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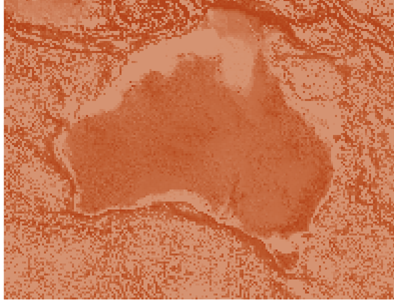

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The Australian Coast

Teacher notes and student activities

A. D. Short

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GEOSCIENCE AUSTRALIA
RECORD 2014/50

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Australian Government
Geoscience Australia

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Contents

1 Introduction

The coast is a critical part of the Australian economy and culture and contains many of the nation's iconic environmental features, such as the Great Barrier Reef, tropical mangrove forests and well known tourists attractions like Bondi Beach. The Australian mainland coastline along with that of Tasmania measures approximately 36 000 kilometres, making it one of the longest national coastlines in the world. In terms of its physical form, the coast comprises approximately 15 000 kilometres of sandy beaches, several thousand kilometres of sheltered muddy coast and estuarine shores, and about 12 000 kilometres of exposed rocky shore. Australia also has jurisdiction over seven remote offshore territories which are not included in this booklet.

The Australian coast has extensive variations in climate, oceanography, geology and biological ecosystems. It faces three major oceans and several seas, and extends from tropical to temperate latitudes and from humid to dry climates (Figure 1.1).

As natural and human-induced (**anthropogenic**) processes have an impact on and change the Australian coast, it is important to sustainably manage and utilise these areas. This booklet is designed to inform you and your students about the major physical environmental characteristics of the Australian coast. It also provides an outline of the major physical processes which shape the coast as well as an introduction to the human-induced processes which impact upon Australia's coast.

Note to teachers: *The Australian Coast: Teacher notes and student activities* has been developed to provide teachers with a comprehensive resource for the education of secondary students studying Earth Science and Geography. Please check that the student activities are appropriate for your cohort of pupils.

Other titles in this series include:
Earthquakes – Teacher notes and student activities
Landslides – Teacher notes and student activities
Tsunami – Teacher notes and student activities
Weathering and Erosion – Teacher notes and student activities

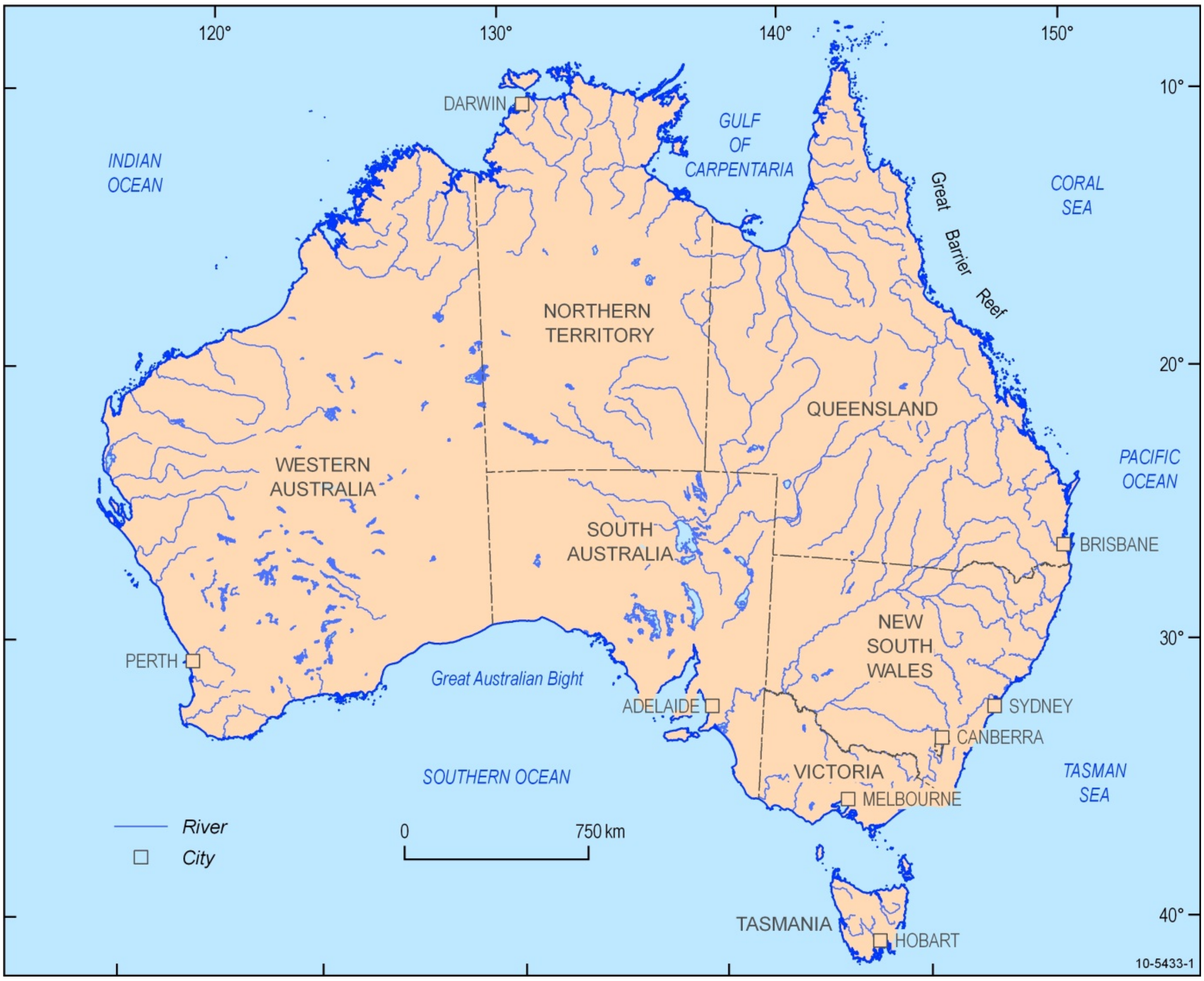


Figure 1.1 : Map of Australia showing its coastline and surrounding oceans and seas, capital cities and river systems. Source: Geoscience Australia.

2 What is the coast?

Each summer many Australians head for the coast or the beach to play on the sand, relax, surf, swim or fish. Most coastal cities have grown rapidly over the past few decades, with around 86 per cent of the population currently within 30 kilometres of the shoreline. Many Australians have relocated to the coast because of a strong economic attraction resulting from coastal development and the desirable lifestyle it can provide; a shift in the distribution of the population known colloquially as a sea change. It is important to understand the coastal systems and their often fragile ecosystems.

So what does it mean when we say we are going to the coast or to the beach? The coastal zone can be defined in terms of the coastal plains and hills and the shallow coastal sea adjacent to the shoreline, which is predominantly a so-called open marine environment. It also extends inland through tidally influenced coastal waterways which form estuarine environments as a result of the interaction of marine and terrestrial processes.

The coastal zone is also defined in legal terms in relation to coastal waters. For more information on the legal jurisdictions refer to the Geoscience Australia publication, Australian Maritime Jurisdiction booklet or visit the Geoscience Australia website.

The Australian coast can be broadly divided into a tropical northern coast and a temperate southern coast, which differ in their **oceanographic** and atmospheric processes, **geomorphic** features and **ecosystems** (Table 2.1).

Table 2.1: Comparison of oceanographic and atmospheric processes of northern tropical and southern temperate coasts.

	Northern/Tropical	Southern/Temperate
Climate	Tropical (humid-monsoonal)	Temperate (humid-dry)
Waves	Low (<1m)	Moderate-high (1 - 3m)
Tides	High (2 - 12m)	Low (0.5 - 3m)
Winds	Low-moderate south easterly trade winds	Moderate to high south westerlies

Table 2.2: Comparison of geomorphological systems of northern tropical and southern temperate coasts.

Northern/Tropical	Southern/Temperate
Tide-dominated beaches and tidal flats	Wave-dominated beaches
Limited dunes	Extensive dunes
Low energy rocky shore	High energy rocky shore
Numerous rivers, deltas and estuaries	Small rivers, limited estuaries

Table 2.3: Comparison of ecosystems of northern tropical and southern temperate coasts.

Northern/Tropical	Southern/Temperate
Extensive mangroves	Limited mangroves
Tropical species	Temperate species
Coral reefs	Seagrass and shelf carbonates

3 How do coasts form?

Coasts are a product of the interaction of the Earth's four great "spheres":

- the lithosphere
- the hydrosphere
- the atmosphere
- the biosphere.

These four subsystems, or spheres, are the reason the coast is dynamic. It is along the coast that all four spheres continuously interact (Figure 3.1).

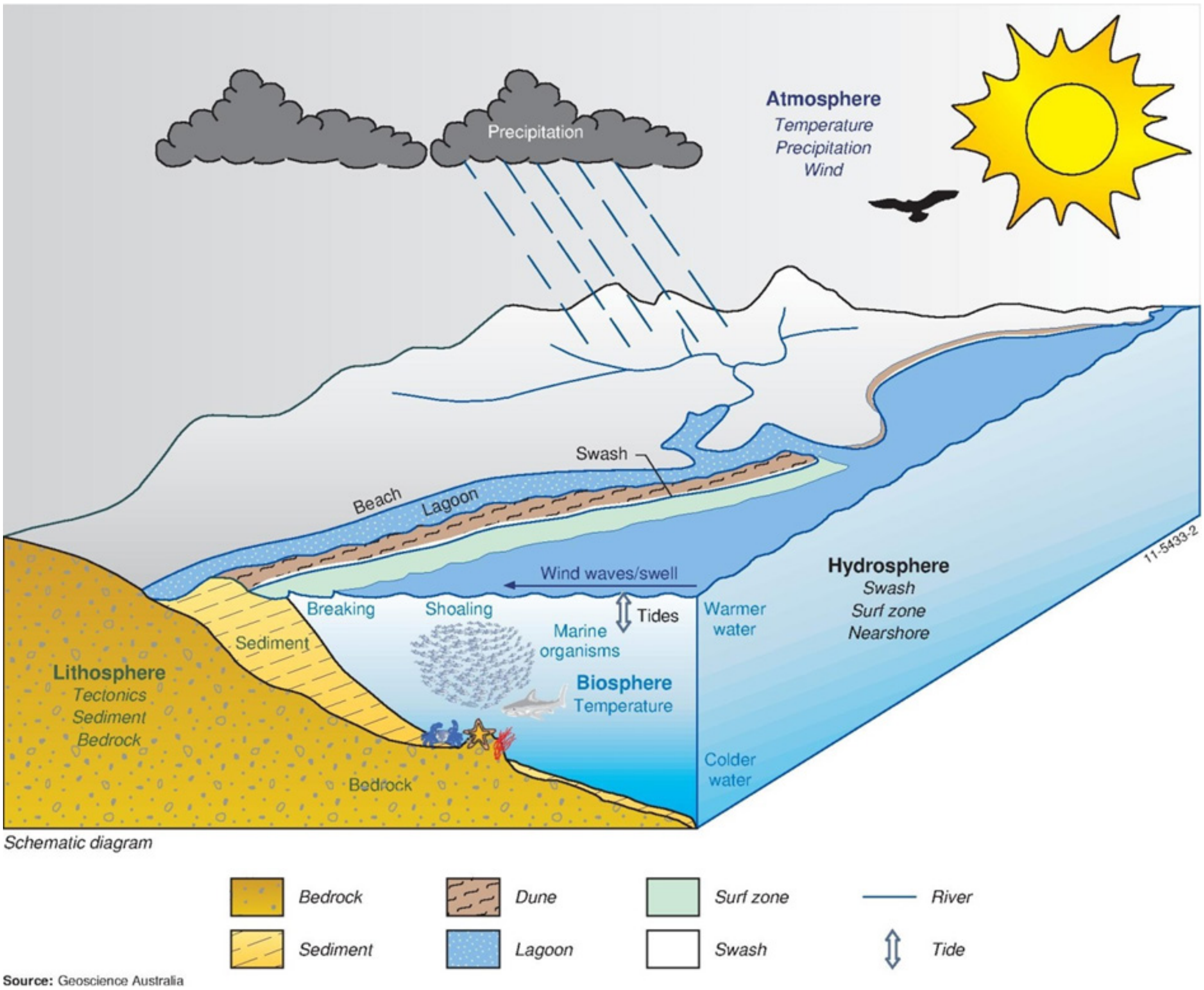


Figure 3.1: A block diagram of a typical sandy section of the Australian coast showing the contribution of the four spheres (lithosphere, hydrosphere, atmosphere and biosphere) to the coastal system. Source: Geoscience Australia, adapted from the OzCoasts web site: www.ozcoast.org.au.

The nature of any section of coast depends on the contribution of each sphere (Table 2.1). The height of the sea (**sea level**) changes over **geological time** (thousand to millions of years) and in the past has completely changed the shape and location of the coast.

There is concern about how rapidly expanding coastal urban developments and communities will be affected by future sea levels and any associated consequences such as shoreline erosion, **inundation** of low-lying areas and higher water temperatures.

Coasts are naturally dynamic environments, constantly evolving and changing as a result of natural processes. For instance, estuaries slowly infill with sediment, river deltas deliver sediment to the **shore** where it is mobilised by waves and currents, and beaches rapidly erode during storms, taking months or years to recover.

Humans have modified the Australian coastline, resulting in alterations to coastal sedimentary systems. These changes include

- constructing housing estates in former wetlands
- altering river discharge and river-mouth shape and currents with training walls
- installing sea walls and groynes on popular beaches to control erosion
- dredging estuaries for navigation and urban expansion.

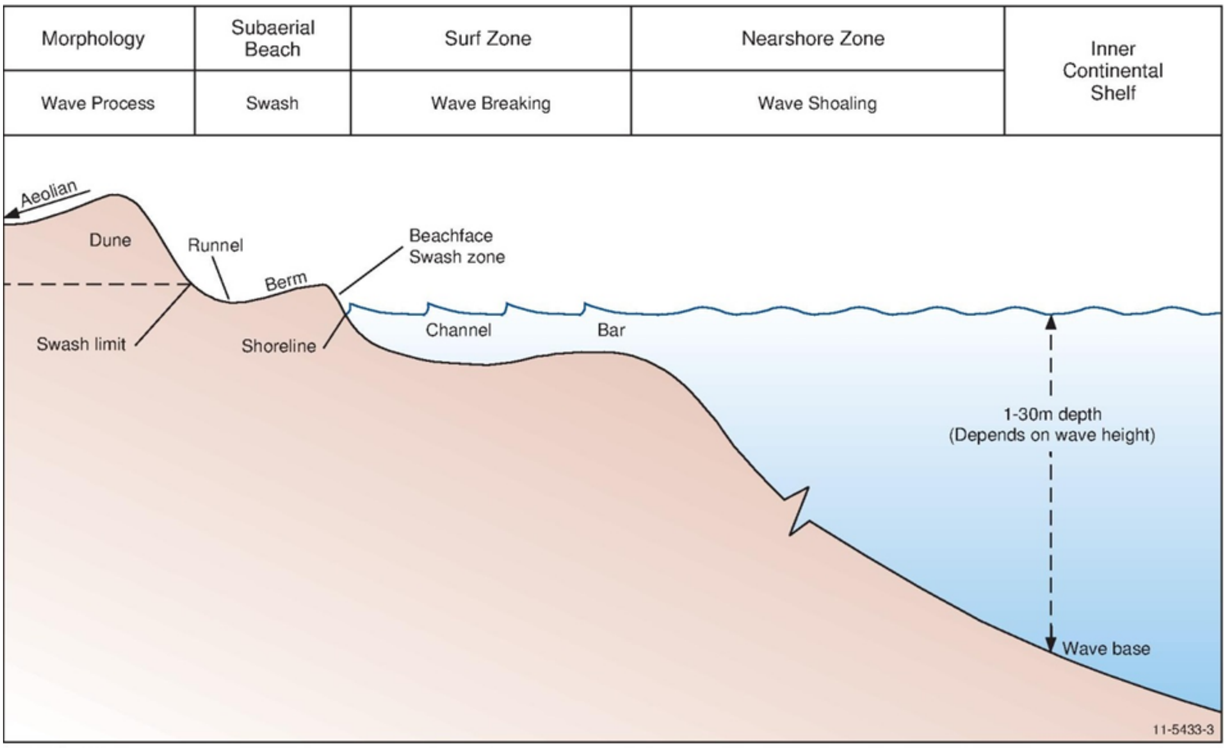
Activity: Sea Change at Bayside.

3.1 Beaches

Beaches occupy half of the Australian **open coast**. There are 10 685 beach systems in Australia, and they are a vital and iconic part of the coastal landscape and ecosystem. Most Australian beaches are quite short and average 1.4 kilometres in length, although some extend for several kilometres. For the most part they are bounded by rocky headlands or reefs and are backed, and, in some cases, flanked by some form of sand dune.

Beaches form as a result of **waves** depositing sediment (usually sand, but occasionally pebbles and boulders) at the shore. They extend from the wave base, across the near-shore and surf zone, to the swash zone where waves run up the beach (Figure 3.2).

The **wave base** is the depth from which waves can move sand shoreward. The **near-shore zone** is where waves interact with the seabed, and in doing so **shoal** and **refract** until they reach shallow water and break. Shoaling is when waves increase in height as they enter shallower water, while refraction is the bending of waves, in this case when they move around headlands or into open bays. The **surf zone** is a dynamic area of breaking waves and is associated with wave-generated currents, including onshore, longshore and seaward moving **rip currents**. Finally, waves reach the beach face or shoreline, collapse and run up the beach as swash and return as **backwash** in the **swash zone**. The swash deposits sand and builds a seaward sloping swash zone which is usually backed by a nearly horizontal dry **berm** or bank where most people sit when they visit the beach.



Source: Geoscience Australia

Figure 3.2: Profile or cross-section of a typical wave-dominated beach showing the near-shore zone, the surf zone, and finally the swash zone. The depth and width of a beach will increase with increasing wave height. Source: Geoscience Australia, adapted from Short and Woodroffe, 2009.

3.2 Beach types

Beaches extend right around the Australian coast. As the waves, **tides** and type of sand change around the coast, so does the character of the beaches. There are two main beach types in Australia: wave-dominated beaches located mainly in the south, and tide-dominated beaches located mainly around the northern coastline (Figure 3.3).

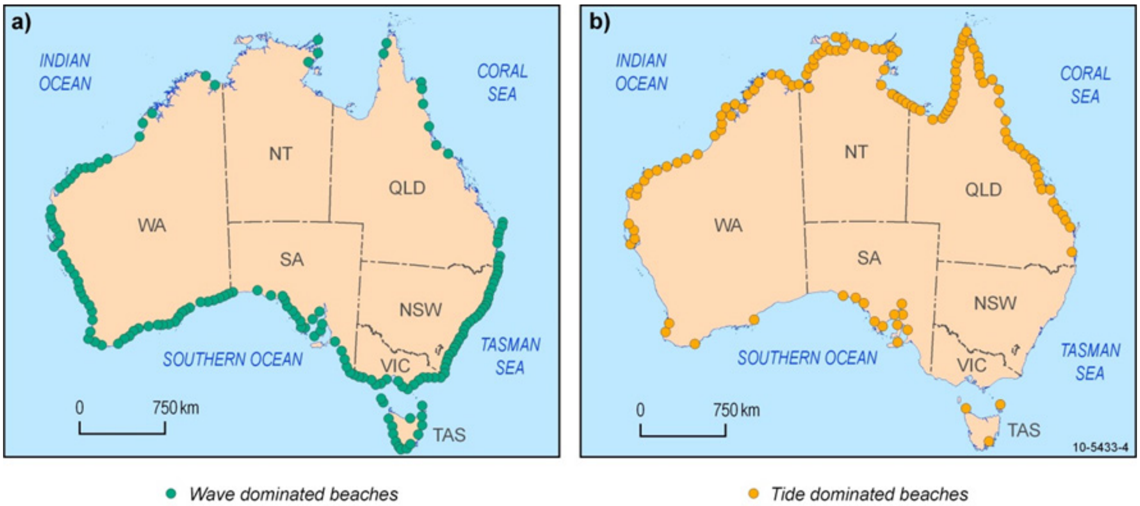


Figure 3.3: Distribution of a) wave-dominated beaches and b) tide-dominated beaches. Source: Geoscience Australia

Along the southern Australian coast the waves are usually large and the tides are small, with breaking waves and a wide surf zone being the common characteristics of the beaches. These are known as wave-dominated beaches (Figure 3.3). They usually have a surf zone in which waves shape the sandy seabed into **bars** and troughs, and strong rip currents flow seaward. Rip currents (Figure 3.4) begin as incoming waves which create underwater sandbars close to shore (1). These waves push more water in between the sandbar and the shore, creating a rip feeder (2) until a portion of the sandbar collapses, allowing this water to rush back to sea through a narrow gap (3). Once the rip current has flowed through the gap, it spreads out (4).

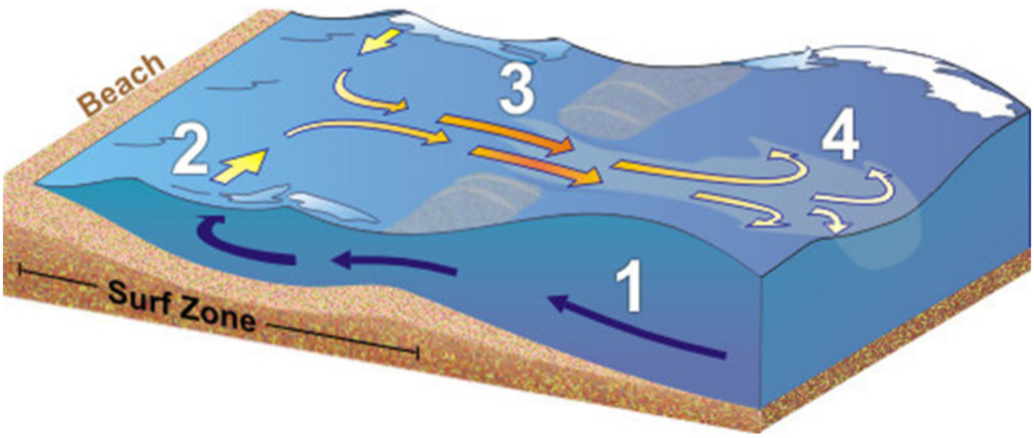


Figure 3.4: The stages in the formation of a rip current. Source: National Oceanic and Atmospheric Administration. Source: http://www.srh.noaa.gov/jetstream/ocean/ripcurrents.htm (Accessed 30 October 2012).

