climate science research—the Queensland Climate Change Centre of Excellence (QCCCE). QCCCE provides information on climate science, variability and extreme events to Queensland Government policy makers and planners.

Key messages

- It is imperative to establish a sound scientific basis to effectively respond to climate change in Queensland coastal communities.
- Incorporating climate change into decision making for coastal management will take significant resources and time. However, given the Intergovernmental Panel on Climate Change sea level rise estimate of up to 0.79 metres over the next 90 years, there is sufficient time to undertake the necessary planning and implementation.
- The sea level rise figure used in the new *Queensland Coastal Plan* will continue to be reviewed and improved with the latest climate change information.
- The Improved Coastal Mapping Project will help identify vulnerable areas of the Queensland coast and visualise the impacts of climate change including sea level rise, storm tide inundation and coastal erosion.

National overview

The Australian Government has identified 'coasts and oceans' as one of the top five key research challenges in climate change science. In 2008, the *Australian Government Inquiry into Climate Change and Environmental Impacts on Coastal Communities* received over 100 submissions and one clear message emerged—the need for national leadership in managing climate change in the coastal zone.

The Inquiry report made 47 recommendations, one of which was to conduct a risk assessment of climate change to Australia's coasts. In response, the Australian Government released *Climate Change Risks to Australia's Coast—A First Pass National Assessment* in 2009³. This report provides an initial assessment of the future implications of climate change for Australia's coastal zone. It focuses on risks to settlements, infrastructure, ecosystems and industries in the coastal zone.

The Australian Government also recently released a report from the national climate change forum *Developing a national coastal adaptation agenda*⁵⁶ that identifies the need for sound information to support decision making.

Recognising the vulnerability of Indigenous communities to the impacts of climate change, with over half of these communities within 20 kilometres of the coast, the Australian Government undertook a specific risk assessment. The *Risks from Climate Change to Indigenous Communities in the Tropical North of Australia report*⁴¹ examines the potential impacts of climate change on Indigenous settlements and communities across tropical northern Australia, including the Torres Strait Islands.

Coastal areas will be vulnerable to inundation from sea level rise in different ways, largely due to their topography (the elevation and shape of the coastal landforms). A key part of coastal vulnerability assessment is the identification and mapping of coastal substrates and landforms (geomorphic types) and their sensitivity to potential coastal impacts of climate change and sea level rise. These impacts include accelerated erosion and coastline recession, increased slumping or rock-fall hazards and changing dune mobility.

The Australian Government's first step in addressing coastal vulnerability on a national scale was to commission the Smartline map project⁵⁷. The Smartline Coastal Geomorphic Map of Australia is a detailed map of the coastal landform types ('geomorphology') of continental Australia and most adjacent islands (excluding the Great Barrier Reef). As a geomorphic map it represents not just the topography of the coast, but also indicates the composition of the coastal landforms—rock, coral, sand, mud or boulders. The Australian Government's next step was the National Coastal Vulnerability Assessment to determine the number of buildings along the coast which would be vulnerable to coastal erosion. This assessment combined information on the erodability of the coast from Smartline with data from the National Exposure Information System (NEXIS) developed by Geoscience Australia⁵⁸.

In 2010, the Australian Government released sea level rise maps for urban areas around Australia, including Brisbane and the Gold and Sunshine coasts. The maps have been developed for three sea level rise scenarios: low (0.5 metres), medium (0.8 metres) and high (1.1 metres). These maps are not a substitute for more detailed studies which need to take into account the local factors needed in decision making.

The CSIRO is also involved in research to increase our capacity to adapt to climate change. The Wealth from Oceans Flagship is providing Australia's governments, industries and communities with the scientific knowledge, tools and approaches to make wise decisions about our use of coastal environments.

A key initiative under the Our Resilient Coastal Australia research theme is the development of BLUElink. This \$33 million program is developing an ocean modelling and analysis capability to make accurate forecasts of ocean conditions in the Australian region. CSIRO anticipates that as more near-shore bathymetric data becomes available, this could be extended to include modelling of coastal waters.

Coastal Futures is another research stream in this theme and is developing tools for decision making such as the Coastal Management Strategy Evaluation. This tool values key coastal assets and services to provide important information to decision makers in evaluating key trade-offs.