Some examples of these types of wave-dominated beaches in southern Australia are Dog Fence Beach (SA), Lighthouse Beach (NSW), Myles Beach (TAS) and Number One Beach (NSW).

Dog Fence Beach (Figure 3.5) receives high waves from the Southern Ocean, which break across a 500-metre wide surf zone and is typical of high-energy southern Australian beaches. Lighthouse Beach (Figure 3.5) receives moderate waves, which break across a bar cut by deep rip channels, while Myles Beach (Figure 3.5) shows a strong rip flowing out through the surf. Rip currents make beaches hazardous for swimming, and those near population centres are patrolled by lifeguards.

Number One Beach (Figure 3.5) is a lower energy beach where the waves break close to shore with small rip channels grading into a beach without forming bars. This is typical of the more sheltered beaches around the southern coast.

Figure 3.5: Wave-dominated beaches a) Dog Fence Beach (SA), b) Lighthouse Beach (NSW), c) Myles Beach (T) and d) Number One Beach (NSW). Source: Photograph by AD Short.

In northern Australia, tides may reach several metres in height and waves are usually small, making the beaches very different to those in the south. These beaches are known as tide-dominated or tide-modified (Figure 3.3) and usually have a small beach at the elevation of high tide, with wide tidal flats exposed at low tide. They have little or no surf and no rips.

Eighty Mile Beach (WA) (Figure 3.6a) at low tide exposes a 500 metre wide inter-tidal zone, while Hut Point Beach (NT) (Figure 3.6b) reveals a narrow high tide beach with exposed mud tidal flats and mangroves in the foreground.

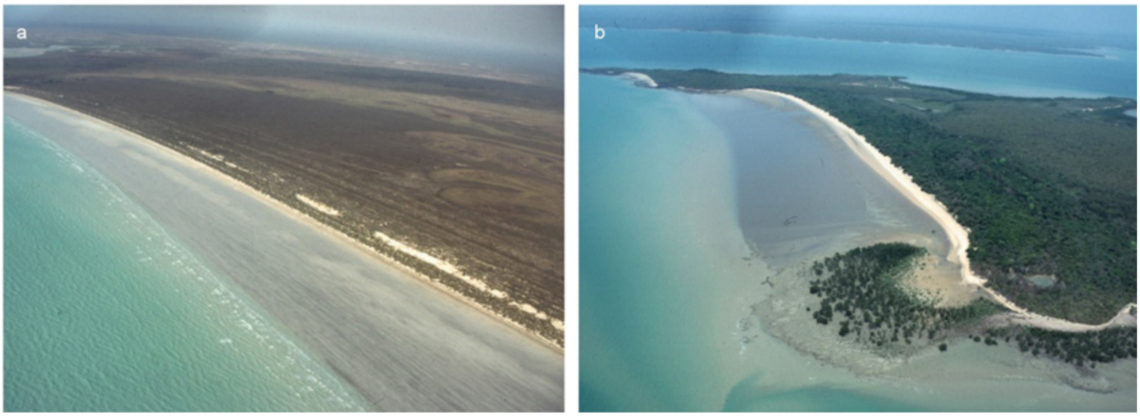


Figure 3.6: Tide-modified beaches shown at low tide. a) Eighty Mile Beach (WA) and b) Hut Point Beach (NT). Source: Photographs by A D Short.

3.3 Sediment transport

Waves transport sand onshore to build beaches. When storm waves **erode** a beach, the sand is quickly carried by large rips and deposited out in the surf and near-shore zones (Figure 3.2). The sand is returned to the beach over a period of months to years by wave action in moderate weather conditions. This is known as the **cycle of erosion and accretion** (Figure 3.7).

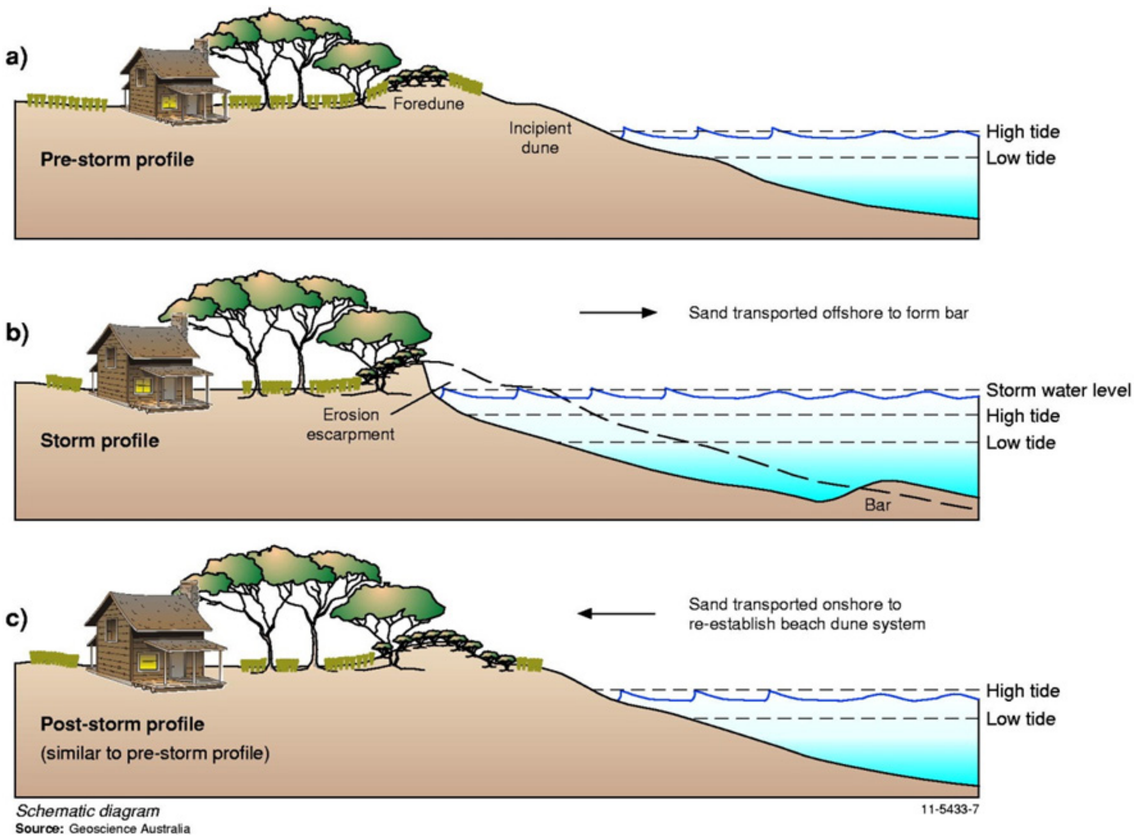


Figure 3.7: The beach erosion and accretion cycle with a balanced sediment budget. Source: Geoscience Australia, adapted from NSW Department of Land and Water Conservation, 2001.

Waves arriving at an angle to the beach can transport sand along the shoreline. In Australia, where waves arrive mostly from the south, there are three major **longshore transport** systems (Figure 3.8) which extend to Shark Bay (WA) in the west and to Fraser Island (Qld) in the east. There are also a number of smaller, more localised systems. In these systems sand is moved along the shore by breaking waves and wave-generated currents. On a typical wave-dominated east and west coast beach, most sand is moved northward during periods of higher waves, particularly in the outer surf zone where waves break heavily.

If more sand is eroded and moved offshore or along shore than sand entering the system, there will be a negative **sediment budget** and the beach will erode. If beaches have a balanced sediment budget they will remain stable. Human interference with longshore sand transport also can lead to beach erosion.

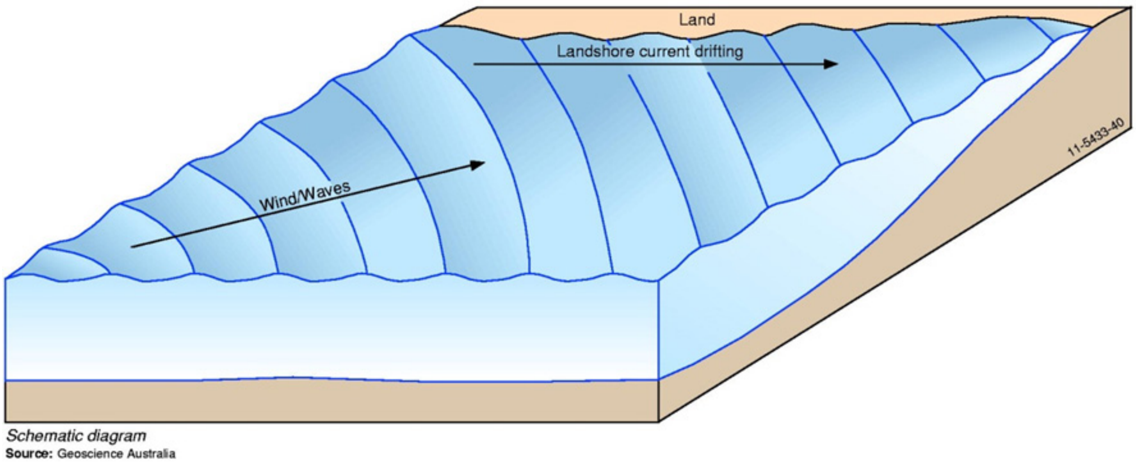


Figure 3.8: Longshore drift generated by waves that are aligned at an angle to the shoreline. Source: Geoscience Australia

3.4 Coastal dunes

Coastal sand dunes back most Australian beaches. Sand dunes form when strong winds blow fine to medium sized sand particles inland from the beach. The transported sand will settle when the wind drops or it becomes trapped by vegetation. Most sand settles initially in the **incipient fore-dune**, typically a low *Spinifex* (grass) covered dune located immediately behind the berm and one that is periodically eroded by waves (Figure 3.9). It is usually backed by the **fore-dune**, a larger, five to 20 metre high dune vegetated by shrubs (acacia, banksia and tea tree) and even small eucalyptus trees.

Figure 3.9: Spinifex covered incipient foredune, northern NSW. Source: Photograph by A D Short.

Any dune behind the fore-dune is known as the **back-dune** and, if stable, will be vegetated by plants or trees that are typically indigenous to the region. In Australia this can range from tropical rain forest to eucalyptus woodlands or shrubs (Figure 3.10).

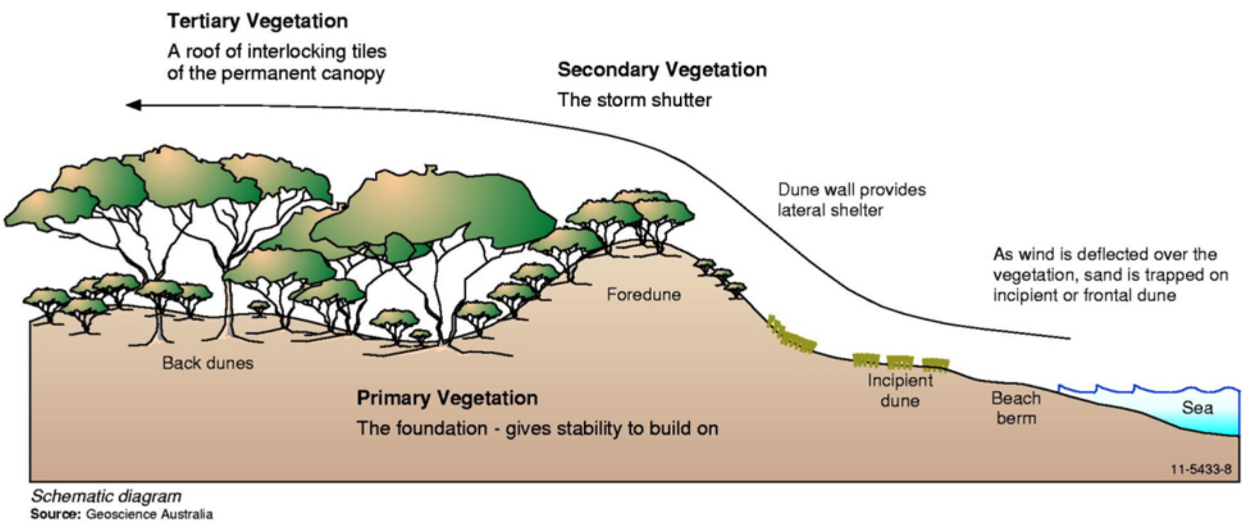


Figure 3.10: A typical coastal dune system showing the transition from a bare beach berm to grasses on the incipient fore-dune, shrubs on the fore-dune and trees in the back-dune area. Source: Geoscience Australia, adapted from NSW Department of Land and Water Conservation, 2001.

If the fore-dune remains stable and sand is added to the beach (positive sediment budget) the shoreline will build seaward and a new fore-dune will develop. This can result in a series of fore-dunes forming a barrier (Figure 3.11). A **barrier** is a large scale wave-tide-wind deposited sand system consisting of the beach, dunes and even tidal inlets.

Figure 3.11: Fore-dune ridge plain Rivoli Bay (SA). Source: Photograph by A D Short.

A **regressive barrier** is when the shoreline moves seawards. These regressive barriers tend to form in lower to moderate energy coastal environments right around the Australian coast, with some having built seaward four to five kilometres.

Examples of these regressive barriers are found in Guichen and Rivoli bays (SA), Rockingham (WA), Broulee and Disaster bays (NSW), and Cowley Beach (Qld).

There are more than 2500 coastal sand barriers (dune systems) around Australia occupying 12 000 kilometres, or 40 per cent of the open coast. They range in size from a few small fore-dunes to the massive Fraser Island, the largest island of its type on Earth. Barriers are fronted by dynamic beaches and are composed of unconsolidated sand, which, if exposed, will blow inland. They underlie the entire Gold Coast (Qld), much of coastal Adelaide (SA) and Perth (WA) and popular Sydney beach suburbs such as Bondi and Manly (NSW).

Wind can blow the sand further inland to form a **transgressive dune** (i.e. beach sediment moves onshore from the shoreline). Transgressive dunes occur as **blowouts** in the fore-dune where the sides are stabilised by vegetation and sand is blown out of the centre to create a hollow (Figure 3.12a). If a blowout moves inland it assumes a parabolic dune shape with stabilised sides and a migrating front. Transgressive dunes tend to form in the lee of the prevailing wind in regions of strong onshore winds on higher energy beaches. In contrast, dunes without vegetation are aligned to the predominant wind direction as transverse dunes (Figure 3.12b) and can migrate inland at rates of between five and 10 metres a year.

However, some coastal sand dunes do not conform to these typical dune systems. For example, in Kalbarri National Park (WA) there are large 45˚ natural sand dunes, including an 85 metre high sand crater known as the Superbowl. These large sand dunes are popular with sand surfing and four wheel drive enthusiasts.

Dunes that do not conform to the typical dune systems shape are often the result of environmental degradation. For example, at Old Eucla in Western Australia, the town was abandoned in 1929 after the dunes became destabilised as a result of over-grazing, largely by an infestation of rabbits. As a consequence, the dunes began to creep inland to eventually bury many buildings.

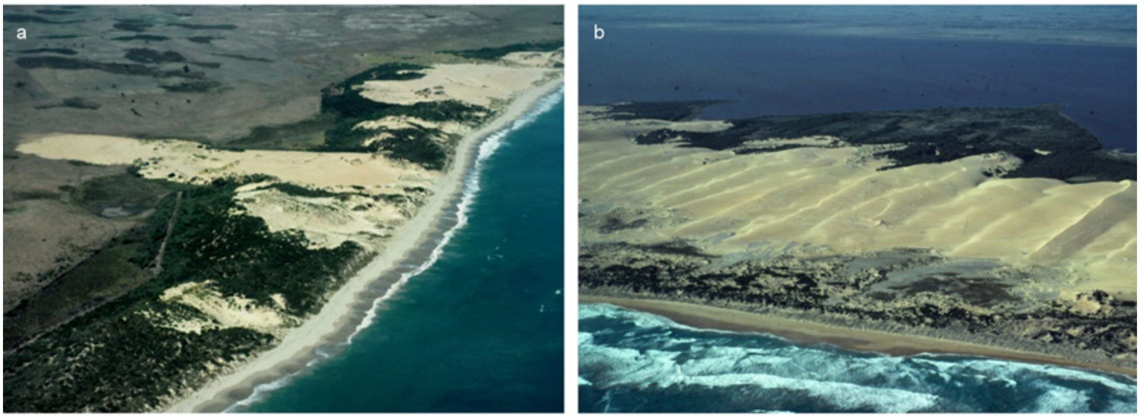


Figure 3.12: a) Blowouts, Wright Bay (SA) and b) bare transverse dunes, Canunda Beach (SA). Source: Photographs by A D Short.

Activity: Dune Drifting.

4 Rocky coast shorelines

Rocky shores constitute 40 per cent of the Australia's open coast with many forming headlands characterised by steep sea cliffs. The Nullarbor cliffs in southern Australia extend for 200 kilometres, forming one of the longest stretches of cliff coastline in the world (Figure 4.1).

The characteristics of a rocky shore depend on:

- the geology, or type and structure of the rock which forms the shoreline
- atmospheric and marine processes which impact the shore such as erosion and weathering
- marine organisms and other biological diversity occupying the area.

Figure 4.1: The Nullarbor Plain and cliffs along the Australian Bight fronting the Southern Ocean. Source: Wikimedia Commons, photograph by Nachoman-au.

4.1 Geology

The geology of the coast includes igneous, sedimentary and metamorphic rock types. Rock types have different degrees of hardness based on the properties of the constituent mineral grains and the way that they are bound together. For example, hard granite is made of interlocking crystals and can be resistant to even very high wave energy (Figure 4.2). In contrast, weakly cemented porous sediment may be eroded by relatively low energy waves.

The condition of the rock will also have an effect on its behaviour. Rocks that are highly fractured will wear away faster than more coherent, unfractured rocks, and layered sedimentary rocks will deteriorate differently depending on whether the layers are horizontal or tilted. As a result, each has a different resistance to erosion and weathering.

Figure 4.2: The sloping granite at Remarkable Rocks (SA) has endured limited erosion despite relatively high waves. Source: Photograph by A D Short.

WHAT IS THE DIFFERENCE BETWEEN WEATHERING AND EROSION?

Erosion: The removal of surface rock material by a 'transportation agent': wind, water, ice or gravity.

Particles become loosened in the first place by weathering.

Weathering: A process that decomposes rocks. Chemical weathering changes the chemical composition of at least some of the minerals in the rock. Mechanical weathering physically breaks rocks into fragments.

'If a particle is loosened, chemically or mechanically, but stays put, call it weathering. Once the particle starts moving, call it erosion.'
(Adapted from www.nature.nps.gov/geology/usgsnps/misc/gweaero.html)

4.2 Weathering[1]

Weathering is the process in which the texture and composition of rocks and sediments change after being exposed at the Earth's surface to weathering agents such as water, oxygen, organic and inorganic acids and large temperature fluctuations. These changes can occur in place or after transportation. The process of weathering can be chemical or physical (mechanical). On the coast, both of these processes play a significant part in shaping the landscape.

4.2.1 Chemical weathering

Water is the most important substance in chemical weathering. Porous rock, such as sandstone commonly found along coastlines, is especially susceptible to chemical weathering (Figure 4.3). Rain water is slightly acidic, and chemically reacts with minerals in the rock forming new minerals and salts. Chemical weathering is also the first step in the production of soil.

There are three main types of chemical weathering:

1. Solution – dissolving of rock in acidic rainwater
2. Hydrolysis – chemical breakdown of rocks by acid, producing clays and salts
3. Oxidation – reaction of rock with oxygen and water. In the case of iron-rich rocks, the result is rusty-coloured surfaces.

Example of a common chemical weathering reaction:

[1] More information in Geoscience Australia's *'Weathering, erosion, landforms and regolith'* booklet.

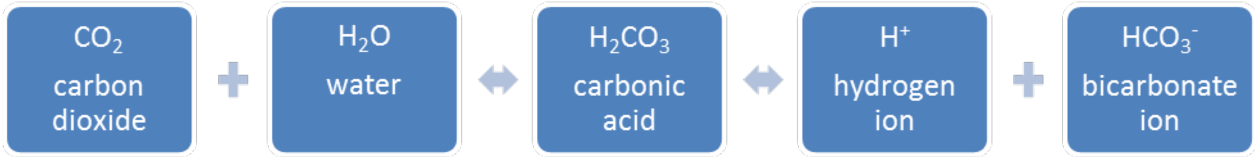


Figure 4.3: The Twelve Apostles in Victoria are the remnants of erosion of relatively soft marine limestone. Source: Wikimedia Commons, photograph by Richard Mikalsen.

4.2.2 Physical weathering

Physical weathering is caused by temperature changes, pressure changes, formation of frosts and abrasion by wind-blown sand.

Rocks can suffer from thermal stress if they are repeatedly heated and cooled, such as rocks in the desert. Rocks expand in the heat and contract in the cold. Over time, the stress causes layers to peel off the rock.

If water gets trapped in pores or fractures in the rock, and then freezes, the ice can cause the rock to split (freeze-thaw). This is because ice takes up more space than water and pushes against the rock as it expands.

Sand can be transported by wind and abrade (wear off by scraping) rock surfaces. In some cases, severe sand storms cars have had their paint removed. Sand and pebbles suspended in water can scour coastal rocks.

Air pressure can also crack, break and splinter rock. The mechanism is as follows: a wave strikes a cliff face, compressing air in the cracks of the rocks. This high pressure air exerts pressure on the surrounding rock. In addition, when the wave retreats, the air expands explosively, also putting stress on the rock. Over time, the cracks will grow and the rock will begin to fall apart.

4.2.3 Coastal weathering

Sea cliffs and platforms which are exposed to ongoing wetting and drying can produce a range of intricate weathering features (Figure 4.4). When salt water washed into the pores of sedimentary rocks evaporates, ions present in the water can precipitate out to form salts. As the salt crystals grow, pressures they exert on the rock may be large enough to cause the rock to disintegrate. The result is known as **salt weathering**, or **salt plucking**. An example of salt weathering is honeycomb weathering, where softer, less consolidated sediments are worn away leaving behind those areas with better cemented grains.

Figure 4.4: a) Rock platform surface at Avoca Head (NSW and b) honeycomb weathering in a sandstone cliff face. Source: Photographs by a) A D Short and b) Wikimedia Commons, photograph by Richard Mikalsen.

4.3 Erosion

The removal of weathered materials from where they were formed is called **erosion**. The products of erosion can be transported by gravity, water, wind or glaciers.

Most erosion on coasts is due to the action of waves. Erosion occurs not only in the surf zone, but also below and above the sea surface. During storms waves pound the shore well above high tide level. The constant pounding of the waves on cliffs and beaches can loosen rocks. Waves are excellent at transporting sand and small rock fragments. These, in turn, are very good at rubbing and grinding surfaces below and just above water level in a process known as abrasion. In this manner, weathering and erosion are related – the abrasion loosens and breaks down the rock (i.e. weathering) and the wave action washes the particles away (i.e. erosion).

4.4 Coastal formations

4.4.1 Rock platforms

A common result of weathering and erosion on Australian coastlines is the formation of **rock platforms** (Figure 4.5). These structures project seaward from the base of a rocky headland. They are found in the zone between high tide and low tide.

Figure 4.5: Wave quarrying of jointed shale beds exposed in the rock platform at Narrabeen Head, Sydney (NSW). Source: Photograph by A D Short.

The layers typically seen in sedimentary rock, such as sandstone, conglomerate and shale are known as bedding planes. Horizontal bedding planes in combination with vertical joints (cracks in rocks) gives the characteristic rectangular shapes of many rock platforms.

Wave action is the primary force at work in the formation of rock platforms (wave-cut platforms). A combination of the huge force with which the waves pound on the rocks and the pneumatic effects of changing air pressure in the cracks between rocks cut cliffs faces back to create notches at their base. These notches become caves, and as the cliff is undercut further, the rock above will collapse in rockfalls and landslides. The result is rock platforms (Figure 4.6) which are further abraded to a smooth surface by rock fragments in the tides washing back and forth in the surf zone. Depending on the rock type, chemical weathering may also play a part in the breakdown of the rock.

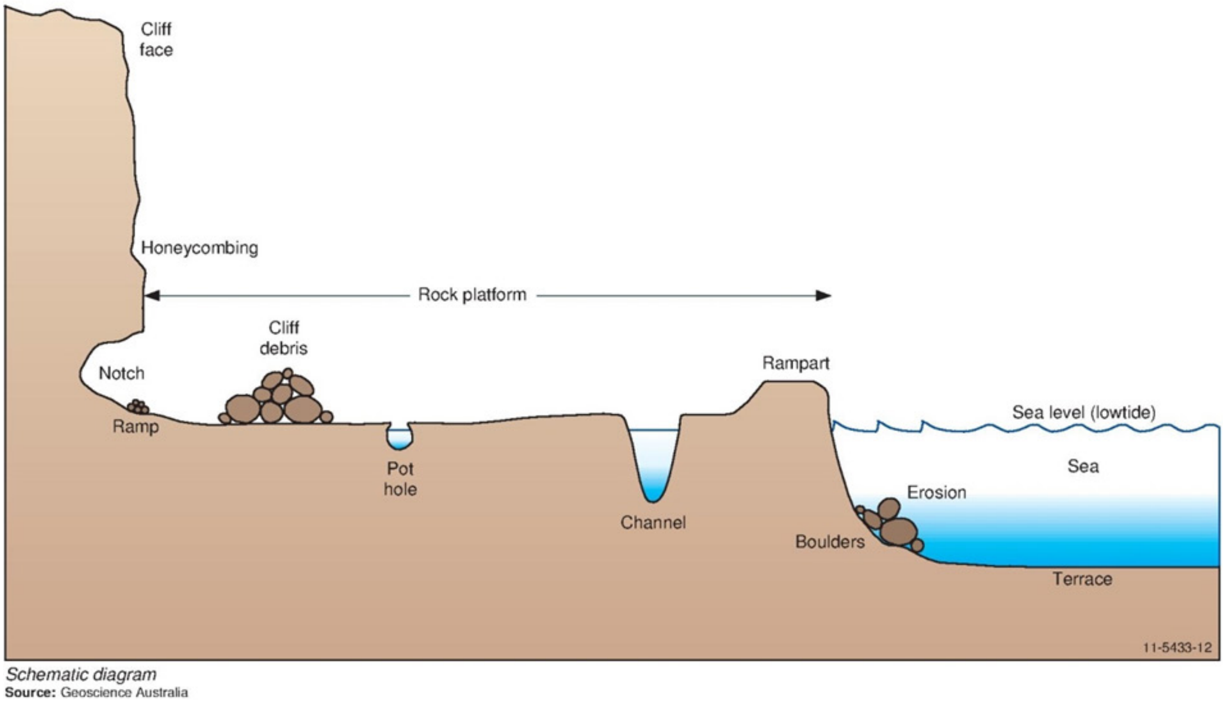


Figure 4.6: Schematic diagram of an eroding cliff, rock platform and rampart, with the roughly horizontal platform, notched cliff and differential weathering associated with joints (channel) and more resistant rock types. Source: Geoscience Australia

4.4.2 Sea stacks

Soft rocks are easily worn down due to wave action, producing spectacular formations. One of Australia's most famous stretches of coastline is the Twelve Apostles (Figure 4.3); they are the remnants of more resistant rocks left after wave erosion of the coastal cliff-line.

Sea caves are the first step in the formation of **stacks**. **Wave quarrying** is the act of waves wearing away rocks along lines of weakness, particularly bedding and joint lines. Waves strip the soil and surface rock to expose and then slowly erode the underlying bedrock face. When two sea caves form on either side of a narrow headland it may become exposed to wave attack on all fronts. The caves eventually erode inwards towards each other leaving a natural arch. If the arch further erodes, an isolated sea stack remains. A sea stack is composed of more resistant rock than those surrounding it, and often the stack may form without the process of forming arches. Stacks are very common in Port Campbell in Victoria, the Twelve Apostles being perhaps the most famous.

Activity: New Coast.

5 Estuaries and deltas

5.1 Estuary

An **estuary** is a semi-enclosed coastal body of water where salt water from the ocean mixes with fresh water flowing from the land. Australia has more than 900 relatively large estuaries and many smaller estuaries, with most located along the northern, eastern and southwest coasts. Some of these estuaries are the site of major cities, towns and coastal communities, such as the Derwent River estuary in Hobart, Tasmania (Figure 5.1).

Figure 5.1: The Derwent River estuary in Hobart, Tasmania. Source: Wikimedia Commons, photograph by Enoch Lau.

Estuaries are influenced by tides and river input and most have waves at their mouths. There are three major types dependent on the dominant processes which led to their present form: tide-dominated, wave-dominated and river-dominated. Each type has its own distinct shape, processes, management requirements and vulnerability to natural or human impacts.

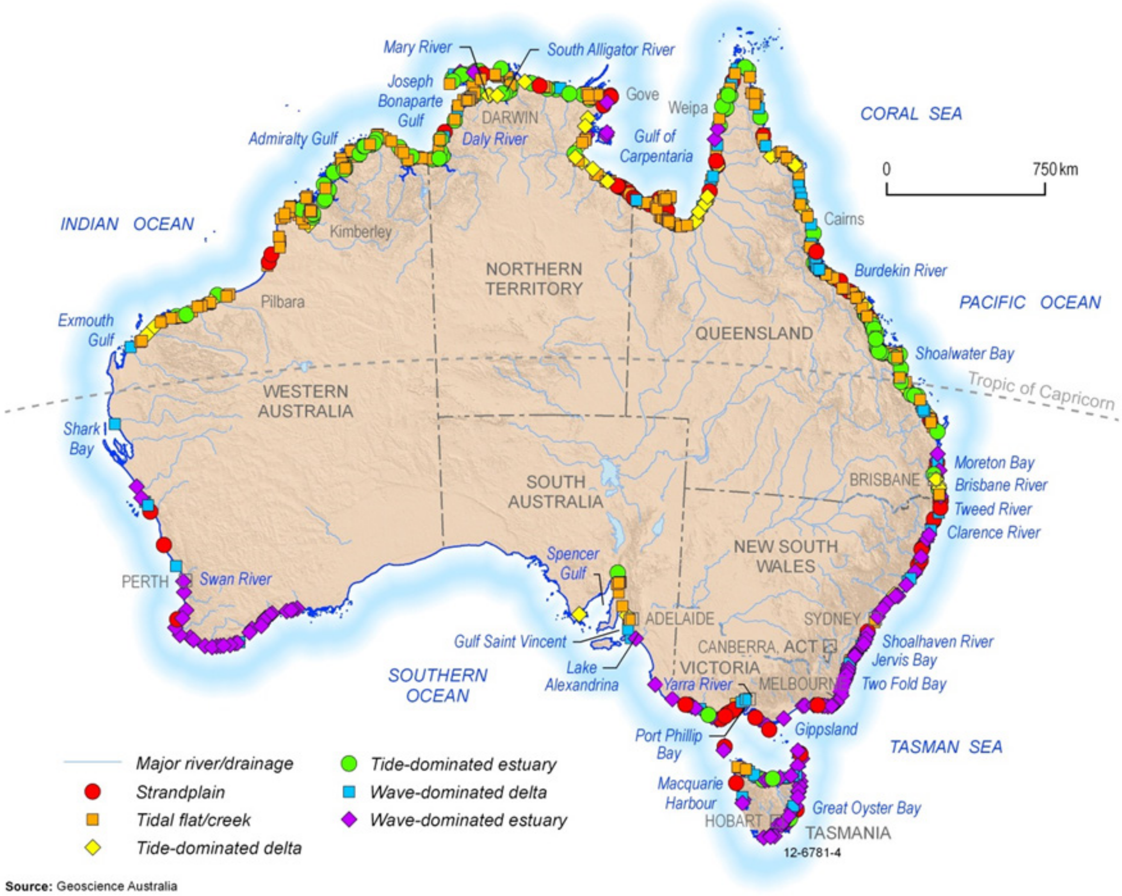


Figure 5.2: The distribution of gulfs and different estuary types around the Australian coast. Source: Geoscience Australia.

In the case of wave-dominated estuaries, waves build beaches, dunes and barriers parallel to the shore. Tide-dominated estuaries, in contrast, will develop tidal flats and creeks which extend inland, while those estuaries dominated by rivers have **deltas** protruding out into the sea.

As river input, tidal range and wave height vary around the Australian coast so too does the contribution of each factor, resulting in the formation of different types of estuarine environments and ecosystems.

The ternary diagram (Figure 5.3) arranges estuarine systems based on the relative contribution of waves, tides and rivers.

Activity: Estuarine Escapades.

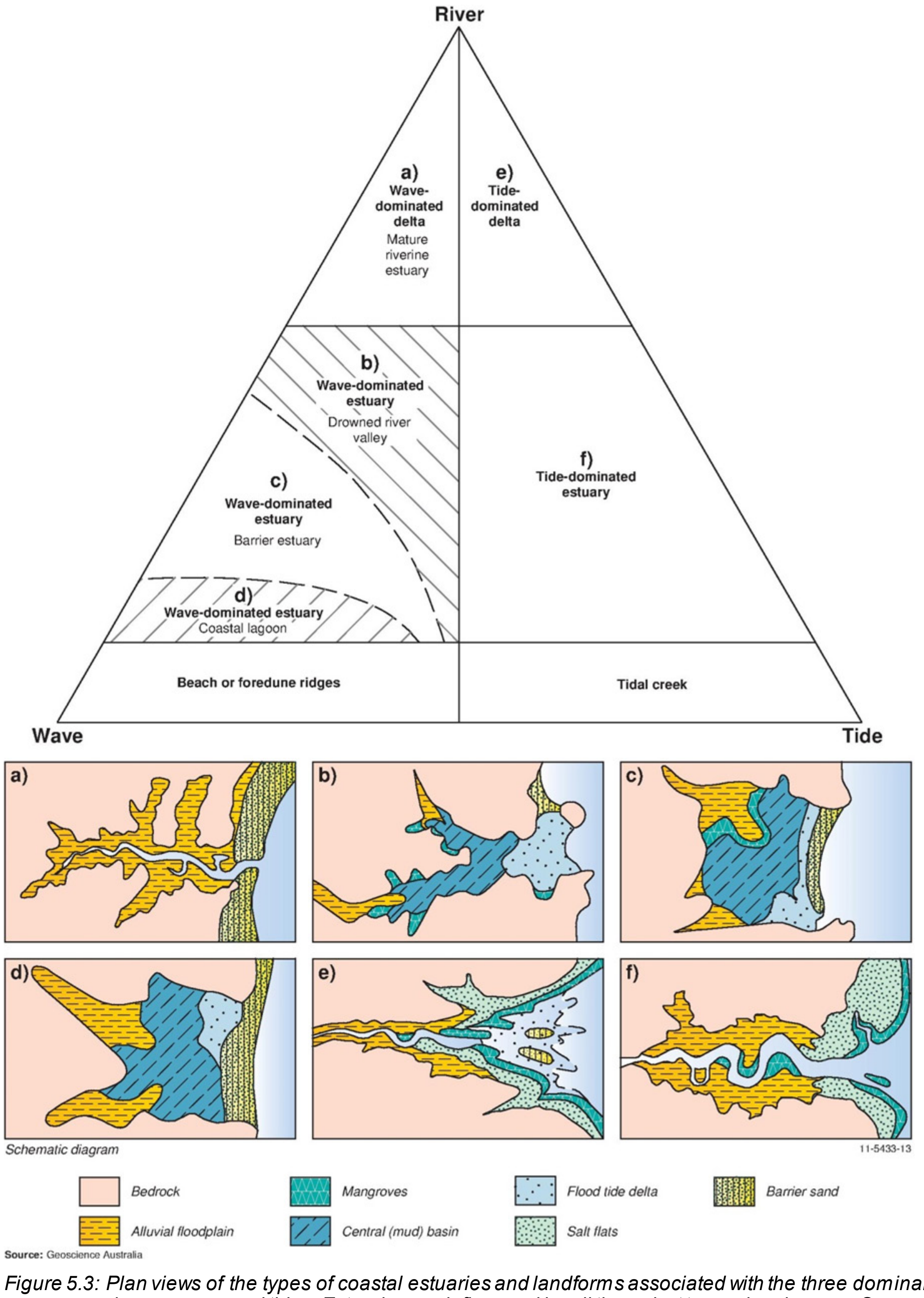


Figure 5.3: Plan views of the types of coastal estuaries and landforms associated with the three dominant processes, rivers, waves and tides. Estuaries are influenced by all three, but to varying degrees. Source: Geoscience Australia, adapted from Short and Woodroffe, 2009.

5.2 Deltas

A delta is formed from the deposition of sediment carried by a river. When a flowing river reaches a standing body of water (e.g. lake or ocean), or an inland region where the water can spread out, it drops its load of sediment. These deposits clog up the exits of the river, so the water is forced to seek new outlets, creating smaller streams. Over time, the new paths spread out, allowing material to be deposited in a large fan shape. This is called a **delta**, named after the upper case Greek letter of a similar shape.

Only about 50 per cent of Australia's rivers flow to the sea and some of those have well defined deltas, particularly those on the humid tropical northern coast. During the summer wet season these rivers transport large volumes of mud and sand which is deposited to build deltas that fill bays and protrude seaward (Figure 5.4 and Figure 5.5).

Major river-dominated deltas include the Burdekin River Delta and Fitzroy River Delta in Queensland. Other noteworthy regions are the southern Gulf of Carpentaria in northern Queensland/Northern Territory and the Kimberley region in northern Western Australia, including the Fitzroy River at Derby in WA.

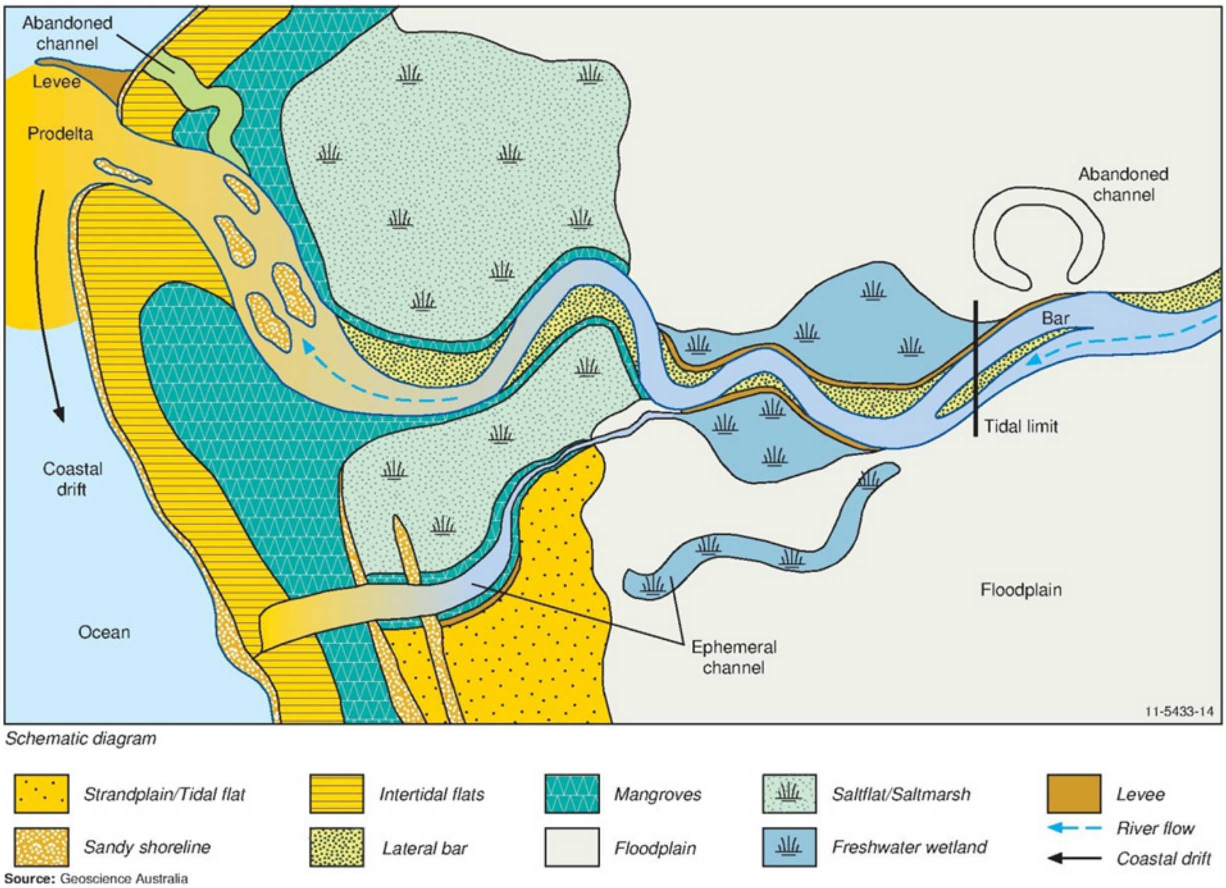


Figure 5.4: A tide dominated delta, which is actively depositing sediment at the coast both building the coast seaward as well as being reworked along the shore by waves. Source: Geoscience Australia, adapted from the OzCoasts web site: www.ozcoast.org.au.

Figure 5.5: The Gasgoyne River, Carnarvon (WA) delivers sand to the mouth of the delta, where it is reworked northward as shoals and spits to eventually join the neighbouring five kilometre-wide beach ridge plain. Source: Photograph by A D Short.

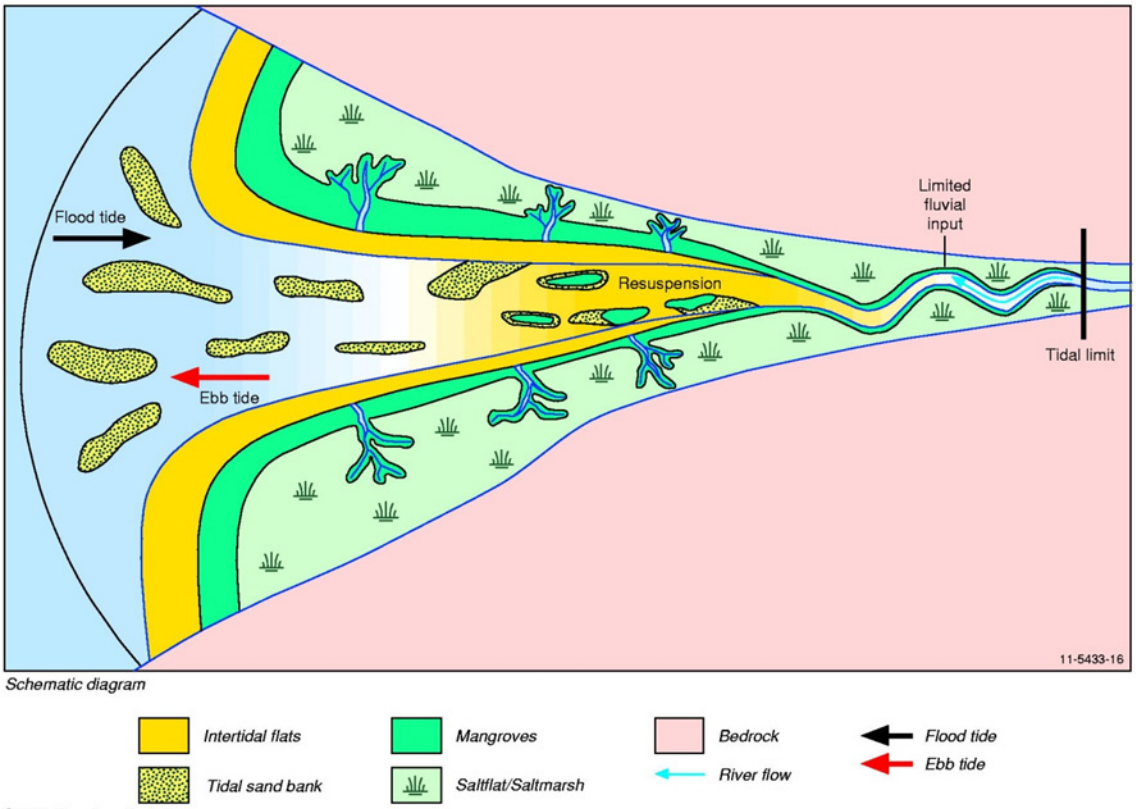
WHAT IS THE DIFFERENCE BETWEEN ESTUARIES AND DELTAS?

A *delta* is a landform at the mouth of a river. It is formed from sediments (e.g. silt, sand and small rocks) that are carried downstream in the river and deposited at the mouth.

An *estuary* is where a river meets the sea, and fresh water meets salty water. A delta is a type of estuary.