The Climate Adaptation Flagship is a CSIRO initiative and part of the National Research Flagships program that aims to deliver scientific solutions to advance Australia's most important national objectives. The South East Queensland Climate Adaptation Research Initiative (SEQCARI) is a partnership between the Queensland and Australian governments, the CSIRO Climate Adaptation Flagship, Griffith University, the University of the Sunshine Coast and the University of Queensland. SEQCARI is providing research outcomes that enable the region to adapt and prepare for the impacts of climate change.

The CSIRO Climate Adaptation Flagship research includes a recent case study on the likely impacts of coastal inundation on south-east Queensland. The study showed that the Southern Queensland region is vulnerable to rising sea levels and storm surges, due to high numbers of at risk properties coupled with an increasing population⁵². The Urban Infrastructure Project under this flagship aims to determine the major climate change hazards and vulnerabilities, and risks to human settlements, buildings and infrastructure. This will involve the development of climate change hazard spatial maps with a major focus on extreme events including storm surge, extreme wind gusts and cyclones.

Queensland initiatives

The Queensland Government's climate change strategy, *ClimateQ: toward a greener Queensland*, was released in 2009. It contains a range of initiatives which will deliver information and tools to help mitigate and adapt to the impacts of climate change.

Specific initiatives to improve the understanding of local climate change impacts and the availability of mapping and data to support climate change vulnerability assessments of the coastal zone include:

- Improved Coastal Mapping Project—\$8 million is being invested over three years to deliver accurate and up-to-date interactive maps to identify vulnerable areas of the Queensland coast and visualise the impacts of a range of climate scenarios. Stakeholders, including developers and local governments, will be able to use the maps to:
 - ▶ identify and visualise areas likely to be at increased risk from coastal hazards in order to inform land-use planning and the location of future infrastructure and development
 - ▶ identify areas that are likely to be more vulnerable to coastal erosion
 - ▶ provide storm tide flooding assessments that will inform disaster management planning.
- Storm Tide Mapping Project—as a result of this project, storm tide inundation maps are now available for populated areas of Queensland most at risk from storm tides including the Burdekin, Whitsundays, Cairns, Mackay, Palm Island and Wide Bay Burnett.
- Gulf of Carpentaria Storm Tide Study—this study will produce numerical simulations of tropical cyclone storm surge, waves and wave effects for the region; and inundation mapping of selected locations under current and future scenarios. The study is scheduled for release in late 2011 and will provide inundation mapping to support improved emergency response, planning and public awareness.
- Coincident flooding—through the National Disaster Resilience Program, QCCCE will determine the significance of the risk from coincident riverine flooding and storm tide inundation in coastal areas of Queensland. The project will identify and map coastal areas and associated catchments that are likely to be at increased risk from coincident flooding, and determine the implications of climate change on the combination of riverine and storm tide flood events. The results of the project will inform disaster management response, State government policy and planning, and climate change adaptation strategies.
- Tsunami modelling—numerical simulations of tsunami scenarios will assess the near-shore tsunami hazard for specific sections of Queensland's east coast and will be followed by inundation modelling of two locations.
- Wave and storm tide monitoring—the Queensland Government established a monitoring program in the 1970s. It continues to maintain and collect data from 13 wave-rider buoys and 24 storm tide gauges located along the Queensland coast from the Gold Coast to Weipa.
- Improved climate projections for Queensland—in collaboration with the CSIRO, QCCCE is tailoring global climate change projections to increase the robustness of Queensland regional climate change projections. Projections for 13 Queensland regions were released in 2009 for use in climate risk vulnerability projections, policy development and planning (see www.climatechange.qld.gov.au).
- Global Climate Modelling Experiments—QCCCE is collaborating with the CSIRO to produce climate change projection data sets supporting preparation of the Intergovernmental Panel on Climate Change Fifth Assessment Report due to be released in 2013–14. This joint research project involves climate modelling experiments using CSIRO's Mk3.6 global climate model, data processing and public release of the data sets.

This work will ensure that climate processes affecting Queensland are adequately considered in this international assessment.

- The Queensland Smart State project: Future Coastlines—the Queensland Government has invested \$1 million in a collaborative project between QCCCE, CSIRO, Gold Coast City Council, Griffith University and DHI consultants to model the impact of extreme events on coastal environments.
- The Queensland Government has invested \$3 million towards the establishment of the National Climate Change Adaptation Research Facility (NCCARF) to support the development of climate change adaptation research plans across a range of sectors. Coastal impacts are addressed through the Infrastructure and Synthesis and Integration research themes. Quarterly FORNSAT (Forum for NCCARF interaction with states and territories) meetings provide an opportunity to collaborate and share ideas with other states on climate change research, policies and programs.