5.3 Tide-dominated estuaries

Tide-dominated estuaries prevail across tropical northern Australia where tides are generally high and waves are low. They produce wide funnel-shaped mouths and long, deep tidal channels where strong currents transport sediment into the estuary. Sediment such as sand and gravel will be deposited to form **tidal banks** and shoals within channels. Alternatively, fine sediment such as silt and mud form wide inter-tidal flats fringed or largely covered by extensive mangroves, which are in turn backed by salt flats and salt marshes. At the tidal limit, a mix of river and marine sediment accumulates (Figure 5.6 and Figure 5.7). These estuaries are a major habitat for animal and plant life and are the domain of Australia's large saltwater crocodile population. Some examples of tide-dominated systems are the Ord River (WA), Victoria, Daly and Roper rivers (NT) and Normandy River (Qld).



Source: Geoscience Australia

Figure 5.6: Tide-dominated estuaries have wide funnel-shaped mouths that narrow into a meandering upriver section. They are fringed by wide mangrove-lined tidal flats backed by supratidal salt flats. Source: Geoscience Australia, adapted from the OzCoasts web site: www.ozcoast.org.au.

Figure 5.7: a) The funnel shaped mouth of the Towns River (southern Gulf of Carpentaria) is backed by extensive mangroves then salt flats, and b) a small tide dominated tidal creek in the southern gulf, with mangroves fringing the creek and open coast, while extensive salt flats extend inland. Source: Photographs by A D Short.

5.4 Wave-dominated estuaries

The mouth of a **wave-dominated estuary** has relatively high wave energy compared to the prevailing tidal and river energy. Waves can build sand barriers along the coast and form a **barrier estuary** (Figure 5.8). Waves transport sediment towards the inlet of the estuary, building a sand bar or barrier across the estuary mouth. Sand transported from the beach into the inlet by waves and tidal flow accumulates just inside the estuary mouth to form a **flood tide delta**. The typical narrow inlet and shallow delta of these estuaries further constricts the volume of water that flows through the entrance. The water body trapped behind the barrier is called a **lagoon**.

Often at the landward end of the estuary a small river or creek flows into the lagoon, depositing a small **fluvial delta** composed of mixed sediments, such as mud, sand and gravel. Much of the finer mud and silt is deposited in the quieter waters of the lagoon, known as the **central basin**. This same material is flushed out to sea during a flood as **turbid** (murky) water. Over time, sediment deposited by the river and delta will fill the lagoon and form an extensive **floodplain**.

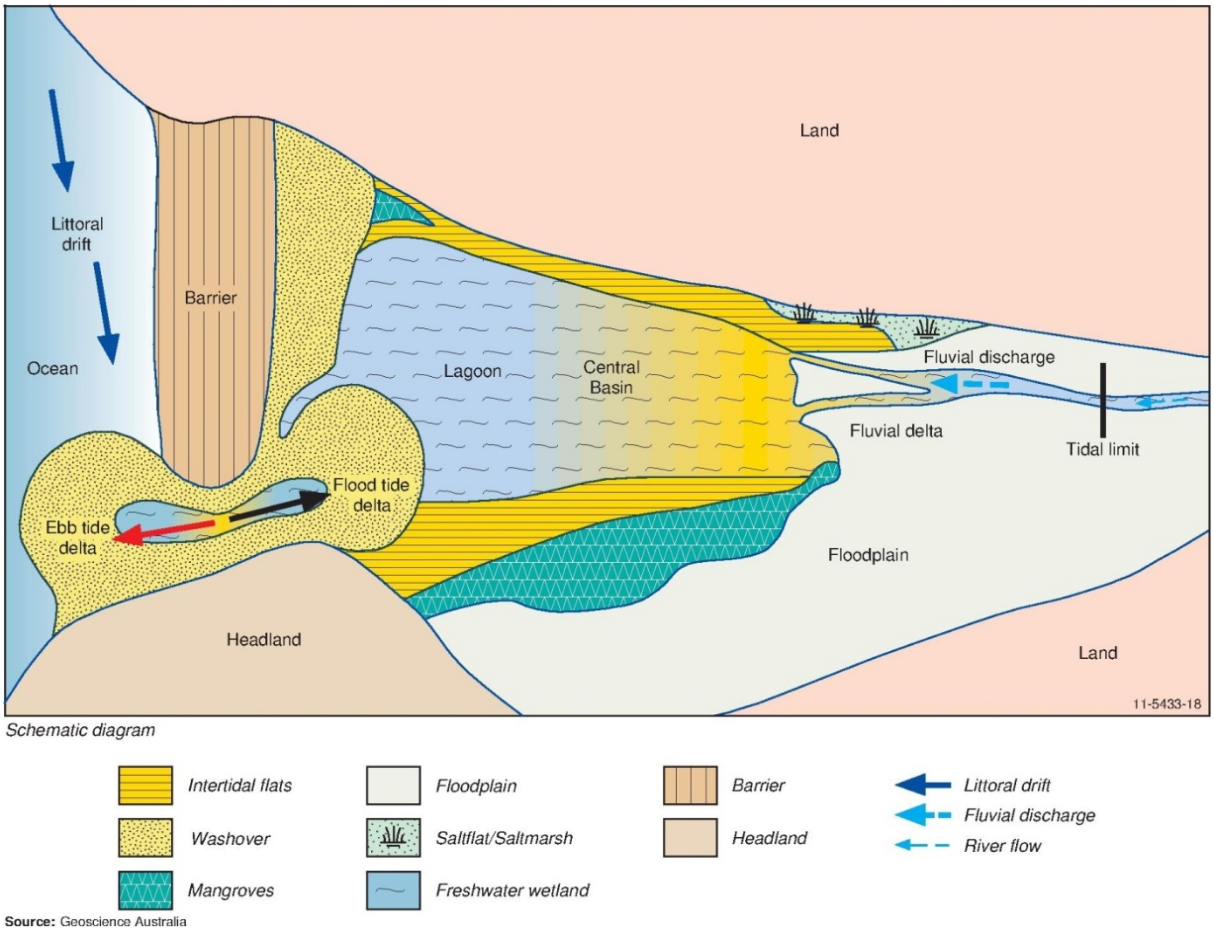


Figure 5.8: Wave-dominated estuaries are partly blocked by a sand barrier deposited by waves and wind, with constricted tidal flow through the estuary mouth where the flood-tide and ebb-tide deltas are deposited. River-deposited sediments build a fluvial delta at the head of the estuary and mud settles out in the deeper central basin. Source: Geoscience Australia, adapted from the OzCoasts website: www.ozcoast.org.au.

Barrier estuaries are important habitats, especially in southern Australia, with seagrass often covering the central basin and mangroves growing towards the entrance. These sites are favoured for recreation and fishing. Examples of barrier estuaries are at Narrabeen, Tuross (Figure 5.9) and Lake Macquarie (NSW), Wigan Inlet (Vic.), the Coorong (SA) and Blackwood River (WA).

Figure 5.9: The mouth of the wave-dominated Tuross River estuary is partially blocked by a sand barrier and flood tidal delta, with a river deposited fluvial delta and estuarine basin behind. Source: NSW Department of Environment, Climate Change and Water.

Coastal lagoons form where small creeks and streams are periodically blocked from the sea by sand barriers, causing the freshwater to accumulate in the lagoon. During heavy rain the water level of the lagoon rises and can breach the barrier and the lagoon can flow into the sea. The breached barrier is then filled by sand deposited by waves, trapping a mix of sea and fresh water to form a **brackish** (salty) lagoon. This cycle of closed and opened barriers has led these ponds to be called **intermittently closed** and **open lagoons** (Figure 5.10). They are most common in southern New South Wales, Victoria and southwest Western Australia.

Figure 5.10: Wamberal Lagoon (NSW) is a typical usually blocked coastal lagoon or intermittent closed and open coastal lagoon. Source: Photograph by A D Short.

In southeast and southwest Australia many estuaries are susceptible to the impact of urban and rural run-off, which can pollute the water and sediments in the estuary basin. The impact of this can result in temporary or permanent bans on fishing, such as those for Sydney Harbour and the Swan River in Perth (WA). Pollution is particularly harmful in intermittently closed and open lagoons where water exchange with the sea is limited. To ensure pollution does not build up, some intermittently closed and open lagoons are opened to the sea by mechanical intervention (Figure 5.11a). Western Australia's Peel estuary has a new permanent opening to the sea, known as the Dawesville Channel. This was constructed to improve the exchange of water between the estuary and the ocean (Figure 5.11b).

Figure 5.11: a) Sand being removed from the mouth of Narrabeen Lagoon (NSW) to improve water flow through the narrow and often blocked, entrance, and b) the Dawesville Channel was opened in 1994 to provide a new and permanent opening to the sea for the large Peel Estuary in Western Australia. Source: Photographs by a) A D Short and b) Port Boulevard Marina < http://www.pbddevelopments.com.au/projects/port-bouvard-marina >

6 Reefs

A reef is a narrow chain of rock, coral or sand just above or just below the surface of the sea.

Natural reefs are made of rock or coral. Artificial reefs are commonly made of concrete or ship wrecks.

Coral reefs are a type of reef made by a carbonate depositional process, in this case the skeletal remains of coral. Other organisms that also contribute to reef building or carbonate coastal sediments include algae, molluscs, barnacles, bryozoans and sponges. The structures, formed from solid limestone, are continuously producing, breaking down and redistributing sediments. The result is a structure which is rigid and wave-resistant.

Coral reefs are typically found in waters of 18 degrees Celsius or more.

6.1 Coral reefs

Coral reefs are one of Australia's largest tourist attractions, but more importantly, play an important role along our coastline. Coral reefs:

- protect the coast from strong waves and tropical storms
- provide habitat and shelter for reef organisms
- assist in the carbon and nitrogen cycles
- help with the recycling of nutrients
- provide essential nutrients for the marine food chain.

In terms of the benefits to the Australian population, the fishing and tourism industries are dependent on the reefs to generate billions of dollars a year.

A study of coral growth patterns also provide a clear record of climatic events over millions of years, as well as records of recent major storms and human impacts.

Reefs form out of limestone from the skeletons of millions of tiny marine animals and plants. Coral polyps are the main reef builders. These tiny animals feed on microscopic plankton and even some small fish. Calcium carbonate is produced by much of the coral, and over time becomes limestone.

Coral cannot grow above sea level and due to its need for sunlight, rarely grows below 120 m below the ocean surface where the light levels are significantly less. They grow very slowly, at an average of 2 cm in diameter and up to 25 cm in height per year.

6.2 Fringing reef

Fringing coral reefs are attached to the shore and are typically only found in the tropical north of Australia. Prime examples of fringing coastal reefs are the Ningaloo coast in the Kimberley, and some in the Northern Territory and eastern Cape York Peninsula.

The beaches are usually steep and composed of coarse coral fragments. The reef flats can range from 30 m to 2000 m in width. Once the reef grows up to sea level, they prevent the waves from reaching the beach except at high tide. This means the reef is exposed most of the time.

6.3 Barrier reef

Barrier reefs, such as the Great Barrier Reef in tropical Queensland, are separated from the shore by a deep channel. They form along the edge of the continental shelf. In some places, the reefs grow high and form narrow walls.

Case study: Ningaloo Reef

Ningaloo Reef extends almost 300 km along the coast of central Western Australia, forming a near-continuous fringing coral-reef system. Listed as part of the Ningaloo Coast World Heritage Area in June 2011, it is the largest fringing reef in Australia and the only example in the world of a fringing reef located along the west coast of a continent.

The reef forms here because, unlike other continental west-coast currents, the Leeuwin Current feeds warm tropical waters southwards onto the narrow continental shelf. In places, the reef is only 200 m from the shore, which, along with the shallow lagoon, provides an accessible amenity for tourism (particularly ecotourism activities like watching whale sharks come to feed at times of coral spawning).

Case study: Great Barrier Reef

At 2300 km long, the Great Barrier Reef is the largest coral reef system in the world. It is harbours one of the most complex and diverse ecosystems in the world. The reef we see today is no more than 8000 years old, though there were coral reefs along the continental shelf 20 000 years ago.

For most of this length, the reef is not visible from the mainland. Being so far from the shore, it is mostly protected from anthropogenic activities, leaving many parts of the reef in pristine condition. In the 150 years since townships have been built near the reef, inflow of sediment has increased four to five times.

‘The reef itself is also a major driver of economic activity. For example, during 2007, reef tourism generated AUS $5B, compared with AUS $140M by the long-established fishing industry. Although reef tourism is big business, the perception of the coast is still largely framed by its utility for recreational fishing. The clear-water outer reefs sit tens of kilometres offshore; there are no true surfing beaches; and, during the wet season, swimming is dangerous due to the presence of highly venomous jellyfish.’ (Shaping a Nation, Chapter 6.)

The health of the coast is closely tied to the state of the Great Barrier Reef. Water flowing out to the reef flows through coastal habitats. Not only are these coastal habitats important feeding and breeding grounds for marine species, they also trap and filter sediment and nutrients from water entering the reef. Over time, these coastal habitats are being infilled, modified or cleared.

Various authorities, both Federal and State, have established policies and processes for the long-term management of the reef. These include policies on restrictions on tourism, mooring of boats and ships, sewage disposal and fishing.

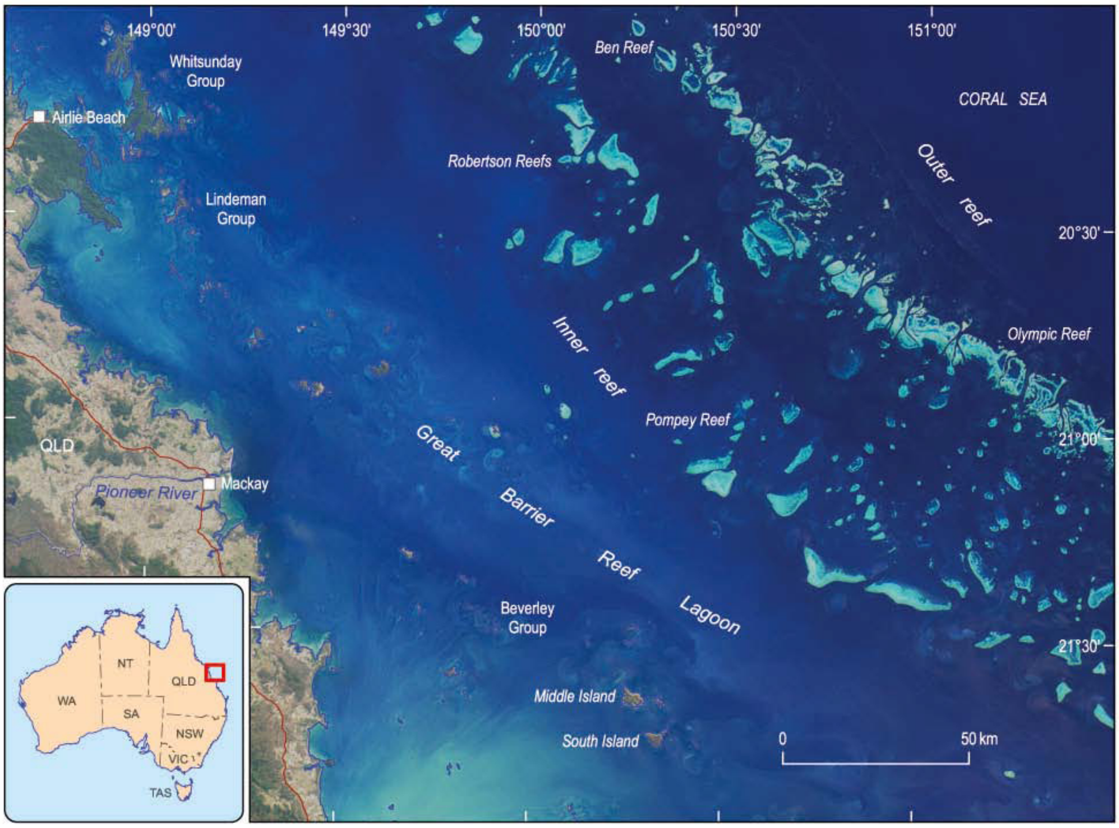


Figure 6.1: Satellite image of the southern part of the Great Barrier Reef, highlighting numerous reefs and shoals and the lagoon used for shipping. (Source: NASA)

7 Sea level changes

7.1 Natural changes in sea level

The height of the sea changes significantly over long periods of time. Sea level change is produced by both **plate tectonics** and by changes in climate.

As tectonic plates slowly move they change the shape, area and volume of the ocean basins, resulting in more or less space being available for seawater. These changes cause sea levels to rise and fall.

A similar situation occurs when the climate warms and cools. The cooler conditions give rise to ice ages or glacial periods; water locked up in ice sheets cannot replenish the oceans and the sea levels drop. When the climate is warmer, the ice melts, leading to higher sea levels.

During the recent glaciation, large ice sheets accumulated in North America, Greenland, northern Europe and at the poles. The associated drop in sea level was as much as 120 metres. The ice sheets melted and the sea level rose when the climate warmed. It has been calculated that this rise and fall has occurred more than 20 times in the past two million years. If the current ice sheets on Antarctica and Greenland were to melt, the sea level could rise by 90 metres.

The last major rise in sea level began 18 000 years ago marking the end of the last ice age. Rising at an average rate of 1.1 metres each century, the sea reached its present level about 6500 years ago (Figure 7.1). The current position of the Australian coast is relatively new. In many places the coastal zone is still adjusting to the flooding of the **continental shelf**.

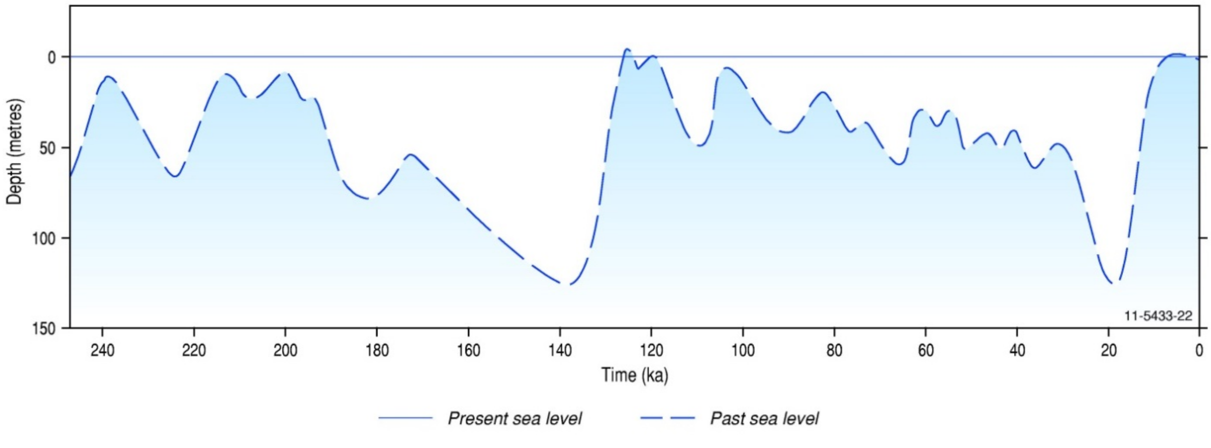


Figure 7.1: A plot of sea level over the past 240 000 years, showing the regular rises and falls. Note the last major rise of 120 metres between 18 000 and 6500 years ago. The unit 'ka' on the x axis is a thousand years. Source: Geoscience Australia

At the continental scale, the last rise in sea level resulted in:

- the flooding of Torres and Bass straits, isolating mainland Australia from New Guinea and Tasmania
- the formation of the shallow Queensland shelf to provide the broad shallow platform for growth of the Great Barrier Reef
- the creation of every coastal bay and valley, e.g., Port Phillip Bay and Sydney Harbour.

As the sea level rose, waves and tides delivered sand to the coast, which helped build beaches, provided sediment to backing dunes and partially filled in estuaries.

Note: At a local or regional scale the height of the land (and relative height of the sea and coastal position) may also be affected by:

- crustal loading by lava, sediment or ice sheets causing the crust to 'lower'
- erosion of rocks or melting of ice sheets which removes mass from parts of the crust, allowing it to 'rebound' upwards (this is known as isostacy, where there is equilibrium in the earth's lithosphere as it 'floats' on the mantle).

Old beach and dune systems inland provide strong evidence for high sea levels in the past. The largest dune system in Australia is the ancient Murravian Gulf covering present day southeast South Australia, western Victoria and south western New South Wales (Figure 7.2). Waves from the Southern Ocean built long barriers in the Murravian Gulf, similar to the 200 kilometre long modern Coorong barrier in South Australia. At the same time, tectonic activity associated with the Mount Gambier volcanic area has been slowly uplifting the entire gulf, so that each barrier system is increasingly stranded increasingly further inland. Today more than 20 major barriers exist, extending up to 400 kilometres inland in the Murravian Gulf.

Today, factors which affect sea level include tides, storm surges and even regional tectonics. Over the past 6000 years, the overall global sea level has fallen a metre or two, but there is evidence to suggest that this trend is being reversed by changes in the Earth's climate.

Figure 7.2: The Murravian Gulf has been filled with successive sand barriers (dashed lines) over the past five million years, each representing a former shoreline. They have in part been preserved by the gradual uplift of the gulf. Source: Geoscience Australia, adapted from Short and Woodroffe, 2009.

7.2 Impact of climate change on sea level and the coast

Since the 1960s, an increase in carbon dioxide (CO_2) and other greenhouse gas emissions has led to the mean temperature in Australia rising by about 0.7 ˚C. Based on modelling of the likely impact of the gases and associated temperature rises, the sea level is predicted to rise by several centimetres by 2110. This prediction is attributed to two key factors, the thermal expansion of ocean surface waters (as ocean water warms it will also expand) and the increase in available water as a result of melting glaciers and ice sheets.

Sea level rise will have its greatest affect in low-lying areas, which include parts of some towns and cities, coastal rivers, floodplains, estuaries, wetlands, coastal lakes and tidal flats and rich delta agricultural land (Figure 7.3a). These areas are likely to experience changes such as:

- a retreat of shorelines inland
- saltwater intrusion into freshwater environments
- increased oceanic influence (greater tide and wave impacts) which could deepen estuaries and make them more salty
- ecosystems being affected as habitats are flooded, destroyed or moved inland
- potential migration of tide-dependent salt marshes, mangroves and sea grasses (if space is available to move)
- coral reefs drowning or growing upwards to keep up with the rise in sea water level.

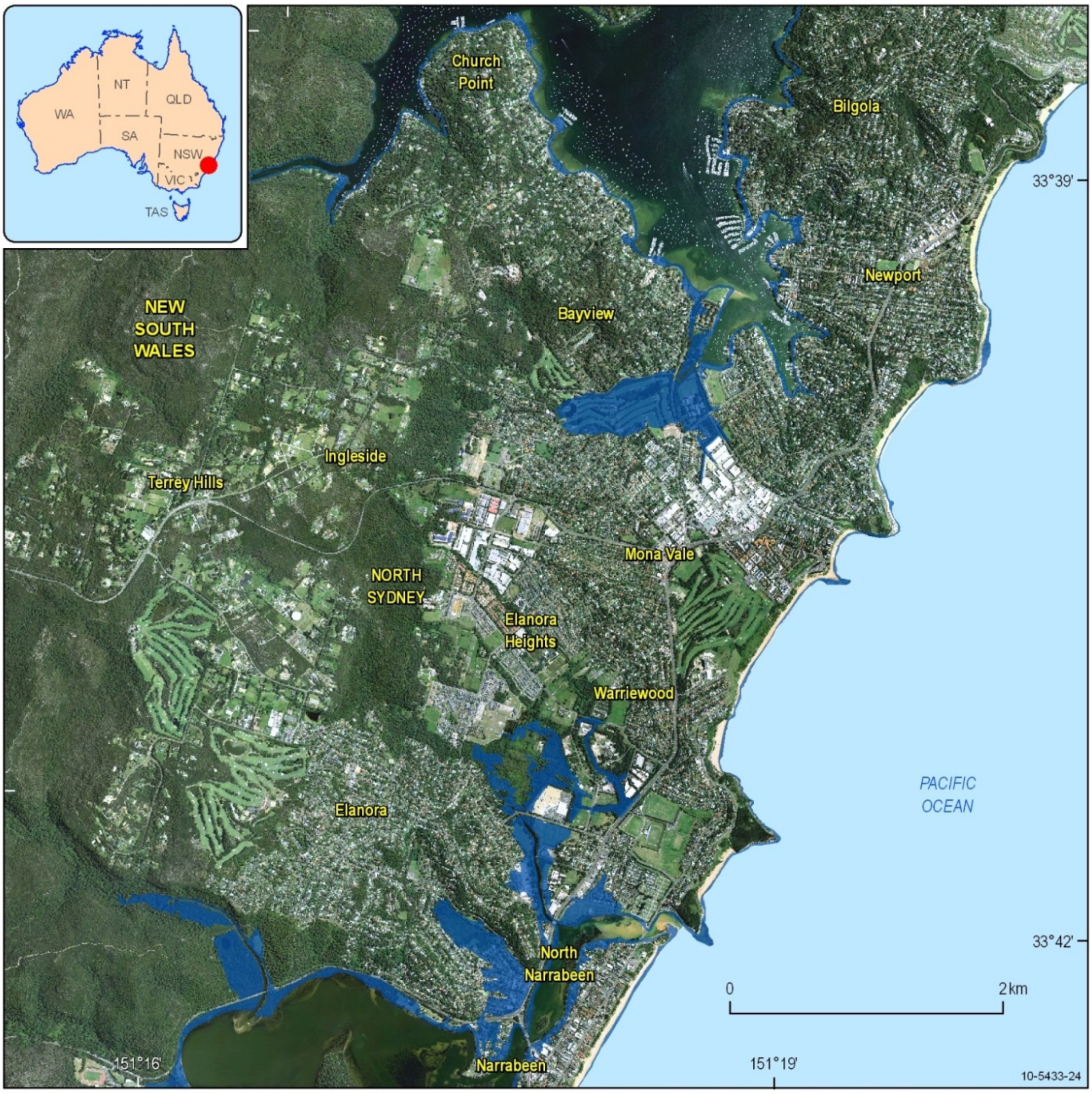
It is estimated that a one metre rise in sea level around the world would affect about one billion people who live in low-lying coastal areas. In addition to sea level rise, it is predicted that tropical cyclones in Australia will become more intense and track further south. This predicted change is expected to result in variations to wave activity and lead to adjustments to shoreline sediment systems.

Figure 7.3: These images illustrate some of the issues that may arise from climate-change induced sea level rises. a) Beach erosion at Old Bar (NSW) is threatening houses and resorts, b) rock seawall at West Beach (Adelaide, SA) protects the road but degrades beach amenity and safety, and c) beach sand nourishment (pumping sand onto the beach) at Greenmount (Qld), resulted in a 100 metre wide beach. Source: Photographs by A D Short.

Most Australian beaches are undeveloped or isolated and will not require human intervention to address sea level changes. However, on hundreds of developed beaches, human intervention may be necessary to protect houses and infrastructure at risk (Figure 7.4). On these beaches, any response to the predicted changes will depend on the level of impact. Choices include:

- nourishing with sand to maintain the beach and protect adjacent infrastructure (Figure 7.3c)
- doing nothing and letting the beaches erode
- letting the beaches retreat and seeing how far they retreat
- defending cities with seawalls but considering whether this will lead to the beach being degraded (Figure 7.3b).

Steep rocky coastlines would be relatively safe from inundation, but may suffer from faster cliff erosion as they become more exposed to wave energy.



Source: Geoscience Australia

2.2m Australian Height Datum

Figure 7.4: View of Sydney's northern beaches depicting how a one metre rise in sea level could inundate low-lying estuarine areas (dark blue) more than the steeper open coast using computer modelling. Source: Geoscience Australia

Activity: Sea Change at Bayside.

8 Impact of human activity on coasts

Australia was settled by Europeans in 1788. Since that time the population has remained concentrated around the coast. This is partly because the coastal zone was the site of all early settlements. Australia's coastline has been an excellent site for developers as choice real estate is located within a close proximity to spectacular coastal views.

Many early settlements in Australia were located on estuaries, which provided ready access to safe anchorage and freshwater. These settlements subsequently became the sites of most major cities and towns and the estuaries were developed as ports for industry and transport. Eventually, the housing and the population's various recreational activities resulted in:

- and clearing
- estuary reclamation (Figure 8.1)
- accelerated sediment run-off
- pollution
- the introduction of exotic plant and animal species, including marine pests.

Of Australia's more than 900 larger estuaries, 17 per cent are classified as modified and 11 per cent as severely modified (as of 2001). In addition, away from urban areas, the rich estuarine and delta floodplains have become the site of intense agriculture, particularly in Tasmania, Queensland, the north coast of New South Wales and southwest Western Australia.

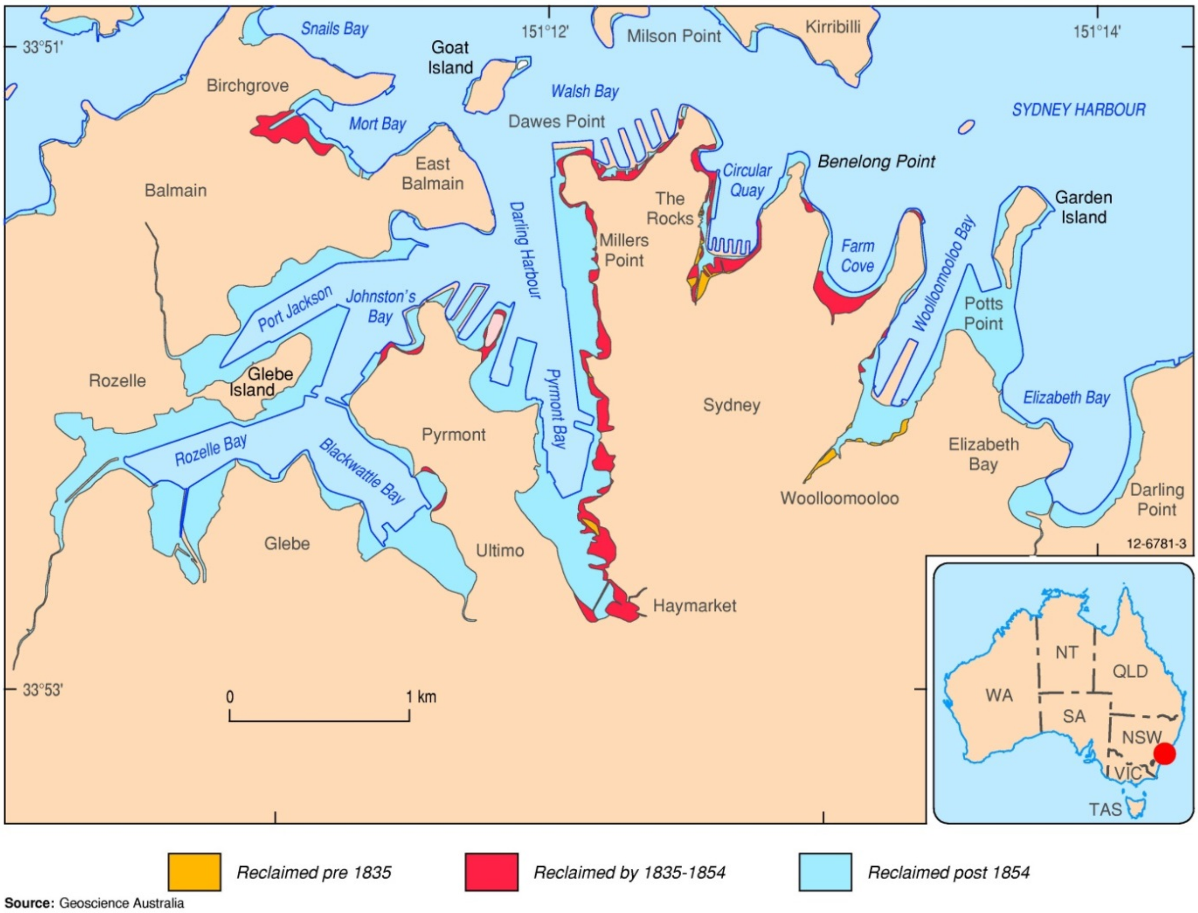


Figure 8.1: Land reclamation in Sydney Harbour around the central business district has linked Garden Island to the mainland and includes extensive areas of Glebe Island, Darling Harbour and Wooloomooloo. Source: Geoscience Australia, adapted from Birch et al. 2009.

8.1 Human modified estuaries

Estuaries around Australia have been studied and classified according to their environmental conditions, taking into account the degree to which they have been modified or the impact of changes since European settlement. They can be loosely classified as either near pristine or heavily modified estuaries.

8.1.1 Near pristine estuaries

An estuary is classified as being near pristine if it has the following characteristics:

- a high proportion of natural vegetation cover in its catchment
- minimal changes to stream flow in the catchment
- no intervention to the tidal system
- minimal disturbance from catchment land use
- minimal changes to floodplain and estuary ecology
- low impact from human use of the estuary
- minimal impact from pests and weeds.

It is important to have near pristine estuaries because they are necessary for the conservation of marine species, terrestrial communities and ecosystems. They provide a well-preserved habitat for plants and animals and a breeding site for many migratory animals. These environments often support fishing and recreational activities. Near-pristine estuaries provide a standard from which all other estuaries can be graded. Fifty per cent of Australian estuaries have been identified as being near pristine.

A survey by Geoscience Australia found that most of Australia's near pristine estuaries are located in tropical northern Australia and temperate western Tasmania, away from population centres. However, they are found also in developed areas of Australia within, or near to, National and State parks.

8.1.2 Heavily modified estuaries

To be defined as a heavily modified estuary, the system must be physically altered by human activity resulting in a substantial change in character. The modifications are not temporary nor intermittent. Modifications include changing the flow of the river, building of dikes, introduction of foreign plants and animals, and lowered water quality by the addition of wastes.

8.2 'Sea change' population movements

For many years beaches and dunes were considered worthless land unsuitable for agriculture or grazing because of the low fertility of the sandy soil and extensive low-lying areas prone to flooding. Small coastal communities usually developed around estuary-based ports, which were used for shipping and transport until the 1950s.

Road improvements and increased vehicle ownership resulted in more people travelling to and along the coast for recreation, usually camping or staying in caravan parks. Since the 1960s there has been a sea change shift as many people began retiring on the coast and the former coastal ports became holiday destinations. In addition, a buoyant economy, which has driven the rapid growth of industries and services, has led to a rapid expansion of most coastal cities and regional towns. The resulting population growth is placing huge pressure on communities, coastal resources and environmental health.

A major concern about this population shift is the lateral spread of communities along the coastal zone, which is known as ribbon development. This form of development can lead to cities or towns becoming over-extended, making them difficult to manage and service, and can lead to degradation of the coastal environment.

Building on fore-dunes and headlands is risky because the beach or dunes can erode and headlands can collapse, which could inevitably ruin the coast's visual appeal (Figure 8.2). To avoid this situation, new developments need to be built behind the fore-dune and away from cliffs, with an additional buffer zone in case of future inundation and erosion.

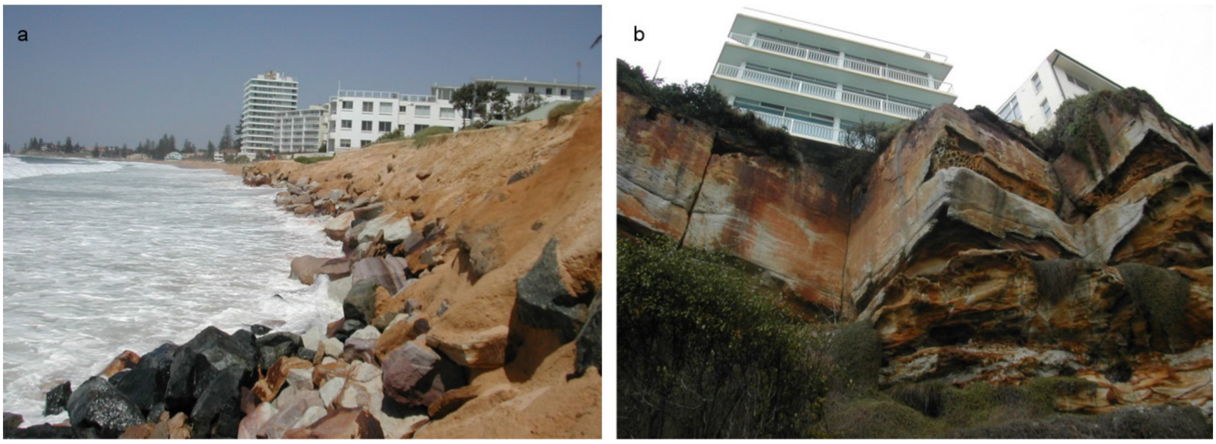


Figure 8.2: a) Houses and high-rise apartments built on the beach and fore-dune at Collaroy (NSW) are now protected by a rock seawall, and b) cliff top high rise apartments hang over the eroding cliff at Queenscliff (NSW). Source: Photographs by A D Short.

Increased discharge of contaminated stormwater, sewerage and sediment into the sea has accompanied land clearing and new development along the coastal fringe. This problem can be mitigated by stronger management of building sites, control of stormwater by sedimentation tanks and storage, and recycling or treatment of all sewerage before it is released on the coast (Figure 8.3).

Figure 8.3: Storm water outlet on the beach at Wynyard. Source: Real Tasmania website, photograph by bandi, 2010.

The introduction of exotic flora and fauna is a major concern. In eastern Australia, the South African Bitou bush has invaded fore-dunes, while beach weeds such as sea spurge and sea wheat grass have invaded fore-dunes across southern Australia. These weeds replace native species and have an impact on fauna. In the case of the Bitou bush it can lead to more unstable dune systems, making them prone to wind erosion. Bitou has been called the 'cane toad of the dunes'. Physical removal, aerial spraying and the introduction of a moth to attack the Bitou seeds are being used to combat the proliferation of the bush.

One of the most noticeable impacts at the shoreline has been the construction of structures designed to manage the coast, sometimes with un-intended negative consequences. For example, in New South Wales 22 training walls of rock were built during the 1970s at the mouth of rivers and some estuaries to improve navigation. Some training walls, such as those at the Tweed River and Brunswick River, severely disrupted longshore sand transport. This led to erosion down drift from the training walls on Queensland's Gold Coast beaches north of the Tweed River and the complete erosion of the Sheltering Palms community at Brunswick. This phenomenon also occurred at Glenelg (SA) (Figure 8.4) and at the Peel Estuary (WA) (Figure 5.11).

Seawalls are rock or concrete structures built along many beaches where erosion has threatened property. If exposed on the beach they can be a hazard to the public and can lead to accelerated erosion when waves break against them. In some cases, they are considered to be an eyesore. Where the seawalls are built further back and covered by dunes, particularly in combination with **beach nourishment** (adding sand), they act as a retaining wall in case of severe erosion. Examples of this can be found along Queensland's Gold Coast beaches.

Figure 8.4: The heavily modified mouth of the Patawalonga River, Glenelg (SA) has a barrage to stop saltwater intrusion, two training walls for navigation, a detached breakwater to trap sand and a permanent dredge to pump sand north across the river mouth. Note the offset in the beach between the southern (right side of image) and northern side. Source: Photograph by S Daw.

Groynes are timber or rock structures built as fingers at right-angles to the shore and extending into the surf. They are designed to reduce longshore drift of sand and trap sand against the up-drift side of the groyne. However, while sand is trapped on one side it is eroded from the down-drift side, resulting in re-alignment of the beach (Figure 8.5). A single groyne can be useful in certain locations when used as an artificial headland to realign a beach. However, a series of groynes, which is termed a **groyne field**, can exacerbate beach erosion because they generate rip currents against the structure. This results in sand being transported offshore where it may be lost or transported along the coast at faster rates.

Figure 8.5: Eroding bluffs, a low wooden groyne and rock seawall at Ardrossan (SA). Note the offset in the shoreline owing to the groyne. Source: Photograph A D Short.

Breakwaters are rock structures built parallel to the shore to reduce the impact of waves on the coast. In Australia they are usually attached to the shore and built in association with ports to provide a quieter and safer anchorage. They are more common in parts of Queensland, South Australia and Western Australia (Figure 8.6) where estuaries with natural anchorage are few. A type of submerged breakwater, called a **surfing reef**, is designed to produce a good surfing break, as at Cable Beach in Broome (WA) and Narrowneck on Queensland's Gold Coast.

Figure 8.6: Fremantle (WA) has both training walls at the Swan River mouth (left) and an attached breakwater sheltering the anchorage at Challenger Harbour (right). Source: Photograph by A D Short.

Some coastal areas have undergone development for their natural resources. **Sand mining**, for example, occurs along sandy coastlines to recover aggregate and minerals.

Aggregate mining of sand for the construction industry removes the sand and leaves a hole, as at Kurnell in Sydney and Beachmere in northern Moreton Bay. Mining usually occurs in the backing dunes rather than the beach.

Heavy mineral mining removes the grains made of heavy minerals (such as rutile, ilmenite, zircon, monazite), which is usually less than two per cent of the sand. The remaining sand is then returned and is reshaped and covered with topsoil and new vegetation to resemble the original landscape. This occurs on North Stradbroke Island (Qld), the last remaining mine on the east coast (Figure 8.7).

There was considerable mining activity of these heavy minerals in eastern Australia up until the 1980s, but this was stopped in most locations for environmental reasons.

Rutile is a form of titanium dioxide. In its native form it can be used in white pigments for paints and ceramics. Once processed, titanium metal can be used for the building of aircraft.

From zircon we can retrieve zirconium, an element with a high melting point which is applied as a coating in foundries and nuclear reactors.

Ilmenite is a titanium-iron oxide which can also be made into a white pigment for use in ceramics, textile, paint and dental applications.

Monazite contains radioactive elements which can be used in the nuclear industry.

Figure 8.7: Floating dredge in a heavy mineral sand mine near Seal Rocks (NSW) extracting sand from Pleistocene sand dunes. This mine no longer operates. Source: Photograph by A D Short.

Beach nourishment involves bringing sand from an external source to build up a beach. This has only been applied on a large scale on the Queensland Gold Coast and metropolitan beaches in Adelaide. With predictions of rising sea level threatening many more developed beaches it is likely beach nourishment will be used increasingly around the Australian coast. Sydney coastal councils have joined forces to investigate the use of beach nourishment to maintain the city's beaches and protect shore front properties.

While the effect on our coastlines by humans has been detrimental, the recent development of coastal policies and coastal management plans by governments has resulted in a more responsible approach to coastal management and development such as:

- treatment of sewerage before it is pumped into estuaries and oceans
- environmental impact assessments undertaken before building
- sand mining areas reshaped and revegetated to mimic their original environment
- more national parks and marine parks established
- local communities more engaged in managing the coast in their area.

Activity: Resort Impacts.

9 Case study: Development of the Gold Coast

The Gold Coast in Queensland continues to be one of the fastest growing areas in Australia and has become the country's sixth largest city, overtaking Hobart and Canberra. A building boom which initially spread along the beaches and dunes (Figure 9.1) and extended inland accompanied this rapid growth in population. In the development process, canal estates, shopping centres and tourist accommodation and entertainment centres were built on what previously were dunes and a coastal swampland.

Figure 9.1: The Gold Coast is among the most intensively developed section of the Australian coast. Source: Wikimedia commons, photograph by E-CDB January 10, 2006.

The rapid growth and development of the Gold Coast has led to loss and damage of much of the environment and ecosystems in the area. This is largely a result of development, which have stripped the beaches and dunes, the backing swamp and the hinterland regions.

This section provides you with a comprehensive case study of coastal development issues on the Queensland Gold Coast. It also provides examples of how more balanced approaches can help sustainably manage coastal regions.

9.1 Location

The Gold Coast is located 65 kilometres southeast of Brisbane and extends from Southport in the north for 32 kilometres south to Coolangatta on the New South Wales border.

9.2 History

Between 1842 and 1889 the area was mainly used for logging and cattle grazing, with slow development during the late 19th and early 20th centuries. By the 1950s there were a few hotels, shops, holiday houses, cafes and camping grounds accompanied by a slow expansion of housing estates and a population of 20 000. After World War II expansion increased with a land sales boom in the area, and the first motel opened in 1949. The settlement was renamed the Gold Coast in 1958 and in the 1960s, when high-rise construction started, the area was increasingly marketed for interstate and later international tourism. The population more than doubled to 53 000 by 1967, reaching 375 000 in 1996 and 527 000 in 2011. Neighbouring Tweed Heads adds to the overall population in the region with a total of 90 000 residents in 2011.

9.3 Geomorphology

The Gold Coast consists of four headland bound beaches (Figure 9.2) backed by low dunes. In the past, the beaches were backed by high dunes and wide swampy areas leading to the rugged hinterland of the McPherson Range which rises to 500 metres.