Future challenges

The Queensland Government is committed to improving our understanding of the impacts of climate change on sea level rise, the generation of cyclones, wave variability, and changes in storm frequency and intensity. This will better inform planning and adaptation strategies for Queensland coastal communities.

Potential future challenges include:

- acquiring higher resolution, near-shore bathymetry data to better understand the impacts of sea level rise on coastal geomorphology
- enhancing meteorological, sea level and coastal ocean observations data to better validate modelling of sea level extremes from storm surges and wave set-up
- developing a consistent methodology for storm tide inundation and coincident flooding studies for Queensland to better inform planning and emergency response decisions
- developing a methodology to estimate coastal recession from sea level rise to help improve risk assessment and adaptation planning.

Ongoing data acquisition, research and modelling will support improved planning processes which can better accommodate and adapt to the impacts of climate change.

This publication provides the community, planners, policy and decision makers with information to enhance a strong understanding of physical coastal processes and the vulnerability of the Queensland coast to climate change.

The Queensland Government, through the Queensland Climate Change Centre of Excellence is committed to providing the latest climate science information and regional projections for Queensland. Sea level is projected to rise gradually over the next 90 years allowing time to make the hard decisions; however, we need to start planning now.

Combined with the new *Queensland Coastal Plan*, the Improved Coastal Mapping Project and regionally focused climate change projections this publication will help Queenslanders to understand, plan for and adapt to the expected impacts of climate change.



Glossary

adaptation: adjustment in natural or human systems in response to actual or expected climatic changes or their effect, which moderates harm or exploits beneficial opportunities.

astronomical tide ('tide'): the periodic rise and fall of the water of oceans, seas and bays, caused mainly by the gravitational interactions between the Earth, moon and sun.

Australian Height Datum (AHD): the level (adopted by the National Mapping Council of Australia) to which all heights for topographic mapping is to be referred.

average return interval: a measure of risk used by engineers and insurers describing the average time between events of a given magnitude. For example, a 1 in 100 year event has a 1 per cent probability of occurring in any given year.

bathymetric data: measurements of the depth of a body of water.

beach-ridge plain: beach ridges are successive upper-shoreface deposits that have been deposited seaward of their predecessors on a prograding coastline. They are usually separated by narrow swales (depressions) of varying width and depth depending on how closely the successive ridge crests have been formed. A broad sequence of such ridges is called a beach-ridge plain.

Bruun Rule: a commonly used method for estimating the response of a sandy coast to rising sea levels.

climate change: a change of climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods.

CSIRO: Commonwealth Scientific and Industrial Research Organisation, Australia's national science agency.

coast: the strip of land that extends from the coastline inland to the first major change in landforms that are no longer influenced by coastal processes.

coastline: generally refers to the line forming the boundary between the land and the water.

coastal accretion: the accumulation or building up of beach sediments. Continued accumulation of sediments allows the coastline to advance seawards ('prograde').

coastal erosion: the wearing away of the coastline or removal of beach sediments through wave action or tidal currents. Continued erosion leads to a landwards shift in the coastline ('retreat').

coastal flooding: flooding by ocean waters of low-lying areas caused by high sea level events such as storm tide inundation or king tides.

coastal hazards: the collective term used to describe storm tide inundation, coastal erosion and sea level rise inundation.

coincident flooding: the combination of coastal (ocean water) flooding from storm tide with rainfall-induced riverine (freshwater) flooding.

coastal processes: marine, physical, meteorological and biological activities that interact with the geology and sediments to produce a particular coastal system environment.

coastal protection works: includes hard protection works that armour the beach such as concrete and rock seawalls; groynes and artificial reefs that encourage the accumulation of sand on the coast and sand nourishment, where sand is artificially placing or pumping onto the coast.

coastal squeeze: the process by which as sea level rises, the area available for the coastal ecosystems and habitats such as saltmarshes and mangroves to migrate landward reduces due to coastal development close to the coast.

coastal zone: the coastal waters and land within five kilometres of the coast or below 10 metres Australian Height Datum (AHD: mean level to which all mapping heights are to be referred), whichever is furthest inland.

diurnal tide: a tide with only one high water and one low water occurring during a 24-hour period.

Defined Storm Tide Event (DSTE): the event (measured in terms of likelihood of reoccurrence) and associated inundation level adopted to manage the development of a particular area. The defined storm tide event is equivalent to a 1 in 100 year average return interval unless otherwise indicated.

dunes: deposits of wind-blown sand that build up behind sandy beaches.