The Nerang River drains the northern half of the coast and has been deflected northward to enter the sea at the now engineered Nerang entrance. Tallebudgera and Currumbin creeks drain the southern half of the Gold Coast and flow out against headlands and the larger Tweed River just south of the New South Wales and Queensland border. Rocky basaltic headlands and platforms occur between the headlands and beaches at Miami, Burleigh, Currumbin, Greenmount and Point Danger.

The persistent southerly waves set up a strong northwards longshore drift and has transported sand along the New South Wales north coast, across the Tweed River mouth and around Point Danger to supply the Gold Coast beaches. This northerly movement of sand throughout the Quaternary Period (past two million years) has supplied all the Gold Coast beaches and further north has built the large sand deposits of Stradbroke, Moreton, Bribie, Cooloola and Fraser Islands.

Figure 9.2: The Gold Coast, which extends from the Nerang River Entrance to Tweed Heads. Note the long beaches, northward deflection of the Nerang River and extensive canal estates in the former swampland. Source: Geoscience Australia

9.4 Canal estates development

The initial Gold Coast development was restricted to the dunes, a 200 to 700 metre wide strip of elevated land. This led to the present elongated coastal development, which intruded onto the fore-dune and even the beach and grew in height with the 320 metre high Q1 at Surfers Paradise being among Australia's tallest buildings. Following development of the elevated dunes, attention turned to the 0.5 to 7.5 kilometre wide swampland. Beginning in 1957, these swamplands were transformed into a series of interlinked canal estates up to five kilometres wide and extending about 50 kilometres between Sanctuary Cove and Palm Beach. These estates greatly increased the land available for housing, most with waterfrontages that dominate much of the Gold Coast landscape (Figure 9.3). To the west of the swampland the higher hinterland has been developed for industrial estates, the main north-south transport corridor and residential areas.

Figure 9.3: Canal estates have transformed the former swamp land into waterfront residential areas, shown here at Broadbeach. Source: Geoscience Australia

However, development of the canal estates has resulted in a number of environmental problems such as hindrance to wildlife, poor water quality and algae blooms. This occurred when the former swamps were dredged and sulphuric acid was released from the soil. The acid entered the canals, rivers and creeks causing harm to fish and other marine organisms. Because of the canals poor water circulation, the new inputs of fertilisers and the urban run-off from the estates contaminated the water.

As well as the effects on wildlife and the environment, the development of the canal estates has had an impact on the livelihoods of residents and on infrastructure; their low-lying nature and poor drainage makes them prone to flooding and vulnerable to sea level rise.

9.5 Dune management

Severe beach erosion was recorded as early as 1894 and became a major issue in 1967 when a series of 11 major cyclones eroded the beach and placed property and roads at risk. In response, the Gold Coast City Council commissioned the Dutch Delft Hydraulic Laboratory to undertake a comprehensive study of the Gold Coast beaches to evaluate its issues and develop possible solutions.

A number of projects were undertaken to ensure the long-term future of the beaches. These included:

- building a retaining seawall the length of the Gold Coast during the 1970s to permanently protect roads and property against further erosion (Figure 9.4a)
- covering the seawall with a vegetated dune to trap wind-blown sand and provide a backdrop to the beach as well as controlling pedestrian traffic with fencing (Figure 9.4b)
- undertaking beach nourishment to widen the beach, initially by pumping sand from the Tweed River dredging it from offshore then pumping it from Letitia Spit on the southern side of the Tweed River in New South Wales (Figure 9.4a and b)
- changing the previously shifting mouth of the Nerang River entrance with construction of two training walls and installation of a permanent system to pump sand from under the Nerang River entrance to South Stradbroke Island
- constructing a submerged surfing reef at Narrowneck to protect and widen the beach.

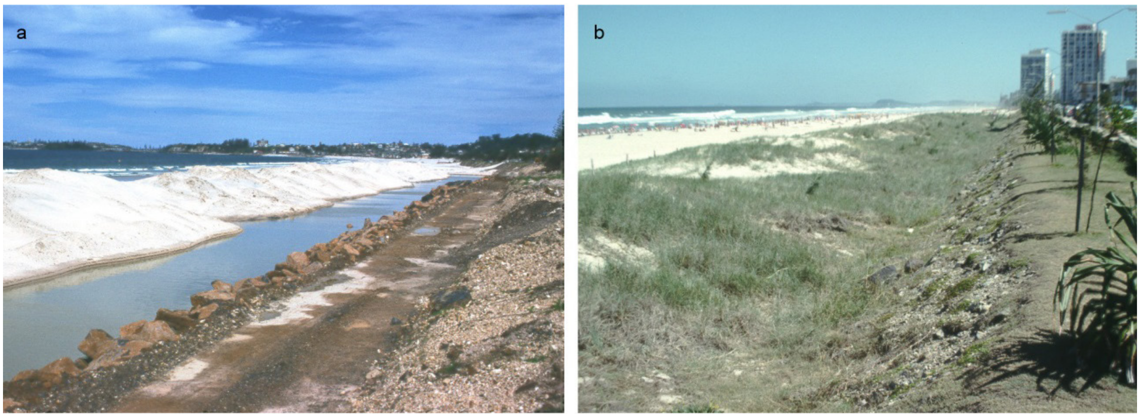


Figure 9.4: a) Construction of the terminal seawall in 1979. The wall extends the full length of the Gold Coast, and b) the seawall is now fronted by a nourished beach and fore-dune and usually is covered by sand and vegetation. Source: Photographs by A D Short.

In an effort to reduce beach erosion on the Gold Coast, a major sand pumping system has been established. Sand is pumped from Letitia Spit on the southern side of the mouth of the Tweed River at a rate of about 500 000 cubic metres a year to beaches on the northern side of the river (Figure 9.5). This sand is then allowed to move naturally northward along the coast to retain the natural flow of sand and form the beaches. The initial pumping resulted in a large accumulation of sand between Snapper Rocks and Kirra which produced the famous Superbank surf break, but smothered the equally famous Kirra surf break. However, as the sand continues to move northwards, both areas can return to a more natural state.

A wider beach and fore-dune act as a sand store, which, during periods of high waves (generated by cyclones and storms) can be eroded with the retaining seawall acting as a last line of defence. Following any cyclone and storm erosion, the sand can be returned to the beaches by beach nourishment and by fore-dune reconstruction.

Source: Geoscience Australia

Figure 9.5: a) View towards the trained Tweed River mouth and the Letitia Spit sand pumping jetty. b) The Tweed River Mouth sand by-passing system pumps sand from the southern (NSW) side of the entrance to outlets on the northern (Qld) side. Source: a) Photographs by A D Short, b) Geoscience Australia.

9.6 Beach use and management

Since the 1950s the Gold Coast beaches have been the major attraction, encouraging both national and international visitors to the area for recreational activities such as surfing, endurance swimming events and lifesaving contests. As the name suggests, the beaches are considered to be a true surfer's paradise.

With the regular influx of visitors, the local authorities and individual organisations have implemented programs to ensure the public safety on the stretch of beaches along what is a wave and rip-dominated stretch of shore. The beaches are patrolled by 21 surf lifesaving clubs and have a total of 30 lifeguard towers with many towers operating all year round (Figure 9.6). Signs providing advice on beach usage and safety are located at each beach entry point.

Figure 9.6: Beach safety on the Gold Coast involves lifeguard towers, surf clubs, mobile patrols, signage and lifeguard patrols all year round. Source: Photograph by A D Short.

Since 2000, video cameras have been used on beaches to observe wave and beach conditions and the position of the shoreline. This information is monitored through a central control panel at Burleigh Heads. Weekly reports on the width and condition of the beaches are compiled from the video surveillance to evaluate beach hazards and the risk to swimmers.

The Gold Coast beaches are considered to be the most actively managed in Australia.

Activity: Gold Coast – Case Study activity

Conclusion

The attraction of the Australian coast with its spectacular views and excellent surf, coupled with a long period of economic growth, has promoted significant development along the country's coastline. The Gold Coast provides an excellent example of rapid population growth and development on Australia's coasts. The appeal of the coastal city lifestyle is counteracted by the growing awareness of rising sea levels which could flood low-lying coastal areas. It is important, therefore, for all Australians to be educated about the natural processes of Australia's coastal systems and the fragile nature of their ecosystems. Education provides the foundation needed for well-informed coastal management and prevention of human-induced degradation to our coast. The Australian coast will continue to change and adapt, but it is important to be aware of how its ecosystems can be protected while also enjoying its beauty and appeal.

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Bureau of Meteorology: http://www.bom.gov.au/climate/change

BurleighCam Gold Coast Surf Report Queensland Australia: http://www.burleighcam.com.au

Coastal Watch: http://www.coastalwatch.com

CoastalCOMS Logo: http://www.coastalcoms.com

Geoscience Australia website: http://www.ga.gov.au

Gold Coast City Council: http://www.goldcoast.qld.gov.au

MESA – The Marine Education Society of Australasia: http://www.mesa.edu.au

OzCoasts Climate change: Sea level rise maps: http://www.ozcoasts.org.au/climate/sd_visual.jsp

OzCoasts website: http://www.ozcoasts.gov.au

The Sydney Coastal Councils Group website: http://www.sydneycoastalcouncils.com.au

Aerial photographs

Ballina to Coolangatta. May 1947. 15,000', SVY 122, Run 1, 401 and 402, K17
Tambourine. Nov 1966, 25,000', CAB 285, Run 2A, 92 and 93, RC9, Adastraphoto
Tweed Heads. Nov 1966. 25.000', CABC 1, Run 4, 26, RC9, Adastraphoto
Tweed Heads Nth to Springbrook. August 1930. 15,000', Run 17AN, 02699.

Have you visited Geoscience Australia's website?

www.ga.gov.au/education

Glossary

Anthropogenic	Caused or created by human activity.
Back-dune	A dune that is behind the fore-dune.
Backwash	Water flowing back down the beach face after a wave has broken on shore.
Bar	A bank of beach sediment which is submerged for at least part of the tidal cycle. They may extend right along the beach or they may be discontinuous.
Barrier	A bank of deposited beach sediment separating a coastal lagoon and estuary from the open ocean. Barriers may be continuous or broken into small chains.
Barrier estuary	A body of water which is partially enclosed by an elongated ridge of sediment that has been built up by wave action with one or more rivers flowing into it and with a free connection to the open ocean.
Beach	Sediment including sand, shingle, boulders and rocks which accumulate along the shore.
Beach nourishment	Bringing sand from an external source to build or replenish a beach.
Berm	A barrier or mound of sand constructed by wave action pushing and depositing sand on the shore.
Blowout	A hole created in the surface of a sand dune by wind.
Brackish	Slightly saline (salty) water.
Central basin	They are environments in the deeper and quieter parts of estuaries and often form on the shore side of barriers such as sand or rock bars. Sedimentary, central basins typically comprise poorly-sorted, organic-rich sub-tidal mud and sandy mud. There shallower margins often feature coarser sands which result from the action of wind waves and fluctuating water levels.
Coastal area	The area of land and water between the shore and the inland limit of water penetration.
Coastal inland dune	Sand that has been carried inland by wind and deposited on the beach.
Continental shelf	The sub-marine margin of continental plates. The shelves have a shallow sea up to 200 metres deep followed by a gentle downward slope to the abyss.
Coral reef	An offshore platform of limestone rock, which is made up primarily of skeletons of tiny marine organisms, called coral polyps, and lung corals.
Currents	Movement of part of the large water body in response to prevailing winds, waves, tides, freshwater, salinity and temperature.
Delta	The low-lying area found at the mouth of a river formed after sediments have been deposited.
Ebb tide delta	An inter-tidal or sub-tidal bar or shoal, typically triangular or lobate, formed on the outer or seaward side of a tidal inlet or river channel or gap between barrier islands.
Ecosystem(s)	The complex system of plants, animals, and communities of organisms interacting with their environment.

Erosion	The process of wearing away rocks and soil and their transportation to other locations.
Estuary	A semi-enclosed coastal body of water where salt water from the ocean mixes with freshwater draining from the land.
Flood tide delta	An inter-tidal or sub-tidal bar or shoal, typically triangular or lobate, formed on the inner side of a tidal inlet or river channel or gap between barrier islands.
Floodplain	An area of flat land on either side of a river channel. It is formed from the deposition of unconsolidated sediments during flood events. May experience occasional to frequent flooding and is scarred by older river channels creating features such as meander scrolls and oxbow lakes.
Fluvial delta	A delta formed by the deposition of sediment at the mouth of a river where that river flows into an estuary, lake or reservoir.
Fore-dune	A coastal dune or ridge that is parallel to the shoreline of the ocean and generally stabilised by vegetation.
Geomorphic	Relating to or resembling the Earth's surface landforms. See geomorphology.
Geomorphology	Characteristics, origin and development of landforms.
Groyne	A shore protection structure built perpendicular to the shore which is designed to trap sediment.
Homogenous	Rock that is composed of the same properties.
Inundation	The flooding of land not normally submerged.
Incipient fore-dune	A ridge of dune running parallel to the shore of a water body, on the vegetated part of the shore.
Lagoon	An estuary totally or partially enclosed by a spit or barrier island.
Lee	The side of an object which is sheltered from wind or waves.
Lithology	Structure, composition, hardness and texture of a rock.
Longshore Transport	The movement of sediment parallel to the shore (also referred to as longshore drift).
Mangroves	Mangroves consist of trees and shrubs which grow along sheltered inter-tidal shores, particularly in tropical regions.
Near-shore zone	The zone extending seaward from the surf zone from where waves begin to break to the wave base, typically at water depths of 20 to 30 metres.
Oceanographic	relating to the scientific study of oceans. See Oceanography.
Oceanography	The scientific study of the oceans, their physical characteristics and the life which exists within them.
Open coast	Section of coastline which is exposed to the open ocean and subsequent wave energy.
Parabolic dune	A dune with a curved nose of spilling sand advancing landward with trailing, roughly parallel, arms of partly vegetated sand. Formed or maintained by wind moving the fine sand and strong onshore winds. Formed as blowouts and migrate inland.
Plate tectonics	The theory that Earth's lithosphere is broken into plates which move in relation to one another, shifting continents and stimulating earthquakes and volcanic eruptions.

Rampart	A rock structure formed by wave erosion located at the sea-ward portion of a shore platform. Their form varies depending on the rock type and structure.
Refract	The process by which the direction of a wave that is approaching the shore changes as it moves into shallow water.
Regressive barrier	An elongate ridge of sediment built up by wave action, tides and Aeolian (wind) processes that is mitigating or mitigated seaward as sea level have fallen.
Ribbon development	The development of buildings and communities along the coast in a linear progression.
Rip currents	A strong surface current flowing out to sea from the shore.
Rip-feeder currents	The currents which flow parallel to the shore before meeting and turning seaward to form the neck of a rip current.

Rock platform (shore platform)

A flat or gently sloping smooth rock surface formed in the zone between high and low tide levels.

Run-off	The flow across the land surface of water which accumulates on the surface when the rainfall rate exceeds the infiltration capacity of the soil.
Salt crystallising	Type of mechanical weathering whereby salt crystals left in rocks by evaporated salt water grows and forces apart crevices.
Salt flats	A flat area of salt left by the total evaporation of water from land which was previously subject to occasional tidal flooding.
Salt marsh	A community of plants and animals which grow along coastal rivers and are on the edge of lakes, seas, oceans and canals.
Sea change	The movement of people from inland areas to take up residence on the coast.
Sediment budget	The balance of the sediment volume which comes and goes from a particular section of an estuary or coast.
Shoal	To move from deep water towards more shallow water. A shoaling effect is when a wave increases in height as it enters shallow water.
Shore	Land along the edge of the sea, usually between the high and low tide marks.
Shoreline	Where the water and land meet.
Spit	A beach which branches from the coast and may end in a landward projection.
Surf zone	This zone extends from the shoreline to where waves break.
Swash	The movement of water and sediment onto a beach after the wave has broken.
Swash zone	The zone extending from the upper limit of swash to the shoreline and includes the upper-horizontal, usually dry, berm and the sloping beachface where waves run up and down the beach as swash.
Thermal expansion	The tendency of matter to expand as it heats.
Tidal bank	Elongated sandy sediment shoals near the mouth of macro-tidal dominated estuaries or on the seafloor. Generally aligned parallel to the dominant tidal direction. In an estuary, the shoals represent the initial site of deposition from the channel and may be exposed at low tide.

Tidal delta	An inter-tidal or sub-tidal bar or shoal formed through the deposition of sediment on both the inner (flood delta) and outer (ebb delta) side of a tidal inlet. It is formed primarily by changing tidal currents that sweep in and out of the inlet. Triangular or lobate and commonly composed of sand.
Tidal limit	This is the furthest point upstream that a tidal variation in water can be observed.
Tide	Movement of the water in seas and oceans which is caused by the gravitational effects of the moon and the sun in relation to the Earth.
Trade winds	The winds which blow from the sub-tropical belts of high pressure towards the equatorial region of low pressure, from the northeast in the northern hemisphere and from the southeast in the southern hemisphere.
Transgressive dune	Low relief sand dunes which are actively migrating landwards because of onshore wind action. Generally, unstable with sparse vegetation and active blowouts.
Transverse dune	Bare sand dunes which are aligned crossways to the prevailing wind direction. Asymmetrical in shape with the windward slope a lower slope that the downwind slope.
Wave	Ripples formed on the surface of water produced by winds blowing over a waterbody.
Wave base	The depth at which waves begin to interact with the seabed and may mobilise sediment.
Wave quarrying	The erosion of blocks of rock by waves on a coastal platform.
Weathering	Breakdown of rocks and sediment on the Earth's surface as a result of chemical or mechanical means.

The Australian Coast –
Student activities

Dune Drifting

Recommended Age: Secondary

After searching in the local library, you have come across the original data of a 1920s survey conducted across the beach and dunes of South Racecourse Beach. This survey measured the height above sea level and the types of plants found across a 50 metre transect. Another group undertook a similar survey in 2011.

Using the data, construct cross sections of the profile of South Racecourse Beach - one for 1920 and another for 2011 – in the grids provided.

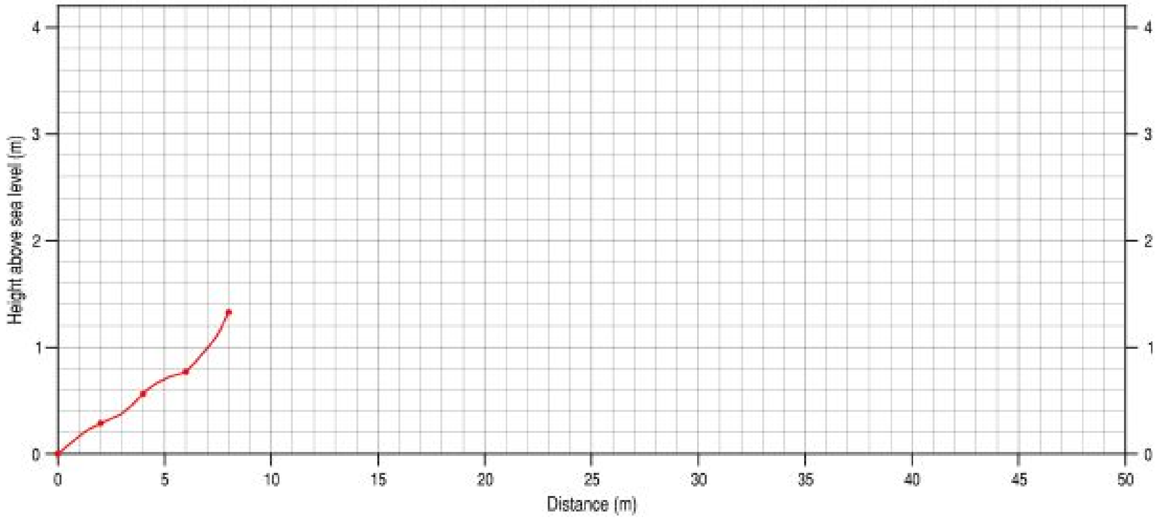
Data for Beach Profile – South Racecourse Beach, 1920

Distance (m)	Height above sea level (m)	Plant types
0	0	None
2	0.3	None
4	0.6	None
6	0.8	None
8	1.4	None
10	1.8	None
12	1.8	None
14	1.7	None
16	1.7	Spinifex grass
18	1.8	Spinifex grass, pennywort
20	2.1	Spinifex grass, pennywort
22	2.3	Spinifex grass, pennywort, pigface
24	2.1	Spinifex grass, pennywort, pigface
26	2.0	Spinifex grass, pennywort
28	2.4	Spinifex grass, pennywort, dune wattle
30	3.2	Spinifex grass, dune wattle, small tea tree
32	3.7	Spinifex grass, dune wattle, small tea tree
34	3.7	Spinifex grass, dune wattle, small tea tree
36	3.3	Dune wattle, small tea tree
38	2.8	Dune wattle, small acacia
40	2.3	Dune wattle, small tea tree, native geranium
42	2.5	Dune wattle, medium tea tree
44	2.8	Dune wattle, medium tea tree
46	2.7	Medium tea tree, small Banksia
48	2.4	Medium Banksia, medium tea tree
50	2.6	Medium Banksia, coastal gum

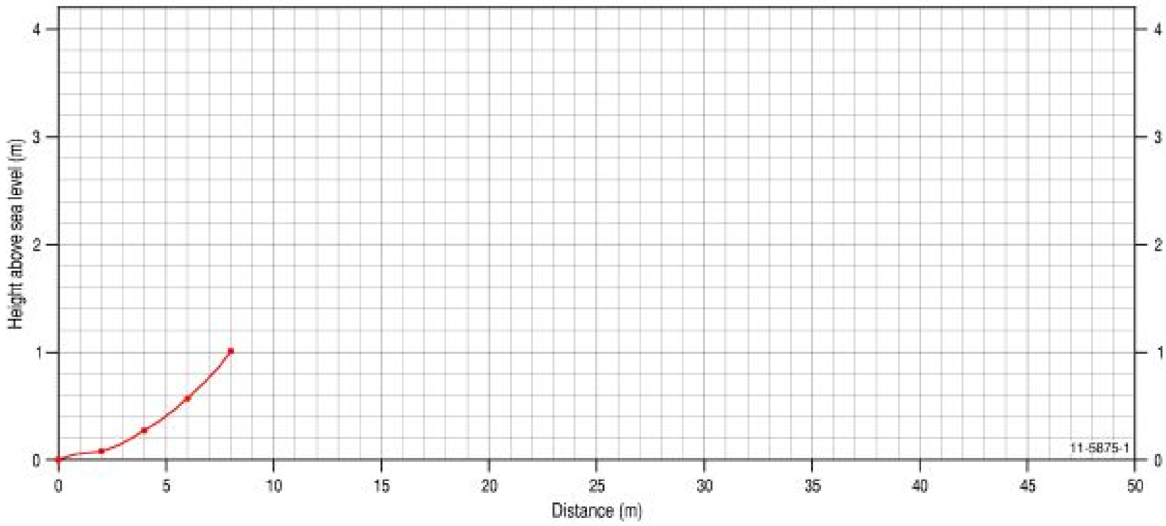
Data for Beach Profile – South Racecourse Beach, 2011

Distance (m)	Height above sea level (m)	Plant types
0	0	None
2	0.1	None
4	0.3	None
6	0.6	None
8	1.0	None
10	1.7	None
12	1.6	None
14	1.5	None
16	1.3	None
18	1.2	None
20	1.3	None
22	1.4	Spinifex grass
24	1.6	Spinifex grass, pennywort
26	2.2	Spinifex grass, pennywort, sea rocket
28	2.7	Spinifex grass, pennywort, sea rocket
30	3.0	Spinifex grass, pennywort, dune wattle
32	2.9	Spinifex grass, pennywort, dune wattle
34	2.8	Spinifex grass, dune wattle, small tea tree
36	2.6	None
38	2.5	Spinifex grass, dune wattle, small tea tree
40	2.4	None
42	2.2	None
44	2.1	Spinifex grass, dune wattle, small tea tree
46	2.1	Dune wattle, medium tea tree, small Banksia (dead)
48	2.2	Medium Banksia, medium tea tree
50	2.2	Medium Banksia, medium tea tree

Profile of South Racecourse Beach — 1920



Profile of South Racecourse Beach — 2011



Use the information and figures from the 'Coastal dunes' section in the booklet to answer the following questions.