El Niño Southern Oscillation (ENSO): year-to-year fluctuations in atmospheric pressure, ocean temperatures and rainfall associated with El Niño (the warming of the oceans in the equatorial eastern and central Pacific). El Niño tends to bring below-average rainfall. 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 negative during El Niño events. La Niña is the opposite of El Niño and occurs when the SOI is positive. La Niña tends to bring above-average rain over much of Australia.

East Coast Lows: intense low-pressure systems which occur off the eastern coast of Australia and mainly affect southern Queensland and New South Wales.

geomorphology: the scientific study of landforms, their origin and evolution. A geomorphologist is a person who studies in this field.

highest astronomical tide (HAT): the highest tide level that can be predicted to occur under any combination of astronomical conditions. (Note also lowest astronomical tide (LAT): the lowest tide level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions).

Holocene: the most recent geological period of time defining an interglacial period that began approximately 12 000–10 000 years ago and continues to the present.

Inter-decadal Pacific Oscillation (IPO): an irregular inter-decadal sea-surface temperatures in the Pacific Ocean which modulates the strength and frequency of the El Niño Southern Oscillation (ENSO), also known as the Pacific Decadal Oscillation (PDO).

inundation: ocean water covering low-lying areas during high sea level events such as storm tides and king tides.

king tide: any high water level well above average, commonly applied to the two spring tides that are the highest for the year—one during summer and one in winter.

longshore: along the coast; for example, the movement of sand and currents along the coast or sand bars aligned parallel to the coastline.

neap tides: tides of decreased range occurring semi-monthly around the times of the first and last quarters of the moon.

near-shore: the area of ocean close to the coast that is affected by waves, tides and longshore currents.

overtop: waves or water going over the top of coastal structures or landforms and contributing to coastal flooding.

mean water level: a tidal level reflecting the average surface level of a body of water; used mainly in the areas with little or no tidal range.

mean sea level: a tidal datum; the arithmetic mean of hourly heights of the sea at the tidal station observed over a period of time (ideally 19 years).

micro-tidal: coasts with a maximum spring tidal range of less than 2 metres.

meso-tidal: coasts with a maximum spring tidal range of 2–4 metres.

macro-tidal: coasts with a maximum spring tidal range of over 4 metres.

Pleistocene: the geological period of time that spanned the period between 12 000 to 2 million years ago.

sand nourishment: the artificial placing or pumping of sand within a coastal system to encourage the build up of the coast and protection against coastal erosion.

sea level rise: an increase in the mean level of the 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.

semi-diurnal tide: a tide with a period of approximately 12 hours, that is, two high waters and two low waters (or two ebb and two flood cycles) during a tidal day.

south-east trade winds: the prevailing winds over the tropical ocean that blow persistently from the south-east (toward the north-west) in the southern hemisphere.

spring tides: tides of increased range occurring semi-monthly near the times of full moon and new moon.

still water level: the level that the sea-surface would assume in the absence of wind waves (not to be confused with mean sea level or mean tide level).

storm surge: a temporary increase in the height of the sea at a particular location, due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is the excess height of water above the level expected from tidal variation alone at that time and place.

storm tide: the absolute combined mean water level reached when storm surge is combined with the normal astronomical tide variation and the wave contribution at the coast. The storm tide level must be accurately predicted to determine the extent of coastal inundation.

swell waves: ocean waves that have travelled outside the area of wave generation. While being formed by the wind they are called wind waves; however, once they leave the area of formation they are called swell waves.

tide-dominated coasts: coasts where tides are the dominant process shaping the coastline. They occur in areas of Queensland that experience spring tide ranges of more than 2 metres and average low wave energy conditions (less than 0.5 metres).

tropical cyclone: intense low-pressure system in which winds of at least 63 kilometres per hour whirl in a clockwise direction (in the southern hemisphere) around a small calm 'eye'.

vulnerability: the 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 set-up: the rise in the mean water level above the still water elevation of the sea produced when a wave breaks on the coast. It can be very important during storm events as it results in a further increase in water level above the tide and surge levels.

wave run-up: the vertical distance above the mean water level reached by the uprush of water produced when a wave breaks on the coast.

wave-dominated coasts: coasts where waves are the dominant process shaping the coastline. They occur mainly on the open southern Australian coast where the spring tide range is predominantly less than 1.5 metres and average waves range from 0.5–3.0 metres.

wind waves: ocean waves resulting from the action of the wind on the surface of water.

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