1. Identify and label the following features on each beach profile.
   - Berm
   - Incipient dune
   - Fore dune
   - Back dune
2. Describe how the profile has changed over time.

____

____

____

3. Using the 1920 profile, identify and draw a line between each of the major vegetation zones.
4. How have these zones changed over time?

____

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____

South Racecourse beach has become a location for a variety of human activities including four wheel driving, fishing and general beach use.

5. How can scientists use historical data to better manage a natural resource, like this beach? Also, discuss what can be done to ensure that future generations have the opportunity to enjoy this beach.

____

____

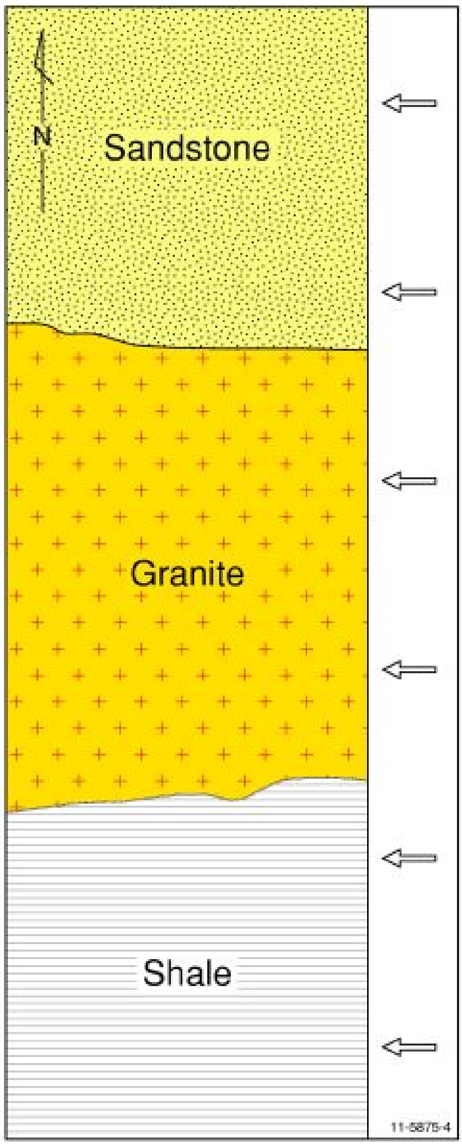
____

New coast

Recommended Age: Secondary

Imagine if you could watch the weathering and erosion of a new piece of rocky coastland over a long period of time. You would be able to see the influence of the local geology on the formation of bays and headlands.

Three rock types make up the new coastline shown. The ocean waves are hitting the coast evenly from the east (shown by arrows).



1. Imagine that each rock weathers and erodes at the rates described below.
   - Sandstone: very resistant to weathering and erosion.
   - Granite: slightly resistant to weathering and erosion.
   - Shale: not very resistant to weathering and erosion.

Draw on the map a possible shoreline after years of erosion in a green pencil.

2. Now imagine that these rocks erode at the following rates:
   - Sandstone: very resistant to weathering and erosion.
   - Granite: not very resistant to weathering and erosion.
   - Shale: slightly resistant to weathering and erosion.

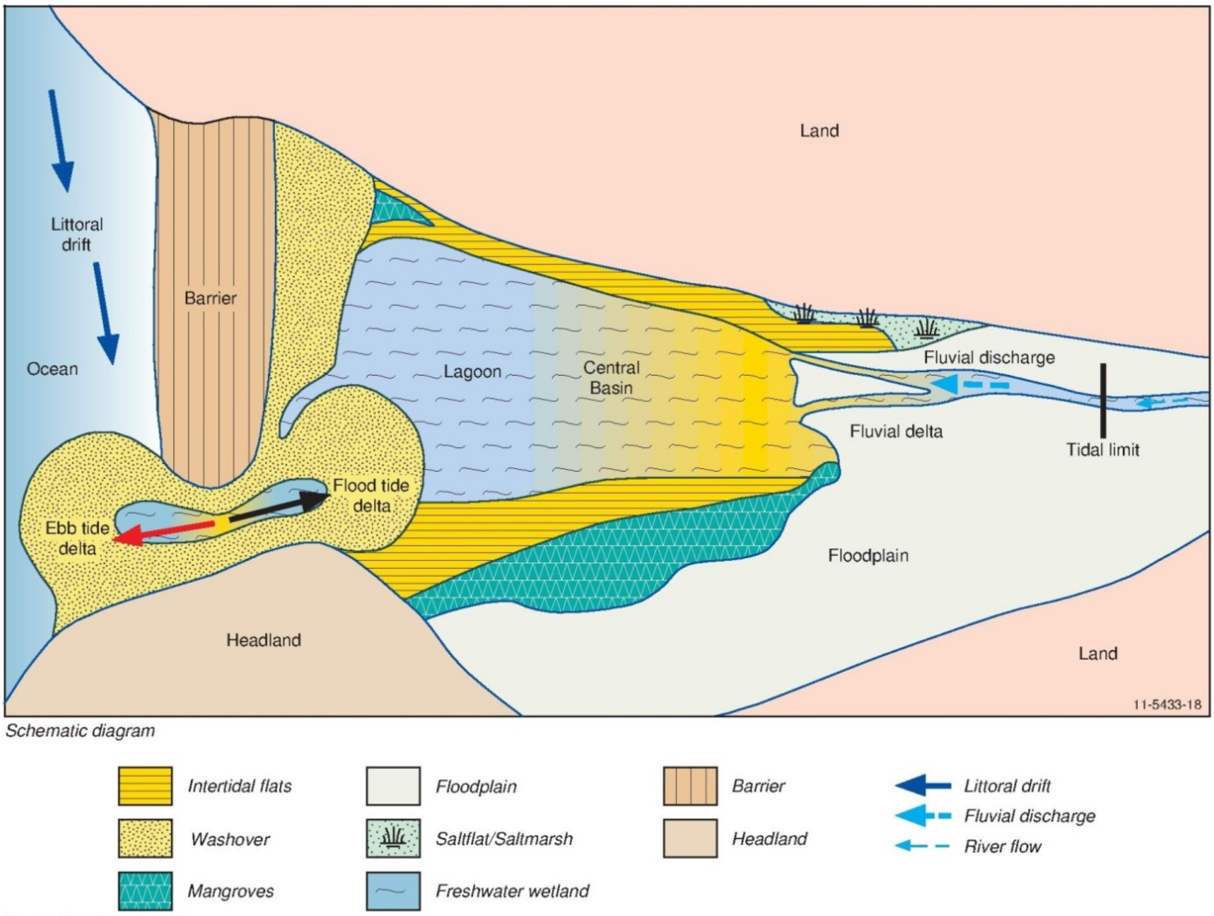
Draw a line on the map using a red pencil a possible shoreline after years of erosion.

3. What other factors would you need to consider if you wanted to predict the shape of the coastline in a real situation?

Estuarine escapades

Recommended Age: Secondary

Use the wave-dominated estuary diagram to answer questions 1 to 3.



Source: Geoscience Australia

1. What do you think would happen to the sand barrier if the littoral (longshore) drift changed by 180 degrees (assume North is at the top of the page)?

2. Explain what might happen if the barrier of the estuary basin grew across the opening and enclosed the estuary. Describe what changes would occur to the physical characteristics of the water in the estuary basin.

3. If the barrier did enclose the estuary, what could you do to improve the water quality?

4. Explain what changes you would expect to occur to a wave-dominated estuary if tidal energy became greater than wave energy.

5. Explain the effects of the following changes to a tide-dominated estuary.
   a. The vegetation in the area surrounding the estuary is cleared.

   b. Over a period of ten years the rainfall in the estuary catchment area gradually increased from 820 mm to over 1000 mm per year.

   c. Sea level rose by 100 centimetres.

____

6. Using the estuary image below, answer the following questions.

a. List three features from the estuary to support its classification as a tide-dominated estuary.

1. ____

2. ____

3. ____

b. This estuary is in a 'pristine' condition. What do we mean by this term?

c. Explain how the development of a town around this estuary would change the environment of the estuary and the surrounding area. Discuss how it would change the 'pristine' features negatively.

Sea change at Bayside

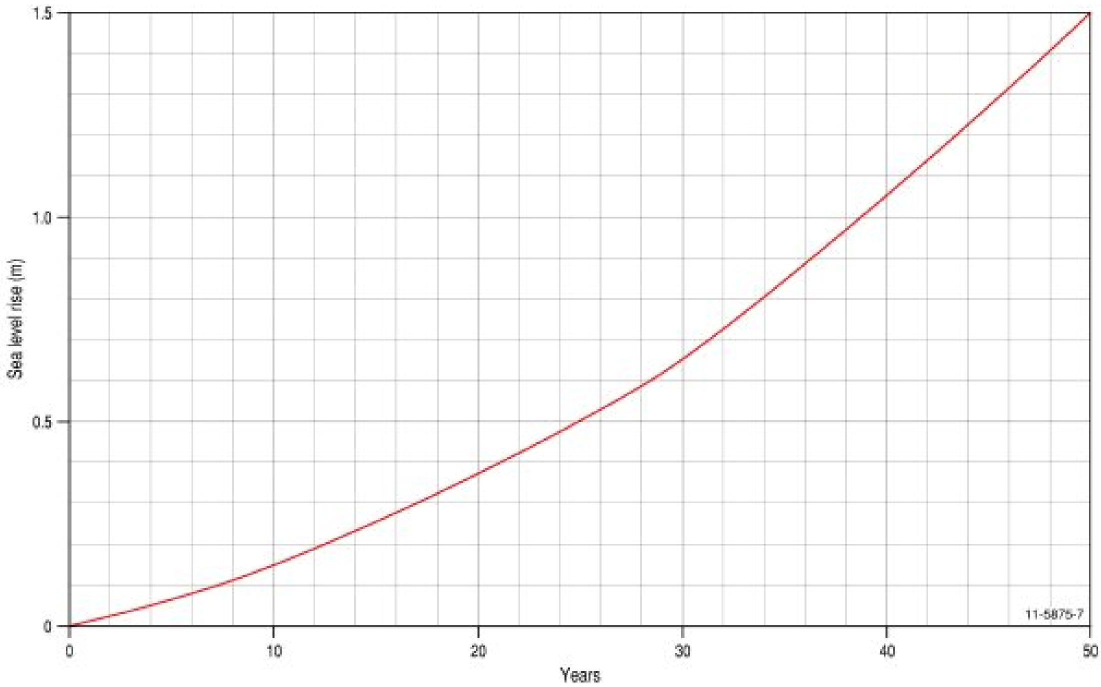
Recommended Age: Lower secondary

The township of Bayside relies heavily on ocean resources for its survival. The only industry is a fish-canning factory that employs 80 percent of the population. The small hamlet also has a hospital, supermarket and a pre-school.

The Bayside Progress Society is concerned that the town's future is under threat due to sea level rises caused by temperature rises in the global climate.

They have asked you, a coastal geo-morphologist, to provide them with a map that shows the position of the coastline in 25 years and 50 years. To do this you have found a graph that shows the maximum possible sea-level rise that this part of the coast could undergo over the next 50 years.

Graph of the maximum possible sea-level rise in the Bayside-Cliffdale Region



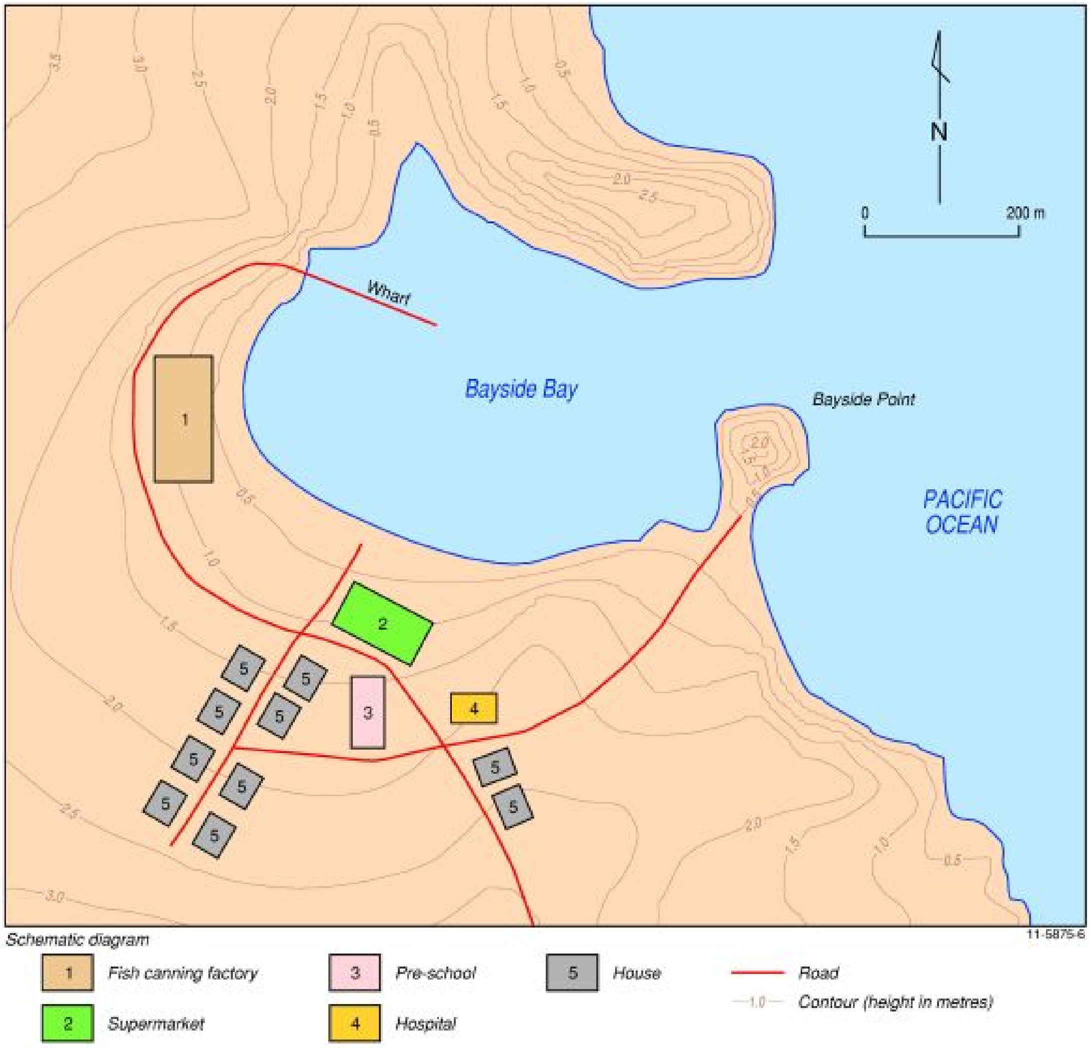
1. Using the graph, calculate the predicted sea level at Bayside in:

10 years: ________

25 years: ________

50 years: ________

2. Draw lines onto the map of the predicted sea level at Bayside in 25 years and 50 years. Shade all areas that will be under water in 25 years with one colour, and then using another colour shade all the areas that will be under water in 50 years.



3. What buildings (if any) will need to move in the future in order to protect them from the effect of sea-level rises in:

10 years' time: ____

25 years' time: ____

50 years' time: ____

4. Will there be significant change to the local coastline in 25 years? What would be the significant new features of this coastal area?

5. Using the graph and map, figure out when the pre-school may begin to be under threat from the possible sea-level rise.

6. If the damaging waves all come from storms to the south-east of Bayside, how many years from now will the wharf area become exposed to these waves?

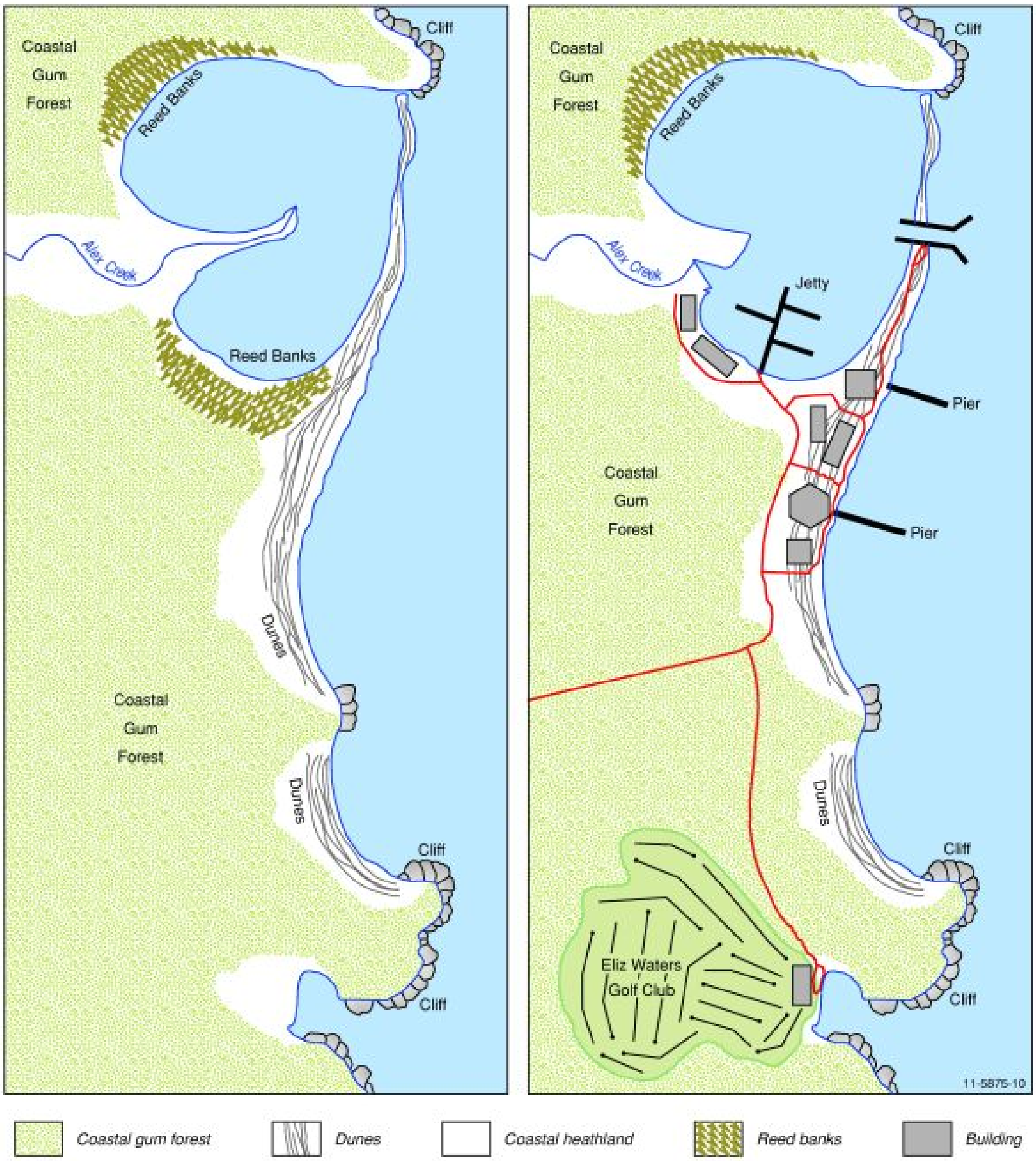
7. You discover that the data used to construct the graph was gathered using only one type of scientific evidence, and that it provides the maximum possible results only. What could you do to ensure that you act in a scientific and ethical way using this data?

Resort Impacts

Recommended Age: Lower secondary

In 1985, a development company proposed to build a resort around Eliz lagoon. The new resort, "Eliz Waters", has now been operating for over 25 years and has made a substantial impact on the coastal features.

Maps from 1985 and 2011



A new environmentally conscious owner has just purchased the development. She has asked you to research the changes and provide her with some information about where developments could take place in future and which environments would be off-limits.

You have discovered two maps of the area.

1. List the features of the resort and impact on the environment. For example, building on the sand dunes could lead to the erosion of sand dunes. What major changes to the natural coastline can you identify?

2. On the 2011 map, draw a line around some areas which the resort could use to show its visitors examples of the original environment. Why did you choose these areas?

Coastal research study

Recommended Age: Secondary

Simon Sandfeld, the chief engineer for the local town council, has just become the Mayor of a large city, Jessville. You have taken over his position as chief engineer and must learn the aspects of the job quickly.

You live in a small town, Jamestown, which is a quiet fishing spot on the north-east coast of Australia. There are long white sandy beaches, with high sand dunes behind them, ideal for fishing, surfing and water sports. The area has a warm tropical climate and has attracted many visitors from southern Australia over the past few years.

While the annual influx of tourists to the area has been great for the economy of the area, it has also brought several problems that you need to address. Your town had several roads built to take local traffic and there were a couple of small motels and a camping ground next to the Megahan River. A small row of shops is situated along the road behind the back dunes.

However, with the need to cater for the influx of tourists, building has been occurring without any thought to the environmental stability of the area. Car parks were constructed directly behind the dunes after they were flattened with a bulldozer. The area around the car parks was then turfed and shelters were built for picnickers. Some visitors to the area parked along the back dunes and trampled through vegetation to get to the beach. This caused erosion and in some areas, dune blowouts.

As chief engineer your job is to prevent further erosion of the dune system and make sure that controlled development takes place within an area that is not fragile. To do this you need to:

- liase with other coastal councils that have experienced a similar problem,
- become familiar with how dune systems develop and evolve
- find out what causes erosion on dunes, and how this can be controlled
- report back to the council your findings and suggest ways that they can address the problems caused by the increase in population.

Useful websites for your research

You can visit the following websites and browse for information about dune systems and how they can be successfully managed to control erosion.

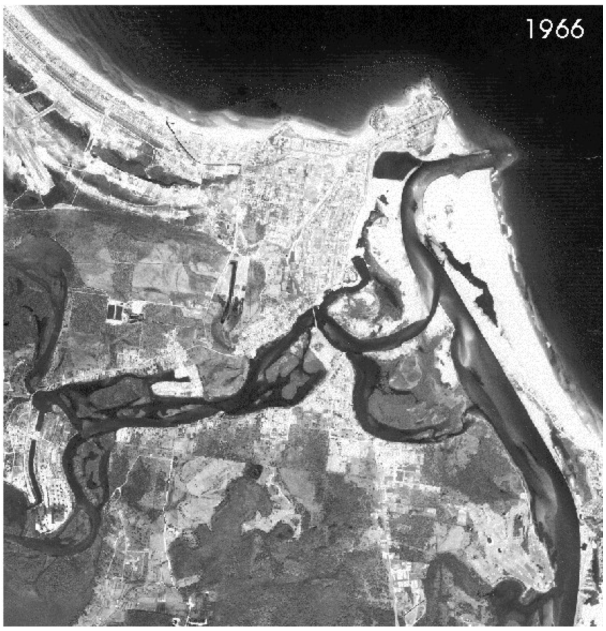
These sites may give you information about marine environments that you could link into your research project. Council information may also be helpful with building practices and so on.

- CSIRO: www.csiro.au (Go to the 'Wealth from Oceans Flagship' section)
- South Australian Department of Environment and Natural Resources: www.environment.sa.gov.au (Go to the 'Coastal and marine' section)

- Queensland Department of Environment and Resource Management: http://www.derm.qld.gov.au/
- Victorian Department of Sustainability and Environment (DSE): www.dse.vic.gov.au (Go to the 'Coasts' section)
- Federal Department of the Environment: www.environment.gov.au
- Geoscience Australia: http://www.ga.gov.au/scientific-topics/marine
- Gold Coast City Council: www.goldcoast.qld.gov.au
- NSW Office of Environment and Heritage: http://www.environment.nsw.gov.au/ (Go to Coastal and floodplain management)
- Oz Coasts: Australian Online Coastal Information: www.ozcoasts.gov.au
- The Australian Institute for Marine Science: www.aims.gov.au

Gold Coast: Case study

Recommended Age: Secondary



1977

1. Study the aerial and oblique photographs taken of Tweed Heads in 1947, 1966 and 1997.

   a. What evidence can you find in the photograph to suggest why breakwaters were built in the Tweed River entrance?

____

____

____

   b. What effect did the development of breakwaters have on the beaches immediately north of this area?

____

____

____

   c. Describe two methods that could be used to address the loss of sand being supplied to the northerly beaches.

(i) ____

(ii) ____

2. Look at the images 1947, 1966 & 1990s of Tweed Heads. Describe landform features or land uses that are

   a. the same:

____

____

____

   b. different:

____

____

____

   c. Comment on the positive and negative effects that these changes could have on the surrounding environment and on the people who lived there.

____

3. The aerial photograph of the Nerang River on the Gold Coast in 1966 shows the development of canals throughout residential areas. Photographic evidence from 1930 (shown) until 1955 reveals that canal development had not begun. Recent photographs of the Gold Coast show that many more canal estates have been constructed.

   a. Why do you think the area around the Nerang River was suited to the development of canal estates?

   b. What future problems might be associated with canal estates?

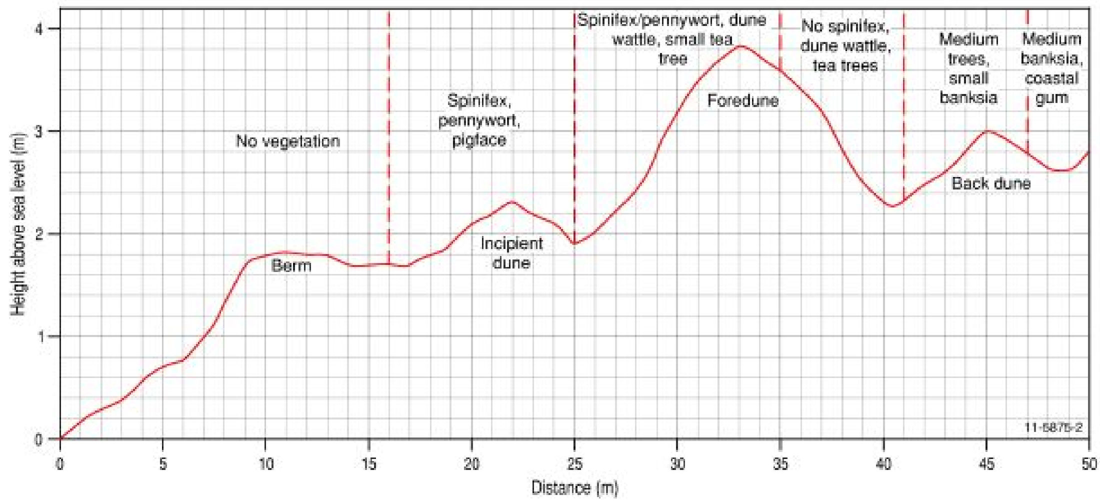
4. Why do you think that the Gold Coast region has become a popular tourist destination for both international and Australian tourists?

5. Use an online mapping tool to look at the current extent of development of the Gold Coast region.

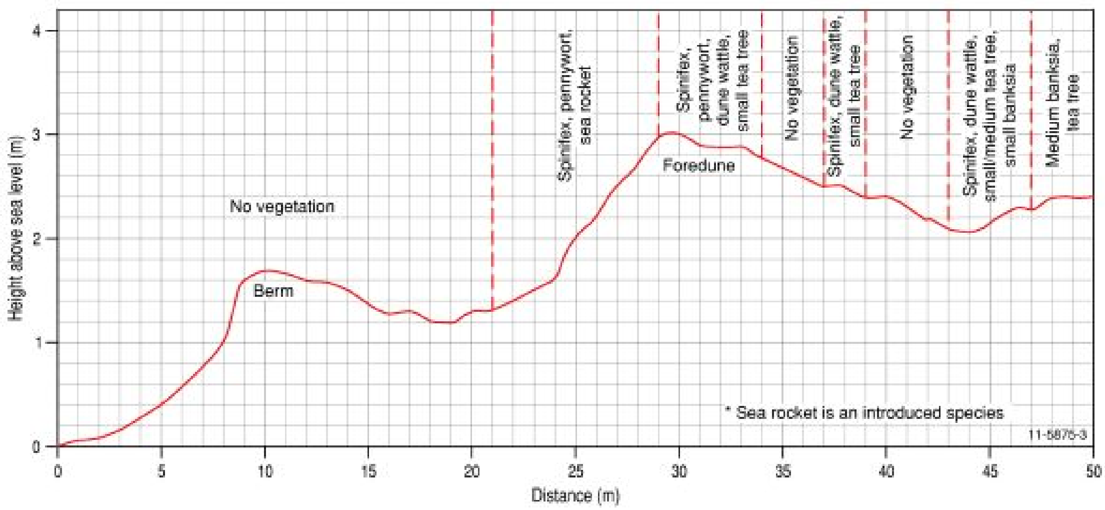
The Australian Coast –
Student activities answer sheets

Dune Drifting

Profile of South Racecourse Beach — 1920



Profile of South Racecourse Beach — 2011



2. Describe how the profile has changed over time.

Incipient dune has disappeared between 1920 – 2011. Large swale (a low tract of land) formed behind original berm. No back dune in 2011. 1920 beach face is slightly steeper. Fore dune slightly lower in 2011.

4. How have these zones changed over time?

In 1920 dunes quite heavily vegetated and vegetation growth started closer to the waterline coastal gums vegetated the back dune.

In 2011 there are areas of no vegetation behind fore dune less dune wattle and small banksias behind fore dune.

5. How can scientists use historical data to better manage a natural resource, like this beach, and what could be done to ensure that future generations would be able to utilise the beach for their enjoyment?

Restrict certain areas of beach to pedestrians and vehicle traffic by using:

board and chain walks through dunes

fences installed on upper beaches to catch sand

plant stabilising vegetation on upper dunes and fence this area off.

Ensure that public areas behind the beach (dunes) is well maintained (lawn areas kept mown, to stop seeds from spreading).

New Coast

3. What other factors would you need to consider if you wanted to predict the shape of the coastline in a real situation?

Factors such as:

sea level changes

human intervention measures (like breakwaters)

seasonal effects of tides, ocean currents and waves on littoral (longshore) drift.

Estuarine escapades

1. What do you think would happen to the sand barrier if the littoral (longshore) drift changed from a northerly to a southerly direction?

The sand barrier would form from the opposite headland in opposite direction.

2. Explain what might happen if the barrier of the estuary basin grew across the opening and enclosed the estuary. Describe what changes would occur to the physical characteristics in the water of the estuary basin.

The water would become stagnant because there would be little mixing or flushing of the estuarine water. Perhaps, the estuary basin would be more susceptible to sediment accumulation from the river.

3. If the barrier did enclose the estuary, what could you do to improve the water quality?

You could make an opening through the barrier so that water could flow backwards and forwards, allowing for the estuary to be flushed out.

4. Explain what changes you would expect to occur to a wave-dominated estuary if tidal energy became greater than wave energy.

Shape of mouth may change resulting in the estuary becoming muddier. There would be less susceptibility to urban/rural runoff and less dominance by spit.

5. Explain the effects of the following changes to a tide-dominated estuary.

a) The vegetation in the area surrounding is cleared.

The effects would be an increase in runoff and siltation problems as sediment input increases. There also may be an increase in sedimentation near the river mouth and associated habitat changes.

b) Over a period of ten years the rainfall in the estuary catchment area gradually increased from 820mm to over 1000 mm per year.

The effects will be that the river water may increase into the estuary. There may be an increase in erosion that would lead to an increase in siltation.

c) Sea level rose by 100 centimetres.

The effects will be that tidal flats will flood frequently and may change the habitat. The mangrove area will also be further under water.

6. Using the Estuary image below, answer the following questions.

a) List three features from the estuary to support its classification as a tide-dominated estuary.

Funnel-shaped mouth.

No narrow entrance.

Lack of barrier across entrance.

b) This estuary is in a 'pristine' condition. What do we mean by this term?

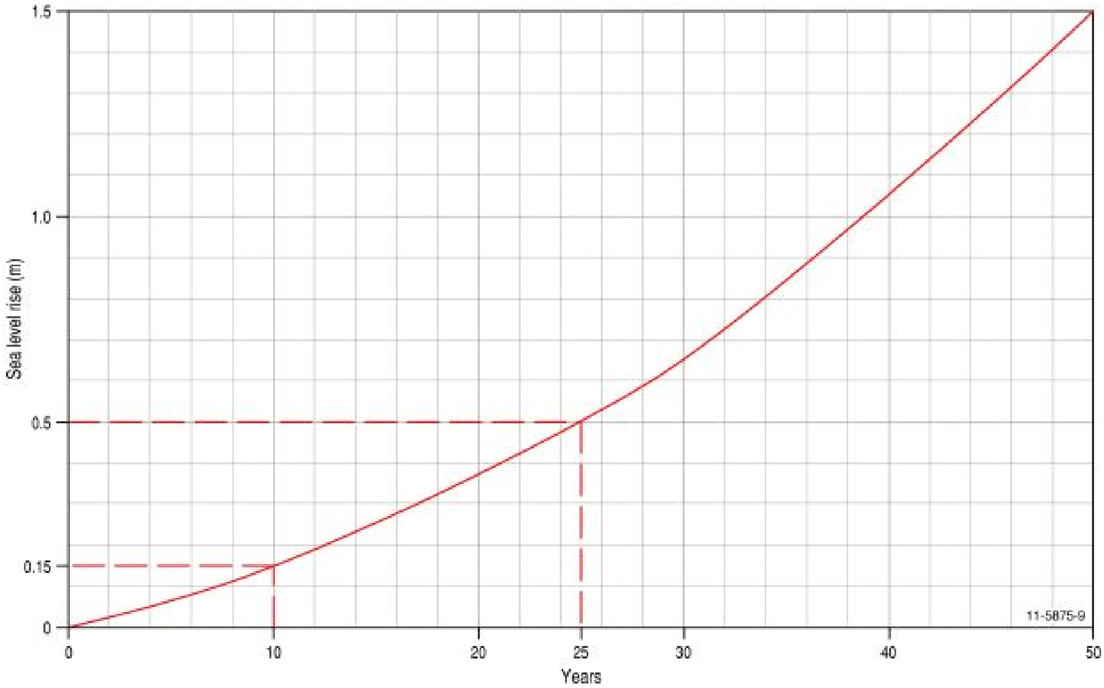
There is a high percentage of natural vegetation, little surrounding of urban/rural land use, therefore ensuring little runoff into the estuary and minimal impact from weeds or pests.

c) Explain how the development of a town around this estuary would change the environment of the estuary and the surrounding area. Discuss how it would change the 'pristine' features negatively.

Development would influence severely on the ecology of the estuary, minimise breeding grounds for animals and may alter the area for commercial and recreational fishing uses.

Sea change at Bayside

Graph of the maximum possible sea-level rise in the Bayside-Cliffdale Region



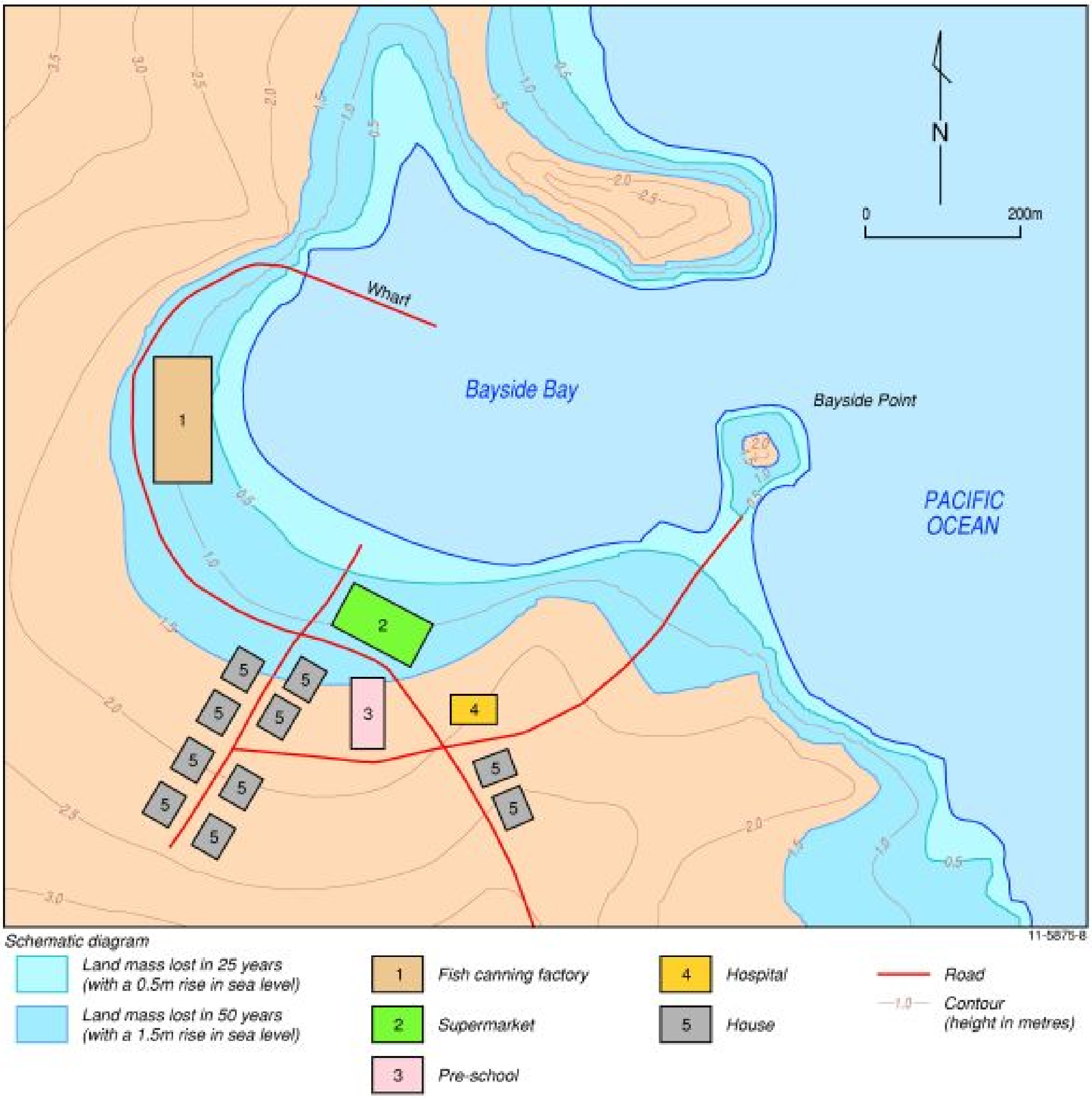
1. Using the graph, calculate the predicted sea level at Bayside in:

10 years: *0.15 metres*

25 years: *0.50 metres*

50 years: *1.50 metres*

2. Draw lines onto the map of the predicted sea level at Bayside in 25 years and 50 years. Shade all areas that will be under water in 25 years with one pencil, and all the areas that will be under water in 50 years with another pencil.



3. What buildings (if any) will need to move in the future in order to protect the community from the effect of sea-level rises at:

10 years: *Little effect – no building will need to be moved.*

25 years: *Fish canning factory and the supermarket will need to move.*

50 years: *Almost everything will need to move as the water level would threaten nearby infrastructure.*

4. Will there be significant change to the local coastline in 25 years? What would be the significant new features of this coastal area?

Quite a lot of the coast will be inundated along the shore in the next 25 years. Also, Bayside Point will become an island instead of a peninsula.

5. Using the graph, figure out when the pre-school may begin to be under threat from the possible sea-live rise.

Approximately 50 years.

6. If the damaging waves all come from storms to the south-east of Bayside, how many years from now will the wharf area become exposed to these waves?

Approximately 20 years when the area south-east of the wharf is under water and the headland becomes an island.

7. You discover that the data used to construct the graph was gathered using only one type of scientific evidence, and that it provides the maximum possible results only. What could you do to ensure that you act in a scientifically and ethical way using this data?

To act scientifically you will need other data sources, not just one. To act ethically you should inform your clients that you have only used one data source which produced maximum results.

Resort impacts

1. List the features of the resort and impact on the environment. For example, building on the sand dunes could lead to the erosion of sand dunes. What major changes to the natural coastline can you identify?

Eliz Waters Golf Club is built behind the bay in the coastal gum forest. Therefore, deforestation has occurred resulting in less vegetation. This increases soil erosion and water runoff onto the beach.

Breakwaters pour out through barrier to ocean. Therefore, sand would build up in the south and would deplete around the cliffed headland.

Urban development around the coast results in greater pollution and destruction of reed banks and the environmental habitat.

Alex Creek was altered and changes were made to the original watercourse.

2. On the 2011 map, draw a line around some areas which the resort could use to show its visitors examples of the original environment. Why did you choose these areas?

The reed banks north of Alex Creek. These have remained largely untouched.

Dunes along headland between resort and Golf club. These dunes are in their original condition.

Cliffed headland east of Eliz Waters. This portrays the original geology of the area.

Gold Coast: Case study

1. Study the aerial and oblique photographs taken of Tweed Heads in 1947, 1966 and 1997.

a) What evidence can you find in the photograph to suggest why breakwaters were built in the Tweed River entrance?

To stop sand siltation from River blocking entrance and to restrict growth of spit across River mouth.

b) What effect did the development of breakwaters have on the beaches immediately north of this area?

Sand supply depleted to northern beaches

More sand building up before breakwater to south.

c) Describe two methods that could be used to address the loss of sand being supplied to the northerly beaches.

(i) permanent sand-bypass system

(ii) dredging sand from off-shore to nourish beach – remove breakwaters!

2. Look at the images 1947, 1966 & 1990s of Tweed Heads. Describe landform features or land uses that are

a) the same: *position of entrance, shape of headland, Letita spit, agriculture to south.*

b) different: *expansion of urban area – along northern beachers, and along river. Also urban area in south east of 1966 photo. More land cleared for agricultural use. River mouth widened – breakwaters used. Airport developed.*

c) Comment on the effect that these changes could have on the surrounding environment and the people who lived there.

Positive = increased service centres as urban development occurs. For example, roads, transport, shopping, banking facilities, jobs, recreational centres.

Negative = original vegetation destroyed, increase in erosion, runoff. Beach system changed due to river breakwaters affecting longshore drift. Dune erosion with development along area behind beach.

4. The aerial photograph of the Nerang River on the Gold Coast in 1966 shows the development of canals throughout residential areas. Photographic evidence from 1930 (shown) until 1955 reveals that canal development had not begun. Recent photographs of the Gold Coast show that many more canal estates have been constructed.

a) Why do you think the area around the Nerang River was suited to the development of canal estates?

Lots of natural waterways leading into Nerang River which can be altered to facilitate canals.

b) What future problems might be associated with canal estates?

Subsistence and flooding

5. Why do you think that the Gold Coast region has become a popular tourist destination for both international and Australian tourists?

Great summer/winter temperatures, nice clean beaches, facilities for tourists – theme parks, shopping centres, etc. Area behind beaches for tourists with other experiences like bushwalking.